CREDIT VALLEY CONSERVATION

IMAX Parking Lot Retrofit

Location: Mississauga
Constructed: 2013

Case Study

Business and Multi-Residential

Project Objectives, Design and Performance

- Design and construct a better functioning parking lot that upgraded stormwater management infrastructure with modern low impact development (LID) features.
- Benefit from project partnerships to enable a variety of innovative stormwater management technologies to be integrated into the IMAX parking lot including permeable pavers, Jellyfish® Filter, bioswales and Sorbitive® Media.
- Conduct infrastructure performance assessment to directly address knowledge gaps impeding the wide-scale adoption of LID technologies in Ontario.

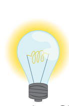
Overcoming Barriers and Lessons Learned

- Challenging soil conditions were encountered on site requiring a conservative design that provides sufficent drainage infrastructure and structural support.
- Coordination and a transparent design process between CVC, product suppliers, the design team and academic experts ensured the successful integration of performance assessment infrastructure into the IMAX parking lot.
- Contractor and IMAX staff worked together to ensure that IMAX could conduct business as usual during the construction phase.
- To ensure that construction is performed properly and proceeds on time, be sure to have an individual experienced in LID construction and design is a great asset on the job site. They act as a resource and liaison between the contractor, client and other stakeholders.

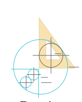
Practices Implemented


Bioretention


Permeable Pavement


Innovative SWM

Barriers and Issues Encountered


Design


Construction and Comissioning

Case Study Outline

The IMAX case study consists of the following sections:

Overview

IMAX Corporation (IMAX) headquarters is located within the Sheridan Business Park at 2525 Speakman Drive in Mississauga, Ontario and is part of the Lake Ontario Shoreline West Subwatershed, as shown in see Figure 1.

In 2012 IMAX retrofitted its parking lot with a variety of innovative low impact development (LID) stormwater management technologies. These technologies collect, adsorb and filter pollutants from stormwater runoff before it is discharged into Sheridan Creek, Rattray Marsh (a provincially significant wetland) and eventually Lake Ontario, the source of drinking water for 8 million people.

The IMAX parking lot retrofit was completed in partnership with Credit Valley Conservation (CVC), as part of the Province of Ontario's Showcasing Water Innovation (SWI) program. The province continues to partner with CVC though its Infrastructure and Risk Assessment Program (IPRA).

Goals and Drivers

The primary goals of this retrofit project directly impact IMAX and the surrounding natural environment, while supplementary goals have many indirect benefits. They represent the long-term and watershed-scale objectives.

Primary Goals

- Provide a parking lot that functions efficiently and has enhanced aesthetic value.
- Expand parking lot to accommodate the company's projected employee growth.
- Lower operational costs.
- Limit IMAX's potential stormwater utility cost

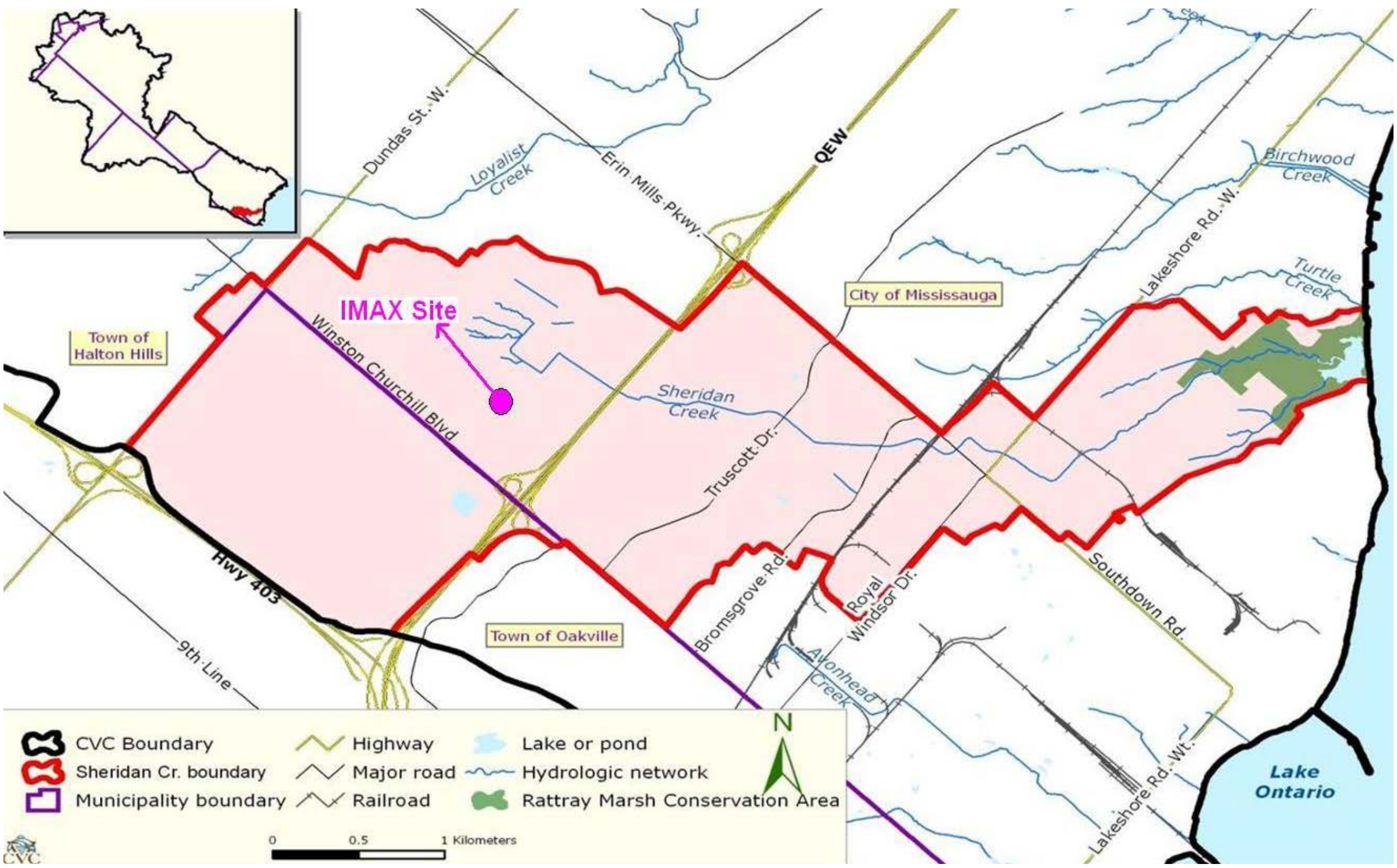


Figure 1: Map showing the location of IMAX within the Sheridan Creek watershed.

Primary Goals (continued)

- Upgrade the existing parking lot and stormwater management infrastructure from asphalt and traditional stormwater conveyance systems (i.e. catch basins) to modern LID techniques. These upgrades will provide quantity and quality control and improve stormwater management within the urbanized area.

- Provide direct benefits to the local water system by reducing erosion, increasing groundwater recharge, sustaining natural hydrologic flows of rivers and creeks.

- Assist municipalities in meeting their stormwater objectives for fully developed areas with no stormwater controls.

- Position IMAX as an environmentally sustainable company.

Supplementary Goals

- Increase long-term shareholder value by attracting investors through corporate sustainability.

- Show superior performance and favorable risk/return profiles by being a leader in sustainability.

- Reduce likelihood of flooding and associated liability issues.

- Reduce carbon footprint with potential carbon offsets.

- Provide social benefits including creation of local green jobs, and improved public and community health.

- Provide environmental benefits such as reduced urban heat island effect, increased natural carbon sequestration, increased climate change resilience, and healthy Great Lakes.

- Meet municipal sustainability planning provisions.

- Increase property value.

Project Successes

The project successes include:

Environmental innovation – The IMAX project is one of the first commercial LID parking lot retrofits in Ontario. It incorporates a variety of LID technologies, including permeable pavement, dry swales (bioswales), grassed swales, and other proprietary systems. These stormwater management technologies improve stormwater quality by removing suspended solids from runoff. Suspended solids carry unwanted contaminants and nutrients into waterways and natural areas. These technologies also reduce the quantity of stormwater runoff from the site.

Figure 2: Groundbreaking ceremony

Better Functioning Parking Lot – the IMAX parking lot retrofit with LID provides a better functioning parking lot with improved drainage and aesthetics. The old parking lot posed a number of issues including crumbling asphalt and year-round ponding, which would flood the outdoor electrical cabinets causing power outages in the building.

Figure 3: CVC staff demonstrating the effectiveness of the permeable pavers at infiltrating water

Joint partnership - IMAX worked with CVC, the City of Mississauga, and product suppliers including Unilock, Imbrium Systems, Hanson Pipe and Precast. These partnerships allowed the project to incorporate several innovative stormwater management technologies.

Creating Green Jobs & Building Market Capacity for Innovative Technologies - the project is also spurring the growth of Ontario green jobs through the use and promotion of the specialized stormwater management systems – the Jellyfish® Filter, and Sorbtive® Media. Testing of these new products will expand the market for designers, contractors, suppliers and manufacturers.

Demonstration Showcase – LID features at IMAX Corporation have been showcased through numerous presentations, events, media and site tours. Notably, CVC and IMAX won the 2013 Minister's Award for Environmental Excellence.

Performance monitoring – An experimental design template was developed in partnership with the Ontario Centres of Excellence, the University of Guelph, Imbrium and Unilock. A multi-year performance evaluation program is underway to monitor the performance of the LID practices and technologies installed at IMAX.

Figure 4: Monitoring team completing field work

Overcoming Barriers and Lessons Learned

Table 1 outlines this project's barriers, issues and lessons learned discovered by the project team

Table 1: IMAX project barriers, challenges, solutions and lessons learned.

Project phase	Barrier/challenge	Solution	Lessons
Design	High bedrock areas, excess groundwater and weak subsoil conditions created design challenges for the permeable paver parking lot.	Permeable pavers were limited to areas without high bedrock depths. Weak subsoil conditions were managed using conservative design approaches Other professionals including geotechnical engineers and geosynthetic product suppliers/ manufacturers were included to come up with the best solution. Sufficient drainage infrastructure was integrated into the design to solve the problem of saturated soil conditions.	Pre-design activities including site condition characterizations are a critical element in the design process.
	Low-bearing capacity soils were found throughout the permeable pavement locations.	A high-strength woven monofilament geotextile (Tencate's RS380i) was used to support the permeable pavement.	New innovative technologies can help you to meet design goals and objectives. In this case, the geotextile provided the required structural strength without sacrificing hydraulic capacities.
	Performance monitoring infrastructure and proprietary stormwater management technologies had to be integrated with other infrastructure and within current site conditions.	Full coordination and a transparent design process between CVC, University of Guelph, product suppliers, and the design team ensured the successful integration of performance monitoring and LID infrastructure within the main design elements.	Integrating proprietary units may require customization. This process requires input from all parties. Confirm product manufacturing times, costs, delivery charges, and installation responsibilities product suppliers.
	There was not enough clearance in some manholes to accommodate monitoring equipment such as Autosamplers.	Manholes were made as shallow as possible to accommodate the weir structure (which requires at least four feet of clearance) and the Autosamplers were installed above ground in a stainless steel box in a low-traffic grassed area.	Monitoring teams should be included during the design process to ensure all equipment is properly integrated into the design.
	Designated snow storage areas were not sufficient to accommodate snow plough volumes.	Bioswales were designed to provide snow storage areas.	When planning and designing for snow storage areas, extra consideration should be given to location and infiltration areas.
	During the 2013 winter season, mild weather caused the snow to melt. Slush and ice buildup around overflows limited flow capacity and sent runoff into the parking lot.	Overflows were temporarily lowered to encourage flow and reinstated the following spring. Secondary overflows were installed upstream near the curb cut inlets to the bioswales to act as "fail safe" in the event that downstream overflows suffer blockages.	Plan snow storage areas by estimating required snow storage volumes. LID practice can be used as snow storage areas if necessary.
Construction	At least half of the original parking capacity had to be maintained during the construction process. The project had to maintain tight timelines to ensure this client request could be fulfilled.	The contractor and IMAX staff worked together to develop daily strategies to manage on-site parking and site activities.	Sufficient construction supervision and administration is important for the success of LID projects
	When pouring the asphalt, the contractor had difficulty achieving mild slopes with long linear runs.	Contractors used specialized equipment to come as close as possible to meeting grades.	LID retrofits should be designed with higher surface slopes and short drainage lengths.
	Bioretention soil media samples failed several inspections.	The contract administrator conducted a site visit of the mechanical mixing operation and verified material sources with product supplier.	Mixing and sampling procedures should be clearly stated in contract documents and verification of the supplier's material sources should be verified prior to sampling.

Project phase	Barrier/challenge	Solution	Lessons
Erosion and sediment control	Heavy duty sediment fencing does not provide practical erosion and sediment control for bioswales surrounded by curbs, sidewalks or other obstructions.	Sacrificial pieces of filter fabric placed on top of the clearstone reservoirs protect the bioswale infrastructure from contamination.	LID-specific erosion and sedimentation controls should be specified in the contract document. These types of projects require simple and creative ways to protect LID practices.
Monitoring	Discharge from LID practices can be very low since these systems are effective means of adsorbing, infiltrating and detaining stormwater.	To monitor outflow, the team installed v notch weirs equipped with water level loggers to measure low flows accurately.	V-notch weirs are recommended to measure low flow with high accuracy.
	During the early stages of the monitoring program, flow was observed at some monitoring locations and not others.	The team performed water and pressure tests to identify the leak in the system and rectify the defects.	Anomalies with monitoring data may be an indication that there are design or construction deficiencies.
	The treatment train design created multiple scenarios where runoff could bypass treatment. These scenarios need to be accounted for when interpreting water quality data.	A series of observational wells (deep and shallow), were installed within each bioswale to identify which rain event causes overflow or surcharging conditions.	Following an adaptive approach and making minor refinements to the monitoring protocols may be necessary.
Operations and maintenance	Cool temperatures delayed the final asphalt coat which required a curing period. As a result, water beading occurred making the surface slippery and hazardous in the winter.	A winter safety map was created to designate pathways to the office entrance.	Accommodating unforeseen issues and providing assistance when needed will create satisfied clients.
	The roll up curb worked well for snow ploughing and storage; however, the standard barrier curb was damaged during the first winter and had to be replaced at the client's expense.	To address winter maintenance concerns, marked stakes were installed along the curb line. The project team recommended installing a rubber edge for the snow plough to avoid scraping pavers.	A plan was developed with the winter maintenance contractor that outlined the optimal snow pile locations and areas that needed to be avoided or flagged. A maintenance map ensures there is no interference with the functionality of the parking lot or the monitoring activities.

Pre-Retrofit Site Conditions

The IMAX retrofit site included the existing employee parking lot (0.62 hectares) and a portion of the main driveway (1370m^2) which connects the main entrance from Speakman Drive to the loading docks located along the west side of the building (Figure 5). It also includes some of the surrounding natural area.

Figure 5: IMAX site – Pre-retrofit conditions

The pre-retrofit parking lot was a traditional asphalt surface. A relatively level standard curb-and-gutter system provided drainage. Lands to the west and north of the site are at higher grades that slope toward the parking lot. The surface runoff from these higher grades are intercepted by grass swales and directed to a naturalized wetland at the northeast corner of the site. From there it drains to a concrete weir structure then to municipal storm sewers.

The pre-retrofit parking lot surface was in poor condition with signs of severe cracking, rutting, and spalling throughout the facility (Figure 6).

Figure 6:Pre-retrofit conditions - degraded asphalt

Wet weather events caused sustained standing water within pot holes and large cracks. Before it flowed overland to the nearest catch basins, groundwater from the high elevation areas pooled between the existing curb and asphalt surface (Figure 7).

Figure 7: Pre-retrofit conditions: Groundwater seepage from surrounding high areas.

Poorly draining subsoils created saturated conditions that quickly degraded the asphalt surface, causing frequent ice build-up during winter months. Build-up resulted in increased salt application during de-icing operations (Figure 8). This salt negatively impacted the quality of stormwater runoff leaving the site.

Figure 8: Pre-retrofit conditions - Excessive winter salt application

LID Planning and Regulations

In 2007-2008 CVC was developing the Sheridan Creek Watershed Study. Through the landowner contact process, IMAX granted CVC permission to access the wetland on the grounds of the corporate head office to better assess the existing conditions within the watershed. IMAX was asked to participate in a series of focus groups designed to refine the Watershed Study by identifying key natural resources and features, environmental issues, and other questions the study should answer.

In July 2007 a representative from IMAX participated in a bus tour for the focus group. The group visited various sites within Sheridan Business Park and received information on the benefits of LID practices that might suit the location. The IMAX parking lot was a stop on the tour. During the visit, the IMAX representative identified concerns such as poor drainage, formation of ice during winter, infrastructure damage, and watershed contamination. Following the tour, IMAX and CVC continued to discuss the possible options for retrofitting the parking lot with LID and developing a working partnership. As part of the Showcasing Water Innovation fund, CVC made cash and in-kind contributions towards the upgrade and construction of the parking lot. CVC covered the monitoring infrastructure costs.

Prior to construction, CVC and the IMAX design team contacted the City of Mississauga and Ministry of the Environment representatives to verify any approval requirements for the work to be undertaken as part of the project.

