Appendix C

Case Studies

Case Study

Elm Drive

Location: Mississuaga
Constructed: May 2011

Road Right-of-Way Retrofit

Project Objectives, Design & Performance

- Construction issues arose due to inadequate design documentation (no schedule indicating pipe sizes provided)
- Contractor, designer, municipality and CVC communicated and worked together closely to overcome issues and complete construction
- Design drawings should be as detailed as possible, including details for non-standard components, detailed pipe schedule, and complete sets of dimensions

Overcoming Barriers & Lessons Learned

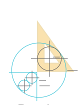
- Street retrofit comprised of six bioretention planters and permeable pavement that treats and infiltrates road runoff on adjacent school property
- Retrofit used to mitigate flood risk within the Cooksville Creek Watershed
- LID retrofit operating successfully, reducing the runoff volume from a 2 year return storm by 78%

Practices Implemented


Bioretention


Permeable Pavement

Barriers & Issues Encountered

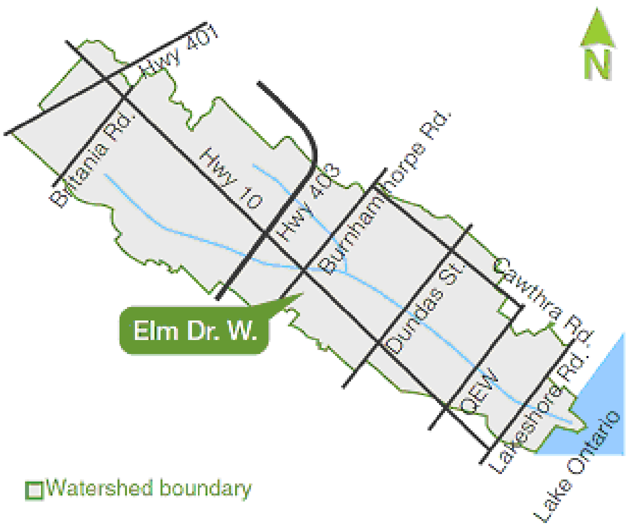

Design


Construction & Comissioning


Operation & Maintenance

Overview

The Elm Drive low impact development (LID) road retrofit is located on Elm Drive West, just south of the Square One Shopping Centre in Mississauga, Ontario.



The street retrofit is located on Elm Drive West in Mississauga, ON, within the Cooksville Creek watershed

The Elm Drive project incorporates both permeable paver lay-bys within the road right of way (on City of Mississauga property) and bioretention planters on the adjoining property owned by the Peel District School Board (PDSB). Runoff flows from Elm Drive West onto the permeable paver lay-by and into to the bioretention planters.

Goals and Drivers

There are several goals and drivers that prompted the LID retrofit of Elm Drive West:

- Ease the burden (runoff volume) on existing municipal storm sewers within the Cooksville Creek watershed
- Upgrading the existing roadway and stormwater management infrastructure from soft shoulders and grass ditches to curb and gutter with modern LID techniques.
- Providing stormwater treatment, thereby improving the quality of stormwater discharged to Cooksville Creek.
- Establishing a LID road retrofit demonstration site that can be used to showcase the effectiveness of LID practices to various Ontario stakeholders
- Providing a site where the stormwater quality control, quantity control and water balance benefits as well as long-term life cycle activities could be assessed under real-world conditions.

Successes

The successes achieved with this project include:

Innovative project – The Elm Drive project is one of the first green street retrofits to take place in Ontario. The LID retrofit improves stormwater quality and reduces runoff at the site.

Joint partnership – A partnership was formed between three stakeholders: the City of Mississauga the PDSB and Credit Valley Conservation (CVC). This partnership allowed the City to maintain the LID infrastructure, part of which is located on PDSB property. CVC provided design, construction assistance and is conducting performance monitoring and maintenance inspections.

Demonstration showcase – The LID features at Elm Drive have been showcased through numerous presentations, events and site tours. These efforts have helped educate numerous stakeholders on the benefits of LID.

Performance – Preliminary monitoring indicates that LID features are performing well, and that for the majority of rainfall events (up to 95% of all events) little to no stormwater runoff leaves the site.

Overcoming Barriers and Lessons Learned

As with any project, there will be challenges faced by the parties involved. The barriers and issues encountered with this project include:

- The preliminary design of the bioretention planters included a 'flow dissipater' at the inlet to each planter. Review of the design showed that the flow dissipaters might cause the stormwater to bypass the bioretention media in the planters .
- Grading of the bioretention planters had to take into account matching existing grades at the construction boundaries, as well as working around existing light poles.
- Non-standard right-of-way details had to be used to convey all stormwater runoff to the bioretention planters, as the downstream storm sewer infrastructure provided a constraint to the invert of the storm sewer infrastructure within the bioretention planters.
- The construction drawings should have included additional details, including more dimensions and additional detail information and views.
- The utility locates did not pick up an underground fiber optic cable.

- Trades were unfamiliar with requirements for working with infiltration technologies and in infiltration areas.
- Although plantings meet the requirements of LID functionality, they did not meet the aesthetic expectations of local residents.
- Public safety concerns were brought forward by PDSB. The bioretention planters were a fall safety concern for students and local residents.

The following approaches were used to address these barriers:

- The flow dissipater design was revised to consist of river stone mixed with bioretention soil media to avoid any short-circuiting of the bioretention planters.
- The City of Mississauga and CVC worked with the designer to come up with a non-standard right-of-way design and grading to allow the system to work within all the existing constraints.
- The contractor worked closely with the City, designer and CVC to troubleshoot problems as they arose.
- CVC worked with the City to update landscape plantings were updated, incorporating both trees and shrubs into the bioretention planters which provided additional color, greater seasonal interest, and vertical height.
- Installation of fences around bioretention planters addressed safety concern for students and local residents.

Lessons learned:

- Coordination with all utility companies should be completed prior to the design to ensure all existing utilities are identified.
- Field investigation prior to design is critical. Observing how the site and adjacent areas are used daily will provide critical insight into how the LID feature should be designed (i.e., identify where smokers congregate and avoid installing permeable pavement in these areas).
- Design drawings should be as detailed as possible, including dimensioning of all components and location of all existing utilities and constraints.
- Landscape design plans needs to meet both functional and aesthetic expectations.
- When constructing LID facilities, ensure that an appropriate benchmark is used for surveying to ensure proper and accurate layout.
- Sediment and erosion control guidelines should provide clear guidance for protection of infiltration areas in LID practices and inspectors should ensure that these requirements are being met.
- As LID is a new stormwater management approach for many contractors, it is recommended that municipalities budget for increased site inspection and supervision and construction meetings to address any issues as they arise.

Planning and Regulations

Coordination with project partners, stakeholders, and local Councillors is important with early LID adoption. Prior to and during the design process, project partners worked together to negotiate the terms of the project, including the roles and responsibilities of each party. To facilitate this process, CVC worked with the Ward Councillor and the local PDSB trustee. Support from these representatives helped ensure that the project had buy-in from both City and PDSB staff. It also led to a successful agreement granting the City access to PDSB property for stormwater management and maintenance activities.

Design

Prior to implementing the retrofit project, Elm Drive consisted of a roadway with soft shoulders and a grass drainage ditch.

Elm Drive West pre-development

The stormwater management retrofit was designed to capture stormwater runoff and convey it through permeable pavers and bioretention planters before discharging any remaining runoff to the existing storm sewer system. This was achieved by implementing a road cross-section which is sloped to one side of the road (using a “side shed” configuration) towards the permeable pavers and bioretention planters with all runoff conveyed to LID features via overland flow.

Pre-treatment

Permeable pavement as well as catchbasin sumps and ‘snouts’ are used to pre-treat storm runoff before it is conveyed to the bioretention planters. Permeable pavement filters sediment and debris as runoff infiltrates through a layer of clear stone. Excess runoff is then collected in the catchbasin where debris and sediment is given time to settle out in the sump. The ‘snouts’ are placed on the end of the pipes conveying stormwater from the catchbasin to the bioretention planters. The ‘snout’ prevents floating debris and oils from entering the planters.

Bioretention Planters

Bioretention planters consist of layers of varying types of aggregate. The excavated trench is lined with non woven geotextile and the first layer of aggregate is high performance bedding. There is a 250mmØ HDPE peforated pipe that runs through each of the planters within the first layer of high performance bedding. The bedding is comprised of angular washed limestone free of dirt or small fines.

Perforated pipe covered in high performance bedding

Above the high performance bedding are retaining walls for bioretention planters. Non woven geotextile lines the first layer of the wall. A 150mm thick course concrete sand filter layer is then placed on top, followed by the 450mm filter media mix (sand and mixed organic compost, detailed in the Bioretention Soil Media table).

Bioretention planter with beginnings of retaining wall

Bioretention Soil Media	
Component	**Percentage by Weight**
Sand (2.0 to 0.05mmØ)	85 – 88%
Fines (<0.05mmØ)	8 – 12%
Organic Matter	3 – 5%

Each of the six planters has a catchbasin that empties into the planter through a 200mm corrugated HDPE pipe. Within the planter, there is a 300mm thick layer of 100-150mmØ river run stone on top of a 100mm thick 19mmØ clearstone bed. This layer is placed where stormwater flows into each planter and acts as the flow dissipator and spreader.

Completed bioretention planters, showing flow dissipater (foreground) and salt-tolerant native plants (background)

The flow of stormwater through permeable pavement and catchbasins into the bioretention planters is illustrated in the next figure.

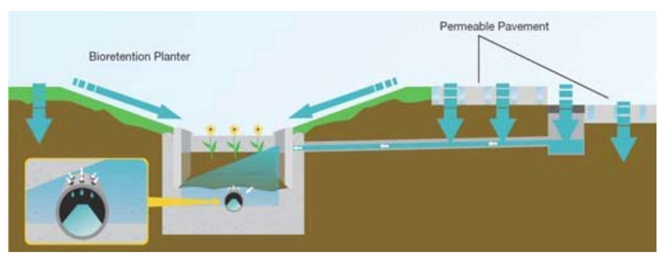


Illustration of permeable pavers & bioretention planter (cross section)

Permeable Pavement

The permeable pavement was installed in the lay-by as well as the sidewalk, totalling an area of 670 m^2. The subbase aggregate is lined in geotextile, contains a 150mmØ subdrain, with a 400mm layer of 50mmØ clear stone, followed by a 250mm layer of 19mmØ clear stone. The setting bed aggregate consists of a 50mm layer of 6mmØ high performance bedding.

The lay-by is a charcoal Unilock Eco-optiloc 26cmx26cm, with 2-5mmØ washed limestone gravel joint aggregate. The sidewalk is a Unilock Eco-priora 12x24cm in herringbone pattern, with 2-5mmØ washed limestone gravel joint aggregate.

Runoff is filtered and dissipated as it percolates through the numerous layers below the pavers. Any runoff from higher flows is directed to bioretention planters through catchbasins and is temporarily stored before discharging to Cooksville Creek.

Completed permeable pavement lay by and sidewalk

Design Issues

The design of the bioretention planters identified a need to incorporate use of a rock flow dissipater where runoff discharges into the planter (shown in the forefront of the *completed bioretention planter* figure). The intention of this dissipater was to slow the velocity of the incoming road runoff and to encourage sheet flow across the planter. However, this feature was placed directly over top of the high performance bedding, creating a path of least resistance directly to the granular material at the base of the planters and permitted runoff to bypass the bioretention soil media and the plants.

To address this issue, some of the soil media in each bioretention planter was raked into the flow dissipation area. The soil media filled the voids in the riverstone, thereby increasing the amount of flow that is directed as sheet flow across the entire planter.

Key Facts

Issues

- Flow dissipaters in bioretention planters initially permitted stormwater to bypass the soil media, preventing the plants within the planters from receiving sufficient water.

Solutions & Lessons Learned

- Bioretention soil media was raked into the flow dissipater to improve flow of stormwater through the entire planter.
- When designing bioretention practices, care must be taken to ensure that there are no means to "short circuit" it. This requires a review of the site grading, slopes and materials used in the bioretention planter.
- Flow dissipaters should not be placed on high permeability materials with direct connections to the underdrains.

For further guidance and LID design best practices, refer to the LID Design Guide.

Construction and Commissioning

Construction took place over a period of seven months, during which time a variety of issues were encountered by the contractor.

Construction Drawings

A site servicing plan and a site grading plan were provided for the construction of this project. However as this project included several features that the contractor had not previously constructed, additional detail should have been provided on the drawings. To provide additional clarity and reduce the potential for error the drawings should include a profile view of the storm services through the bioretention planters, and detailed dimensions of any non-standard items. While cross sections for the planters were provided, the addition of a profile view would have eliminated the contractor's confusion regarding the dimensions and layout of the planters. A plan drawing of the planters, with notes on where improvements could have been made is depicted on the next page.

Another issue that arose during construction included perforated and non-perforated pipe segments. While the total length of pipe between manholes was specified, the drawing did not include specific locations and length of the perforated segments, making it difficult for the contractor to judge the actual placement of the pipes. The addition of a profile view of the storm services would have made all lengths and inverts clear to the contractor.

Another issue that was faced was the 'trench plugs'. The details provided for these plugs in the construction tender, and how they could be improved, are highlighted in the figure below.

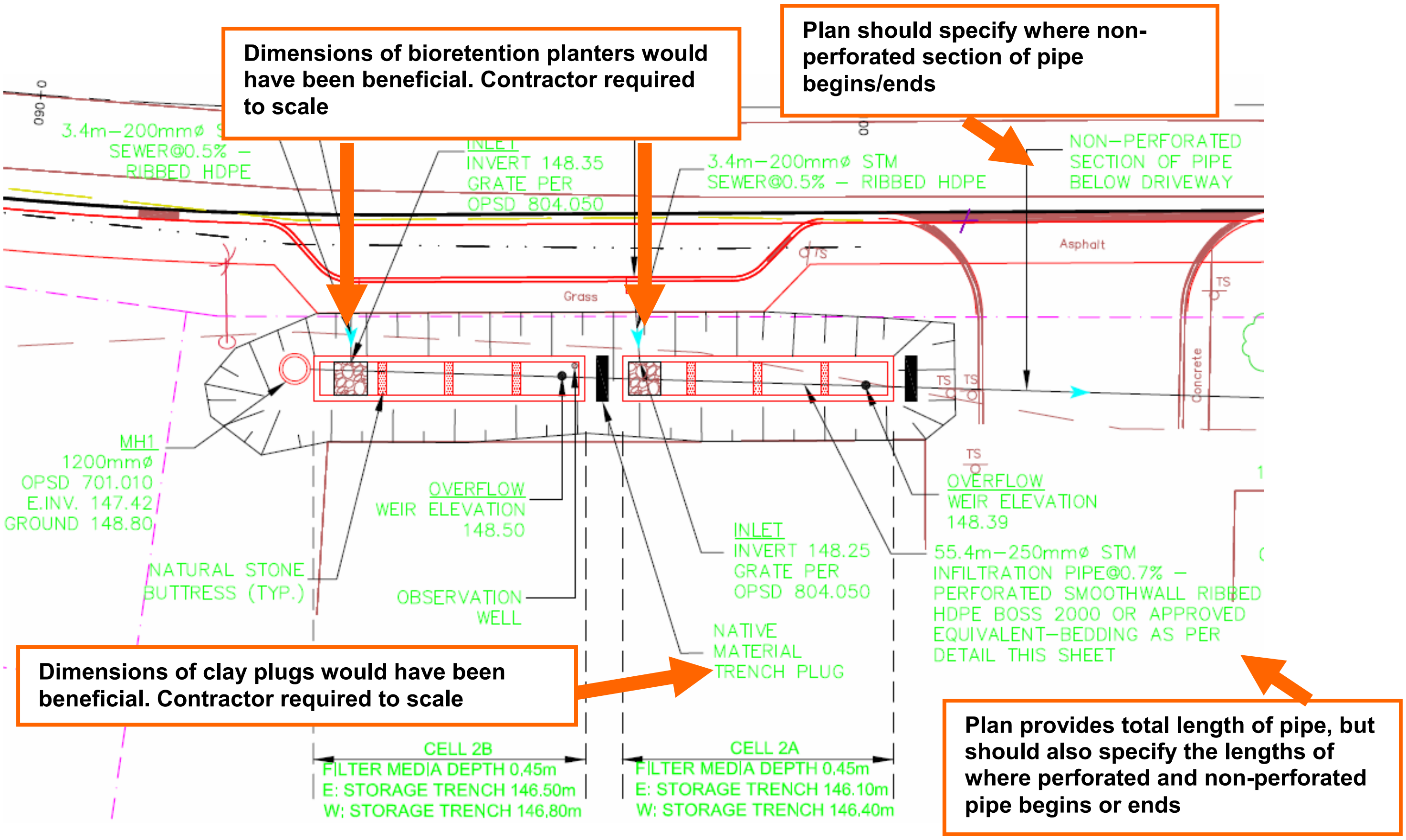
SP 14 Trench Plugs

Trench Plugs as noted on the drawings shall consist of compacted native clay or silt material extending 0.3m minimum into the native material on the trench walls and base. All material for trench plugs shall be approved onsite by the Consultant/City Representative.