The City of Mississauga indicated that a storm sewer connection approval and Erosion and Sediment Control Permit may be required. Further discussions determined:

- No Erosion and Sediment Control Permit was required. By-law No. 512-91, as amended, states an Erosion and Sediment Control Permit must be obtained prior to undertaking any land disturbing activities on sites one (1) hectare in size or greater, or on sites of any size that are adjacent to a body of water.
- The City's only requirement for stormwater management in the zoning area of interest was roof controls. The roof area was not impacted as part of the site works and, as such, no stormwater management approval for the work was required. In addition, storm sewer connection approval was not required since the proposed storm sewer works did not cross any existing property lines.

The proposed site servicing plan and stormwater management report were submitted to the City for the records.

Design Concept

Before site design began, the project was intended to incorporate LID features such as permeable pavers, dry swales (bioswales), and proprietary stormwater management units. The intent was to meet client needs such as an expanded parking area, addition of priority and motorcycle parking and a specific aesthetic standard. The implementation of these innovative technologies was driven by design tasks and budget constraints in order to support project partnerships and gather monitoring data.

To accommodate IMAX's expansion requirements, the parking lot was expanded approximately 12.5 m to the north, 8.0m to the east and 3.5 m to the west, thereby increasing the total parking lot area from 6200 m^2 to 8000 m^2 and providing 90 additional parking spaces. Parking stall configurations vary and include motorcycle, compact car, and priority angled parking.

The parking lot surface was a combination of traditional asphalt and permeable pavement. The north part of the parking lot was set to be reconstructed using permeable pavement, whereas the south two thirds used asphalt paving. The proportion of permeable pavers to asphalt was a result of project budget and bedrock constraints. These constraints are described in subsequent sections (see *Pre-design Tasks* and *Detailed Design*). The stormwater runoff that infiltrated through the surface of the permeable pavement was designed to outlet to the isolated wetland where it can infiltrate and evaporate prior to discharging to the municipal storm sewer.

Repaved areas that used traditional asphalt were designed to drain to a series of vegetated bioswales situated within a median that separates the two repaved sections. The bioswales are intended to treat stormwater runoff from the expanded asphalt surfaces.

In addition to the bioswales and permeable pavers, the parking lot area incorporates various proprietary stormwater management technologies including Imbrium's Jellyfish® Filter and Sorbtive® Vault.

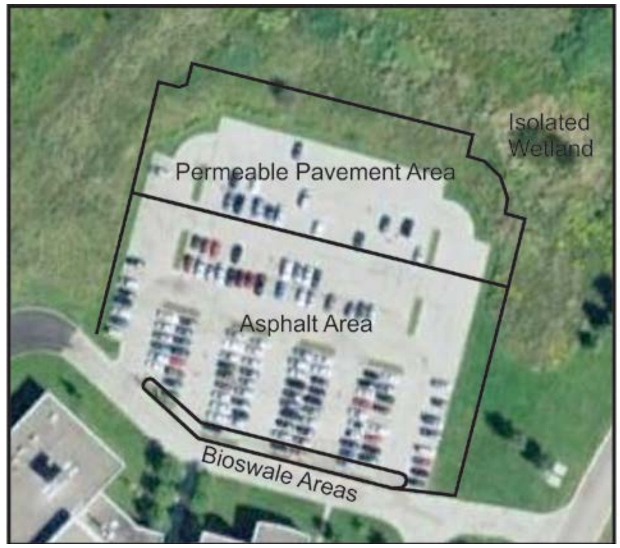


Figure 9: IMAX Retrofit Site – Retrofit Concept

Pre-Design Tasks

Several tasks fully characterized the site conditions and guided the development of the detail design.

Topographic survey

A topographic survey of the site produced base mapping for the design phase and included:

- Topography of the site
- Identification of above ground and below ground services
- Utility locate markings
- Inverts and sizes for existing sewers, catch basins, manholes, etc.
- Location and description of on-site structures;
- Significant vegetation (coordinated with tree inventory assessment)
- Existing parking lot features
- Fence lines and existing landscaping.

Geotechnical investigation

A geotechnical investigation defined subsurface conditions, including information related to soil shear strength, particle-size distribution, observed groundwater levels, soil stratigraphies, moisture content, California Bearing Ratio (CBR) and Standard Proctor moisture-density test.

Infiltration testing

Guelph Permeameter testing was performed in December 2011 to determine the saturated hydraulic conductivity (Kfs) of the in-situ soils. The experimentally determined Kfs was converted to infiltration rate (mm/hr) and a factor of safety corresponding to the non-stratified soil condition was applied per Appendix C of the CVC LID Design Guide. The calculated design infiltration rates ranged from 1.96 – 4.84 mm/hr (Table 2).

Table 2: Infiltration testing results for IMAX

	Design Infiltration Rate (mm/hr)	Safety Factor (SF)	Calculated Design Infiltration Rate (mm/hr)	Testing Depth below surface (m)	Approx. Ground Elev. (m)	Infiltration testing invert (m)
Location 1 (5cm head)	7.43	2.5	2.97	0.55	144.33	143.78
Location 1 (10cm head)	4.91	2.5	1.96	0.55	144.33	143.78
Location 1 (avg. Value)	6.51	2.5	2.6	0.55	144.33	143.78
Location 2 (Dual Head)	12.11	2.5	4.84	1.04	144.25	143.29
Range			1.96 – 4.84			
SF – corresponds to non-stratified soils condition i.e. based on completed geotechnical investigation, less permeable soil horizons within 1.5m below the proposed bottom elevation of the BMP do not exist.						

The calculated design infiltration rate of 2.60 mm/hr (Testing Location 1 – average value) is considered to be the best representation of the actual in-situ soil conditions as a result of:

- Average value of 5 cm and 10 cm single head testing protocol;
- Extended testing intervals (15 minute); and
- Duration of total test time resulting in greater resolution in 'slow' clay soils (2.5-3 hrs total test time at both the 5 cm and 10 cm head respectively);

The average design infiltration rate was 2.60 mm/hr for the IMAX site which was used as the basis for design calculations for the LID practices.

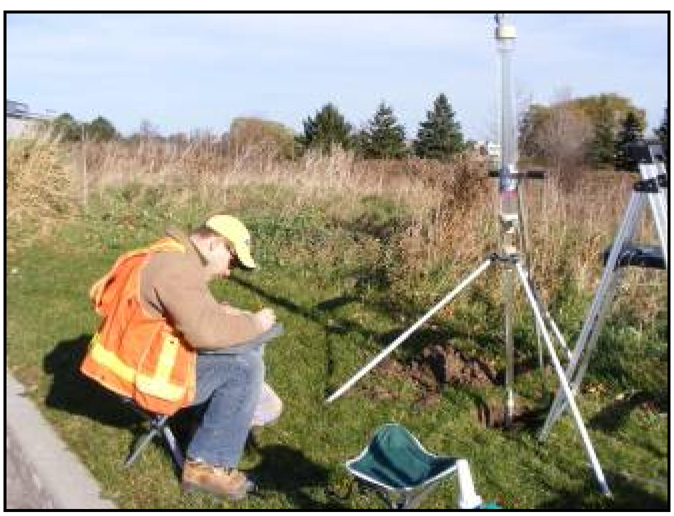


Figure 10: Infiltration testing conducted at IMAX.

Groundwater monitoring

Groundwater monitoring established seasonally high groundwater levels. This determined the applicable design criteria for the LID practices implemented per the CVC LID Design Guide.

Design Considerations and Constraints

Following the completion of the initial site reconnaissance and pre-design tasks, the team identified design constraints, including:

- Areas of high bedrock
- Low structural strength of subgrade material
- Saturated soil conditions
- Integration of monitoring infrastructure and equipment
- Customization of proprietary stormwater management technologies

These sections further describe the relevance of the design constraints and the prescribed solutions.

Bedrock Constraints

Borehole investigations discovered bedrock formations within 1.0 m of the ground surface throughout the south half of the existing parking lot area whereas the north half consisted of fill material. The Low Impact Development Planning and Design Guide do not recommend installing permeable pavement where bedrock is within 1.0 m of the ground surface. This recommendation eliminated the use of permeable pavement of the south half of the parking lot. The project budget refined the ultimate boundary line and proportions of permeable pavement versus asphalt used.

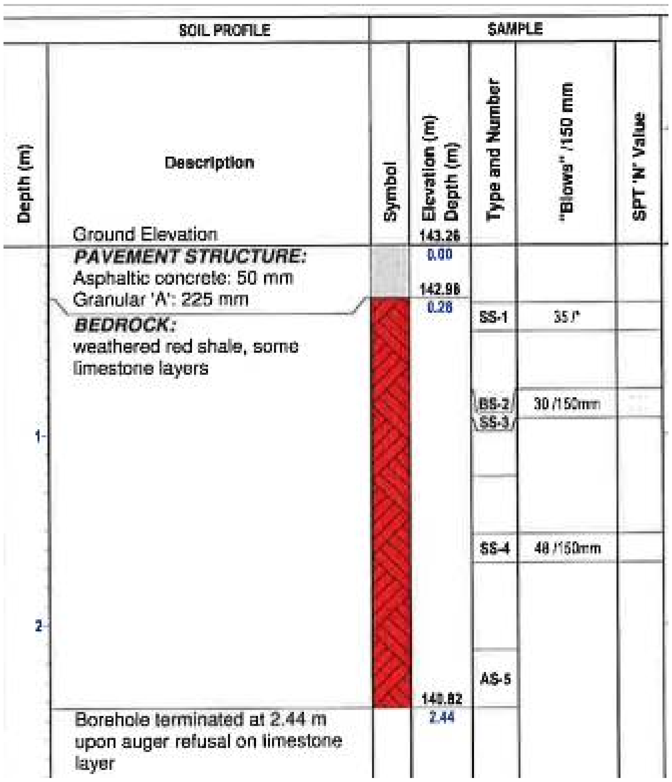


Figure 11: Borehole stratigraphy used to determine bedrock constraints at the site

Low bearing silty clay soils – Soaked California Bearing Ratio (CBR)

The results of the 96-hour soak CBR analysis concluded that the low bearing, silty clay fill material located on the north half of the parking lot had a Soaked CBR value of 0.4%.This value presented a potential constraint to permeable pavement design.

Permeable interlocking concrete pavers (PICP) structural design for vehicular applications assumes a minimum soil CBR value of 3-4%. Geotechnical engineers were consulted in regards to the nature of the soaked CBR testing methodology. It was determined that the 96-hour soak analysis could be revised to a soaked CBR analysis of 1.0% based on the limitation that the permeable pavement base would be:

- Free draining via the designed underdrain system; and
- Accumulated water within the sub-base would be held for a maximum period of 24 hours.

To augment the low soil stability of the sub-soils, the project team selected a high-strength woven monofilament geotextile (RS380i) to provide reinforcement strength and base course confinement, as well as high flow rates for infiltration and soil retention capabilities (Figure 12).

Figure 12: Tencate's Geotextile (RS390i).

RS380i was chosen because it provides three times the flow rates of other woven geotextiles without sacrificing strength. The product specifications are listed in Table 3.

Table 3: Mechanical properties of Tencate's RS380i

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value
STRENGTH			
Tensile Modulus @ 2% strain (CD)	ASTM D4595	kN/m (lbs/ft)	744 (51000)
HYDRAULIC			
Flow Rate	ASTM D4491	l/min/m^2 (gal/min/ft^2)	3056 (75)
Permittivity	ASTM D4491	sec-1	0.9
SOIL RETENTION			
Apparent Opening Size (AOS)1	ASTM D4751	mm (U.S. Sieve)	0.43 (40)
Pore Size 095	ASTM D6767	microns	365 3
Pore Size 050	ASTM D6767	microns	185 3
SOIL INTERACTION			
Interaction Coefficient2	ASTM D5321	--	0.89
Factory Seam Strength	ASTM D4884	kN/m (lbs/ft)	39.4 (2700)
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	80
1 ASTM D 4751: AOS is a Maximum Opening Diameter Value 2 Interaction Coefficient value is for sand or gravel 3 Typical Values			

To ensure the RS380i product could adequately provide reinforcement strength to native soils, the project team performed a reinforced slope stability analysis (ReSSA). The subsequent report used subsoil parameters determined during the geotechnical investigation to simulate AASHTO H-20 truck loading over a 4.6m (15ft) width.

Saturated soil conditions

The IMAX parking lot is situated in the low point of the property. The surrounding land is elevated approximately 2-3 m higher than the parking surface. Pre-retrofit, groundwater seepage from the surrounding highlands and low permeability of the subsoils caused saturated conditions for days following wet weather events. The constant saturation of the subsoils weakened the supporting structure for the existing asphalt surface causing severe asphalt degradation. Throughout the winter, water would build up in the potholes and turn to ice which put employees at risk for slipping. Salt was extensively applied to eliminate the ice and risk of slipping (Figure 13).

Figure 13: Asphalt degradation at IMAX parking lot and extensive salt application.

Integration of infrastructure

Incorporating a sophisticated monitoring program required customized infrastructure. "Off-the-shelf" stormwater technologies also had to be customized to fit with other design elements and the site constraints. A fully coordinated and transparent design process between the CVC, University of Guelph, product suppliers and the design team ensured the successful integration of monitoring infrastructure and LID measures with the main design elements and site conditions.

Detailed Design

The primary LID design practices incorporated into the IMAX retrofit project included:

- Permeable pavers
- Bioswales
- Grass swales
- Jellyfish® Filter
- Sorbtive® Vault

Figure 14 identifies the locations of the LID practices on the site.

Figure 14: General layout and location of LID practices in the IMAX parking lot retrofit.

Permeable pavement

Permeable pavement allows for the filtration, storage, and infiltration of stormwater into the subsoil. Compared to traditional impervious paving surfaces like concrete and asphalt, permeable pavement can significantly reduce stormwater flows. The IMAX design acts as both a subsurface detention basin and a filter to improve water quality.

Bedrock and project budget determined the layout and location of the permeable pavement. The site contains approximately 3145 m^2 of Unilock's Eco-Optiloc pavers. A structural analysis and hydrologic analysis determined the permeable pavement cross-section design and associated aggregate depths.

The structural design method was a combination of the AASHTO flexible pavement design methodology and the Interlocking Concrete Pavement Institute (ICPI) Design Guide, 4th edition, D.R. Smith (2011). This process requires the designer to find the appropriate combination of pavement surface and base material to meet or exceed the required Structural Number (SN) determined by the traffic load or Effective Single-Axis Loading (ESAL).

Given the low CBR values of the subgrade materials, subsequent analyses were performed to ensure the appropriate combination of pavement surface and base material would meet or exceed the required SN.

The recommended permeable pavement cross-section consists of an 80 mm thick pavement stone, overlain 50 mm bedding course consisting of No.8 angular chip stone (5-7 mm ø), (commonly referred to as High Performance Base (HPB)), and two types of base material. The two types of open-graded base materials used for the permeable pavement design included 20 mm ø clearstone and Granular "O" (a Ministry of Transportation standard mix design). The open grade 20mm ø clearstone has a cross-section depth of 500 mm while the Granular “O” has a cross-section depth of 350 mm. Both are overlain the high strength woven multi-layered geotextile (Tencate’s RS380i) separating the aggregate from the sub-grade fill material. The surface voids of the pavers are filled with the same HPB which makes up the bedding course. Table 4 provides a comparison of PICP paver cross-section, the respective aggregate depths and stratigraphy.

Table 4: Permeable pavement design cross-sections

System Component/ Parameter	Value	
	Cross-section No. 1: Open Graded angular 20 mm ø stone PICP Cross-section	Cross-section No. 2: Granular ‘O’ PICP Cross-section
Paver Thickness and Type	80 mm – Eco Optiloc(R) by Unilock	
Bedding	50 mm of No.8 angular chip stone (5-7 mm ø)	
Aggregate Depth	500 mm	350 mm
Geotextile	Woven multi-layered geotextile (RS380i)	
Total PICP Surface Area	3145 m^2	
Approx. Surface Dimensions	48 m x 34 m (1500 m^2)	48 m x 34 m (1645 m^2)
Total Excavation Depth	630 mm	480 mm
Total Storage	348 m^3 *	141 m^3 **
Underdrain System	200 mm ø perforated HDPE main collection pipe	150mm ø perforated HDPE Laterals 200mm ø perforated HDPE main collection pipe
Drawdown time based on max pipe flow –Hydrologic Analysis) Assumes complete dewatering of base material and instantaneous storage)	12.2 hrs	4.95 hrs
* assumes a 40% void ratio ** assumes a 20% void ratio		

In preparation of the base material installation, the geotextile was placed directly on the prepared subgrade and rolled out flat and tight with no folds. Adjacent rolls were overlapped and held in place by workers as base material was placed on top as demonstrated in Figures 15 and 16.

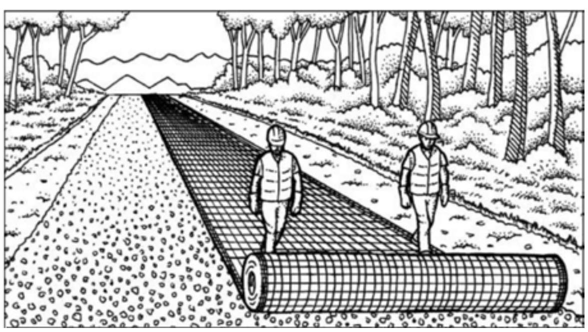


Figure 15: Roll geotextile onto flattened subgrade surface.