More details on dimensions and instructions for installation of the trench plugs would have been beneficial to ensure that there is no short-circuiting of stormwater flow.

Construction inspection & Supervision

During the construction of the bioretention planters there was only part-time site inspection and supervision. However, the construction of low impact development facilities is fairly new and many contractors have little to no experience with these types of facilities. Therefore regular weekly on-site meetings would have ensured that the contractor was clear on the design requirements as the construction proceeds and that any questions or concerns would have been raised and addressed during the construction.



Section of the servicing plan, showing two of the bioretention planters

Future LID projects would benefit from weekly on-site meetings to review the design and direct the contractor on any issues they have. Engineers and contractors are also encouraged to read CVC's LID Construction Guide for further guidance with LID best practices.

Site Layout and Surveying

To minimize errors and keep construction on track, a survey crew should be on site to assist in establishing and confirming elevations. At Elm Drive, surveyors verified the elevations of the inverts of buried pipes to ensure that the correct excavated depth was attained and storage volumes were met.

A curb was used as a benchmark, creating challenges, as the alignment skewed one of the bioretention planters before the oversight was noticed. Care should be given to ensure proper and accurate benchmarks are used.

Erosion and Sediment Control (ESC), and Protection of Infiltration Areas

Protection of the infiltration areas is critical to the success and long term functionality of any LID infiltration project. During construction, bioretention planters were kept offline by protecting the catchbasins connected to the planters. Each catchbasin grate was covered with geotextile and a heavy solid steel plate was placed on top to minimize any stormwater flow into the planters.

Steps were also taken to minimize the interaction of native clay soils with engineered media. Planters were lined with geotextile and a sacrificial geotextile layer was layered on top of the surface. When clay fell in to the high performance material after rain events, the contractor was required to remove them from the bioretention planter.

Working with sub-contractors or material suppliers can also bring ESC challenges. Sub-contractors must be orientated to the site and told the importance of avoiding infiltration areas. During the construction of Elm Drive, a ready mix truck accidently washed out where permeable pavers were to be installed. Since this feature is designed for water infiltration, any concrete below the pavers will significantly hinder its performance. The inspector was notified immediately and reminded the contractor of proper site procedures with respect to equipment cleaning near infiltration areas. Sites where permeable pavers are being installed should have a designated wash out area for cement trucks.

Temporary geotextile placed to prevent contamination

When preparing the tender documents, it is very important to provide sediment and erosion control guidelines with emphasis on protecting the infiltration areas. In addition, a site inspector who understands the need for proper ESC in LID construction should be hired.

Warranty

The warranty is a critical component in the construction of LID features. It provides the project manager with a tool to address any issues during or after construction, prior to assumption. When drafting the tender, the warranty must be as specific as possible in regards to guarantee on work, maintenance and replacement of materials, any associated costs in rectifying deficiencies, and the parties responsible for the work. For example, if the bioretention media needs to be replaced, there are costs associated with plant removal, soil removal, disposal, and replacement. This may require sub-contractors to come back to the site. The warranty should address roles and responsibilities specifically in the tender as outlined in the figure below.

SP 16 Filter Media

Filter media is to be comprised of a mix of organic matter and sand in the following proportions:

85-88% sand (grain size 2.0-0.05mm)

8-12% fines (less than 0.05mm)

3-5% organic matter

Filter media is to remain free from contamination from clay, in-situ soils or other debris throughout the duration of the construction period.

The tender should specify party(ies) responsible for plant soil replacement, if soil was not installed to specifications

Omissions can cause significant delays and increase the overall cost of the project. The Elm Drive project, tender specified the frequency of weeding (once monthly). However, inclusion of a specification for the frequency of inspection of plants or replacement of dead plants would have been beneficial. The figure below outlines the need for maintenance operations from substantial completion but should have included frequency to ensure a functioning and aesthetically pleasing landscape. Aesthetics play a large role in the acceptance of LID by both the general public and decision makers. Replacing plants immediately ensures that the site looks as it was intended.

Maintenance during Establishment Period

Perform following maintenance operations from time of planting to Substantial Completion:

7. Remove dead or broken branches from plant material.

Specification for the frequency of plant health inspections and replacement of dead plants would have provided value.

Once the warranty terms are agreed upon, one of the most crucial parts of a successful project rests on enforcing the terms of the contract. A warranty may be agreed upon by both parties and signed accordingly, however enforcing the items in the contract is a necessary requirement that is often overlooked.

Economics (Capital and O&M Costs)

The costs for the retrofit are provided in the following table.

Capital Costs (including labour and materials)	
Item	**Cost**
Consultant fees	$60,000
Roadwork *(excavation and grading, granular material, hot-mix asphalt & curbs)*	$240,000
Permeable pavement lay-by and sidewalk *(granular material, UNILOCK Eco-Prioria & Eco-Optiloc pavers and curbs)*	$55,000
Storm sewers *(manholes, catchbasins and subdrain)*	$50,000
Bioretention planters *(excavation and grading, planter retaining walls, clear stone, bioretention soil media, landscaping)*	$150,000
Boulevard & miscellaneous *(tree removal, topsoil strip and stockpile, sod, spread topsoil and fine grade)*	$30,000
TOTAL	**$585,000**

Many of the costs incurred with this project are typical for a road reconstruction project where an older road with a rural cross section (with roadside ditches) is converted to a modern municipal road right of way standard. Additional LID elements include the permeable pavement lay-by and side walk, at $55,000, and the six bioretention planters installed at a cost of $150,000. The total cost for the LID elements was $205,000, 35% of the total road reconstruction cost.

Of note from the Capital Costs Table is the low cost of storm sewers for the project. As all of the runoff was directed to the permeable lay-bys via a side-shed slope, the number of catchbasins and length of storm sewer piping beneath the ROW was minimized, reducing construction costs of the retrofit for this item. Costs were further reduced by scheduling the construction of the LID features in conjunction with the road work taking place on Elm Drive W. It is recommended that municipal stormwater managers work closely with other departments to identify opportunities to schedule LID retrofits with other municipal infrastructure upgrade projects as a way to reduce costs.

As with any demonstration project, costs incurred with this project are likely higher than they would be for projects with already established standards and work practices. As consultants, contractors and material suppliers become more familiar with the design and construction of LID practices the costs of LID road retrofits will decrease over time.

As is typical for many demonstration projects, additional unexpected costs were incurred at Elm Drive shortly following construction. The City and the PDSB identified safety issues with the drop in elevation in the planters, necessitating the installation of safety fencing around the perimeter of the planters. The initial planting plan was also lacking in seasonal visual interest, which led to poor aesthetics. A landscape contractor was hired to install the fencing and to augment the plantings to improve aesthetics and safety at the site. The total cost for these items was $30,000. Further details regarding how these challenges were overcome are discussed in the Operations & Maintenance section.

Key Facts

Issues

- Additional detailed dimensions on the construction drawings are required to clarify design requirements and reduce the potential for error.
- A cement truck was observed washing out the remainder of its load in the area where the permeable pavers were to be installed.
- Tender documents should be specific with regards to the degree of maintenance (such as parties responsible, the frequency of weeding, and replacement of dead plants) expected during the warranty period.

Solutions & Lessons Learned

- To ensure sufficient infiltration capacity, cement and adjoining contaminated materials were removed prior to installation of the permeable pavers.
- Education and signage should be provided to ensure that all contractors and sub-contractors are aware of the LID features at the site and the need to keep infiltration areas uncontaminated.
- Surveyors should ensure that proper and accurate benchmarks are used to minimize issues or confusion with surveys during construction.
- Engineering drawings should provide sufficient dimensions, detail views and notes to aid contractors installing LID practices.
- Tenders must include special provisions that address issues specific to infiltration practices/LID – including protecting infiltration areas from contamination and remediation requirements if contaminated; post-construction performance verification and remediation requirements if not performing adequately); and maintenance of plant health and dead plant removal.

Operations and Maintenance

Maintenance

Maintenance is an important aspect in ensuring the proper function of LID practices, particularly during the initial establishment phase. It may be necessary to follow-up with the contractor post-construction to ensure that activities specified within the maintenance agreement are taking place.

In general, it is recommended that the contractor perform the following maintenance operations from time of planting to substantial completion:

- Water to maintain soil moisture conditions for optimum establishment, growth and health of plant material without causing erosion.
- For evergreen plant material, water thoroughly in late fall prior to freeze-up to saturate soil around root system.
- Remove weeds monthly.
- Replace or re-spread damaged, missing or disturbed mulch.
- For non-mulched areas, cultivate as required to keep top layer of soil friable.

- Apply pesticides in accordance with Federal, Provincial and Municipal regulations and when required by the City to control insects, fungus and disease. Product approval must be maintained from the City prior to application.
- Keep trunk protection and guy wires in proper repair and adjustment.
- Remove and replace dead plants and plants not in healthy growing conditions. Make replacements in the same manner as specified for original plants.

Maintenance by CVC staff and contractor staff

One of the key lessons learned from this project is the importance of aesthetics. Initially, each bioretention planter contained only one plant species as the intention was to have one plant species blossom in every season. However, this resulted in the site looking dreary the majority of the time as most planters did not show any colour.

Once the initial warranty expired and plants were replaced as needed, CVC worked with a landscaper that supplemented the original plantings. Increased watering and care has improved the health of these plantings. Plants found in the bioretention planters are as follows:

- 'Franksred' Red Maple
- Peegee Hydrangea
- Bayberry
- Dart's Gold Ninebark
- Black Lace Elder

New fence around bioretention planters and revised plantings

Since safety concerns arose over the winter, trees were planted in the planters to give a better visual indicator of their depth during snow covered months. In addition to the new trees, a fence was erected around the perimeter of each planter for safety reasons. These unforeseen issues arose after the first winter and solutions were implemented immediately the following year.

In order to avoid safety and design issues, a site visit by designers is warranted. This will help them to understand how the site is being utilized on a daily basis. Permeable pavers were installed in an area where students smoke. In the case of Elm Drive this is an issue that a site visit could have managed by possibly considering signage or another deterrent to avoid spent butts fall into the gaps between the permeable pavers, increasing the possibility of clogging and decreasing the aesthetics of the site. Another possibility is to avoid installing LID practices in these areas.

In order to reduce maintenance and operation costs, some contractors wait until the warranty period is nearly complete before they carry out any of the required maintenance. Such practice needs to change as it leaves the aesthetics of the site in poor condition for the duration of the warranty. It also hinders long term plant health and growth.

Signage

As a critical part of educating the public, signage was erected on the property to notify students and general public about the bioretention planters and permeable pavers. Since most of the engineering happens below the ground it is very difficult for the public to visualize and understand the functions of these features.

Signage depicts the bioretention planters (rain garden) and connection with the permeable pavers

CVC used a highly visual approach to give the public a view below the ground without cumbersome displays. Anyone walking by can read the simple text and look through the hole, aligning the real life bioretention planters with the display. They will have an immediate sense of what was engineered below the ground and how permeable pavement was linked to the bioretention planters. Easy-to-understand text was used to ensure that general public could understand it. The term rain garden was substituted for bioretention planters.

Once the signage was installed, students immediately began to stop and read about the features. There was also a notable decrease in the amount of trash being thrown into the planters. The signage helped the students to understand the purpose of LID features and make an emotional connection with them, leading them to care more about the site's appearance and function within their community.

Long Term Performance

Demonstrating that LID works in the real world and provides quantifiable stormwater management quantity and quality control benefits is critical to overcoming barriers and concerns among municipalities, regulatory agencies, developers, businesses and other stakeholders. To help address the concerns and barriers expressed by our stakeholders, CVC is currently undertaking a comprehensive infrastructure assessment at Elm Drive to monitor its performance in managing stormwater runoff at the site. This infrastructure assessment is being overseen by an expert advisory committee consisting municipalities, regional government, the MOE, consultants, and universities.

In December 2012 the advisory committee prioritized study objectives for LID infrastructure assessments. Understanding maintenance and operation requirements and life cycle costs are the top priorities of the stakeholders. These study objectives are directly relevant to effective asset management. Better understanding the performance and stormwater benefits of LID in poorly draining soils, and performance associated with the treatment train design approach were also identified as top study priorities. As Elm Drive includes a treatment train approach, is situated in poorly draining soils, and is continuously assessed for maintenance and life cycle costs, the infrastructure assessment underway at the site is well suited to answering the questions of CVC's advisory committee and our broader stakeholders.

The infrastructure assessment began in 2011 shortly after construction and is now in its third year of monitoring. The assessment involves continuously monitoring precipitation and the discharge from the site (after treatment by the permeable pavers and LID planters. Monitoring staff employ an on-site rain gauge, monitoring wells within the planters, and have equipped a manhole at the end of the facility with specialized equipment to measure the flow, volume and quality of stormwater leaving the site. Flow-weighted water quality samples are analyzed for TSS, and a broad spectrum of nutrients and metals for all events producing discharge. Inflow is estimated by the amount of precipitation and the catchment characteristics of the site. Over the course of the 2011 and 2012 monitoring period the performance assessment has recorded 105 precipitation events. The size distribution of these events mirror historic trends for the region.

One of the first, and very significant, findings from the infrastructure assessment is that a majority of events do not produce any discharge from the site – for these events all runoff is infiltrated on-site. At Elm Drive, events less than 25 mm are entirely absorbed by the system. It is important to note that events of 25 mm or less make up 95% of the total annual rainfall events for the region. See the following figure for further details.