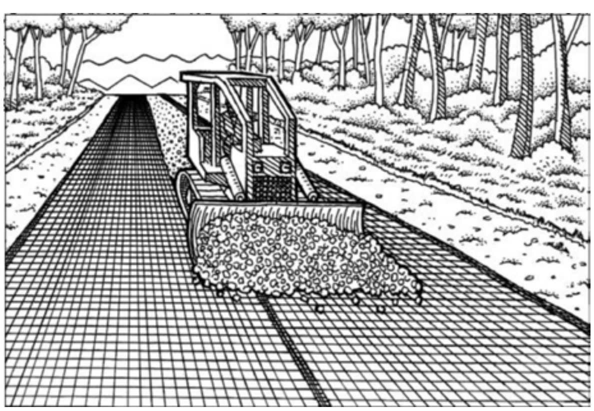


Figure 16: Base material placement onto geotextile.

Figure 17: Geogrid laid on subgrade.

Typically permeable pavement is constructed using 20 mm ø clearstone due to its high void space properties, used for storing water quality control volumes. With a higher void ratio more stormwater can be stored subsurface and detained for longer periods of time. The structural design of permeable pavement dictates the minimum depth of base material required to support the pavement structure. Typically, structural requirements grossly exceeded the depths of base material required to achieve the required water quality control storage volumes, especially when using 20 mm ø clearstone.

Granular “O” was used at the IMAX retrofit site in order to explore alternative options for base materials that would be free draining like 20 mm ø clearstone but may be more suitable for applications where water quality storage volumes are less. Additional benefits, such as comparing their relative performance from a water quality and quantity, economical and structural perspective, were also explored.

The following tables detail the specified base course gradations utilized in the permeable pavement cross sections. Tables 5 and 6 summarize the particle size distribution for both the 20 mm ø clearstone and Granular "O" base materials.

Table 5: 20 mm ø clearstone particle size distribution

20mm ø / ASTM C 33 No 57	
Sieve Size	**Percent Passing**
37.5 mm	100
25 mm	95 to 100
12.5 mm	25 to 60
No. 4 (4.75 mm)	0 to 10
No. 8 (2.36 mm)	0 to 5

Table 6: Granular "O" particle size distribution

Granular 'O'	
Sieve Size	**Percent Passing**
26.5 mm	100
19 mm	85 to 95
13.2 mm	60 to 80
9.5 mm	50 to 70
No. 4 (4.75 mm)	20 to 45
No. 16 (1.18 mm)	0 to 15
75µm	0 to 5

Granular "O" material was placed under the west half of the permeable pavement area while the 20 mm ø clearstone was located on the east half. To effectively monitor the water quality and quantity performance of the two base materials, a Geosynthetic Clay Liner (GCL) spanned the boundary of the two base materials and permeable pavement to asphalt interface. The liner was keyed into the subgrade and sides of the excavation to ensure the base materials are fully separated, hydraulically. This configuration is shown in Figures 18 and 19.

Figure 18: 20 mm ø angular clearstone and Granular "O".

Figure 19: Impermeable liner separating asphalt from permeable paver sections.

Each type of base material is underdrained by a separate network of piping and subsurface infrastructure as show in Figure 20. During the course of the monitoring program, samples collected from the underdrain below the Granular "O" area are separate from those collected from the 20 mm ø clearstone areas. Depending on the results of the performance evaluation, the use of Granular "O" as an alternative base material for LID practices may prove beneficial from both a water quality and quantity perspective.

Figure 20: Underdrain configurations.

Figure 21 shows the layout of the underdrains and maintenance hole in which the water samples and flow monitoring are conducted.

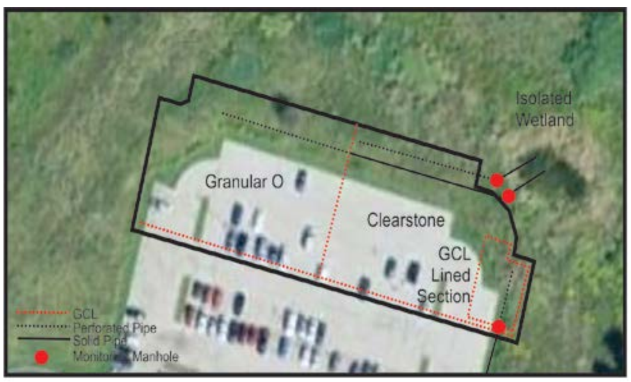


Figure 21: Permeable pavement underdrain layout

In the event runoff volumes exceed the capacity of the permeable pavers and underdrain system, excess flow discharge through a curb cut located at the northeast corner of the pavers (Figure 22) to an isolated wetland, and ultimately, enters the municipal storm sewer.

Figure 22: Overflow curb cut to wetland.

Granular "O" possesses better compaction properties than 20mm ø clearstone. This property allowed for reduced thickness of the base material. The unit cost of Granular "O" is higher but the reduced quantity of material required resulted in a cost savings compared to the 20mm ø clearstone section. Table 7 below contains a cost comparison of these base materials.

Table 7: Area of each base material

Parameter	Granular "O"	20mm ø clearstone
Area (m^2)	1632	1504
\$/m^2	30	37
*Geogrid costs not included		

Since the introduction of LID and other infiltration practices as feasible stormwater management techniques, one major concern has been their potential risk to sensitive groundwater resources and recharge areas. The concerns many municipalities and agencies have involves the potential of infiltrated stormwater contaminants, specifically chlorides from winter de-icing operations, entering sensitive drinking water sources. As part of the project's monitoring program, the effectiveness of GCLs as an impermeable liner option for LID practices is being assessed.

An area of permeable pavement and the entire base structure beneath it was isolated using the GCLs. The GCL was installed on top of the geotextile and wrapped up the sides of the excavation and the boundary between adjacent base materials and terminated just below the permeable paver surface (Figures 23 and 24). The overlapping seams were sealed with bentonite.

Figure 23: GCL installed along base material on top of the geotextile.

Figure 24:20 mm ø clearstone being wrapped with GCL.

Three perforated pipes were installed beneath the liner and join to vertical observation wells located behind the parking lot curb adjacent to the testing location. A simple dye test released on the surface of the permeable pavement determines whether the liner prevents leaks from LID practices. If dye is observed within the observation wells, water from the isolated section would be leaking from the GCL.

Bioswales (dry swales)

Bioswales (also known as dry swales) are soil filter systems that temporarily store and filter stormwater runoff. Bioswales rely on the engineered media bed placed below the channel invert to provide runoff reductions and improved water quality. Runoff treated by the media bed flows into an underdrain, which conveys treated runoff to the downstream infrastructure. The underdrain system consists of a perforated pipe within a gravel layer placed below the engineered media bed. Bioswales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees

The project site incorporates a series of three bioswales located within the median that separates the main driveway from the parking lot area.

- Bioswale #1 (IX-2): West end, upstream of the Sorbtive® Vault polishing unit.
- Bioswale #2 (IX-3): Between the other bioswales and downstream of the Jellyfish® Filter pre-treatment system.
- Bioswale #3 (IX-4): Furthest east within the median, closest to the driveway entrance from Speakman Drive. Figure 25 is an example of a completed bioswale.

Figure 25: Bioswale after construction and landscaping.

A fourth sodded covered bioswale was installed along the west edge of the parking lot to intercept runoff from the surrounding highlands and groundwater inflow to provide free draining conditions for the parking lot.

The bioswale underdrain system consists of an excavated trench lined with non-woven geotextile and filled with an open void 20 mm Ø clearstone. 200 mm Ø HDPE perforated pipes situated within the clearstone bedding underdrain the entire length of each bioswale. The 20 mm Ø clearstone bedding material is fully wrapped with non-woven geotextile so that it overlaps. This covers the top of the clearstone bedding material. Figure 26 shows the lining of the bioswale.

Figure 26: Bioswale with non woven geotextile, 20 mm Ø clearstone with a 200 mm Ø HDPE perforated pipe.

A 300 – 450 mm thick layer of engineered filter media mix) is situated on top of the bedding material with the geotextile separating the two bedding layers. This was to avoid any cross contamination between the clearstone and bioretention soil media to maintain the void space. Table 8 demonstrates the composition of the engineered bioretention soil media.

Table 8: Engineered filter media composition/

<table>
<tr><th>Component</th><th>Percentage by weight</th></tr>
<tr><td>Sand (2.0 to 0.05 mm Ø)</td><td>85 – 88%</td></tr>
<tr><td>Fines (<0.05 mm Ø)</td><td>8 – 12%</td></tr>
<tr><td>Organic matter</td><td>3 – 5%</td></tr>
<tr><td colspan="2">Additional requirements
CEC greater than 10mg/100g
pH = 5.5 – 7.5
Hydraulic conductivity greater than 25 mm/hr
No objects greater than 50 mm</td></tr>
</table>

Inlets to each of the three bioswales consist of a simple curb cut in the barrier curb separating the parking lot and driveway areas from the bioswales. Following the inlets, a 150 – 300mm thick layer of 100 – 150 mm Ø round stone was embedded into the media acting as a flow dissipater and spreader for inflows.

Figure 27: Completed bioretention cells, showing flow dissipater and curb cuts.

Runoff volumes that exceed the capacity of the bioswales are conveyed through overflows situated at the downstream limits/low point of the bioswales.

Figure 28: Completed bioretention cell showing ponding. The overflow bypass is conveyed through a riser stand pipe connecting to the underdrain.

Key Facts

Issues:

- During the 2013 winter, mild weather produced significant melt events. Slush and ice buildup around overflows limited flow capacity and backwatered runoff into the parking lot.

Solutions and lessons learned

- Overflows were temporarily lowered to encourage flow and reinstated the following spring
- Secondary overflow was installed upstream near the curb cut inlets to the bioswales to act as a “fail safe” in the event downstream overflows suffer blockages.

All three bioswales were sized to treat runoff volumes during the 25 mm event (water quality event) and the 1-in-10 year storm event per City of Mississauga minor system design criteria from their respective drainage areas. Table 9 summarizes the physical attributes of the bioswales designs.

Table 9: General dimensions of the bioswales

System component/ parameter	Bioswale #1 Sorbtive® Vault (IX-2)	Bioswale #2 Jellyfish® Filter (IX-3)	Bioswale #3 Stand Alone (IX-4)
Top width	3.5 m	3.5 m	3 m
Bottom width	1-1.5 m	1-1.5 m	1-1.5 m
Side slopes	5:1	5:1	5:1
Long. slope	0.50%	0%	0.50%
Total length	14.5 m	19.5 m	22 m

A series of design computations were part of the design of the proposed bioswales, including:

- **Surface area requirement assessment** – Volume-based calculations determined the required bioswale surface area using the physical attributes of the proposed bioswales. It was assumed the facility was intended to function primarily as a filtration unit versus an infiltration unit.

- **Storage assessment** – Flow-based assessment evaluated the proposed design using both a synthetic (generic) 25 mm three-hour event and a 1:10 year (three-hour, Chicago storm) event. This analysis evaluated the storage volume through a flow-based simulation of the facility surface ponding and sub-surface storage. The assessment was designed to be conservative and assumed no underdrains are included (i.e. a zero outflow condition).

Table 10 summarizes the results of these assessments. In general, bioswales #1, #2 and #3 have been designed to achieve a 25 mm and a 51.7 mm water quality event based on the surface area requirement assessment (volume assessment), assuming a media infiltration rate of 50 mm/hr. In addition, the storage assessment (flow-based assessment) as presented in the table demonstrates the ability of the bioswales to accommodate 100% and 71-73.5% of the inflows from the 25 mm and 51.7 mm respectively.

Table 10: Surface area requirements of the bioswales.

Parameter	Bioswale #1 Sorbtive® Vault (IX-2)	Bioswale #2 Jellyfish® Filter (IX-3)	Bioswale #3 Stand Alone (IX-4)
Contributing drainage area *Note: these are as built drainage areas (total impervious area)	1169 m^2	1457 m^2	2709 m^2
Water quality volume (WQV) to be treated *Note: 25 mm event corresponds to 90% of the total annual rainfall depths	28.13 m^3 (25 mm event)	33.75 m^3 (25 mm event)	39.15 m^3 (25 mm event)
Average ponding depth	300 mm		
Engineered media infiltration rate (assumes 50 mm/hr = SF of 2; measured infiltration rates of media range from 80-120 mm/hr)	50 mm/hr		
Native soils infiltration rate	0 - 2.6 mm/hr (bedrock and clay fill respectively)		
Shredded hardwood mulch depth	50 mm		
Drawdown time	24hrs		
Total facility depth Engineered media Gravel detention layer	0.675 m 0.3-0.4 m 0.4 m		
Perforated HDPE underdrain (diameter)	200 mm		
Required surface area of facility*			
Surface area of facility (as designed)	40 m^2	62 m^2	72 m^2
Required surface area of facility to achieve 25 mm water quality treatment	16 m^2	19 m^2	23 m^2
% of 25 mm water quality achieved	100%	100%	100%
Required surface area of facility to achieve 1:10-year(51.7 mm) event water quality treatment*	34 m^2	40 m^2	47 m^2
% of 1:10 year event (51.7mm) mm water quality achieved	100%	100%	100%
Storage assessment (surface ponding and subsurface storage)**			
Total storage volume (as designed)	27.3 m^3	36.6 m^3	41.6 m^3
Required stored and ponded volume -25mm event (% provided)	15.4 m^3 (100%)	20.1 m^3 (100%)	23.3 m^3 (100%)
Required stored and ponded volume -1:10year (51.7 mm) event (% provided)	37.3 m^3 (73.1%)	49.9 m^3 (73.5%)	57.9 m^3 (71.6%)
*Hydraulic facility calculations – Assumes bioswales functions primarily as a filtration unit (not an infiltration unit)			
**Event simulated using a synthetic 25 mm event per Chow, 1983. Assumes no outflow during rain event, facility simulated as a storage unit only.			

Grassed swales

The grassed swales are located to the north side and west side of the parking lot area. They have been designed to accept flow from their contributing drainage areas which are the portions of the surrounding natural areas that slope towards the parking lot area.

As mentioned in previous sections, the grass channel along the west side of the parking lot can be more accurately described as a sodded bioswale as it features similar design elements as the vegetated bioswales with the exception that the surface treatment atop the bioretention soil media is manicured sod. The primary function of the swale is to intercept groundwater seepage before upwelling to the asphalt surface (Figure 29).

Figure 29: Groundwater seeping onto asphalt parking lot at IMAX prior to retrofit.

Figure 30: Grassed swale/sodded covered bioswale located along the west edge of the parking lot

Swale configuration and surface flow capacity computations ensured the swales were adequately sized to convey minor system flows to their respective discharge points. The west swale discharges to a catch basin and north grassed swale discharges to the isolated wetland area located at the northeast corner of the site. Design results for both swales are detailed in Table 11. The grass swales are not monitored for performance.

Table 11: Grassed swale design

System component/ parameter	North swale	West swale
Drainage area (ha)	0.05	0.2
Minor system design peak flow rate (10yr) (m^3/s)	0.0035	0.0137
Minor system design peak flow rate (100yr) (m^3/s)	0.005	0.0195
Avg. top width (m)	2.6	1.1
Avg. bottom width (m)	1	0.5
Avg. side slopes	2:1	1:1
Longitudinal channel slope (%)	0.5	0.5
Avg. channel depth (m)	0.4	0.3
Bankfull channel capacity (m^3/s)	0.72	0.21
Peak flow velocity (10yr) (m/s)	0.19	0.78

Imbrium Jellyfish® Filter

The Jellyfish® Filter is an engineered stormwater quality treatment technology featuring pre-treatment and membrane filtration in a compact stand-alone treatment system that removes a high level and wide variety of stormwater pollutants. Pollutant removal is achieved at high treatment flow rates with minimal head loss and low maintenance costs. Each lightweight Jellyfish® Filter cartridge contains an extraordinarily large amount of membrane surface area, resulting in high flow and pollutant removal capacity.

Figure 31: Jellyfish® Filter conceptual. (Source: Imbrium Systems)

The unit is comprised of four main parts: the concrete vault structure, cartridge decking, cartridges and cartridge caps. The concrete vault houses the internal components and appurtenances of the unit, including the decking and cartridges. The decking is a prefabricated aluminum structure situated inside the vault structure. The aluminum decking supports the cartridges and partitions the vault into two halves. Inflowing runoff from paved surfaces enters the vault on one side which acts as a sump to collect larger particles and debris. Flows proceed underneath the partition (in Figure 31 it is the transparent purple boundary to the right of the cartridges) to the treatment bay containing the cartridges. Runoff is then forced under pressure through the cartridges which remove pollutants and fine-sized particles. The cartridge lids are fastened onto the cartridges and contain flow control orifices to regulate the flow rates through the cartridges to ensure that the design flow rate is not exceeded during large storm events which would otherwise damage the cartridges and/or impede performance. As runoff events subside, filtered water drains down through the Jellyfish® Filter cartridges and sediment that has accumulated on the cartridges is removed and settles to the sump.

The unit installed at IMAX is situated upstream of Bioswale #2. It acts as a pre-treatment measure for stormwater runoff. Flows from the parking lot area enter a curb cut, flow down a concrete channel, and inlet the sump half of the Jellyfish® Filter unit.

Figure 32: Jellyfish® Filter installed at IMAX.

The unit is customized with an aluminum hatch lid for accessibility to the internal components and easy maintenance. A bypass channel (seen to the left of the unit in Figure 32) has been constructed in the event the filter is clogged or flow capacity is exceeded. Excess flows simply back-up the concrete spillway and overflow to the vegetated bioswale.

The Jellyfish® Filter has been designed to treat storm events up to 25 mm with four hi-flow cartridges and two draindown cartridges (Figure 33) able to convey a total design flow rate of 12.60 L/s as summarized in Table 12.

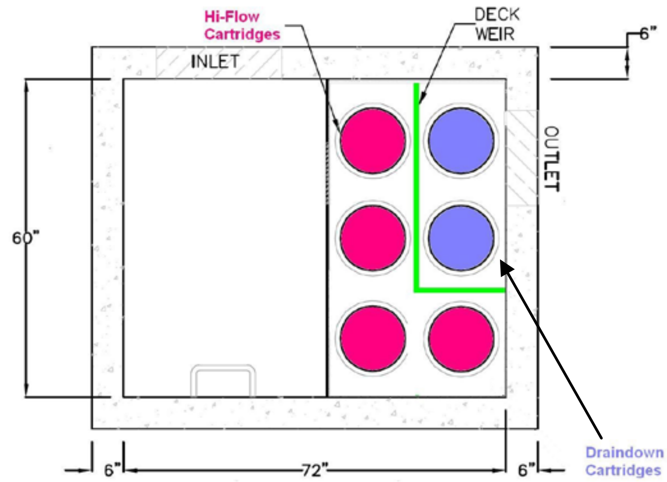


Figure 33: Jellyfish® Filter Plan View (Hi-Flow and Draindown cartridges).

Table 12: Jellyfish® design summary.

Hydrologic Parameters	Value
Design precipitation event (mm)	25
Runoff coefficient	0.95
Water quality discharge (L/s)	9.03
Jellyfish® Filter Design	Value
Hi-Flo treatment flow rate (L/s)	5.55
Draindown treatment flow rate (L/s)	1.39
No. of Hi-Flo cartridges required	4
No. of drawdown cartridges required	2
Total treatment flow rate (L/s)	6.94

Sorbtive® Vault

The Sorbtive® Vault is an engineered stormwater quality treatment technology which incorporates Imbrium Systems' Sorbtive® Media as a tertiary treatment to further polish treated stormwater by filtering it through a bed of Sorbtive® Media, a product with high phosphorus adsorbing properties; thus achieving low total phosphorus effluent concentrations.

Sorbtive® Media is an oxide-coated high surface area reactive engineered media that sorbs and retains large phosphorus dissolved loads with a removal efficiency of 90%. Sorbtive® Media provides between 100 and 1,000 times more pollutant removal capability compared to conventional filtration media; and unlike other media, it does not desorb (leach) pollutants.

Figure 34: Sorbtive® Vault interior

The Sorbtive® Vault is situated at the downstream limit of Bioswale #1 and acts as a tertiary treatment unit to polish treated stormwater from the Bioswale #1 underdrain. Treated stormwater from the bioswale underdrain is distributed to the treatment bay and Sorbtive® Media. Figure 35 shows the various components of the Sorbtive® Vault.

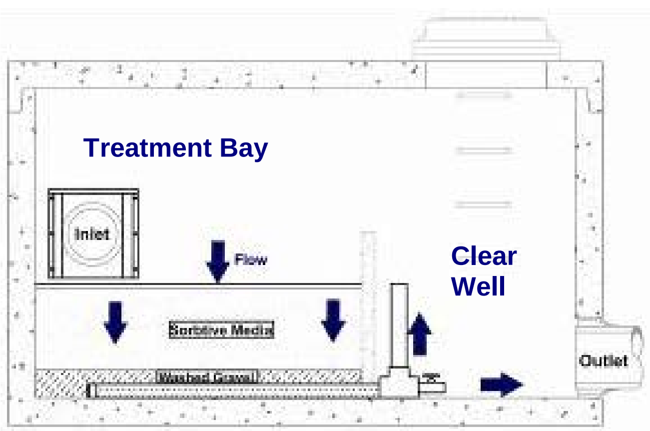


Figure 35: Conceptual of the Sorbtive® Vault installed at IMAX.

Within the treatment bay, an underdrain system is located at the bottom of the vault to collect the treated water and discharge to the clear well. The system functions based on the varying head pressure between the inlet and riser pipes connected to this underdrain system. As the treatment bay fills, stormwater is forced through the Sorbtive® Media and through the PVC riser pipes. Due to the system hydraulics, low flows are maintained through the media which allows for adequate contact time for maximum phosphorus uptake. Flows from the riser pipes simply discharge to the clear well and subsequent outlet pipe.

Sorbtive® Media has optimal performance when the media is free draining and able to dry between wet weather events. To help it drain fully a ball valve situated at the bottom of the media bed is opened slightly. This allows the system to bleed excess water accumulated within the media and gravel layers and ensures flow during rainfall events are forced through the PVC risers.

Furthermore, to ensure that the Sorbtive® Media is not scoured out of the filter bed and constituent uptake capacities are not exhausted during large storm events, the bioswale overflow discharge directly to the clear well, thereby bypassing the Sorbtive® Media filter bed. The overflow is depicted in Figure 36 as the black and white piping situated behind the vault which discharges directly to the clear well. The green pipe is the bioswale underdrain which discharges to the Sorbtive® Media bed.

For more information regarding Sorbtive Media and Sorbtive® Vault systems please refer to www.imbriumsystems.com.

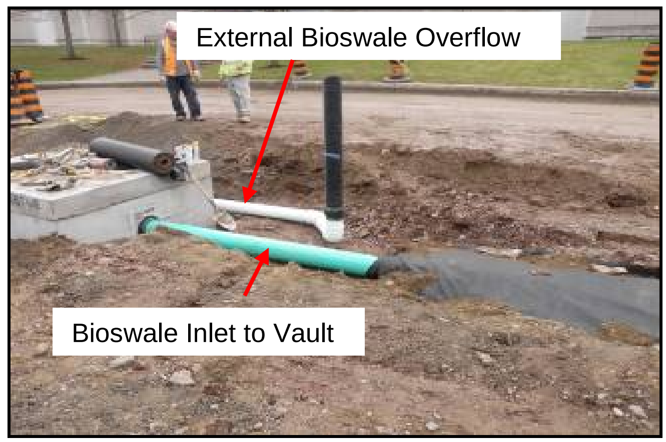


Figure 36: Sorbtive® Vault installed at IMAX and upstream bioswale.

Construction & Commissioning – General Issues

The construction of the IMAX project commenced in October 2012 and concluded December 2012. A few tasks, such as the final coat of asphalt and a few restoration items, were completed during the spring and summer of 2013. During the course of the construction process the project team encountered a variety of challenges and obstacles, some general and others specific to LID.

Client expectations

Client expectations were exceptionally important during the construction process due to IMAX's high standards. Construction timelines, construction, quality and site management were all top priority during the construction process.

Tight timelines

The complexities of the design process lead to the delay of the tendering and construction process. Pressures from IMAX mounted since the IMAX operations required a fully functional parking lot before December. The anticipated work schedule received from the contractor was 41 days, leaving only a single float day to cover any unforeseen delays. IMAX representatives requested daily progress reports to ensure that the project was on schedule and any potential fall backs could be addressed immediately.

Figure 37: Wet conditions during construction due to severe weather.

Within the first several weeks of construction, five days of adverse weather delayed construction activities. To advance the project schedule, weekend work and extended work hours were required.

Site management

IMAX required half of the parking lot to remain in use at all times. To accommodate this request, the contractor and contract administrator performed daily parking operations throughout construction so they did not interfere with the construction. During the construction of the permeable pavement sections, parking was limited to the existing asphalt surfaces. Upon completion, the permeable pavement areas were used as a parking surface while the construction of the new asphalt sections and remaining works were completed.

These measures ensured that adequate parking was available and parking of vehicles was done in a systematic order, especially when existing parking stall markers were removed during asphalt removal works. In addition, construction work and material delivery schedule did not restrict access to delivery locations, main entrance and street through-way.

Construction & Commissioning – LID Specific

The IMAX project site faced several challenges. Here are some items to consider for future LID projects.

Suppliers and partners

Demonstration projects present great opportunities to form teams with suppliers and industry professionals to showcase a certain project or technology. For example, the IMAX Project includes many innovative stormwater technologies and LID practices integrated to demonstrate the performance and effectiveness of a “treatment train” approach. To ensure these treatment trains would function properly and that the team could monitor their effectiveness, many of the technologies required customization. Contract administrators managed coordination between the manufacturers, contractor and client was to ensure the ordering, payment and delivery of materials was correct, on time, and on budget. Open communication between the monitoring and design teams, product suppliers, and clients ensured that all stakeholder interests would be fulfilled.

Bioretention soil media testing

Filter media manufactured for the bioswale were analyzed to verify that the mixtures met the standards outlined in the Low Impact Development Planning and Design Guide.

Figure 38: Bioretention soil media consisting primarily of sand and organic material.

Mechanically mixed bioretention soil media samples were collected and submitted to a certified laboratory for analysis. To minimize contamination from the mixing system, the team passed a minimum of 10 m^3 of filter media through the system and disposed of it. A minimum of three samples were collected from the next

10 m^3 of material, including one from the bottom of the pile (1-3 m^3 of material), the middle (4-6 m^3 of material), and top (7-10 m^3 of material).

A two-point hydrometer test determined the soil textures of the sampled bioretention soil media and categorized the sample into percentages of sand, silt and clay. The test has a minimum detection limited of 2% for each particle size analyzed. The first samples submitted demonstrated 12% clay material and <2% silts which bordered on failure. A second sample was requested to verify manufacturing consistency and determine if the percentage of fines can be reduced. It is preferable to have bioretention soil media samples that demonstrate fine percentages closer to the low end of the acceptable range. The processes of loading, transporting and handling bioretention soil media material can often result in an increase in percent fines by the time the bioretention soil media is installed. Soils high in fines can be easily clog and reduce drawdown times. Clogging will negatively impact the effectiveness of the LID practice.

Figure 39: Mechanically mixing process for bioretention soil media manufacturing.

The second sample failed to meet specifications. This failure was the result of a miscommunication between the soil manufacturer and the personnel at the sourcing yard responsible for mixing the correction materials. To ensure the proper materials were used for the submission of the third sample, field engineers and soil manufacturer met at the mixing yard to verify the raw materials and to observe the mixing operations. Three samples were again collected during the mixing of the bioretention soil media and submitted for analysis. Although the bioretention soil media was marginally low in organics, the sample was accepted as fine percentages were optimal and natural process from landscape material would increase organic percentage over time.

Education

Providing an onsite supervisor as a resource to interpret and explain features of the design drawings to the contractors was highly important during the construction of the IMAX Project. Many of the innovative stormwater technologies and LID practices detailed within the design drawings were not familiar to the contractor onsite.

The design drawings were prepared with enough clarification that the contractor had little difficulty installing and constructing of the design. The design team and contractor could address the challenges the contractor faced. Utilities encountered during construction were either relocated or avoided and design conflicts or alterations were resolved with input from the various stakeholders. General questions and inquiries regarding the various design elements and installation procedures were generated primarily out of interest versus confusion.

Sediment and erosion control

A typical erosion and sedimentation control plan was included with the design drawing. It consisted of catch basin inlet controls and filter socks. No excavated material had to leave the site, so road cleaning operations were limited.

Figure 40: Filter sock installed to protect wetland.

The most difficult ESC operation was controlling the amount of sediment deposited on the permeable pavers once they were designated as the primary parking area. During the construction of the asphalt areas, vehicular traffic had to travel over open aggregate to access the permeable pavers for parking. Through discussions between CVC, the contractor, and construction supervisor, it was decided vehicles would be diverted over washed clearstone and a temporary asphalt access strip prior to accessing the permeable pavers. Access to the permeable pavers was limited to a single location so that the degree of contamination could be managed, monitored, and maintained more efficiently.

Figure 41: Access route to permeable pavement.

Prior to the installation of the bioretention soil media and paving of the asphalt parking areas, sediment socks and sacrificial pieces of filter cloth were installed to protect the bioswale infrastructure from contamination. Sacrificial pieces of filter cloth were installed over the cloth-wrapped clearstone reservoir of the bioswales Prior to the installation of the bioretention soil media; this filter cloth was removed and included any captured contaminating fines. Figure 42 shows how the filter cloth was used.

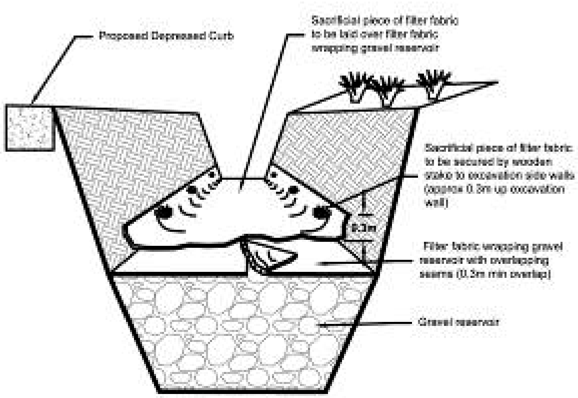


Figure 42: Conceptual of the sacrificial piece of filter cloth used to protect bioswales.

Filter socks were staked in place at the bioswale curb cut to prevent sediment laden runoff from entering the bioswales. These measures were removed once the bioretention soil media was installed and asphalt areas were stabilized.

Figure 43: Sediment socks installed at bioswale curb cuts.

Economic (Capital & O&M Costs)

LID practices are becoming a cost-effective option for businesses. The cost of a retrofit can be balanced against the increasing risks that come with climate change. As extreme storm events increase in frequency, insurance and maintenance costs increase accordingly. Flooding has the potential to do considerable damage to a business. Flood waters can cause property damage and disrupt normal operations. A business can also be found liable if flooding or drainage related issues put individuals at risk, such as from slipping on ice. The costs of construction can be balanced against this potential harm.

The costs involved in a demonstration site are expected to be higher than a typical LID retrofit. In this case, many contributing partners and stakeholders made the project possible. Future LID projects should benefit from the monitoring data collected from the IMAX project.

Table 13 shows the both the estimated and total construction costs for the project. The final cost of the project was well below the budget.

Table 13: Economic costs of the IMAX project

Capital costs	
Item	Cost
Design/consultant fees	$78,000
Estimated cost for construction of bioswale, stormwater technologies, pervious paver, asphalt, lighting and drainage works	$797,000
Actual cost for construction of bioswale, stormwater technologies, pervious paver, asphalt, lighting and drainage works	$776,000

Operations and Maintenance

Adequate maintenance is essential to achieve the long-term stormwater management performance targets. Maintenance requirements for most LID technologies have little difference from most turf, landscaped, or natural area and do not typically require new or specialized equipment. Table 14 is a summary of typical maintenance requirements for the various LID source and conveyance controls. Proprietary technologies have their own maintenance requirements.

Table 14: Typical maintenance requirements for various LID practices

Practice	Maintenance needs
Perforated pipes	Regular maintenance • Clean debris and litter Annual • Inspect stone drainage area. Ensure that the stone fill is level to the ground and that the filter fabric has not become clogged with sediment
Permeable pavement	Regular maintenance • Minimize heavy vehicle traffic, as the weight can compact debris into voids • No construction traffic or materials storage on finished surface. Winter • Use only HPB bedding stone as winter aggregate if necessary • Ploughed snow should be placed within designated snow storage area. Bi-annually • Surface sweeping Annual • Spring inspections to ensure continued infiltration performance
Grassed swales	Regular maintenance • Clean debris and litter • Mowing operations should avoid compaction whenever possible and grass height should be maintained at 15mm. Annual • Inspection of turf condition.
Bioswales	First six months after installation • Inspect after each storm greater than 10mm, or at least twice. Bi-annually • Standard landscape maintenance. Annual • Inspection drainage feature for clogging.

Sorbtive® Vault

- Inspect every four months (excluding winter)
- Check for any trash or debris
- Make sure there is no standing water in treatment bed or clear well
- Ensure the concrete splash block under the inlet pipe (brick) to hold erosion control mat down has not moved
- Ensure discharge pipes are open and clean
- Look for evidence of a water line of sediment or oil/fine silt on the dividing wall
- Sample effluent and analyse to ensure that the phosphorus adsorption capacity has been reached and phosphorus removal remains satisfactory
- As a consequence of a raccoon getting into the Sorbtive® Media and storm sewer, the facility had to be cleaned and a control gate installed, at a cost of $547.

Jellyfish® Filter

- Post-construction inspection is required prior to putting the Jellyfish® Filter into service.
- Routine inspections during the first year of operation to accurately assess the sediment and floatable pollutant accumulation, and to ensure that the automatic backwash feature is functioning properly
- Inspection frequency in subsequent years is based on the maintenance plan developed in the first year
- Perform inspections immediately after oil, fuel or other chemical spill.
- Inspect Jellyfish® Filter from the surface through the standard surface manhole access cover or custom doors.
- Perform sediment and oil depth inspections with a sediment probe and oil dipstick. Measure sediment and oil depth through the maintenance access wall
- Visually inspect for floatable pollutant accumulation, such as litter and hydrocarbons, by shining a flashlight into the maintenance access wall
- Visually inspect the backwash pool for standing water. If at least 12 hours of dry weather have elapsed since the most recent rainfall/runoff event and the backwash pool contains more than three inches of water, the filter cartridges are saturated with sediment. Clean or replace them
- Visually inspect the internal components of the system for obvious damage.
- Maintenance on the Jellyfish® Filter unit at IX-3 is done according to a 3 year program from Minotaur, which costs $880/year to service the jellyfish filters. The cartridges are washed on site and re-installed annually the service also includes an inspection and report. The filters are projected to last 5 years with annual maintenance. The replacement cost is $570/set.

Winter maintenance operations

CVC and IMAX have developed a winter maintenance program that details LID-specific winter operation and maintenance procedures, including the monitoring and controlled application of de-icing salt and snow removal procedures.