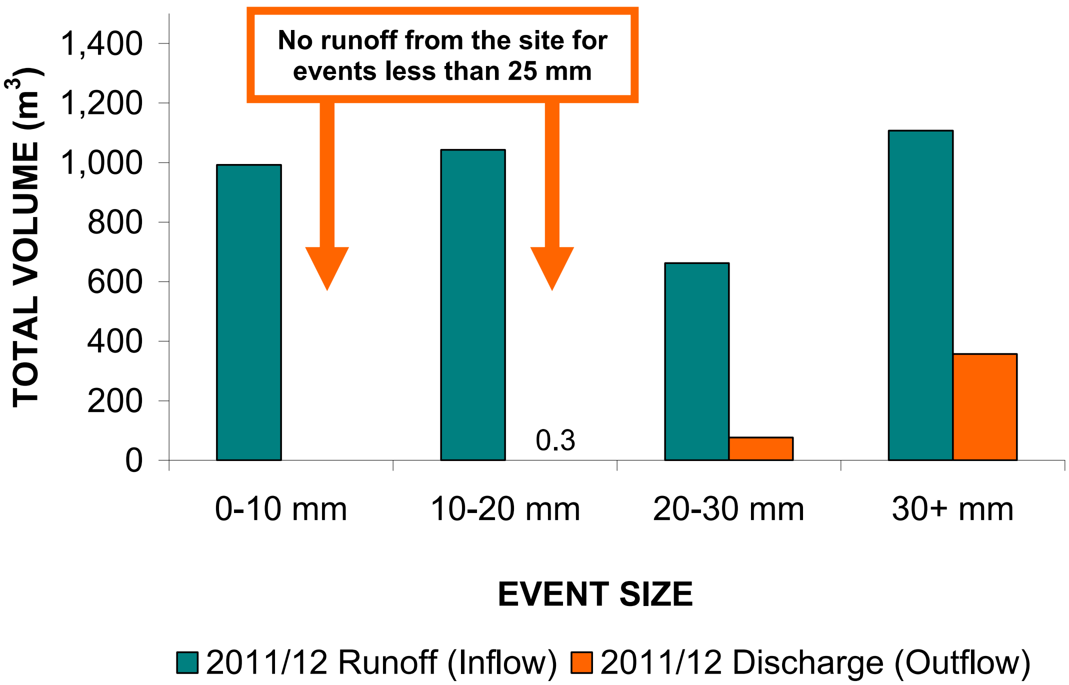


Figure showing the total volume of runoff entering the LID practices at Elm Drive and the measured outflow for the 2011 & 2012 infrastructure assessment period. Flows grouped by size of precipitation event.

Of the 89 events recorded that were 25 mm or less, only one (1% of events) produced discharge from the site. This event was preceded by a larger 30 mm event the previous day. Even with the large preceding event, the volume of runoff leaving the site was still reduced by 60%.

The excellent performance of the LID retrofit at Elm Drive with these smaller, more frequent events, demonstrates that LID can provide excellent erosion control as it goes well beyond satisfying typical erosion control criteria of detaining 5 mm on site. Furthermore, although water balance objectives were not a design objective for the Elm Drive retrofit, the groundwater recharge is estimated to be at least 11 mm for all events, which surpasses the typical stormwater criteria of 3 mm per event.

Infrastructure assessment has also determined the extent to which the LID retrofit provides peak flow control. Two storms comparable to the 2-year return storm have been observed at Elm Drive since monitoring began. Peak flow was reduced by 70% and 100% for these events compared to pre-retrofit conditions. In fact the entire volume was retained on site for one of these events.

An event for which an 85% peak flow reduction was observed is illustrated in the following figure. For this event, volume was reduced by 50%.

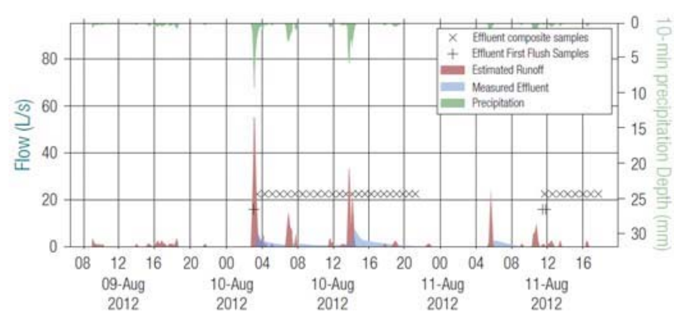
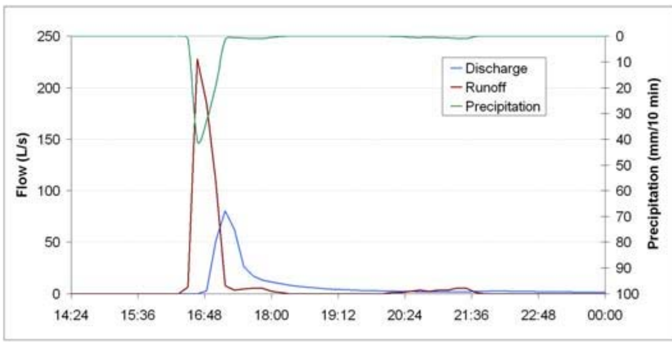


Figure showing the flow entering the LID practices at Elm Drive and the measured reduction in peak flow from the site for a 56 mm rainfall event over a two day period.

From the results of these (and numerous other) events, it is clear that Elm Drive is providing strong site level control.

Events much larger than the 2-year storm have also been recorded at the site. On July 8, 2013 a short duration high intensity rainfall event centralized over parts of Toronto and Mississauga was observed. A rain gauge located at the Elm Drive recorded 104 mm of precipitation over a five hour period, with a 240mm/h peak intensity over a 10 minute interval. Preliminary analysis indicates that this storm event exceeded the 100-year design storm.

The following figure demonstrates how the system performed during this extreme event.



Estimated runoff compared to measured discharge from the Elm Drive site during July 8th storm event (104 mm of rain over 5 hours)

Preliminary data analysis suggests that the LID practices at Elm Drive provided both peak and volume reductions as well as a 40 minute lag time until discharge was observed from the site. These performance findings further illustrate that even in extreme cases, the LID treatment train approach utilized at Elm Drive (and the appropriate native soil conditions) can reduce the burdens on municipal storm systems.

In addition to observing water quantity, quality is also being monitored at the site. Any discharge from the site is sampled and analyzed for TSS, nutrients and metals. Due largely in part to the volume reduction performance, contaminant loading is reduced considerably. 99% of all TSS is removed greatly exceeding the MOE enhanced treatment requirements of 80% removal. The TSS concentration is also below Provincial Water Quality Objectives indicating that discharge from this site does not negatively impact the receiving aquatic environment.

Parameter	Typical Residential Uncontrolled **Concentration** NSQD	Typical Bioretention Effluent **Concentration** BMPDB	Elm Drive Median Effluent **Concentration**	Estimated **Load Reduction** (Accounting Volume Reduction)
Cd µg/L	0.25	0.79	0.09	**94 %**
Pb µg/L	6.00	1.98	0.92	**99 %**
TKN mg/L	1.29	0.64	0.70	**94 %**
TP mg/L	0.27	0.14	0.06	**98 %**
TSS mg/L	**61**	**8**	**14**	**99 %**

Water quality benefit is considerable with the mass loadings of all above contaminants being reduced by more than 94%

To ensure that the infrastructure assessment provides comprehensive data regarding the long-term operation, maintenance and life cycle activities for LID practices, monitoring at the site will continue for an extended time period. Long-term assessment work currently underway includes site inspections and maintenance reports, which will be published to support the needs of our stakeholders.

For further information and monthly updates on the ongoing infrastructure assessment work being undertaken at Elm Drive visit CVC's Elm Drive website or visit bealeader.ca website to access CVC's suite of LID guidance materials.

Acknowledgements

Credit Valley Conservation would like to sincerely thank the following companies, organizations and individuals for their support in the development of this case study:

- Region of Peel
- Ontario Ministry of the Environment
- Peel District School Board
- City of Mississauga
- The Municipal Infrastructure Group
- Pacific Paving
- Fern Ridge Landscaping
- Wright Water Engineers Inc.
- Geosyntec Consultants
- Maxxam Analytics

Version 1.0, Released August 2013

Case Study

Lakeview Neighbourhood

Location: Mississauga
Constructed: August 2012

Road Right-of-Way

Project Objectives, Design and Performance

- Construct one of Ontario's first green streets in a residential neighbourhood using low impact development (LID)
- Retrofit an older neighbourhood to improve drainage, add modern stormwater controls and enhance street aesthetics.
- LID features include boulevard bioretention cells and permeable paver driveway aprons along the road right-of-way.
- Monitor water levels, landscape health and maintenance needs in order to understand the life cycle performance of LID practices.
- Evaluate the performance of LID retrofits in treating stormwater and reducing runoff in a residential setting.

Overcoming Barriers and Lessons Learned

- As the Lakeview project was the first of its kind, the project team had to be flexible and adaptable. Many stakeholders across departments and disciplines provided input during all project phases.
- The project team used an open house style public consultation method to earn project support from neighbourhood residents.
- Site reconnaissance discovered several issues, including fence and driveway encroachments, utilities located in the right of way, traffic safety concerns, and poor grading. All issues were addressed during the planning, design and construction phases.
- Sacrifical pieces of filter fabric laid over top of clearstone reservoirs protected the bioretention infrastructure from contamination. LID projects require simple and creative erosion and sediment control solutions.

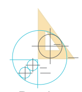
Practices Implemented


Bioretention


Permeable Pavement

Barriers & Issues Encountered


Planning & Regulations


Design


Construction & Comissioning


Operation & Maintenance

Case Study Outline

The Lakeview Project case study consists of the following sections:

Overview

The Lakeview district is a residential neighbourhood within the City of Mississauga. It is located just outside of the Cooksville Creek watershed and drains directly into Lake Ontario, a source of drinking water for over 8.5 million people.

Several residents expressed concerns about the condition and maintenance of the ditches in this older neighbourhood. Ditches had poor water conveyance capacity, locations with standing water, and sections with very steep side slopes. Residents also identified parking encroachment outside the paved area of the road as a concern.

City of Mississauga's Transportation and Works Department decided to retrofit existing ditched streets in the Lakeview neighbourhood in order to address some of these concerns. At the same time, the City choose to address some of the stormwater conveyance and water quality issues by developing a phasing strategy to introduce low impact development (LID) practices.

The City collaborated with Credit Valley Conservation, (CVC), engineering consultant Aquafor Beech Ltd and landscape architect Schollen and Company to implement the Lakeview Project. Existing ditch and culvert systems were replaced with boulevard bioretention and permeable pavement practices within the municipal road right of way (ROW). Permeable pavement was incorporated at the end of resident's driveways and bioretention units were situated along frontages in the boulevard. Portions of both First Street and Third Street between Alexandra Avenue and Meredith Avenue were retrofitted with these features (outlined in **Figure 1**).

The Lakeview project offered a great opportunity to build an LID demonstration showcase that would be a model for future ROW retrofit projects. LID practices constructed in the Lakeview neighbourhood are intended to reduce stormwater runoff and improve water quality flowing into storm sewers and eventually into Lake Ontario. These features have also improved the overall aesthetics of the neighbourhood.

Construction of the Lakeview Project was completed in August, 2012. Since completion, the site has been showcased through multiple presentations, media, events, and site tours. The site has garnered lots of attention from municipal and agency staff across Ontario who are interested in constructing similar retrofits in their area. The local community has also shown a great amount of interest in the project, with many neighbouring residents asking when their streets will be retrofitted.

As part of the partnership with CVC, an infrastructure performance and risk assessment program has been implemented to monitor the performance of the LID practices. Monitoring equipment has been installed to provide localized performance monitoring including both flow and water quality parameters. CVC also conducts regular site visits to document landscape health and maintenance needs.

Figure 1 – Location of the Lakeview Project

Goals and Drivers

There were several primary and supplementary goals and drivers that motivated the Lakeview project. The primary goals describe those directly impacting the City of Mississauga, its residents and the surrounding natural environment. Supplementary goals have many indirect benefits and represent the long-term and wide-scale objectives of LID implementation.

Primary Goals

- Construct LID practices on First Street and Third Street that improve stormwater management within a residential ROW setting.
- Ensure proper drainage and provide treatment within the road ROW in order to increase groundwater recharge, sustain natural flows of rivers and creeks and meet municipal levels of service.
- Demonstrate an alternative to traditional curb and gutter stormwater conveyance that will improve water conveyance and eliminate standing water in the ditches.
- Improve overall aesthetic appearance of the street with attractive plantings.
- Try a new 'open house' style to engage the community in the project. Involve residents in determining the type of street restoration they wanted.
- Address resident concerns regarding drainage difficulties and mowing with ditches by minimizing ditch profile for improved maintenance.
- Demonstrate road ROW stormwater management retrofit within an older residential neighbourhood that meets stormwater objectives for fully developed areas with no stormwater controls.
- Build and monitor LID infrastructure in Ontario.

Supplementary Goals

- Support growth and development of green jobs and build LID expertise within the construction industry.
- Compile long-term data on operation and maintenance needs for LID in the road ROW.
- Evaluate how well native plants can grow in boulevard bioretention units.
- Assist Mississauga in meeting sustainability planning provisions.
- Increases property value and contribute to improved public and community health.
- Support healthy Great Lakes and assist municipalities in meeting sustainability planning provisions.

Project Successes

The following summarizes the successes achieved with this project. Further details are provided throughout the case study.

Innovative Project – The Lakeview Project is one of the first green streets in Ontario. This innovative project marks one of the earliest instances of LID practices implemented in a residential ROW.

Aesthetically Pleasing Street – Several of the LID features enhanced the overall aesthetics of the neighbourhood including the integration of permeable pavement and elaborate planting schemes. The improved aesthetics have sparked interest from surrounding streets, with residents asking when their street will be retrofitted.

Community Amenities – Community amenities such as the Third St parkette provide a public common area and reduce traffic safety concerns.

Demonstration Showcase – LID practices at the Lakeview Project have been showcased through numerous presentations, events, media and site tours. These efforts have helped educate many stakeholders on the benefits of implementing LID.

Performance Assessment – Monitoring infrastructure was successfully installed as part of construction in April 2012. A multi-year performance assessment program is underway in order to evaluate the performance of the LID features.

Construction Adaptation – Design team and contractors worked together to overcome challenging conditions including utilities, space constraints, on-site storage, erosion and sediment control.

Model for Future LID Retrofits – This project serves as a model for addressing stormwater management in older residential neighbourhoods within the Greater Golden Horseshoe area.

Support from Political Champions – Local councillor was a key factor in the success of the Lakeview project. He championed the project by speaking directly with residents about concerns, and regularly showcasing the site to interested parties.

Overcoming Barriers & Lessons Learned

Table 1 lists several barriers and issues encountered during the course of the Lakeview Project as well as how those issues were addressed and the lessons learned by the project team.