Winter salting

Starting in December 2013, road salting and snow removal activities have been monitored. Site operators are to record the volume of road salt applied on the asphalt and permeable pavements. Road salt introduces many pollutants to winter stormwater. Samples of road salt are to be analyzed to assess the type and degree of pollutants introduced to the parking lot by road salting. If feasible, Hydrolab HS-5 may be used to continuously measure parameters such as water temperature, conductivity, chloride and pH at 15-minute intervals.

Plough damage

It was challenge for the contractor to perform maintenance operations such as ploughing. Curbs were not clearly visible to the contractor which resulted in curb damage (Figure 44) and replacement. To address this issue, the project team installed marked stakes by the curb line to inform the contractor when ploughing.

Figure 44: Curb damage due to snow ploughing.

The steel plough used by the contractor scraped the surface of the permeable pavement (Figure 45). Rubber edging was installed on the steel plough to prevent further damage.

Figure 45: Paver scraped by winter plough.

General snow removal

As part of the design, the project team considered designated snow storage areas to limit the amount of snow stored within infiltration practices and risk of covering and clogging overflows. Roll curbs along the east side of the parking lot limit curb damage along the snow removal areas. Working with the contractor, CVC and IMAX have refined the snow removal operations by:

- Reducing the size of snow removing equipment used on the permeable pavement
- Requesting that a rubberized plough edge be used during snow removal
- Using designated snow storage areas and avoiding covering overflows
- Reducing salt application
- Installing marked stakes along curbs to avoid curb damage during ploughing operations.

Key Facts

Issues:

- Although designated snow storage areas were made available along the east and north sides of the parking lot, ploughing distances and snow qualities made it difficult to manage snow volumes within these limited areas.

Solutions and lessons learned

- The bioswales were used as snow storage areas. However, additional consideration should be given to the planning of snow storage areas. Hypothetically, if IMAX was located in a sensitive groundwater recharge area, utilization of the bioswale as snow storage areas may not have been possible. Extra forethought to the location of snow storage areas and use of infiltration areas as snow storage areas (i.e. lined LID practices) is highly recommended during the design and planning phase.

LID Inspection Checklists

CVC monitoring staff has developed an inspection checklist to document obvious visual maintenance needs during routine site visits. Although this information has been collected since 2013, meaningful interpretation can only be made with additional years of monitoring, especially if life-cycle costs are to be calculated.

A checklist format was chosen in order to record site conditions and maintenance needs as accurately as possible. The goal of the checklist is to make inspections simple and straightforward for anyone to complete. There is a corresponding legend to accompany the checklist to give guidance to someone who may not be familiar with LID. Information on maintenance and LID condition is collected each time in the same format, ensuring proper documentation and making it easier to track changes over time which gives consistency to the monitoring results. The checklist data can provide the frequency of maintenance needed for each site and insight into future designs and planning of LID features. Using these checklists, the user can gather data at the site and establish maintenance schedules and costs. This data is important to the functionality and life cycle of LID features.

Permeable pavement inspection results

Sediment accumulation and the presence of trash/debris are consistently low on the permeable pavements (Table 15) Clogging was evident localized areas because of excavated soil that was temporarily stored on permeable pavement during construction activities. Clogging was mainly observed at IX-5. This is a good example of how the frequency and degree of maintenance required can be increased through improper care of LID facilities. By contrast, proper care can minimize the maintenance requirements and prolong the life of green infrastructure.

Table 15: Permeable Pavement Maintenance Inspection Results

IMAX Permeable Pavement Summary Table	Condition	IX-5	IX-6	IX-7
Sediment	Average Category	Good	Good	Good
	% Good	96%	100%	100%
	%Mild	4%	0%	0%
	%Moderate	0%	0%	0%
	%Severe	0%	0%	0%
Trash/Debris	Average Category	Good	Good	Good
	% Good	90%	87%	87%
	%Mild	10%	13%	10%
	%Moderate	0%	0%	3%
	%Severe	0%	0%	0%
Clogging	% of visits clogged	13%	4%	7%

Bioretention inspection results

Vegetation has regularly showed good health during the growing season (Table 16) with the exception of trees that were originally planted in the bioswales as they have low survival rate and require replanting. Such maintenance activities could be reduced by ensuring that only vegetation appropriate to the growing conditions is planted in the bioswales. The extent of bare soil in the bioswale has increased as a result of incoming erosive flows. This is evident as the force of incoming water caused the top mulch layer to be accumulate downstream regular raking in the bioswale to evenly distribute the mulch layer would prevent erosion of the filter media and reduce the extent of bare soil.

Sediment and trash/debris levels are generally low in all bioswale facilities and the bioswale inlets/outlets. The bioswales occasionally experience elevated debris levels on a seasonal basis, likely due to leaf litter in the fall. Only the inlet to the jellyfish regularly shows moderate sediment accumulation.

Table 16: Bioretention Maintenance Inspection Results

IMAX Bioswales Summary Table	Average Category		
Parameter	IX-2	IX-3	IX-4
Bioswale: Bare Soil	Severe	Moderate	Severe
Bioswale: Erosion	Moderate	Moderate	Moderate
Bioswale: Sediment	Mild	Mild	Mild
Bioswale: Trash/Debris	Good	Good	Good
Inlets to Bioswale: Erosion	Mild	Good	Mild
Inlets to Bioswale: Sediment	Mild	Mild	Mild
Inlets to Bioswale: Trash/Debris	Mild	Mild	Good
Outlets in Bioswale: Erosion	Good	Good	Good
Outlets in Bioswale: Sediment	Mild	Good	Mild
Outlets in Bioswale: Trash/Debris	Mild	Good	Mild
Vegetation: Weeds/Invasives	Good	Good	Good

Figure 46: Sediment Accumulation in Jellyfish Filter Inlet

Infrastructure Performance and Risk Assessment

The IMAX Project provides a unique opportunity to construct and evaluate the performance of multiple LID practices for a commercial/industrial application as well as demonstrate the use of LID for retrofit projects.

Despite efforts by the Province of Ontario and conservation authorities, numerous barriers and challenges impede the broader implementation of LID practices. These challenges include (but are not limited to):

- Lack of local performance data with only a handful of physical pilot sites to represent a decade of efforts by CVC and others
- Lack of sustainable municipal funding to demonstrate the long-term performance of LID systems in field scenarios
- Need to update current municipal policies and by-laws to accommodate LID
- Lack of guidance and functional demonstration projects to build capacity and reduce anticipated risks and uncertainties
- Continuing perception among some practitioners that conventional stormwater management can meet today's more comprehensive watershed health targets.

The site's Infrastructure Performance and Risk Assessment Program (IPRA) will directly address several knowledge gaps to elevate confidence in LID technologies within Ontario. The IPRA project involves partnerships between CVC, the University of Guelph and industry partners including IMAX, Aquafor Beech Limited, Unilock and Imbrium.

Research objectives

This study includes seven overarching objectives to meet the interests of CVC as well as the interests of industrial and academic partners. Most importantly, these objectives were structured to address top stakeholder priorities with respect to long-term maintenance and subsequent performance, life-cycle costs, water quantity and quality in poor infiltration soils, and how multiple LID systems work to provide flood control, erosion control, improve water quality and protect natural heritage systems. Other agencies that were consulted in the development of these objectives include municipalities, Ministry of the Environment, Building Industry and Land Development Association (BILD), CTC Source Protection Region, and developers.

Table 17 details the objectives and intent for each objective. Each objective is geared towards answering specific and practical monitoring questions about the performance and operation of LID systems within the CVC watershed and southern Ontario, as detailed in Table 18.

Table 15: The LID performance monitoring objectives and reasoning

Objectives	Reasoning
Apply and demonstrate LID systems within an urban community in the GTA.	Due to lack of guidance and functional example projects, LID implementation has a history of underperforming and not being recognized as part of the broader goals and targets of watershed planning. This project is a demonstration site of LIDs for industrial/commercial applications within the Credit River Watershed.
Evaluate the behaviour of LID technologies as individual and collective systems relative to a traditional asphalt-to-catchbasin system.	Full-sized LID system performance has not been widely studied and some of the designs in this project have never been tested in field installations. LID monitoring studies have tended to be limited to individual installations of a single LID technology versus integrated designs. The IMAX Project uses several LID systems on a single lot. Evaluating the performance of the LIDs implemented at IMAX as a collective system as well as individual systems will demonstrate the environmental benefits of these technologies when used in a treatment train.
Assess designs of permeable pavement systems to meet multiple environmental and non-environmental objectives.	The cost of aggregate bases required for structural pavement design is a barrier. Evaluating the performance of alternative aggregate products may allow permeable pavement to be designed at lower costs for a broader range of uses. Two aggregate bases will be monitored (20 mm clearstone and granular 'O') to determine if one may offer better balance between structural and environmental design objectives than the other. Another barrier limiting the use of permeable pavement is the unknown risk to groundwater systems. The program will test the effectiveness of the geosynthetic clay lined (GCL) section of the permeable pavement. The collected performance data can be used to assess the option of using GCLs as an effective means of lining infiltration systems in groundwater sensitive areas as found in CVC's upper watershed and across southern Ontario. The IMAX design presents the opportunity to test alternative operational settings by controlling drawdown times at underdrain outlets which will explore how environmental benefits may be optimized by regulating outflow.
Evaluate the potential of in-series LID systems (Jellyfish® Filter to bioswale and bioswale to Sorbtive® Media) to maximize water quality improvements.	Monitoring of in-series LIDs is the first of its kind in Canada and performance data from these systems will be used to evaluate whether this treatment-train approach improves stormwater quality. Performance data will also allow managers to analyze costs and benefits of in-series LID systems and determine whether LID practices are enhanced by secondary treatment measures.
Investigate long-term performance of LID systems and the implications to receiving surface and groundwater systems.	With lack of true long-term studies (i.e. > 2 yrs) for LID installations, the experimental design aims to implement a long-term monitoring program for up to 10 years in an effort to create a continuous and the most comprehensive LID performance datasets within North America. Cold climate performance data is sparse and is a critical topic for the adoption of LIDs throughout Canada. Long-term monitoring will identify seasonally-dependent LID performance in terms of both stormwater quantity and quality.
Monitor and assess the O&M needs of LID systems and the subsequent effects on performance.	Questions and concerns regarding O&M continue to impede the use of LID systems. Performance data collected through the monitoring program will be used to plan and adapt maintenance activities. Road de-icers and chloride are pollutants of concern. Researchers will investigate if permeable pavements require less winter maintenance than asphalt surfaces by monitoring winter salting. The IMAX design presents the opportunity to test alternative operational settings by controlling drawdown times at underdrain outlets. By regulating outflow the LID design can be optimized to meet multiple environmental benefits. This will explore how environmental benefits may be optimized by
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.).	CVC will use monitoring program results to produce guidance documents for the design, construction and O&M of LID systems. These documents will provide technical resources for developers, designers, engineers and property owners and support the necessary shift to LID technologies and sustainable stormwater management.

Table 16: The LID performance monitoring questions

Hydrologic questions	Water quality questions
• What are the volume, timing and rate of outflows from the LID systems and asphalt? How do they compare? • What conditions (i.e. rain events) produce no outflow? In other words, what magnitude storm is fully retained? • What conditions (i.e. rain events) cause overflow/bypass? • What are the event-based peak flow reductions, volume reductions and lag coefficients? • What are the overall hydrologic performance statistics for the monitored events (e.g. annual volume reduction, average peak flow reduction, etc.)?	• What are the differences in water quality between LID system outflow and asphalt runoff in terms of TSS, nutrients, heavy metals, and temperature? • What are the event-based removal efficiencies and pollutant loadings? • What is the longer-term water quality performance (e.g. annual TSS removal)?
Design questions	**Long-term questions**
• Could the LID features used at the site reduce the size of pond required downstream if applied in a new development? • What are the differences in performance between granular “O” and 20 mm clearstone as a base layer for permeable pavement? • Do secondary systems (i.e. Jellyfish® Filter and Sorbtive® Media) used with bioretention improve stormwater quality? • Can increasing drawdown time of permeable pavement areas increase the environmental benefits of LID systems?	• How do LID systems perform over the long-term? • Are environmental benefits sustained over the long-term? • What are the seasonal effects on hydrologic behaviour and stormwater quality? • What performance measures may be appropriate to determine potential rebates on development charges, credits on municipal stormwater rates and/or reductions in flood insurance premiums?
Operation and maintenance question	
• Can maintenance activities be linked to overall performance? • What performance thresholds may be appropriate triggers for maintenance activities? • Does regular O&M (such as removal of trash, surface sweeping (twice a yr); inlet structure clean out (monthly); pruning, weeding, mulching, watering, fertilizing)? • Enhance plant survival? • Reduce maintenance costs? • Increased life expectancy of parking lot? • What is the required frequency of other O&M activities? (e.g. media replacement, sediment removal) • What are the life-cycle costs for these LID practices (i.e. permeable pavement, bioretention cells, Jellyfish® Filter unit and the Sorbtive® Vault)	

Data Collection Methods and Equipment

To evaluate the performance of LID systems, researchers monitor climatic (precipitation, temperature etc.) and hydrologic (inflow/run-on, water level/moisture, and outflow) parameters, and collect water samples for water quality analysis. The following sections provide an overview of the methodology used to monitor these parameters.

Climatic

Input parameters are measured using rain gages or tipping buckets located near, or preferably at, the monitored LID. Rain gauges are the most commonly used system for measuring precipitation and a heated device allows for winter measurements. A heated rain gauge was selected and installed on site to collect precipitation data (Figure 47). Precipitation data is logged at a five-minute interval.

Figure 47: Heated rain gauge installed on-site.

Water quantity monitoring

Underdrains or collection pipes serve as access points and outflow from these pipes is measured using stage-based or volume-based methods. Flow measurements at the various monitoring locations are conducted using stage-based flow measurements (i.e. weir and water levels) because:

As a fully operational parking lot all monitoring equipment had to be installed below grade in maintenance holes and monitoring structures such as a vault were not allowed on the property. Manholes did not provide sufficient space for alternative devices such as tipping buckets. There is no access to electrical power at the site and as a result ultrasonic sensors were ruled out.

V-notch weirs are installed and calibrated by consultants within the outlet structures (i.e.: manholes). The V-notch configuration was selected to accurately measure outflows as small as 0.1 L/s with minimal errors. To monitor water level, ISCO 4150 flow loggers have been implemented in the outlet structures for all LID systems (Figure 48).

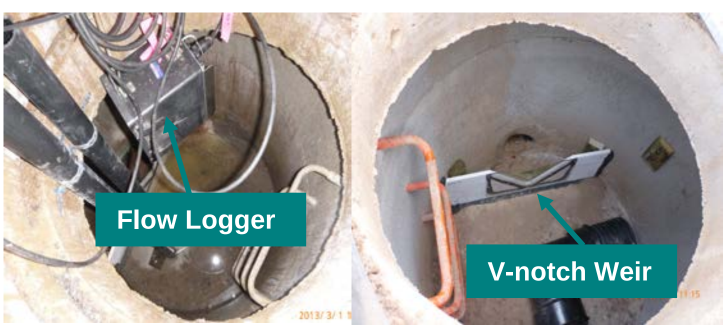


Figure 48: Water quantity monitoring set-up.

The consultant experimented and developed a stage-discharge curve for the V-notch weirs in a lab setting. As shown in Figure 49, the IMAX rating curve is used to convert field measured water level data to discharge (L/s).

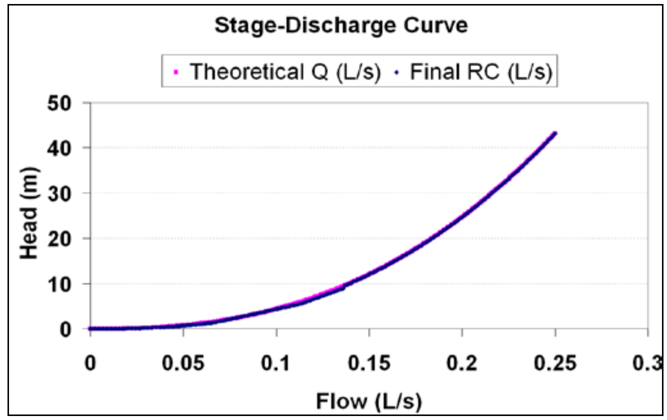


Figure 49: Stage discharge curve from IMAX

Observational wells are used to monitor changes in water level within the bioretention soil media and aggregate bases for both the bioswales and permeable pavement. Industrial organizations, such as the ICPI, recommend wells as a long-term and simple method for monitoring exfiltration rates.

These observational wells help identify which rain events cause overflow or surcharging conditions in the bioswales. Also, the incidence of overflow of permeable pavements can be observed by the presence of runoff draining by way of an adjacent curb-cut to a wetland. If appropriate, permeable pavement runoff can be measured with a weir and water level logger at the curb-cut.

Flow and water level monitoring are continuous and thus, all outflow events are observed. Hydrologic data intervals were chosen to provide the finest resolution possible to better capture the runoff response from small areas. Sampling intervals for each element of the monitoring program:

- Data is logged at a one-minute interval at the control site (with the option to download the data at a preferred interval such as five minutes), and
- Data is logged and downloaded at 10-minute intervals at other monitoring stations.

Water Quantity Monitoring

Following other studies (e.g. Drake et al., 2012; Brown et al., 2012a; Chapman and Horner, 2010; TRCA, 2008) stormwater quality is monitored with flow-proportioned composite samples collected by automatic samplers and analyzed for a variety of common stormwater runoff constituents.

Parameters

Water quality parameters were intentionally chosen to include parameters studied in the existing published literature (refer to summary documents provided by the International Stormwater BMP Database), allowing the quality of the IMAX stormwater and the performance of the LID practices to be interpreted and discussed in context with other LID projects. Parameters were also selected to ensure pollutants of interest/concern as identified in the CVC Impact Monitoring Program 2007-2011 Report were included in the monitoring program.