Table 1 – Summary of the Lakeview Project Barriers, Solutions & Lessons Learned

Project Phase	Issue/Barrier	Solution	Lesson Learned
Planning & Regulations	As the Lakeview project was one of first green street LID projects implemented in Ontario, project partners had to be flexible and adapt, as many aspects of the design and construction were new.	A multi-departmental and public consultation process was used to provide input during each phase of the planning and design process.	Consulting with all of the partners at an early stage ensures everyone is on the same page and there aren't big surprises later in the development process.
	Several design issues were identified early in the construction process.	Site reconnaissance was completed in order to evaluate site conditions and identify potential issues that may affect the design. Foreseeable design barriers should be confronted as early in the design process as possible.	Site reconnaissance is a necessary step in the design process that helps ensure issues are identified early in the design process.
	The partners wanted to increase participation and engagement of residents in the public information centres.	Additional opportunities for resident input were provided. Multiple public meetings and events such as community barbeques were held in order to engage public interest and encourage public attendance to information sessions	Going above and beyond the traditional expectations for engaging the public may be necessary to gain public support, especially during demonstration projects.
Design	There were concerns regarding how the LID practices would affect the usability of the streets and what alterations were required to the municipal design standards.	Design concepts were presented to all municipal departments to gain a perspective of the sites usability, maintenance and overall function Technical considerations were obtained for all municipal departments and examples of the infrastructure that was to be installed as part of the LID project was provided to municipal staff.	It is recommended that the all parties who will be affected by the project get involved during the design process. This is key to flushing out any potential issues that might be encountered later in the project.
	As Lakeview was an older neighbourhood, there were several fence and driveway encroachments.	Due to the number of encroachments, the scope of project was ultimately reduced	Encroachment issues should be identified during the planning phase prior to project initiation to ensure that such issues are addressed before the design phases is undertaken
	Utilities were located within the municipal right of way, which is common with older residential neighbourhoods.	Utilities were avoided as much as possible during the design phase.	Utilities will always be a concern when retrofitting LID within older neighbourhoods. Utility locates should be performed early in the design process.
	Site reconnaissance showed that there were traffic safety concerns at an intersection in the project area had to be addressed.	A parkette was added to the design to improve the intersection at Alexandra Ave and Third Street.	Site reconnaissance is a necessary step in the design process, as it will help the project team to understand how a site is used on a day-to-day basis. This will inform design decisions.
	The grade of some private properties did not drain towards the road	Provisional lot drains were added to the design drawings.	LID retrofits aim to achieve the best water quality benefits that the site will permit.
	Subsoils had low permeability and there was limited area to achieve water quality volume.	Size of LID practices were maximized to achieve the greatest amount of water quality control possible	

Project Phase	Issue/Barrier	Solution	Lesson Learned
Construction	During construction, design changes were made and some items were deleted.	The project team worked with the City and contractor to agree on diplomatic solutions that benefitted all parties.	Project team and contractor working together often results in an efficient and successful LID construction. Individuals competent in LID construction and design not only provide a resource for other contractors but also act as a liaison between the contractor, client and other stakeholders to ensure that the expectations of all parties are properly coordinated and fulfilled.
	Bioretention soil media was not mixed to standard.	Project team worked with the bioretention soil media supplier to develop an approved mix	Few LID projects the scale of Lakeview has been implemented in Ontario and the supply of specific LID materials is limited. Working with local suppliers to develop LID specific material is part of the evolution of LID implementation
	Utilities and obstructions were found during the construction process.	Minor adjustments to individual design elements were made to avoid or accommodate existing utilities and obstructions. These methods provided a cost effective and efficient means of addressing such construction issues.	Utilities will always be a concern when retrofitting LID within older neighbourhoods. Designers and contractors need to be flexible when implementing LID projects in older neighbourhoods.
	Incorrect materials were delivered to site.	Materials that did not meet the specifications were not used during construction.	Construction supervision and administration is critical to the success of LID projects. Where possible, a contractor or engineer experienced in LID should be on site.
Infrastructure Performance and Risk Assessment	Monitoring equipment could not be placed in the manhole at LV-4 due to space constraints.	Equipment was placed in a metal box on resident's property.	When including an infrastructure performance and risk assessment program at your LID site, ensure infrastructure sizing is adequate for equipment.
	Some plants in the bioretention units grew extremely tall, resulting in resident complaints.	Nuisance species were removed and replaced with shorter, easy maintenance plants.	Qualified landscapers should be involved during the design process. Species selection may need to be revisited after planting, as some species may flourish more than others.
Erosion and Sediment Control	Heavy duty sediment fencing was not practical to provide erosion and sediment control for bioretention units surrounded by curbs, sidewalks or other obstructions.	Creativity is essential when determining the most suitable methods of providing erosion and sediment control. Sacrificial pieces of filter fabric laid over top of the clearstone reservoirs protects the bioretention infrastructure from contamination and wood boards wrapped in filter cloth provided adequate protection of the bioretention systems.	LID specific erosion and sediment controls should be specified in contract documents. Simple and creative ways of protecting LID practices are required since many typical erosion and sediment control are not practical.

Background

The Credit River Water Management Strategy Update (CRWMSU) undertaken by CVC in 2007 developed a detailed inventory of existing resources and key features, reviewed existing and future land use plans, and assessed the potential impacts from proposed land use change within the Credit River watershed. A series of best management practices were evaluated for the watershed with the overarching goal of developing a watershed wide implementation plan for sustainability including definition of the roles of various agencies, policy review, funding arrangements and completion of the ongoing public participation program.

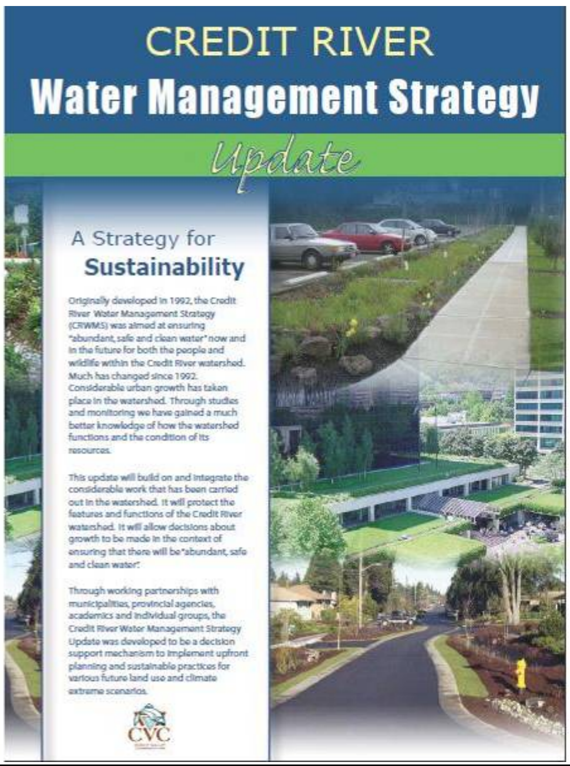


Figure 2 – Cover of the CRWMSU. Full document is available at www.creditvalleyca.ca

The City of Mississauga considered the findings and recommendations from the CRWMSU in the Mississauga Storm Water Quality Control Strategy Update (MSWQCSU). The objective of the update was to develop a comprehensive citywide approach to control the impact of stormwater runoff.

The City completed a comprehensive field reconnaissance program to define LID source, conveyance and downstream opportunities for residential, commercial and industrial environmental conditions. A social marketing study was also undertaken to define the willingness and potential barriers to implementing a wide range of source and conveyance control measures.

A number of streets in the Lakeview community, bounded by Cawthra Road, Lakeshore Road East, Meredith Avenue and the CNR tracks, were previously identified in the City's capital budget for some form of rehabilitation. Following the results of the MSWQCSU, these streets were also identified as opportunities to implement LID practices.

Implementing an LID project was also in accordance with the City's goals to be more environmentally responsible, as outlined in their strategic plan. The City opted to undertake a demonstration project that would include the application of LID practices within the municipal ROW for two streets within the Lakeview community. These included 560 m of First Street between Greaves Avenue and Meredith Avenue, and 120 m of Third Street between Alexandra Avenue and Meredith Avenue, a distance of approximately 120 m. The demonstration site became known as the Lakeview Project.

Lakeview Pre-retrofit Site Conditions

The Lakeview community drainage network consists of a combination of traditional catch basins and sewer networks and roadside ditch and culvert systems that discharge directly to Lake Ontario. **Figure 4** demonstrates the Cawthra drainage network which includes the Lakeview community.

Many residents in the Lakeview community were concerned about the severe degradation of the road surface and issues related to poor drainage. Following wet weather events, standing water was sustained within roadside ditches for prolonged periods. Saturated subsoils and asphalt base layers influenced by poorly draining subsoils are assumed to have assisted the degradation of the asphalt surface.

Figure 3 - Third Street pre-retrofit conditions

Figure 4 – Existing storm sewer conveyance network to Lake Ontario. Cawthra Drainage area is marked by blue and the sewer system is identified by red.

Initial Resident Buy-in

The City approached CVC's Water Resources Management & Restoration department in 2009 with the goal of retrofitting both First Street and Third Street with LID practices. CVC was very interested in promoting these techniques and supporting the neighbourhood residents and provided enthusiastic support for moving ahead with the project.

First Street and Third Street were residential areas identified by the City as overdue for rehabilitation and recognized by local residents as needing upgrades for several years. The intent for the project was to provide residents with a viable solution to address the functional concerns of the worn-out roadside ditches as well as beautify the street.

Early on, it was recognized that a different approach to the public consultation process was necessary. The current outreach on public works projects and environmental endeavours was focused on education, functionality and arcane engineering details. In order to motivate change with the public, the Lakeview project team needed to tap into people's emotional connections because lifestyle changes are driven by intrinsic values. For this reason, the team took a marketing approach. People have an emotional connection with their home's landscape and if individuals can be reached on an emotional level then they will often seek further information.

As this LID demonstration site would take place on residential streets, CVC and the City consulted with a marketing company to gain insight on how to achieve resident buy-in. It was determined that an open house style meeting would be used for the initial approach, rather than a regular presentation followed by question-and-answer style meeting. The open house included various marketing components. These marketing approaches were infused throughout the entire residential outreach component of the project.

The first component in capturing the residents' interest was to use common language to connect with the residents. The first public open house was held on June 25, 2009. Using the name "Lakeview Community Improvement Project" as opposed to stormwater management improvement or road reconstruction open house created buzz and excitement.

The second component to entice residents was a focus on aesthetics. Displays with beautiful landscapes were placed around the room on easels like an art gallery as opposed to having a PowerPoint presentation. This was done to provide homeowners an aesthetic vision they could embrace. The posters helped them visualize the beauty and vibrancy of a sustainable landscape

The third component to gaining residents' buy-in was to engage with them. CVC and City staff dressed casually to create a comfortable atmosphere with the residents. Initially the residents seemed unsure of the project, as it was a new concept. The casual atmosphere allowed residents to interact with staff as they visited the different displays filled with colourful street views and alternative landscape options. Residents started to ask more questions about the project, suggesting they were becoming more interested. They realized if the project went ahead, it would benefit their property in addition to the environment. After everyone was given a chance to visit the various displays, a round circle was held where residents were invited to voice their concerns. These concerns were noted and where possible addressed. Prior to leaving, residents were encouraged to fill out short questionnaires that were used to gauge the level of resident support and gather feedback. The questionnaires also allowed residents to choose which of the proposed LID practice alternatives they preferred in front of their properties.

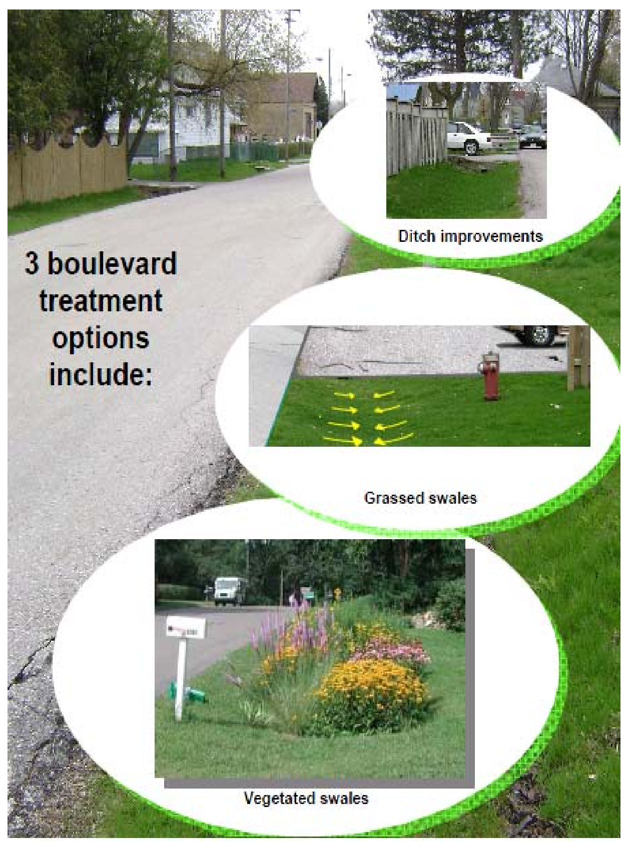


Figure 5 – Conceptual presentation of the alternative landscapes – vegetated swales, grassed swales

The goal of the open house was to gain residents buy-in and gauge their preferred roadside aesthetic, which would eventually guide the overall design concept. With the extra consideration given to creating an open, beautiful and approachable atmosphere, the first open house achieved 95% residential approval to go ahead with the project. This favourable feedback and high percentage of resident buy-in was responsible for advancing the project to design. **Figures 5** and **6** demonstrate the alternatives presented and the responses received from the residents.

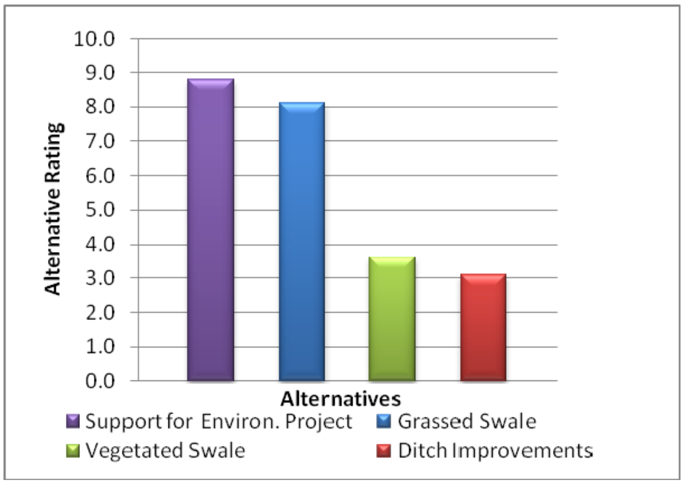


Figure 6 – Residents ratings of the presented landscape alternatives

Building the Project Team

Making the demonstration project happen required a collaborative approach between managers and staff in the City's roadway program and environmental engineering sections as well as input from CVC stormwater specialists. The project also required participation and buy-in from Transportation and Works, as they would have the long-term responsibility of maintaining the new street design. To be a successful the project also needed the full support of City leadership and especially the local Ward 1 Councillor.

Given the innovative nature of the project, a more detailed request for proposals (RFP) was necessary to get the right consultant design team. The City and CVC consulted Seattle Public Utilities, which had 10 years of experience with implementing their Street Edge Alternative (SEA Streets) program. They offered advice and lessons learned on putting together a multi-disciplinary team and how to get the public participation process right.