Preferably samples are analyzed for a complete suite of metals but testing may be limited to key metals if necessary. Priority will be given to pollutants of concern for the Sheridan Creek watershed, pollutants with provincial water quality objectives (PWQO) and pollutants which have been monitored in published research. Priority metals include arsenic, cadmium, chromium, copper, iron, nickel and zinc.

During the spring, summer and fall seasons, the collected samples are analyzed for the following constituents:

- General Quality
    - Total Suspended Solids (TSS)
    - Total Dissolved Solids (TDS)
    - Hardness
    - Chloride
    - Temperature
    - pH
- Nutrients:
    - Phosphorus (total and dissolved)
    - Nitrogen
- Metals

Winter salt monitoring

Road salting and snow removal activities stared in 2013. Working with site operators, the volume of road salt applied on the asphalt and permeable pavement is being recorded. Winter performance monitoring is conducted at all bioretention units; however the permeable pavement is limited to Catchment 7 (see Figure 51) as monitoring stations IX-5 and IX-6 are not operational during the winter months because equipment is removed to prevent freezing.

Road salt introduces many pollutants, beyond sodium and chloride, to winter stormwater. Samples of road salt will be analyzed to assess the type and degree of pollutants introduced to the parking lot by road salting. Electrical conductivity probes are be used to continuously measure conductivity, which can be used to determine chloride concentrations. A laboratory tests are performed to determine the correlation between conductivity and chloride for the site.

Winter samples are anticipated to have a different constituent "make-ups" compared to the other seasons as a result of road salting. Water quality analysis of winter stormwater samples may be limited to only pollutants which are known to be seasonally dependent.

Sampling frequency and equipment

A minimum of 10 precipitation events are sampled per year. Using an adaptive management approach, the monitoring frequency is re-evaluated annually and revised based on observations and monitoring results, such that future programs evolve in order to effectively address the objective of the monitoring program. An ISCO Autosampler was installed at all monitoring stations to collect water quality samples. The Autosampler has sampler holds 24 1-litre bottles (Figure 50).

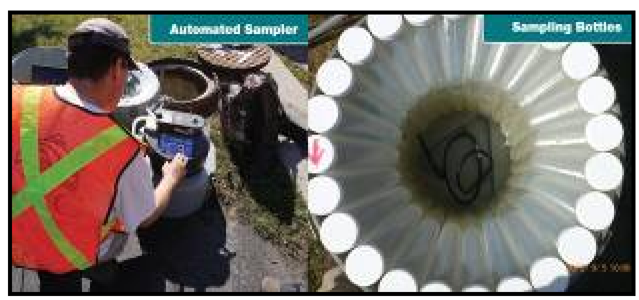


Figure 50: Water quality sampling.

The automatic sampler is programmed to collect samples that allows for a composite sample to be collected for water quality analysis for each event at each outflow monitoring station. When the sampler is triggered, all bottles are filled provided there is sufficient runoff. Bottles that were sampled while outflow was observed are used to generate a flow-weighted composite sample. The sampler is programmed to collect samples at a fixed time interval. The length of time of the sampling program may be increased or reduced depending on the rain event forecasted to provide a flow-weighted composite sample that is representative of the rain event. Once the autosampler program is complete, CVC staff download data and create a flow weighted composite sample for EMC analysis.

CVC's monitoring team visits the site following every rain event and at a minimum every two weeks to check battery power, inspect equipment, and ensure proper operation. Data is downloaded by CVC staff from each piece of equipment using ISCO Flowlink 5 or Hoboware software (or equivalent). Field and lab data management follows CVC's Data Storage, Organization, and QA/QC Protocol.

Monitoring locations

The parking lot was divided into seven subcatchments, defining the drainage area entering each stormwater management system. There are a seven monitoring stations. Figure 51 shows the layout of the retrofit parking lot and outlines the various stormwater management systems. Table 19 summarizes the monitoring tasks for all systems and is followed by a detailed description of each drainage area.

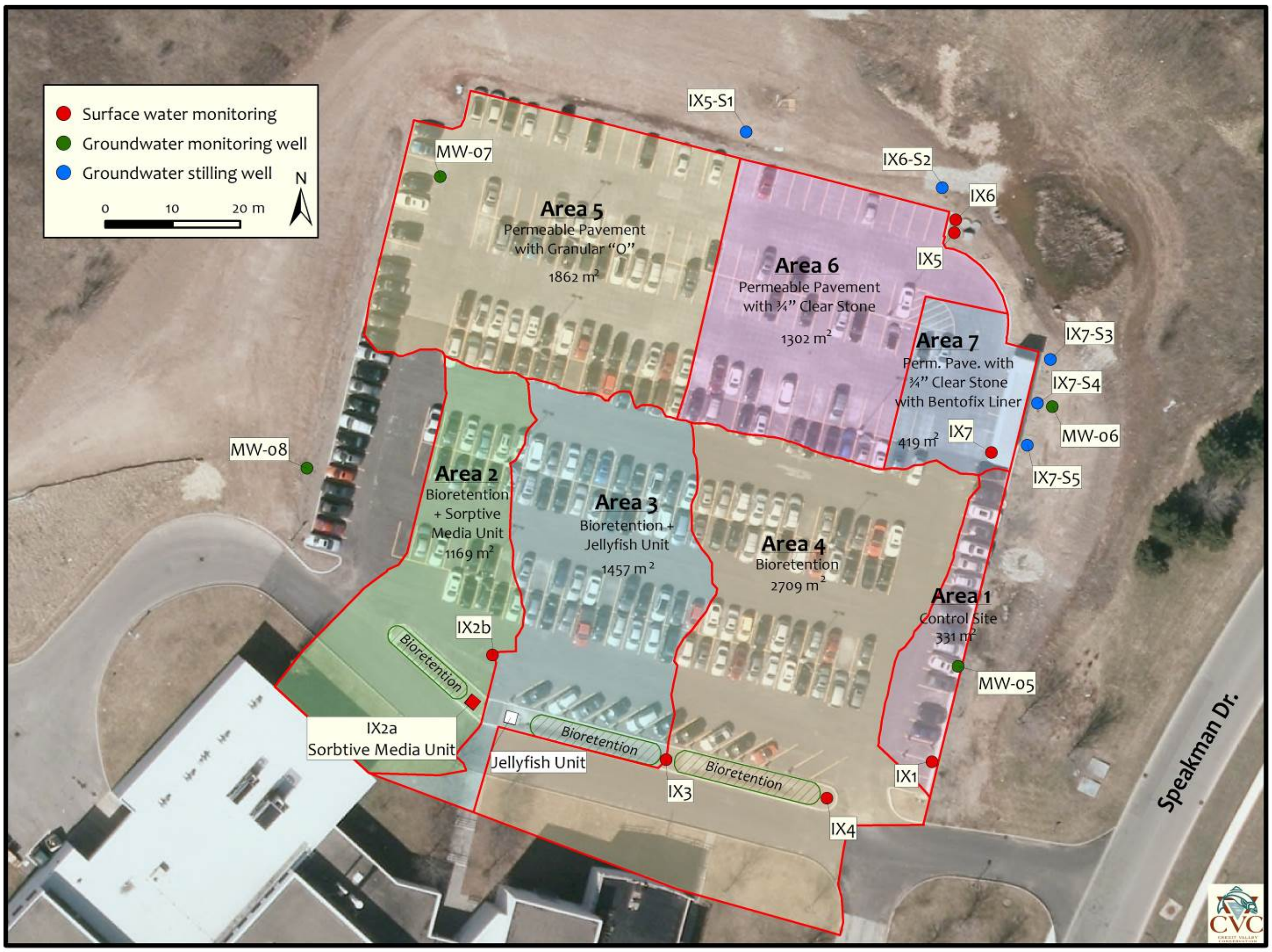


Figure 51: Retrofitted IMAX parking lot, LID systems and monitoring stations Note: Drainage areas listed for Areas 2, 3 and 4 are the impervious fraction.

Table 17: Monitoring stations and associated monitoring tasks.

SWM system	Area	Monitoring activities/description	Priority pollutants	Continuous monitoring	Sampling interval
Control site	Area 1 (IX-1)	Water quality sampler and flow measurement in manhole receiving flow from asphalt parking area	All	Temperature Flow Conductivity	20 min
Bioretention + Sorbtive® Media unit	Area 2 (IX-2)	Water quality sampler and flow measurement in manhole (IX-2b) receiving flow from bioretention and Sorbtive® Media Vault which treats runoff from asphalt parking area	Total Suspended Solids, Total Phosphorus, Dissolved and Particulate Phosphorus, Orthophosphate	Temperature Flow	20 min
Jellyfish® Filter + Bioretention	Area 3 (IX-3)	Water quality sampler and flow measurement in manhole receiving flow from bioretention. Runoff from asphalt parking area is pre-treated by a JellyFish® Filter before entering the bioretention area.	Total Suspended Solids, Total Phosphorus, Dissolved and Particulate Phosphorus, Orthophosphate	Temperature Flow	20 min
Bioretention	Area 4 (IX-4)	Water quality sampler and flow measurement in manhole at outlet of bioretention which treats runoff from asphalt parking area.	All	Temperature Flow	20 min
Permeable pavement with Granular "O"	Area 5 (IX-5)	Water quality sampler and flow measurement (IX-5) in manhole at outlet of permeable pavement system as well as observation well (IX5-S1) to monitor water levels within system.	All	Temperature Flow	60 min
Permeable pavement with ¼" clearstone	Area 6 (IX-6)	Water quality sampler and flow measurement (IX-6) in manhole at outlet of permeable pavement system as well as observation well (IX6-S2) to monitor water levels within system.	All	Temperature Flow	60 min
Permeable pavement with ¼" clearstone and Bentofix liner	Area 7* (IX-7)	Water quality sampler and flow measurement (IX-7) in manhole at outlet of permeable pavement system as well as observation wells connected to collection system below liner to detect leakage (IX7-S3, IX7-S4, IX7-S5).	All	Temperature Flow Conductivity	20 min

* IX-7 will replace IX-5 and IX-6 during the winter time to address equipment freezing issues.

Control area (Area 1, IX-1)

In field-scale research, it is a common practice to monitor runoff from a traditional asphalt catchment that is located near or beside the LID installation (e.g. Drake et al., 2012, TRCA 2008, Collins et al. 2008). Side-by-side testing also ensures that the systems are exposed to the same climatic and geologic conditions while receiving similar pollutant inputs. Ultimately, monitoring a control treatment allows the environmental benefits of LID systems to be measured and reported with greater certainty.

Area 1 (Drainage Area (DA) = 331 m^2), shown in Figure 51, drains stormwater from the portion of the asphalt parking lot which includes the parking laneway and spaces facing Speakman Drive. Stormwater is collected by a traditional twin catch basin (Figure 52) which discharges to the municipal stormsewer, as shown in figure below. Area 1 reflects a conventional stormwater conveyance system and was intended to be the control treatment for the site. Due to unforeseen circumstances influent concentrations obtained for the National Stormwater Quality Database (NSQD) were used to determine the water quality performance of the LID treatments.

Figure 52: Control Site Receiver– Twin Catch Basin

Bioswales (Areas 2, 3 and 4)

Stormwater not managed by the permeable pavements is collected and infiltrated through three separate bioswale systems which incorporate proprietary products such as Imbrium's Jellyfish® Filter and Sorbtive® Vault.

Two observational wells (deep and shallow) have been installed in each of the bioswales equipped with level loggers. The deep observational well helps measure the level of saturation within the subsurface layers (i.e.: bioretention soil media) and the shallow observational well measures surface ponding. The shallow observational well indicates when maximum surface ponding depth is reached and runoff enters the overflow riser pipe directly with no LID treatment.

Stormwater from Area 2 (DA = 1407 m^2) is infiltrated through Bioswale 1, collected in an underdrain and routed to a Sorbtive® Vault. Two of the monitoring stations used for Area 2 include (Figure 53):

- IX-2a, located within the clear well of the Sorbtive® Vault
- IX-2 located within a downstream maintenance hole.

The Sorbtive® Media has a treatment flow rate of 10 gpm per design calculations. Once this flow rate is exceeded, flows bypass the Sorbtive® Media bed by either overtopping the treatment bay baffle or entering the clear well via the overflow. For this treatment train, three scenarios are possible and need to be considered when interpreting the water quality results measured downstream. As shown in Figure 54, the following scenarios can occur:

1. No bypass occurring (Q1 and Q2): runoff received complete bioswale and Sorbtive® Media treatment.

2. Bypass within Sorbtive® Vault (Q3, over baffle wall): runoff received complete bioswale treatment and partial Sorbtive® Media treatment.

3. No treatment (Q4): Bypass via bioswale overflow riser pipe indicates that system is surcharged and runoff monitored downstream is a mixture of flow with no treatment and partial bioswale treatment.

To verify which scenario is in effect and in addition to the deep and shallow observational wells, a third observational well is installed within the Sorbtive® Vault. The well sits on the upstream end of the baffle wall and measures water level above the Sorbtive® Media and triggers when the treatment chamber is overtopped and runoff is no longer receiving Sorbtive® Media treatment.

These observational wells only provide which of the three bypass scenarios is occurring in order to qualify water quality measured downstream. However, in order to quantify the bypass volumes, additional equipment will be required which is currently not feasible due to design restriction (i.e. weir in the Sorbtive® Vault)

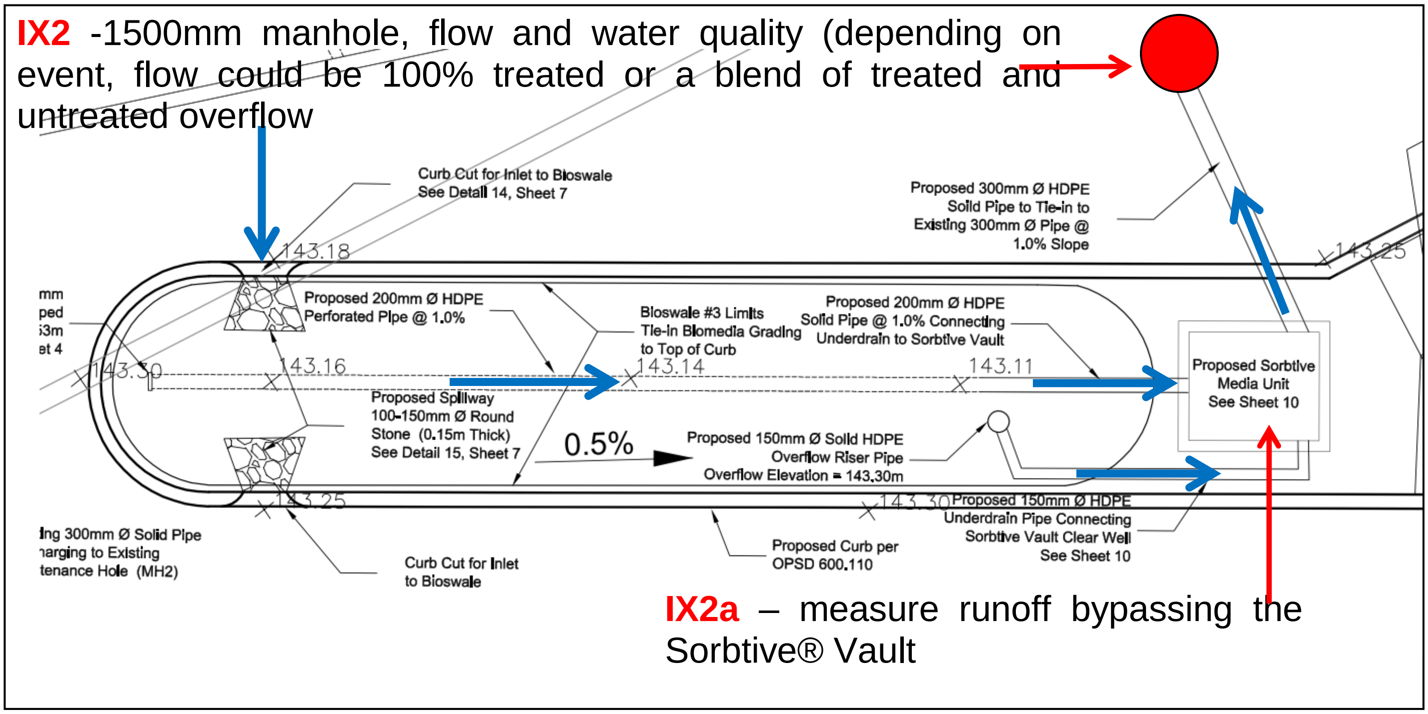


Figure 53: Bioswale Cell 1 Layout (Aquafor Beech, 2012).