Based on these discussions, the following provisions were added to the standard RFP for a City road reconstruction project:

- **Expanded purpose and goals** - The project goals clearly stated the innovative nature of the project, the enhanced stormwater management goals, and the high expectation for aesthetics (see callout box for details).
- **Multi-disciplinary design team** - The RFP emphasized the importance of having sustainable urban and landscape designers as an integrated member of the design team, not just for final input. The landscape designer had to work with the engineer to ensure the chosen landscape would survive and thrive. They also needed to work with the residents to set expectations and gain their buy-in to the project.
- **Hydrologic and hydraulic assessment** - This project required more than the typical evaluation of peak flows. To assess water quality and water balance performance, a continuous modelling approach was also required.
- **Public involvement process** - The 2009 open house brought residents on board with the overall concept. The RFP defined several more meetings with the residents to bring the project to completion. There would still be more public information sharing interactions needed. (see callout box for details)
- **Infrastructure performance assessment provision** - The RFP emphasized that the project would use monitoring equipment to assess water quality and flow. The project designers had to be aware early on that monitoring was a goal and that they need to design for it. This included designing in certain types of structures that would fit the monitoring equipment or ensuring that flows were routed to a particular monitoring port.

Project Goals Stated in the Request for Proposals

1. Implement environmentally responsible LID practises on both First Street and Third Street to provide storm water quality treatment and natural filtration before discharging into the storm sewer system and ultimately Lake Ontario
2. Improve water conveyance and eliminate standing water in the ditches
3. Improve the overall aesthetic appearance of the right of way with attractive plantings where feasible
4. Minimize the ditch profile for improved maintenance
5. Demonstrate new LID designs
6. Assess the performance of the implemented LID practices.

Proposals were evaluated based on experience and understanding of the project in addition to cost. The chosen proposal by engineering consultant Aquafor Beech Limited and landscape architect Schollen & Company best fit the RFP requirements. Their joint proposal brought together a project team with expertise in LID principles, water resources engineering, landscape architecture, and urban planning.

Public Participation Process Specified in RFP

1. **Meeting #1: Kickoff Meeting**
   The consultant team will give a short presentation introducing the project and walk the project area with residents to gather background and feedback.
2. **Meeting #2: Presentation of 60% Plans and Plant Selection**
   Project Team will meet with homeowners and present the engineered concept, and the consultant landscape architect will provide planting plan options for the homeowners to choose from.
3. **Meeting #3: Presentation of 100% drawings and Construction Kickoff:**
   The intent of this meeting is to show the completed plans, set construction expectations, address any final concerns, and discuss the maintenance responsibilities.

Site Reconnaissance

Site reconnassiance and a background review of existing ducumentation was perfromed by the engineering consultant in 2009, which included the review of City mapping, geotechnical reports, and serviceing plans.

During the site reconnaissance a number of key design issues were revealed. Issues identified during the course of the site reconnaissance included:

- Encroachments
- Utilities and obstructions
- Traffic safety
- Flooding and drainage

Encroachments

Since the project was implementing LID pracitces within the municipal road ROW, areas adjacent to the road had to be available for design purposes. In many cases encroachments from private fences, parking areas, and other structures impacted the availablity of space for LID implementation. **Figure 7** demonstrates the type of encroachment observed throughout the site area. A photograph of an encroachment is provided in **Figure 8**.

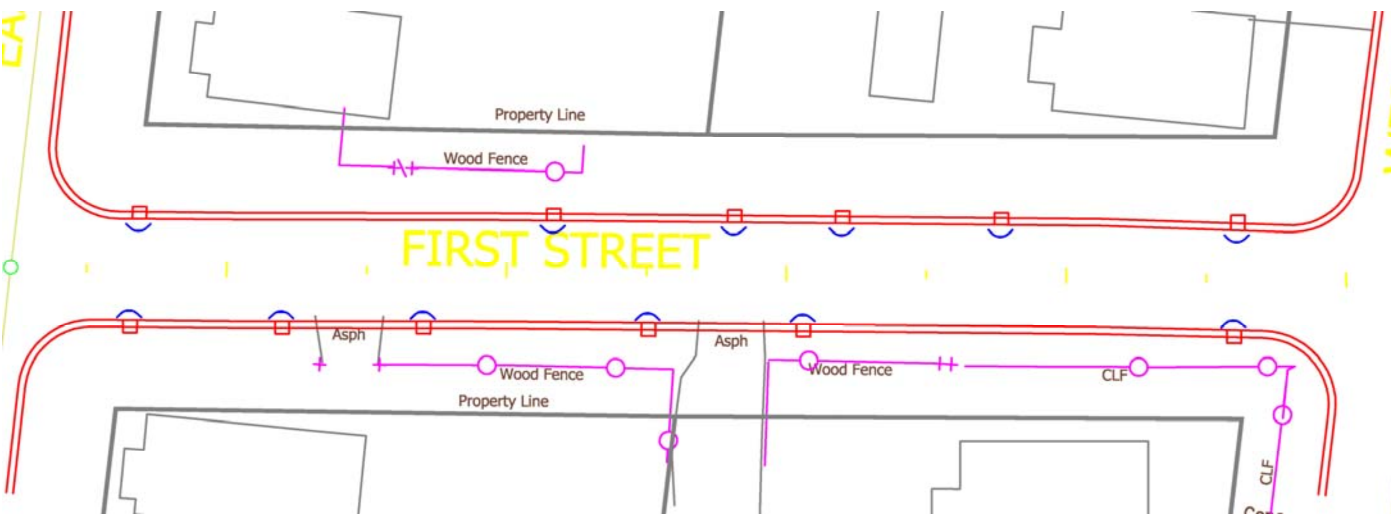


Figure 7 – Encroachment of First Street property line (Grey) versus private wood fence (Magenta)

Figure 8: Fence line encroachment on First Street

Utilities and Obstructions

Utilities both overhead and underground were located throughout the proposed locations for the LID practices. Locate information was surveyed during the completion of pre-design tasks and added to existing mapping to ensure as much utility information was available during the design phase.

Figure 9: Many buried utilities were located along First Street and Third Street, posing a challenge for construction

Other obstructions within the ROW were generally limited to roadside trees; however, signage, established parking areas and other structures were noted during the site reconnaissance.

Traffic Safety

The local road configurations and long, unobstructed, lengths of road posed many safety risks in terms of excessive vehicular speeds and poor line of sights. It was evident during the site reconnaissance and from resident complaints that traffic calming measures and potential road re-alignments should be considered during the design phase.

Flooding and Drainage

Several residents voiced concerns about degraded stormwater and road infrastructure in the Lakeview neighbourhood. Following wet weather events, standing water was sustained within the roadside ditches for prolonged periods. In addition, the age of the area led to many encroachment issues and alterations made to existing lots and drainage system.

Figure 10 and 11: Obstructed and damaged culverts in need of repair.

Figure 12: Ditches filled in for parking purposes

Pre-Design Tasks

Several tasks were undertaken by the engineering consultant to fully characterize the site conditions and guide the development of the detailed design. These include:

- Topographic survey
- Review of geotechnical investigation
- Infiltration testing
- Vegetation assessment

Topographic Survey

A topographic survey of the municipal ROW along First and Third St. was completed in order to produce base mapping for the design phase. The survey included the following site features:

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

Review of Geotechnical Investigation

A geotechnical investigation was undertaken by the City of Mississauga prior to initiation of the project as part of the intended road rehabilitation works. Information related to the subsurface conditions, including particle-size distribution, observed groundwater levels, soil stratigraphies and moisture content were included within the report.

Infiltration Testing

Guelph Permeameter testing was performed in November 2010 to determine the saturated hydraulic conductivity (Kfs) of the in-situ soils. The experimentally determined Kfs was then converted to infiltration rate (mm/hr) and a factor of safety corresponding to the non-stratified soil conditions was applied as per Appendix C of the Low Impact Development Planning and Design Guide. The calculated design infiltration rates for were determined to range from 0.04 – 7.67 mm/hr across the site. The average design infiltration rate was determined to be 5.45 mm/hr for First and Third St and was used as the basis for design calculations for the LID practices.

Figure 13: Infiltration testing conducted at Lakeview

Proposed Design Concept

Design concepts for the Lakeview Project were developed by the landscape architect based on the objectives set by the City including:

- Implementing environmentally responsible LID practices on both First Street and Third Street
- Improving water conveyance and eliminating standing water in the ditches
- Improving the overall aesthetic appearance of the street through attractive plantings
- Minimizing the ditch profile for improved maintenance
- Demonstrating new LID designs that will serve as a template for other street redevelopment projects.

Figure 14 – Artist rendering presented by the landscape architect

The concept incorporated a combination of vegetated and grass bioretention units within the boulevard and permeable pavement at the end of driveways. The concept drawing was presented to the City in April 2010 at which time the project team discussed the overall usability of the street and other design considerations.

The topics of discussion focused on technical considerations, including:

- Driveway widths and replacement
- Road surface improvements
- Sidewalks
- Encroachment issues
- Boulevard drainage
- Aesthetics/landscaping and property impacts
- Traffic safety and parking

All municipal departments that would be involved with the Lakeview Project were presented the design concept. This multi-departmental approach was used to ensure that a basic agreement amongst the departments was obtained prior to presenting concepts to the public or moving forward to subsequent design phases. Issues and potential design constraints were resolved technically by consulting municipal specifications, by-laws, policies and operation procedures which were both general and specific to each individual department. This approach allowed all potential concerns to be addressed during the design phase and lent confidence when presenting these concepts to the public. This approach limited potential causes for delays, re-designs and public confusion during later stages of the planning and design process.

Any of the discussion topics listed which were not resolved technically between the project team and municipal staff guided the focus of subsequent PICs. Public insight and preference would be used to resolve many of the outstanding issues. As such, the decision making process for many of the higher level design elements was considered an organic process in which municipal discussions were built on a foundation of municipal technical requirements and amended using public feedback of the unresolved details. **Table 2** demonstrates the municipal discussions of the aforementioned design issues and the resulting course of action taken following those discussions.

Table 2: Conceptual design issue discussions

Design Issues	Discussion	Action
Driveway width and replacement	The installation of a subsurface conveyance system in the form of bioretention units required resident driveways to be removed and replaced for pipe laying purposes. It was discussed during the conceptual design phase if driveway widths would be limited since many of the existing driveways exceed municipal standards in terms of width and location.	This issue was placed on hold to determine appropriate solution
	The design team suggested replacing driveway sections that crossed the ROW with permeable pavement; however, the City indicated that tie ins with resident owned driveway sections may be difficult and asphalt should be utilized.	Present to public for feedback
Road surface improvements	It was indicated by the design team that existing road widths (asphalt edge to asphalt edge) ranged from 6.0 – 6.4 m. Design concept was laid out as 6.0m from back of curb to back of curb.	Resolved technically per municipal specifications
	The municipality noted that minimum road width for emergency vehicle passage and snow removal had to be 7.4 m from edge of pavement to edge of pavement.	
Sidewalks	Concept assumed that sidewalks would be replaced only where there currently exists a sidewalk	Present to public for feedback
Encroachment issues	Implementation of the concept would require encroachments to be address	City to undertake action through enforcement of by-laws
Boulevard drainage	Connections to the proposed LID infrastructure would need to accommodate sump outlets via bioretention unit underdrains.	Design team addressed by ensuring the design accommodated existing sump outlets
Aesthetics, landscaping and property impacts	Design team required City to confirm the process for contravening existing bylaws relating to noxious weeds, planting heights and type of plant material to be planted in ROW. By-law review and revision would be necessary to address the matter in the long-term	Pending by-law review, there could be short-term by-law contravention.
	Design team suggested allowing residents to choose plant scheme and types to be installed out front of individual homes.	Presented planting options to public again to gauge interest of LID options presented
	Planting options (i.e. sod or perennials) were presented during the initial PIC conducted in June 2009; however, clear direction was not received.	
Traffic safety and parking	Design team suggested the use of permeable parking as parking stalls were existing constraints exist i.e. Telephone poles etc. City indicated that this option should be investigated but raised potential issue with placement of parking stalls in front of residences.	Presented to public for feedback in order to develop a solution.

Despite some of the outstanding issues, the overall Lakeview concept was agreed upon by the various municipal departments and was presented to the public for feedback during a PIC held on July 8, 2010. An 'open house' approach was used at the PIC instead of traditional public consutlation methods. The aim of this approach was to create a more casual and comfortable atmosphere where people could talk directly and on-on-one with members of the project team . Staff on hand were dressed in business casual instead of uniforms to ensure that there was no authoritarian presence at the meeting. The goal was to include residents in the decision making process, and not simply dictate what changes would be made to their street.

During the PIC, residents were encouraged to complete questionnaires which highlighted many of the unresolved issues which were discussed between the design team, CVC, and City of Mississauga.

Figure 15: PIC #2 undertaken to obtain resident input

Residents provided the following feedback during the PIC:

- Issues were was ranked from most important to least important:
  - Parking
  - Water quality
  - Environmental benefits

- Preventing flooding
- Integration with the evnironment
- Improved conveyance
- Integration with existing infrastruction
- Aesthetics

- Sidewalks are not wanted
- Cost is not important
- Would like to maintain existing driveway widths
- 50% now wanted perennial plants (grassed swales preferred per Initial PIC – June 2009)
- 83% had high acceptance of permeable pavement being located across ROW
- 67% of residents were willing to do 2-4hrs of maintenance per month
- Ditch to be eliminated

Community input guided the detailed design and tackled many of the design issues aforementioned. **Table 3** demontrates the resulting actions undertaken for the perviously identified design issues following public consultation.

Key Facts

Issues:
- Design problems related to LID implementation could not be strictly resolved by technical input from municipalities, design teams and agencies.
- Support from the residents would be needed in order to create a successful project.

Solutions and lessons Learned
- Public input is key to determining the solutions that are most appropriate.
- Retrofit projects present unique problems which can be site specific.
- CVC and partners worked together to deliver an open-house style event to encourage greater one-on-one discussion and secure support from residents.

Table 3 - Conceptual Design Revisions Following Public Consultation

Design issues	Actions following municipal discussions	Actions following public feedback
Driveway width and replacement	• This issue was to be further discussed in terms of the potential impacts and determine the appropriate solution. • Present to public for feedback.	Residents preferred driveway widths to remain unaltered. Since driveways would be more formalized within the ROW following rehabilitation, municipal staff identified that this would effectively improve parking availability within residents' driveways. The City also researched local bylaws and realized that parking infractions were minimal throughout the area. Minimal infractions, low traffic and more formalized driveways result in little reason to implement street side parking.
Road surface improvements	• Resolved technically based on municipal specification for allowable road widths • Still present to public for feedback regarding road width alterations	Public feedback corresponded with municipal specifications.
Sidewalks	Present to public to determine obtain feedback regarding the need/want for sidewalks	No new sidewalks were implemented.
Encroachment issues	City to undertake action through enforcement of Bylaws	N/A
Boulevard drainage	Detailed design will accommodate sump outlets	N/A
Aesthetics, landscaping and property impacts	• Design team established planting options to be presented to the public that were accepted by the City's Parks and Operation and Maintenance Departments. • Present to public for feedback • Present planting options to public again	• Residents indicated that they were willing to participate with the maintenance of the plantings • 50% interest in perennials. Further encouraged City to move forward with the project
Traffic safety and parking	Present to public for feedback	Residents identified traffic issues at the intersection of Third St. and Alexandra Ave. due to limits access and poor lines of sight. Area to be investigated during the detailed design phase.

City staff allowed residents to decide on the planting scheme implemented within the boulveard. Using a “dot-mocracy” approch, residents were allowed to choose between two planting schemes: an assortment of perrenial plantings or a tradtional turf options. These options were presented during the second PIC. Residents were assured that the planting scheme that they selected would be what was installed during construction and residents were assured that they could change their minds at any time.