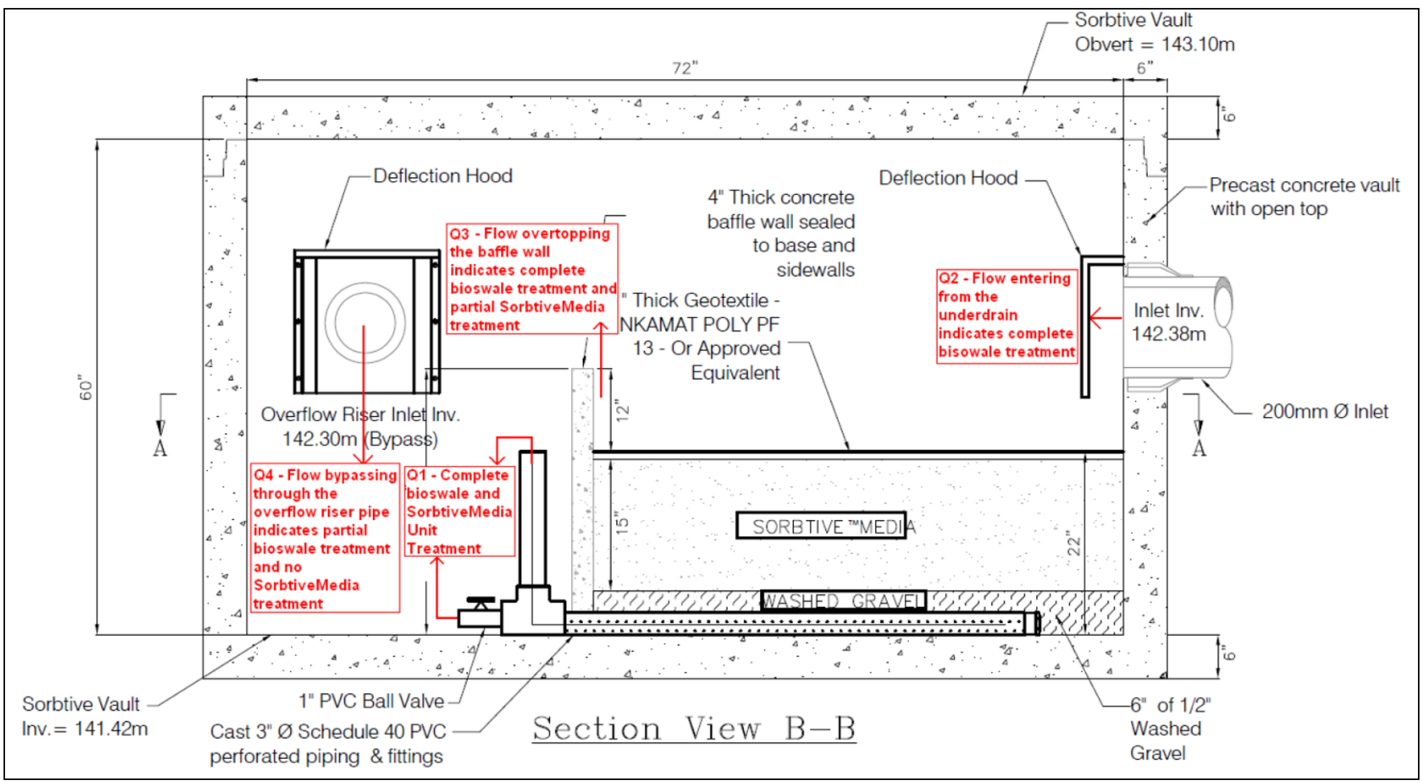


Figure 54: Sorbtive Media Bypass (Aquafor Beech, 2012).

Stormwater from Area 3 (DA = 1491 m^2) is pre-treated by a Jellyfish® Filter unit before discharging to Bioswale 2 (Figure 55). Stormwater collected in the bioswale underdrain is routed to a maintenance hole and monitoring station IX-3, and ultimately discharges to the municipal storm sewer.

The Jellyfish® Filter has a total treatment flow rate of 12.62 L/s and once this flow rate is exceeded, the system is surcharged. Currently, there is no possible way of monitoring the bypass directly due to design and equipment constraints. However, to account for this bypass, events that produce an inflow rate greater than the total treatment flow rate of 12.62 L/s, bypass is to be assumed and accounted for when interpreting water quality data measured downstream at IX-3. When the Jellyfish® Filter surcharges, runoff is be diverted to the bypass channel and flow directly into the bioswale (Figure 56).

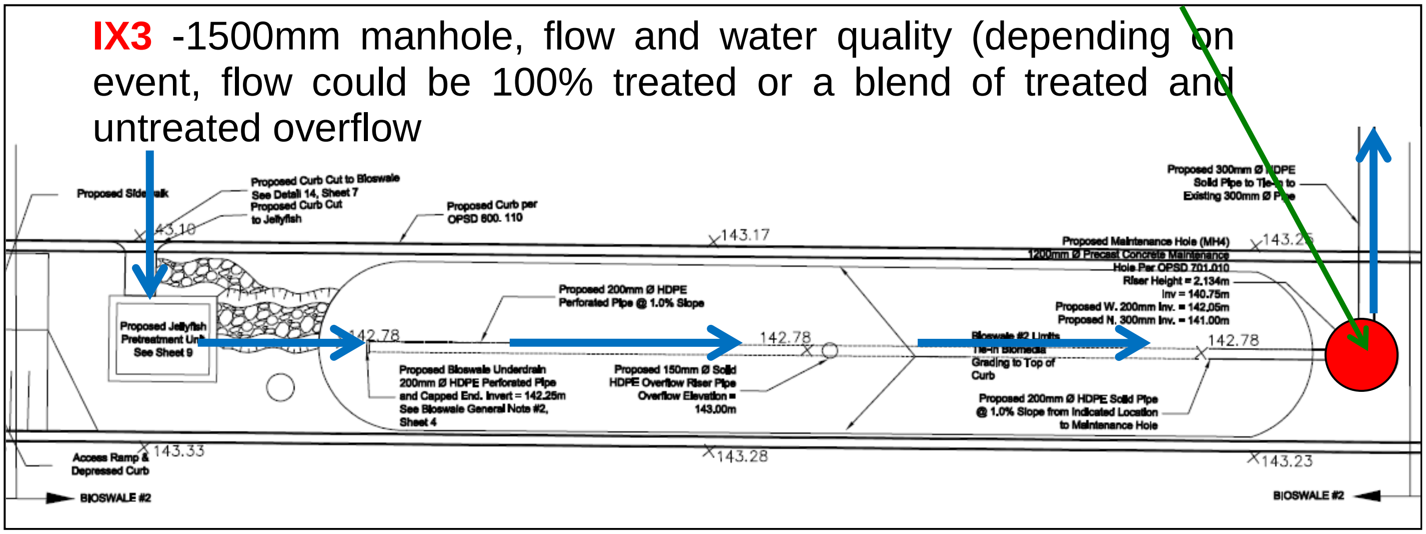


Figure 55: Bioswale Cell 2 layout (Aquafor Beech, 2012).

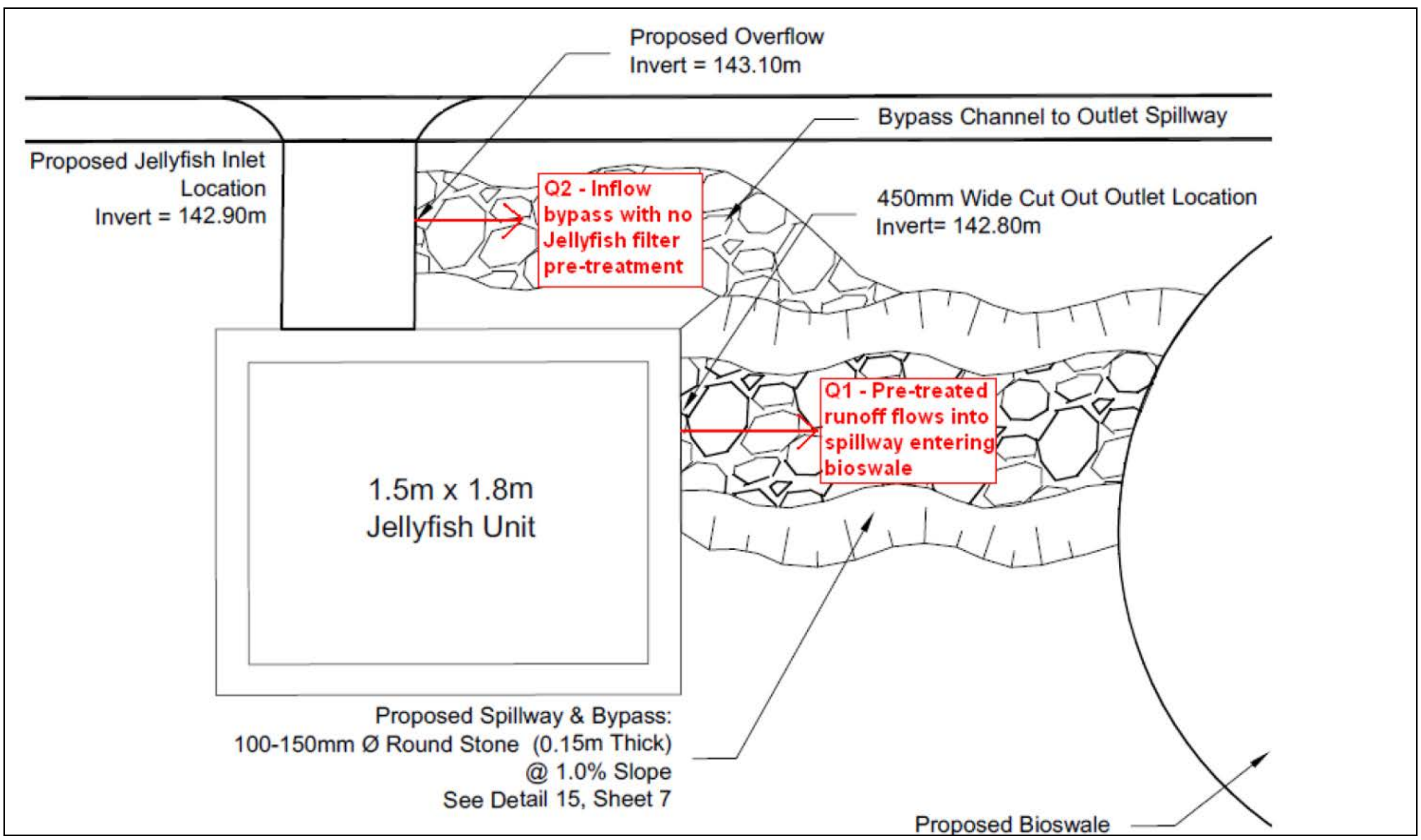


Figure 56: Jellyfish® Filter bypass.

Stormwater from Area 4 (DA = 3166 m^2) is filtrated by Bioswale 3 (Figure 57). Stormwater collected in the underdrain is routed to a maintenance hole and monitoring station, IX-4 which discharges to the municipal storm sewer system. In this case when maximum surface ponding depth is reached, the runoff bypasses through the overflow riser pipe towards the existing storm sewer.

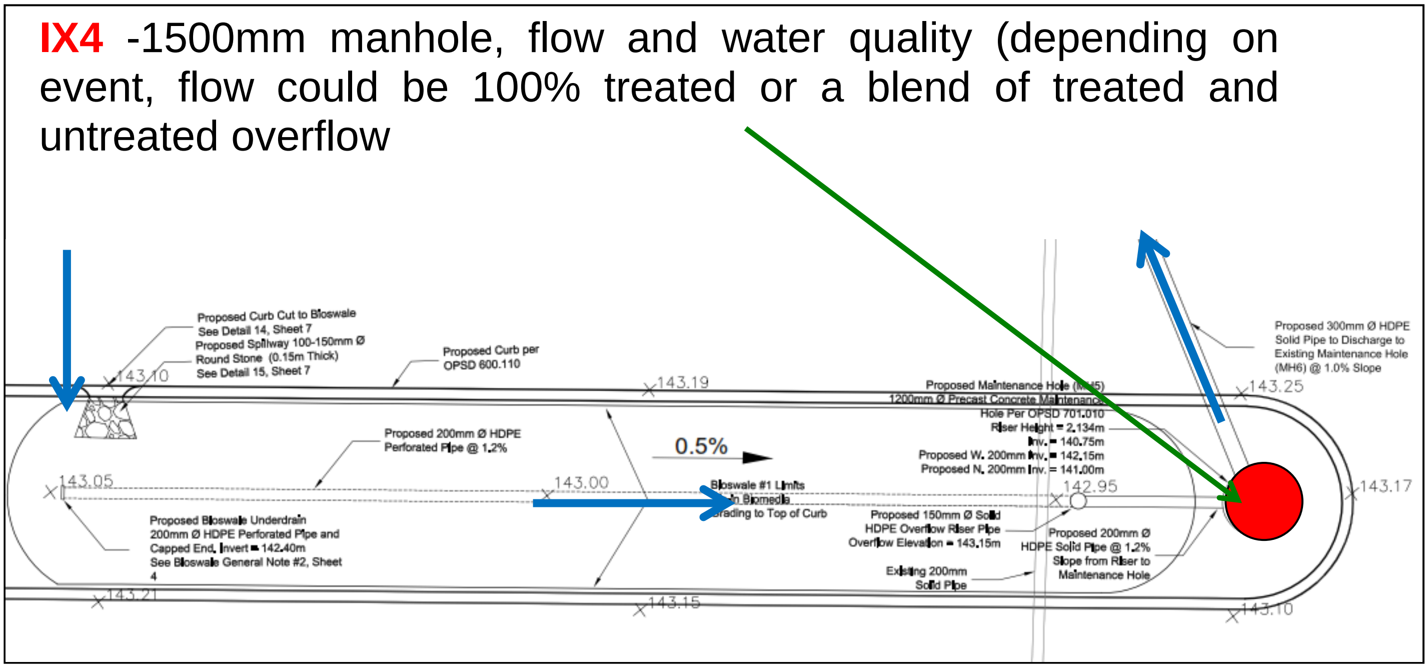


Figure 57: Bioswale Cell 3 layout (Aquafor Beech, 2012).

Permeable pavement (Areas 5, 6 and 7)

Areas 5, 6 and 7 represent the permeable pavement portion of the parking lot (DA = 3133 m^2). The parking lot grading is such that the permeable pavement does not receive run-on from adjacent pavement surfaces. This ensures that the volume of stormwater inputs can be estimated with certainty.

For research purposes, the permeable pavement design was completed using both Granular "O" (Area 5) and 20mm ø clearstone (Area 6 and 7). Boundaries between the two base materials and adjacent asphalt base materials are separated by a geosynthetic clay liner to ensure hydraulic separation. The underdrains for each section of permeable pavement are isolated from one another to ensure that stormwater from each section is collected separately and performance comparisons between the different materials will be possible. As shown in Figure 51, stormwater from Areas 5 and 6 is routed to maintenance holes and monitoring stations IX-5 and IX-6, respectively. Stormwater runoff from IX-5 and IX-6 discharges to an isolated wetland before it enters the municipal sewer system.

Overland flow from the permeable pavement, discharge from the parking lot through a curb cut to the isolated wetland. Water levels within the wetland are managed by a control structure which connects to the municipal storm sewer system. Backwater effects from the wetland are not expected to impact the flows from IX-5 and IX-6 unless an extreme rainfall event occurs.

Outlets from IX-5 and IX-6 are fitted with moveable 90° elbows (shown in Figure 58) which allow researchers to control the water levels beneath the permeable pavement. Elbows are set so that stormwater drains freely from the permeable pavement system. Water levels within the pavement system may be monitored by observation wells which are connected to the underdrain (IX5-S1 & IX6-S2).

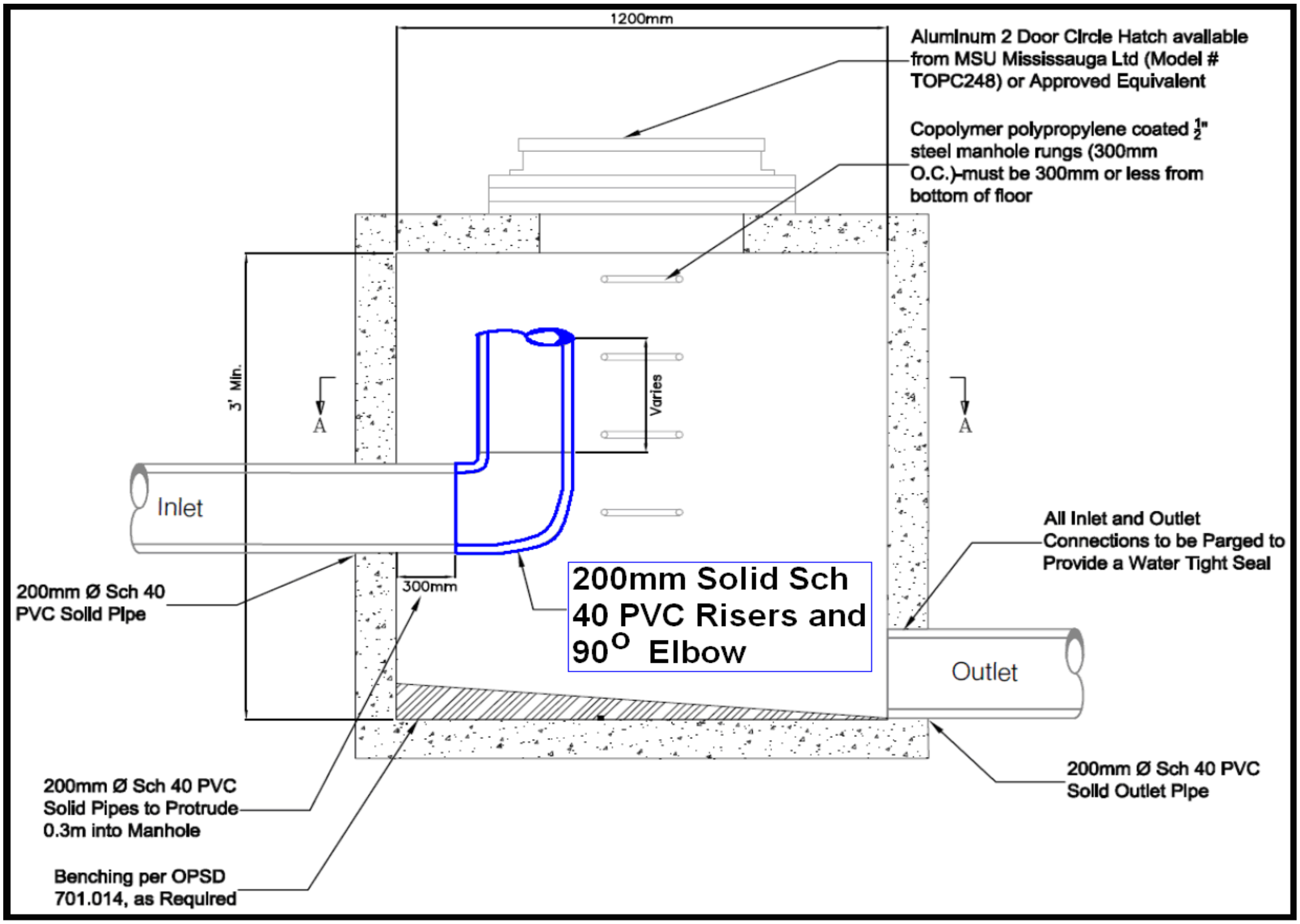


Figure 58: Moveable 90° elbows (Aquafor Beech, 2012).