For residents who did not attend PIC #2, follow up letters were delievered to the residents homes to provide them an opportunity for input on the project. In attempts to receive further input from residents who did not attend or missed PIC #2, the project team and municipality teamed up with the local counciller to engage the public. The councillor engaged residents by attending community meetings and addressing questions and concerns about the Lakeview project.. Although many local residents from the ward attended the information session, no additional input specific to the Lakeview Porject was received.

Figure 16 – Planting schemes presented at PIC #2

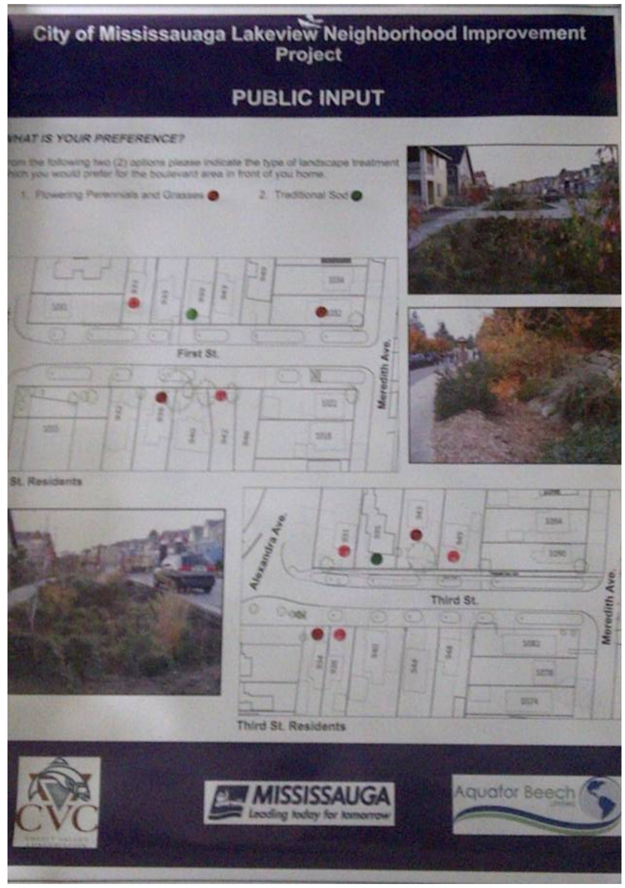


Figure 17 – “Dot-mocracy” board from BBQ hosted by CVC and the Ward Councillor where residents stuck markers on their to indicate their preferred planting scheme

Detailed Design

The detailed design of the Lakeview Project utilized information obtained during the pre-design and conceptual design phase to further develop a design that fulfilled both the municipal and resident objectives.

The following sections provide further insight into the detailed design process and the decisions made that refined the design concept.

General Design Elements

Inlets and Curbs

Municipal staff and members of the project team travelled to other LID related projects within Mississauga to evaluate different types of curb and inlet types that would best suit the Lakeview Project. Barrier, semi mountable, and various types of roll curbs were discussed with several municipal departments. A semi mountable curb was selected for the following reasons:

- It provides a low profile barrier for cars to park against and distinguish limits for snow removal operations
- It provides separation between road and areas adjacent to the curb for safety reasons
- It eases the tie-in of bioretention soil media with the back of curb. A low profile curb barrier decreased the swale depth which complemented resident requests for no deep ditches.

Inlet types were also discussed. Many options for covered inlets or steel grated inlets were proposed. However, concerns regarding snow removal operations damaging the covers discouraged the alternatives**.**

Figure 18 &19 – Covered inlet option (top) and side inlet catch basin (bottom)

A simple curb cut design was selected for the Lakeview project. However, for one of the bioretention units implemented on Third St., side inlet catch basins were used. This would allow the City to assess the difference in maintenance efforts and modifications required in integrating traditional side inlet catch basins with LID design. See Figure 20.

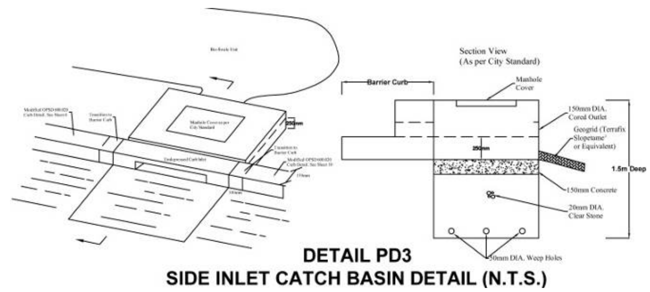


Figure 20 - Design and integration of side inlet catch basins with the boulevard bioretention units.

Usability

Similar to the curb and inlet selections, many other design features were added to the design following discussions related to the overall usability of the site. For example, non-woody vegetation was proposed for the bioretention units since the areas were to be used for snow storage during the winter months. Woody vegetation in the bioretention units would have been damaged by snow load. As such, low maintenance sod and perennial plantings were selected for the landscaping plans

Figure 21 – Perennials planted within bioretention units

Initially, it was proposed that perennials be planted throughout the entire bioretention unit from back of curb to the resident property line. However, the design team felt that encroaching vegetation and lack of available foot space would make it difficult for individuals parking on the street to exit their vehicles. To resolve this issue a 0.6 m buffer was added around the bioretention units which were to be strictly sod. This area would provide access for residents exiting street parked vehicles and also provide a formalized snow storage area. See **Figure 22**.

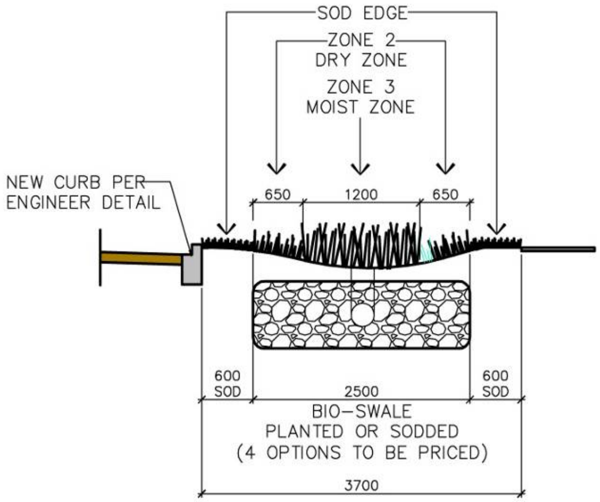


Figure 22 – Bioretention unit planting configuration

Permeable Pavement Driveways

When discussing the overall staging and constructability of the bioretention units and driveway areas, issues related to the type of driveway surface treatment was revisited. Discussions held during the conceptual design phase determined that an asphalt surface treatment would be reinstated in order to tie-in with the asphalt sections on resident properties.

A different sub-base is used in the construction of asphalt driveways compared to permeable pavement. However permeable pavement and bioretention use the same base material, 20mm clearstone. Ensuring that the two types of base materials could be adequately separated to avoid fines contaminating the bioretention reservoirs was a concern. Phasing construction in order to properly incorporate the asphalt driveways would create additional costs and inconvenience to residents. This did not seem to outweigh the additional costs of the permeable pavers or the convenience of using only one type of base material. For these reasons and the fact that the residents highly accepted the aesthetics of the permeable pavement concept, the use of permeable pavement for the driveways was approved.

As an added benefit, the use of permeable pavement within the driveway areas also increased the water quality storage volume provided on-site. Since no formal major systems existed for the Lakeview area the additional storage and decreased runoff volumes was considered an added benefit by the municipal staff.

Figure 23 – Permeable pavement driveways

Parkette

During the detailed design process, a vacant property located at the east corner of the Third St and Alexandra Ave was identified. Municipal staff was able to confirm that this was City owned land.

Previous discussions with residents identified the intersection as a potential traffic hazard due to the existing alignment of the intersection (Third St. being misaligned from one side of Alexandra to the other). The misalignment made lines-of-sight for drivers and pedestrians difficult and there were no defined crossing routes to ensure a safe crossing for pedestrians. **Figure 24** demonstrates the pre-retrofit intersection alignment of Third St and Alexandra Ave.

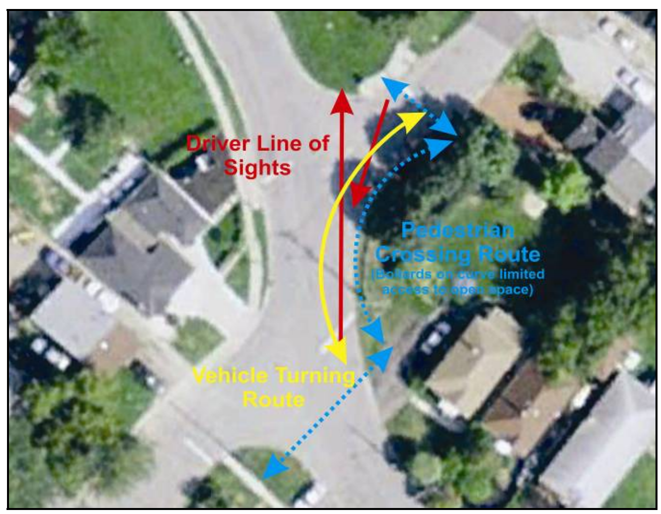


Figure 24 - Third St. and Alexandra Ave Intersection (North being top of page)

In most cases, pedestrians walking westbound on Third St. who wanted to travel southbound on Alexandra Ave were forced to walk along the east curb. Guard rails on the curved profile of the road prohibited pedestrians from walking through the adjacent green areas. The curve in the road and location of the stop lines made lines-of-sight for both pedestrians and drivers difficult.

With no option to realign the intersection, a parkette was proposed for the vacant property. The parkette would not only create a community space for local residents but also provide a safer crossing route for pedestrians. The stop line of Third St. was also moved forward in order to improve driver's line-of-sight to northbound drivers on Alexandra Ave.

Figures 25 & 26 provides an overview of the revised layout and travel route provided by the parkette.

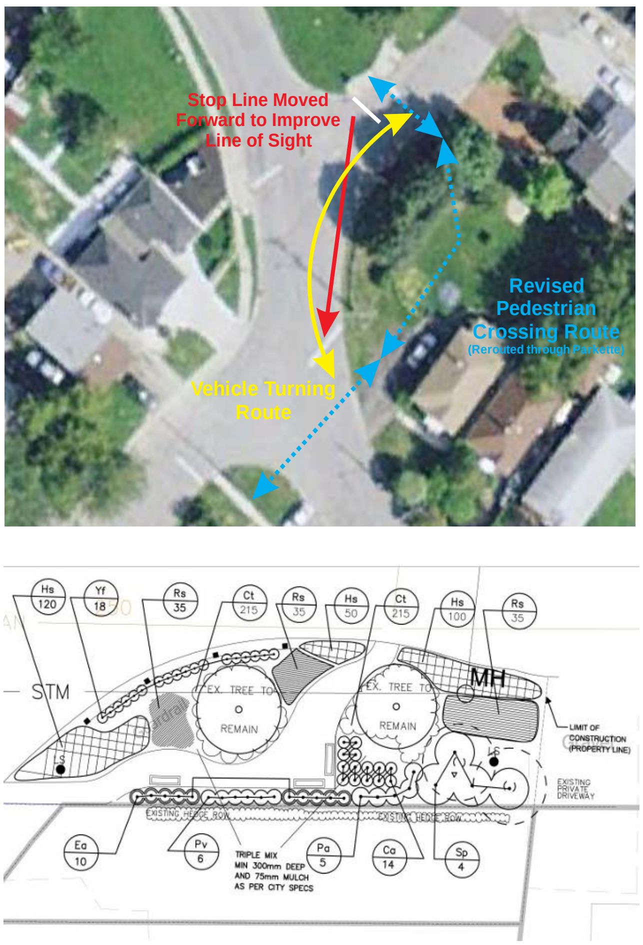


Figure 25 & 26 - Revised pedestrian route and parkette detailed design

Subsurface Infrastructure

The design team and municipal staff discussed the proposed subsurface underdrains and the potential for heaving. They also assessed whether clay plugs were required to isolate the various bioretention cells.

It was established that pipe heaving was not an issue due to the overall depth of underdrain and thickness of the free draining bedding material situated below the invert of the underdrains. Clay plugs were determined to be unnecessary due to the proposed grading of the bioswale and permeable pavement subgrade. The variations between the subgrade of the permeable pavement and boulevard bioretention sections created a series of check dams which would control subsurface flow rates.

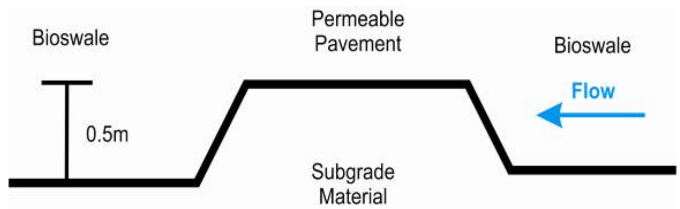


Figure 27 - Grading of the bioretention unit and permeable pavement driveway subgrade.

Technical Design Elements

Drainage Areas

To evaluate the hydrology of the existing and proposed site conditions, drainage areas and runoff coefficients were selected based on previously existing and proposed drainage patterns and land uses per City of Mississauga standards and as determined by the design team.

The existing condition drainage areas were divided by the configuration of the lots and drainage patterns observed during the site reconnaissance. However in several cases surface drainage patterns of individual lots drained to adjacent lots not part of the study area. These questionable areas were nevertheless included to ensure a conservative design and redundancy in case grading of the individual lots was revised in the future.

Hydrologic and Hydraulic Assessments

The hydrologic and hydraulic assessments conducted for the Lakeview project were completed according to City of Mississauga standards for minor system flows to storm sewers which shall be designed using the 10-year storm events. Existing grading created challenges for major storm flows. Nevertheless, the 100 year flow event was evaluated. As such, intensities for the 10-year and 100-year storm events were applied to the rational equation for the existing and redevelopment land use conditions to compute the corresponding peak flow rates and runoff volumes. The rational formula is as follows:

Q=C IA/360;

where

Q=Runoff rate (m^3/s)
C=Runoff coefficient
I=Rainfall intensity (mm/hr)
A=Site area in hectares (Ha)

Underdrain and surface swale capacities and sizing were determined using Manning's equation and runoff flow rates from the individual drainage areas.

LID Design Elements

The primary LID design practices incorporated into the Lakeview Project included permeable pavers and boulevard bioretention units

These LID practices improve water quality and reduce the quantity of runoff reaching local drainage features. The following sections provide additional detail with respect to the characteristics and function of the individual LID practices implemented in the Lakeview Project. **Figure 28** below demonstrates the layout and configuration of the LID practices implemented at the Lakeview site. Sizes of LID practices installed throughout the Lakeview neighbourhood were dictated by the maximum area available for implementation.
Although structural analyses were conducted for the permeable pavers and general sizing calculations were completed for the bioretention units, actual storage volumes were dictated by the following two design constraints:

- Depth of storage available above the underdrain was restricted by the existing ground surface elevations and the tie-in location of the underdrain to the existing storm sewer system
- Width of the systems was restricted by the available distance between the proposed back of curb and property lines

The underdrain of the permeable pavement and bioretention units was installed so that it could be positively connected to existing catch basins or manholes at the termination point of the street (i.e. downstream extent) and sloped so that flow velocities were within the applicable City of Mississauga standards.

Permeable Pavement

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

The design of the permeable pavement cross-section and associated aggregate depths was determined through a structural analysis. The structural design method utilized for the Lakeview site was the AASHTO flexible pavement design methodology, specifically the empirically based AASHTO 1993 Guide for Design of Pavement Structure in combination with the Interlocking Concrete Pavement Institute (ICPI) Design Guide, 4th edition, D.R. Smith (2011). The concepts in

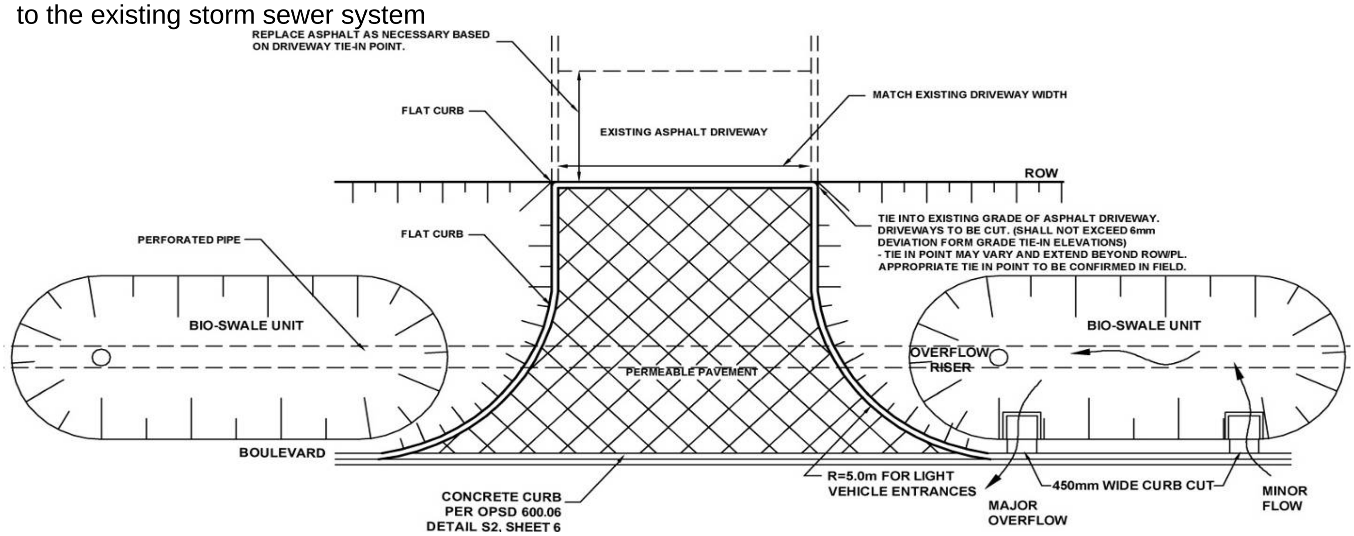


Figure 28 – Configuration and layout of LID features implemented within the residential road ROW

the 1993 guide emerged from tests in the 1950's that established relationships among material types, loads and serviceability using a structural number (or SN) given the traffic load (ESAL's), soil type climatic and moisture conditions. Through this process, the designer finds the appropriate combination of pavement surface and base material to meet or exceed the required SN. Layer coefficients for the various open graded aggregates commonly used in permeable pavement construction are generally recognized as being approximately 30% lower than standard dense-graded materials as such base courses of PICP will typically need to be thicker to compensate for lower strength and stiffness associated with the less dense grading

Based on the subgrade soil strength and computed equivalent axel loads the recommended permeable pavement cross-section was determined. **Table 4** summarizes the components and aggregate depths within the PICP paver cross-section.

Table 4 – Permeable Pavement Design Cross-sections

System component	Value
Paver thickness and type	80 mm – Aqua Paver (by Hanson)
Bedding	50 mm of No.8 angular chip stone (5-7mm ø)
Aggregate depth (min.)	370 mm of No.57 angular clearstone (20 mm ø)
Underdrain bedding depth	100 mm of No.57 angular chip stone (20 mm ø)
Total excavation depth (min.)	500mm
Underdrain system	300 – 375 mm ø perforated HDPE main collection pipe

An aggregate depth of 370mm was used as a minimum based on the result of the structural analysis and the site conditions (**Figure 29** and **30**). In many cases, aggregate depths for the driveways were much greater than 370 mm given the required location of the underdrain.

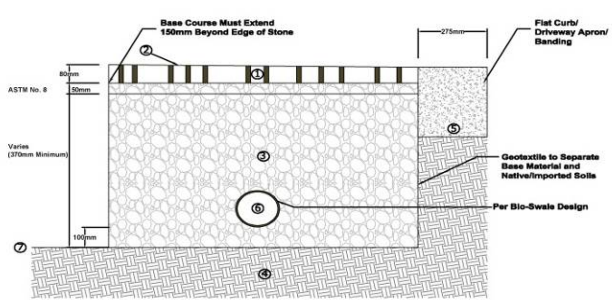


Figure 29 – Permeable pavement driveway cross section

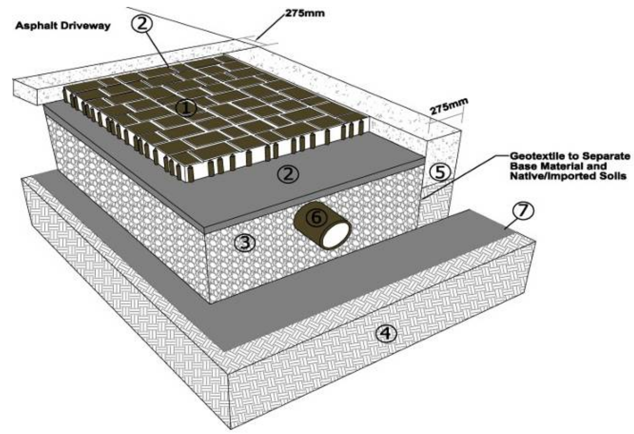


Figure 30 – Permeable pavement driveway exploded cross section

In preparation of the base material installation, a non-woven geotextile was placed directly on the prepared subgrade and up the sides of the excavated trench to prevent fines from the native subsoils from migrating into the clearstone base material. The geotextile was 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. Unlike the preparation of boulevard bioretention unit reservoirs, the top of the permeable pavement base layer was not wrapped with filter fabric.

Figure 31 – Preparation of permeable pavement driveways base material

The following tables detail the specified base course gradations utilized in the permeable pavement cross sections. **Table 5** summarizes the particle size distrbution for 20 mm ø clearstone.

Table 5 – 20mm ø Clearstone Particle Size Distributiuon

20 mm Ø / ASTM C33 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

Clearstone brought to grade was compacted and topped with the No.8 chip stone bedding layer. This layer was compacted prior to the placement of band curbing and permeable pavement.

Figure 32 – Installation of bedding material and permeable pavement

Boulevard Bioretention Units

Bioretention units are soil filter systems that temporarily store and filter runoff. These units rely on the engineered bioretention soil media placed below the channel invert to provide runoff reductions and improve water quality. Runoff treated by the media bed flows into an underdrain, which moves treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer placed below the engineered media bed. On the surface, bioretention units may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Bioretention areas can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

The proposed Lakeview design consisted of individual bioretention units connected in series and located between permeable pavement driveways and property frontages.

A series of design computations were undertaken as part of the design of the proposed bioretention units, including:

1. **Storage Assessment –** Volumetric storage calculations which evaluated the proposed design and its ability to provide adequate storage for the water quality volume for the 25mm event. This analysis was used to determine the quantity of storage to be provided throughout the bioretention unit's profile. As specified in the Low Impact Development Stormwater Management Planning & Design Guide, the maximum depth of the stone permitted below the underdrain was calculated based on the permeability of the native soil material (underdrain required as subsoil infiltration rates were <15 mm/hr).

2. **Surface Area Requirement Assessment** –The recommended surface area of the bioretention units was calculated based on the quantity of water quality storage volume (25mm event) to be provided from the respective drainages and the recommended bioretention unit depth (determined by Assessment #1 and design constraints) and void ratio of the bioretention soil media and clearstone material. In many cases, the required area was much larger than the area actually available within the municipal ROW. As such, the bioretention unit areas were maximized as much as possible given the area available for implementation.

Key Facts

Issues:

- Design constraints made it difficult to accommodate water quality volumes.

Solutions and lessons Learned

- Retrofits should be recognized as opportunities to provide the most amount of water quality benefit possible given the site constraints.

All bioretention units were sized to treat as much of the 25 mm event (water quality event) as permissible by the site conditions. **Table 6** summaries the general physical attributes of the proposed bioretention unit design.

Table 6 – General Dimensions of the Boulevard Bioretention units

System component	Value
Top width	2.5 – 3.0 m
Bottom width	2.5 m
Aggregate depth (Min)	1025 – 950 mm of No.57 angular clearstone (20 mm ø)
Bioretention soil media depth	450 – 600 mm
Underdrain bedding depth	500 mm of No.57 angular chip stone (20 mm ø)
Total excavation depth (Min)	1.5 – 2.0 m
Underdrain system	300 – 375 mm ø perforated HDPE main collection pipe

The bioretention unit underdrain systems consisted of an excavated trench lined with non woven geotextile and filled with an open void 20 mm diameter clearstone. 300 – 375 mm diameter HDPE peforated pipes situated within the clearstone bedding underdrain the entire length of the bioretention units and permeable pavement sections (see **Figure 33**). The 20 mm diameter clearstone bedding material is fully wrapped with non-woven geotextile so that it overlaps to cover the top of the cleanstone bedding material.

Figure 33 - Bioretention unit with non-woven geotextile, 20mm diameter clearstone with an HDPE perforated pipe

Figure 34 demonstrates the varying excavation depths of the permeable pavement and bioretention unit sections. The bioretention areas were excavated deeper to provide additional water quality storage whereas storage below the permeable pavement section was constructed such that pipe bedding material would be provided but prolonged periods of standing water would be minimized in order to protect the structural integrity of the subsoils.

Figure 34 - Varying excavation depths for the bioswale and permeable pavement sections

A 450 mm – 600 mm thick layer of engineered filter media mix (see **Table 7**) was placed on top of the clearstone bedding material with geotextile separating the two materials. This was to avoid bioretention soil media from migrating into the clearstone and filling available void space wihtin the clearstone. **Table 7** demonstrates the composition of the engineered bioretenion soil media.

Table 7 - Bioretention Soil Media Composition

Component	Percentage by weight
Sand (2.0 to 0.05mmØ)	85 – 88%
Fines (<0.05mmØ)	8 – 12%
Organic Matter	3 – 5%
Additional requirements • CEC greater than 10mg/100g • pH = 5.5 – 7.5 • Hydraulic conductivity greater than 25mm/hr • No objects greater than 50mm	

Figure 35 - Bioretention soil media placed within bioretention units along Third St.

Tendering and Preconstruction

Following the completion of the detailed design, contract documents including engineering estimates and tenders were compiled and released for contractor bidding. Significant design changes were made during this phase of the implementation process.

Encroachment Issues

During the detailed design phase the design team undertook an analysis which identified all the existing encroachment infractions located along First St.and Third St. Initial discussions with the City indicated that the general approach to ensure the ROW was available for construction was to enforce the municipal by-laws and have any encroaching structures or property be removed from the municipal ROW. However, further discussions between the municipality and design team determined that due to the significant amount of encroachments, by-law enforcement would be impractical given the scpoe of the infractions. Municipal staff determined that further thought and discussions must be had to determine the appropriate actions to be followed in order to address the encroachment issues. As such, the scope of the Lakeview Project was reduced. The revised scope of the project was limited to First and Thrid St. between Meredith Ave and Alexandra Ave.

Tendering Results

One of the first issues encountered with the Lakeview tender was high bids from contractors. Prices received from contractors were considerably higher compared to engineering estimates. This was presumed to be a result of contractors exploiting the available Infrastructure Stimulus Funds (ISF) provided by Infrastructure Canada to municipalities in order to fund capital works and other municipal projects at the time.

The received tender bids and high prices further supported the motion to reduce the scope of the Lakeview Project and re-tender.

Construction & Commissioning – General Issues

The construction of the Lakeview project commenced in April 2012 and concluded June 2012. During the course of the construction process a variety of challenges and obstacles were encountered, some of which were general and other which were LID specific.

Utilities

Utilities were major construction obstacles given the age of the neighbourhood and combination of overhead and subsurface utilities. On several occasions utilities that were encountered were not identified on the contractor's locate report. These utilities were generally not in service however in a few incidences, old utilities lines were used as conduits for new service lines. Such situations made identifying active utilities difficult and required caution during the construction process. To limit the potential damage to utilities, hand digging for daylighting purposes was used as a standard procedure during the construction.

Figure 36 - Daylighting of Utilities

Although all reasonable actions were taken to avoid damaging utilities, on several occasions utilities were damaged and had to be repaired. Repair costs were incurred by the contractor.

Figure 37 - Damaged water service line

Figure 38 - Examples of utilities being avoided or accommodated

Figure 39 - Repair of a damaged telephone communication line

In situations where utilities interfered with the proposed design, design elements were revised to either avoid or accommodate the utility of concern.

Figure 40 - Existing gas line being avoided by notching the perforated underdrain

Excavation & Grading Issues

Excavation and grading errors and necessary design alterations were common throughout the construction of the Lakeview Project mainly due to the relatively confined working environment and obstacles located within the ROW.

Over Excavation

In order to avoid utilities and other obstacles, the contractor had to alter the extent of excavation either through narrowing, shallowing, deepening or widening the limits of excavation depending on the location of the obstruction. This was generally accepted as long as the final excavation would accommodate the necessary water quality storage volume specified for the design. This was accomplished by compensating for the change in excavation in subsequent sections. For example, if a section of the excavation was narrowed by 0.5 m for over a 10 m length in order to avoid a utility, the subsequent 10 m was widened by 0.5 m to compensate.

Figure 41 – Over-excavation of the bioretention unit trench by the contractor to avoid utilities

Provisional Lot Drainage

Topographic surveys used during the design phase were limited to the extent of the road ROW. Field reconnaissance confirmed much of the lot drainage however survey information of individual lots and private property was not obtained.

As part of the tender documents, provisional lot drainage was added for cases where surface drainage from resident's lots could not drain overland to the bioretention units. During the beginning of the construction, the project team and contractor identified lots which may have surface drainage issues. Following discussions and permission from the residents, surface inlets were installed on private property to collect local lot drainage and discharged to the bioretention unit underdrains.