Area 7 is fully lined with an impermeable geosynthetic clay liner (GCL). The lined area is being evaluated for use in groundwater-sensitive areas where stormwater infiltration is not permitted. The purpose of implementing Area 7 was to determine if GCLs are an effective method of lining infiltration practices (See Figure 59). To test this theory, underdrains were installed beneath the liner and connect to three observation wells (IX7-S3, IX7-S4, and IX7-S5). As a one-time exercise, a dye test could be performed on the surface of the permeable pavement area and collect samples from the observation wells. If the samples demonstrate evidence of the dye release over the permeable pavement, it could be concluded the liner was ineffective.

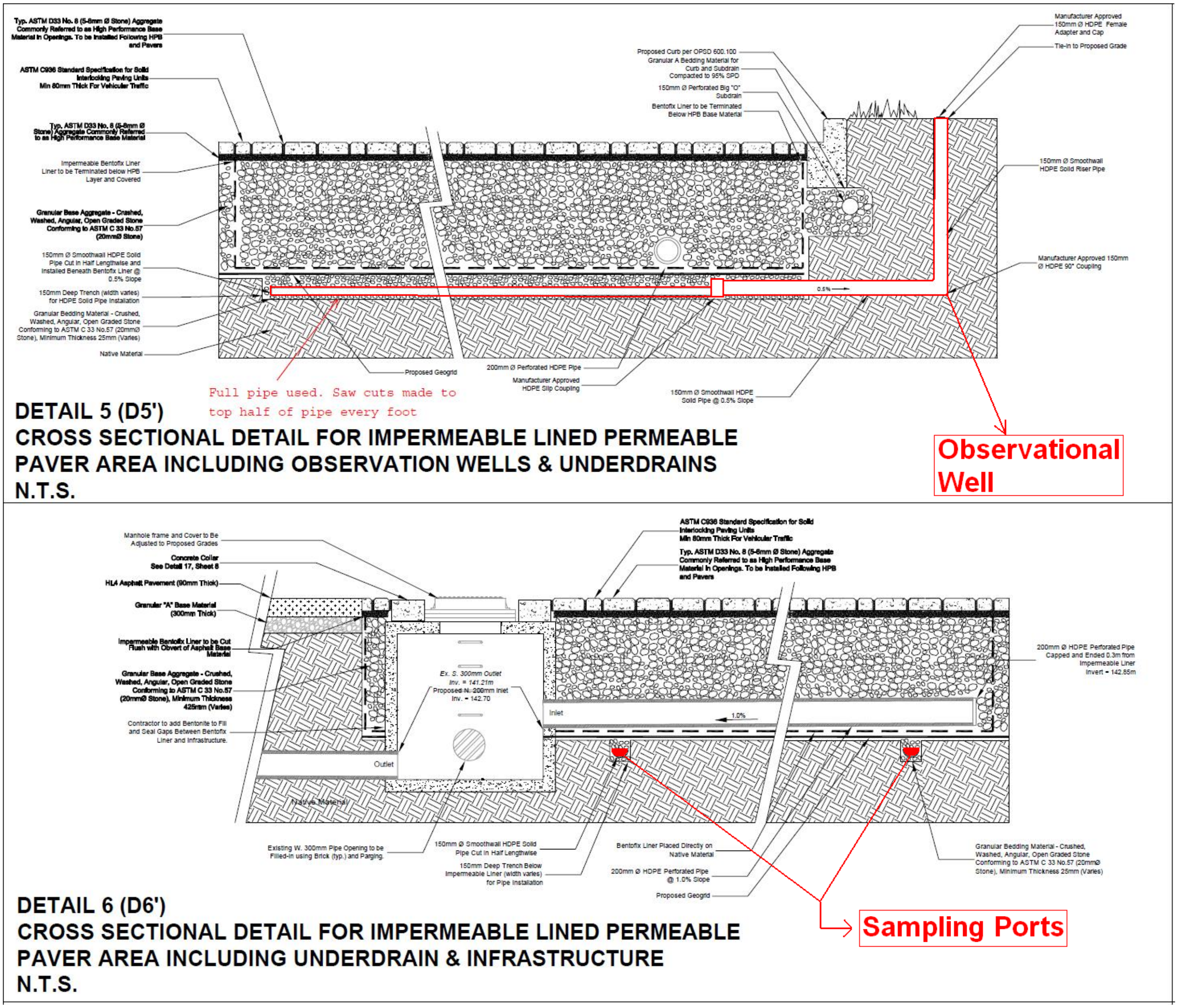


Figure 59: Sampling ports and observational wells for subcatchment 7 (Aquafor Beech, 2012).

Monitoring challenges

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

- Missed rain events
- Accommodation of monitoring equipment

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.

Accommodation of monitoring equipment

A typical monitoring station implemented by CVC consists primarily of a weir plate structure and an Autosampler basket seated on the rim of the maintenance hole. To accommodate these two pieces of equipment, at least six feet of clearance is required between the top and bottom of the maintenance hole.

This criterion was met for all the monitoring stations except for the permeable pavement monitoring locations IX-5 and IX-6. In addition, being adjacent to the man-made wetland, concerns regarding the risk of backwatering and inundation of the monitoring equipment were considered.

Figure 60: IX-5 – weir structure.

To address this issue, the manholes were made as shallow as possible to avoid backwater affect from the wetland and accommodate the weir structure at the same time (installations which include only the weir require a mere four feet of clearance). The Autosamplers were placed in an above ground steel box (Figure 61) in a low traffic landscaped area near the wetland posing no obstructions on the daily use of the parking lot.

Figure 61: Steel box to accommodate Autosamplers.

Water Quantity Performance

Inflows into the seven monitored systems were not measured. Instead they were estimated using the Simple Method (Schueler, 1987) which transforms rainfall depth into flow and volume based on area and impervious cover (NH DEP, 2008). Outflow from each of the systems was measured continuously and reported at 10 minute intervals. There were ongoing challenges with leakages and bypasses that affected the outflow from the control (IX-1) area. As such the data from IX-1 has not been used in the assessment of hydrologic performance. Table 20 summarizes the hydrological performance for the six LID treatments.

Volume reductions measured at IX-2, IX-3 and IX-4 for events up to 25 mm were 90, 78, and 64 per cent, respectively. The catchment area to bioretention area ratio of IX4 is larger (44:1) than that of IX-2 and IX-3 (34:1 and 24:1, respectively) so it has the largest hydraulic loading rate. The typical bioretention to treatment ratio is 15:1. This higher loading rate likely contributes to the poorer hydrologic performance of IX-4.

Volume reductions measured at IX-5, IX-6 and IX-7 for events up to 25 mm were 62, 99 and 97 per cent, respectively. The results for IX-7 were unexpected. This system was constructed with an impermeable liner to prevent infiltration and investigate the potential to use lined systems to achieve some hydrological and water quality benefits without causing deterioration of groundwater quality in sensitive areas. Some water may be lost through wetting of the materials and later evaporation. However, most of the precipitation on the surface of IX-7 was expected to be measured as outflow (i.e. low volume reductions were expected).

IX6 had very high volume reduction. This too was unexpected. Although infiltration was not prevented in this system, the underlying soils were determined to have low hydraulic conductivity and there is an underdrain at the base of the system.

IX-5 achieved much lower volume reduction, compared to IX-6 and IX-7. The design of IX5 differed from IX6 in two ways: 1. Aggregate "O" was used as the base rather than ¾ inch clear stone and 2. There were three lateral underdrains perpendicular to the main collection pipe. Because of the different materials used in the base layer, the aggregate depths also differed between the systems. The lower volume reduction cannot be attributed to the aggregate "O" which includes a broader range of grain sizes. The lateral subdrains could potentially be reducing the opportunity for infiltration into the native materials, compared to IX6. Another possibility is the complete hydraulic separation of this system from other systems or adjacent lands was not achieved.

Table 18: Estimated Runoff Volume Reduction *statistics were calculated independent of each other*

Estimated runoff volume reductions				
Station	Event Count	Mean (%)	Median (%)	Total for events 2 – 25 mm (%)
IX-2	65	90	94	90
IX-3	73	81	86	78
IX-4	73	70	70	64
IX-5	70	70	78	62
IX-6	65	98	100	99
IX-7	71	96	100	97

Water Quality Performance

The bioretention systems are performing similarly to each other. The Sorbtive® Media, used for post-treatment in IX-2, is designed to sorb dissolved phosphorous and physically filter fine sediment and the associated particulate bound phosphorous. The concentrations of phosphorous in the effluent from IX-2 are the lowest among the bioretention system (Table 21) and IX-2 achieved higher load reduction of total phosphorous (85 per cent, Table 22) compared to the other bioretention systems (60 per cent).

The Jellyfish filter, used for pretreatment in IX-3, is designed to remove total suspended solids, including small (i.e. silt) sized particles, and particulate bound contaminants which can include nutrients and metals. IX-3 had the lowest median TSS effluent concentration of any of the bioretention or permeable pavement systems and the highest load reduction of the bioretention systems. The median effluent concentrations of most of the nutrients and metals, however, were higher than those from IX-4 which did not include any pre- or post-treatment.

The performance of the permeable pavement systems was strongly related to the hydrological behavior. The lower percentage load reduction for total suspended solids, total phosphorous and copper (90, 60, and 78 per cent, respectively) at IX-5 was due to the high outflow volumes and the high percentage load reduction (>90 per cent) for all parameters at IX-6 was due to the very low outflow volumes.

Table 21: Median Effluent Event Mean Concentration for Bioretention

	Asphalt to Bioretention to Sorbtive® Vault IX-2	Asphalt to Jellyfish® Filter to Bioretention IX-3	Asphalt to bioretention IX-4
Total Suspended Solids (mg/L)	19	8	13
Total Phosphorus (mg/L)	0.10	0.22	0.15
Dissolved Phosphorus (mg/L)	0.04	0.16	0.14

Table 22: Estimated Mass Load Reduction of Key Parameters

Estimated mass load reductions (%)				
Station	Total Suspended Solids	Total Phosphorus	Nitrate + Nitrite	Zinc
IX-2	97	85	84	98
IX-3	98	60	67	98
IX-4	97	60	66	97
IX-5	90	77	37	91
IX-6	99	98	93	99
IX-7	92	98	90	98

Permeable pavement infiltration test results

University of Guelph and CVC staff completed infiltration testing of the permeable pavement systems at catchments IX-5, IX-6, and IX-7 on June 14, 2013 and August 2, 2013 to determine as built infiltration rates. All sampling was performed as per ASTM C1701.Testing was performed at 18 testing locations on each day, for a total of 36 testing locations. Of these, 18 are located in IX-5 and 18 are located in IX-6 or IX-7. Ten locations are located on the paint lines dividing the parking spaces, 10 are located within the middle of the parking spaces, and 16 are located in the parking area laneways. The findings from the infiltration testing events are assessed below based on two main criteria: sub-base material and location within parking area.

The total average infiltration rates for IX-5 and IX-6/IX-7 are 4192.8 mm/hr and 4844.8 mm/hr, respectively. This was the expected result as the clear stone subbase material in IX-6 and IX-7 has a higher void space than the Granular "O" used in IX-5 and, therefore, allows water to pass through it a faster rate. The infiltration rates observed for both types of sub-base material are within the acceptable range for new permeable pavement systems. A contour map shows the spatial distribution of the infiltration rate throughout the permeable pavement (Figure 62).

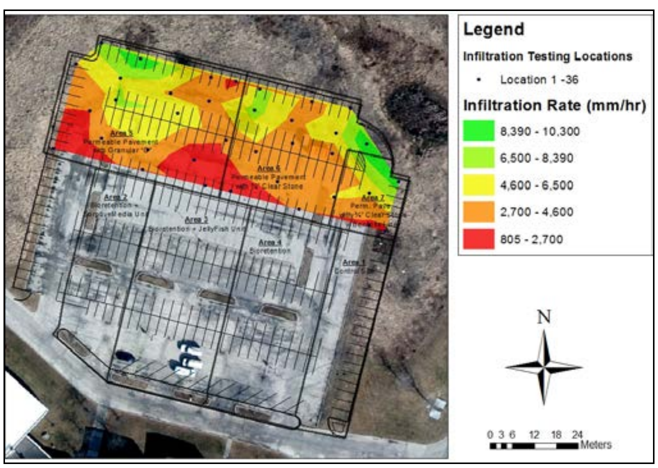


Figure 62: Infiltration rate contour map.

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 infiltration rates based on parking area location was found, as expected, within the centre of the parking stalls. The lowest average infiltration rate based on parking area location, however, is located on the lines dividing parking spaces. 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 paints lines. 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.

Infiltration tests are performed on a yearly basis and changes in infiltration capacity are tracked overtime Additional testing was performed in Winter and Summer 2014. Figure 63 illustrates the magnitude of the change (decline) in infiltration rate between 2013 and Summer 2014.

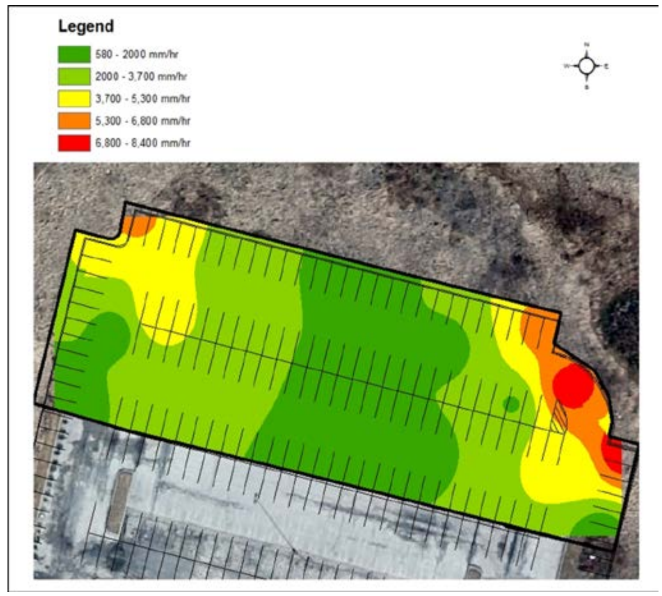


Figure 63: Decline in infiltration rates between 2013 and Summer 2014

Soil sampling results

Soil sampling occurred in each bioretention unit (IX-2, IX-3 and IX-4); all of which receive runoff from asphalt catchment areas. Sampling occurred November 23, 2015 after summer precipitation events but prior to the ground freezing. Soil (filter media) sampling was conducted at two depths at the inlet and outlet of each bioretention cell. Four composite soil samples were collected from three bioretention cells (12 samples total). The shallow and deep samples were collected at approximately 5 cm and 30 cm below the filter media surface at the inlet and outlet of each bioretention unit. Three subsamples from each depth for the inlet and outlet were combined to produce one composite sampleSamples were analyzed by Maxxam Analytics for inorganics, metals and polyaromatic hydrocarbons (PAHs).

Soil quality results were compared to CCME Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME, 2014) and to the Environmental Protection Act, Ontario Reg. 153/04 Table 7 (MOE, 2011) for the appropriate land use. All results fell below the soil condition standards for parameters that had guidelines available. Many parameters had concentrations below the detection limit and there are a there no obvious trends in the parameters of interest between depths for all bioretention units. Concentrations were consistent between bioretention facilities. Table 23 shows for parameters of interest results from the bioswale in Area 4 (IX-4).

Parameter	Detection Limit	CCME Guideline	EPA Guideline	IX-4 Inlet Shallow	IX-4 Inlet Deep	IX-4 Outlet Shallow	IX-4 Outlet Deep
Cadmium (ug/g)	0.5	22	1.9	ND	ND	ND	ND
Copper (ug/g)	2.0	91	230	9.4	4.7	4.3	5.8
Iron (ug/g)	50.0	*	*	5600	5800	5300	5300
Lead (ug/g)	5.0	600	120	ND	ND	ND	ND
Nickel (ug/g)	5.0	89	270	ND	ND	ND	ND
Zinc (ug/g)	5.0	360	340	34	14	14	12
Dissolved Phosphorus (ug/g)	0.2	*	*	2.4	1.2	1.3	1.5
Total Kjeldahl Nitrogen (ug/g)	10.0	*	*	494	547	546	755
Nitrate + Nitrite (ug/g)	3.0	*	*	ND	ND	ND	ND

ND= non detect

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