Figure 42 - Installation of provisional catch basin within resident front lawn

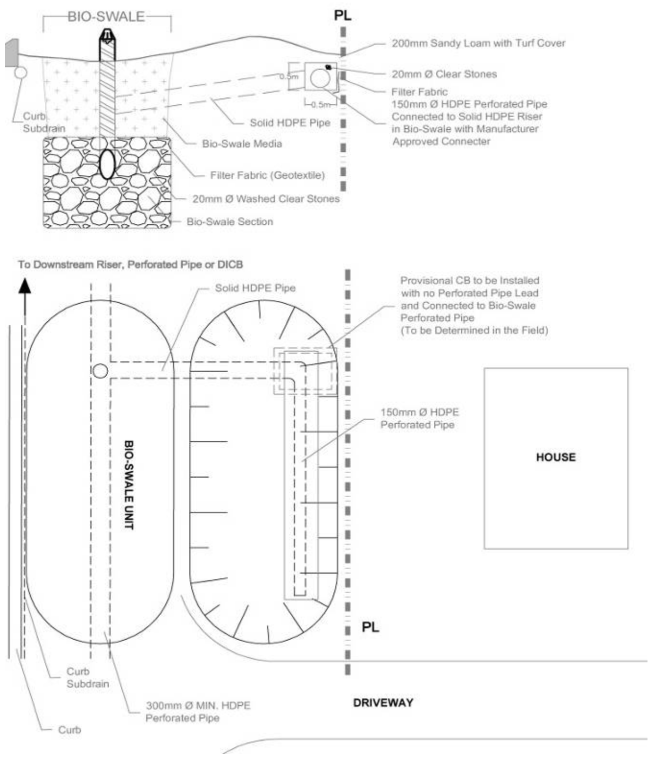


Figure 43 - Detail of provisional lot drainage

Grading Revisions

Grading revisions were required on several occasions due to the lack of survey information of adjacent private properties. During the installation of the sidewalk on Third St., the high point of the sidewalk was constructed higher than the adjacent private property and acted as a barrier between the lot drainage and bioretention units. A design solution had to be provided in order to:

- Prevent lot drainage from building up behind the sidewalk
- Prevent flows over the sidewalk, creating potential safety risk during the winter months.

As such a subdrain was installed along the lot side of the sidewalk to capture local drainage and discharge it to the bioretention unit.

Figures 44 & 45 - Installation of subdrain adjacent to sidewalk (top) and subdrain outlet to bioretention unit (bottom)

Soil and Sod Grading Compensation

During the installation of the sod material, the contractor and designer expected much more settling and compaction of the bioretention soil media to occur. In effect, the sod acted as a barrier to runoff flowing through the curb cut inlets. During larger rainfall events a certain portion of runoff would bypass the inlets as a result. To rectify the deficiency, sod sections near the inlets were removed, soil heights adjusted and the sod reinstalled.

Figure 46 –the sod at the curb cut inlets was too high following construction, creating a barrier for stormwater to enter the bioretention units.

Design Modifications

Design modifications were necessary during the course of construction. General site conditions, in-fill developments and additional infrastructure implemented between the detailed design and construction phases impacted the design.

Culvert Connection

A set of double culverts at the intersection of Meredith Ave. and Third St. were designed to convey drainage from the lots north of Third St. down Meredith Ave towards Lakeshore Blvd. During construction it was determined that an insufficient amount of cover would exist over the culverts should they be installed. Design calculations were revisited to determine if the underdrain system of the bioretention units had sufficient capacity to accept the addition drainage area from the north. With capacity available, a catch basin was installed at the end of the Meredith Ave drainage system to collect the addition drainage. The catch basin outlet pipe was connected directly to the bioretention underdrain.

Figure 47 – Installation of required catch basin

In-fill Development and Sump Connections

Several homes along First St. were redeveloped or renovated between the detailed design phase and construction and were not accounted for during the design process. Sump pumps and lot drainage alterations required several design changes in order to provide drainage for local residents.

Residences with sump pump outlets that were identified during the detailed design phase were provided a new outlet connection to the bioretention unit underdrains. In other cases where residents had undertaken renovations or landscaping projects during the course of construction, design alterations were made to provide residents with outlet connections to the bioretention unit underdrain. These connections were left exposed for resident to later connect to once their renovations were completed.

Curbs

Curb subdrains were specified within the design drawings. During construction the limit of excavation for the bioretention units and permeable pavement was not perfect and much of the native material where the proposed curbs were to be constructed had to be reinstated with clearstone in order to provide a base for the curb installation. With free draining material situated directly underneath the curb and the bioretention unit underdrain in close proximately, subdrains were determined to be unnecessary items and were not installed.

Whether it was a communication or availability error, incorrect curb molds were used on Third St and did not conform to the OPSD standard listed in the design drawings. The design drawings called for a 2” roll curb and instead the subcontractor installed a 4” roll curb. Unfortunately, this caused some grading issues at the inlets and behind the curb since there was now an additional 2” of concrete. In addition, during the tamping of the curb Granular A sub-base, excess Granular A spilled into the bioretention units and had to be removed prior to installation of the soil.

Due to the unique sequencing aspects of LID construction, the concrete subcontractor did not expect to have a significant drop behind the curbs without any soil media. As a result, the contractor’s stakes for the string line were too short and had to be doubled up in order for the string line to be at the correct height.

Figure 48 – Concrete subcontractor doubling up the stakes for the string line

Key Facts

Issues:

- Curb underdrains were considered a Major Item per OPSS Standards

Solutions and lessons Learned

- An exception of OPSS General Condition 8.01.02 – Variation in Tender Quantities subsection B states that In the case of a Major Item ($100,000 or 5% of the total tender value) where the quantity of work performed and/or material supplied by the contractor is less than eighty-five percent (85%) of the tender quantity, the contractor may make a written request to negotiate payment for the portion of actual overheads and fixed costs applicable to the amount of the underrun in excess of fifteen percent (15%) of the tender quantity.
- It is worth noting that design changes may result in payment being made to the contractor as a result. OPSS standards should be consulted prior to making such design changes. In the case of the subdrains, negotiations between the City and contractor were such that either party was satisfied with the agreement.

Delineated Driveway

A 'soldier course' was added during the construction phase (the perpendicular stone shown in **Figure 49**). The soldier course was not specified within the contract document; however, it was added to improve aesthetics and ease construction. This solider course was also used to delineate property lines for residents who shared driveway entrances. This was high valued by residents since driveway ownership was now formalized.

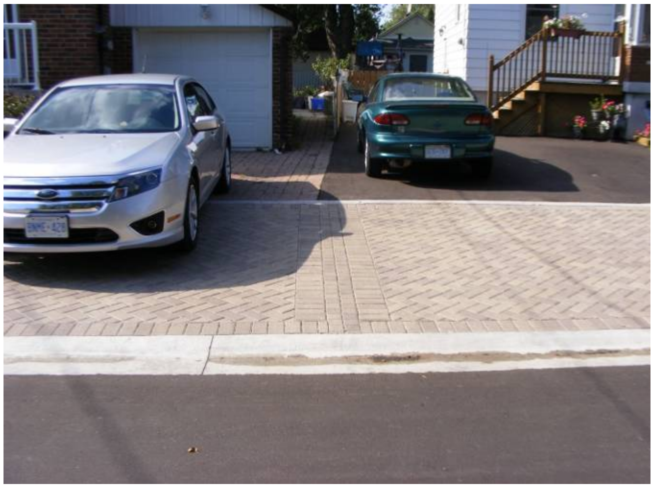


Figure 49 – Soldier course and delineation of driveways

Contractor substitution

Contract documents specified that landscaping tasks must be performed by qualified professionals. The primary contractor insisted that no subcontractor was necessary and attempted to undertake the installation of landscaping items. The contractor was directed to obtain the approved landscaping subcontractor provided in the submitted tender bid. This was enforced due to quality control and assurance purposed.

Access to driveways

Clearstone does not provide a drivable surface stable enough to permit access for vehicles. Temporary plywood access roads were installed across driveways with exposed clearstone aggregate.

Figure 50 – Temporary driveway accesses

Public Expectations and Consultation

Residents of First and Third St were anxious to get work started considering the long wait for the local roads to be rehabilitated. Adhering to proposed construction start times and continual communication with residents regarding project progress and finish dates was highly important. This ongoing communication was sustained between the residents and the project team for the duration of the construction process.

Key Facts

Issues:

- Public expectation for presented design concepts involves ensuring that the end product reflects what was presented.

Solutions and lessons Learned

- Interpretive signage was prepared and posted at the streets undergoing reconstruction. Signage included detailed artist renditions of the finished streetscaping and included information related to the design including its environmental and aesthetic benefits, construction start and end dates, and contact information of project team members.

Third St in artist rendering (top) after construction (bottom)

A community barbecue was also hosted by CVC and the design team during construction to provide an educational experience and opportunity for residents to select the type of restoration measures (i.e. sod or perennial planting) to be implemented on their property. Topics such as maintenance programs, construction issues, and overall concerns were discussed during this process. The local Ward Councillor was also on hand to speak with residents and help promote the project.

Figure 51 - Community barbecue held during Lakeview Project

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 Lakeview 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 issues interpreting the installation and construction of the design. Challenges faced by the contractor were addressed through a cooperative process between the design team and contractor. 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 as opposed to confusion.

Construction & Commissioning – LID Specific

The following section details the challenges faced as part of the implementation of the LID practices at the Lakeview Project and items to consider when implementing future LID projects.

Media Development

Included within the tender documents was the contact information for a local bioretention soil media supplier. The supplier was included since the company was experienced with supplying bioretention soil media and had proven through past projects that their internal operations could produce bioretention media that met the specifications per the Low Impact Development Stormwater Management Planning and Design Guide. The supplier's contact information was provided as a resource for the contractor however he was not obliged to use this supplier.

The awarded contractor did not opt to use the supplier provided within the tender and was cautioned that the development of bioretention soil media and the ability for a supplier to successfully meet specification takes time and numerous testing trials to be successful.

Figure 52 – Bioretention soil media consisting primarily of sand and organic material

The first samples submitted by the contractor's supplier did not meet specifications. The Lakeview design team worked closely with the contractor's chosen supplier to develop the bioretention soil media. First, hand mixed samples were submitted to the lab to get the mix close to the required portions of sand and organic prior to initiating the mechnically mixing process.

Once a passing hand mix sample was received, mechanically mixed bioretention soil media samples were collected and submitted to a certified laboratory for analysis. When a passing mechanically mixed sample was received and it was determined that the supplier could manufacturer the media with confidence, it was accepted for installation.

Key Facts

Issues:

o Contractors may obtain any bioretention soil media supplier they wish provided supplied material meets the CVC specification for mechanically mixed samples.

Solutions and lessons Learned

- Media testing results can be expected approximately 2 - 3 weeks after submission to the lab
- As such, it is necessary to specify within contract documents that the contractor is responsible for any delays suffered as a result of testing and that no compensation will be provided for delays due to media analysis

Media Placement

Prior to placing bioretention soil media within the bioretention units, filter fabric was installed between the media and curb base aggregate to ensure that fines from the Granular "A" material did not contaminate the soil.

Figure 53 – Installation of filter fabric to separate Granular "A" from the bioretention soil media

Permeable Pavement Installation

Per the contract documents and supplier installation guide, permeable pavement stones were to be tamped in place and bedding material (No. 8 stone) swept into the pavement gaps. During construction, bedding material was swept into the pavement gaps before tamping. Excess bedding material left on the permeable pavement was pulverized by the plate tamper, filling the gaps of the pavers with ultra-fine material.

To address this issue, the fine material was removed via a vacuum truck and disposed of. The gaps were subsequently filled with chip stone to ensure free drainage was provided.

Figure 54 – Gaps of permeable pavement filled with fines from tamping activities

During placement of the permeable pavers, a significant amount of fine dust was created by the cutting process when the contractor was creating the soldier course. It was then requested that the contractor cut pavers away from the infiltration area or use a sacrificial piece of geotextile laid on the permeable pavers during cutting.

Figure 55 – Fine dust during cutting of permeable pavers

Quality Control and Assurance

During construction, clearstone supplied to the site did not meet the specification detailed on the drawings which stated that double washed stone was to be provided. The first load supplied to the site consisted of single washed stone. Although seemingly a very minor detail to enforce during construction, the difference between the two types of material are quite distinguishable.

Figure 56 – Double washed (left) vs. single washed (right) clear stone. Specs called for double washed

Sequencing and stockpiling material on site was also critical to successful construction. When storage areas are moved because materials are delivered with too much lead time, chances of contamination increase significantly. Materials were not moved as it was stressed how crucial it was to have infiltration areas free of contaminated materials.

Figure 57 – Bioretention soil media delivered to one of the storage areas

Boulevard Bioretention Unit Vegetation

During the planting phase, staff from the landscape architect was on-site directing and supervising the planting installation and quality of the material delivered to the site. The month of June 2012 was an exceptionally hot month, which sustained a prolonged drought period following the installation of the plant material. It was prudent during the remainder of the summer that the contractor consistently watered the plant material to ensure survival.

Figure 58 – Installation of planting material

With the exception of a few plantings, the majority of the plant material survived until the following growing season.

Complaints were received by local residents regarding a specific plant species that grew vigorously (as high as 7-9 feet tall after the first growing season). The plant species was initially added to the Lakeview planting plan because of its quick establishment, vigorous growth and resistance to harsh growing conditions. From past experience, some plant species do not establish as well within bioretention units because of the harsh growing condition caused by their location adjacent to roadways, the free draining properties of bioretention soil media and contaminates found within the stormwater runoff. As such, more resilient species are added to planting plans to compensate ensure plant establishment.

For the Lakeview project, the growing conditions during the first year must have been favourable enough to stimulate the excessive growth. The plant material was removed from the bioretention units and replaced with a different species with shorter growing heights. See the *Post-Construction* section for details.

Sediment and Erosion Control

An erosion and sedimentation control (ESC) plan was included with the design drawings. It consisted of catch basin inlet controls, filter socks and other LID specific ESCs.

General housekeeping of the site and road cleaning operations were undertaken every couple of days in order to control dust and prevent debris and sediment from washing off the road surfaces.

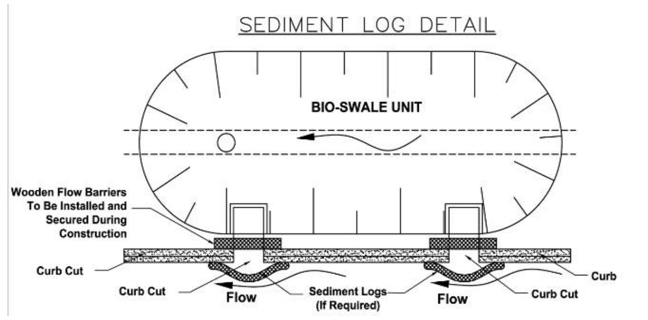


Figure 59 – Sediment Logs Detail for Lakeview

Prior to the installation of the bioretention soil media and paving of the road surface, filter cloth wrapped wooden boards were staked behind curb cuts and sacrificial pieces of filter cloth were installed to protect the bioretention unit infrastructure from contamination. The sacrificial pieces of filter cloth were installed over the cloth wrapped clearstone reservoir of the bioretention unit. This filter cloth was removed prior to in the installation of the bioretention soil media including any contaminating fines which was captured (See **Figure 60**).

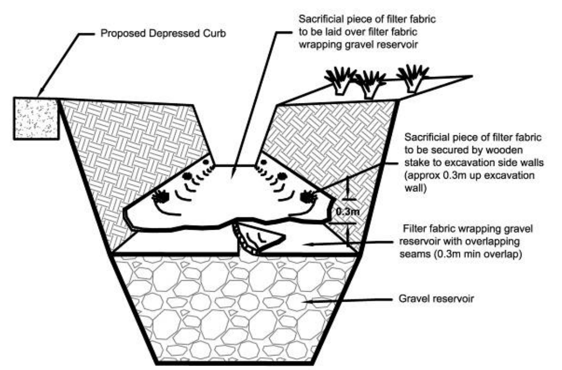


Figure 60 – Conceptual of the sacrificial piece of filter cloth used to protect bioretention units.

Figure 61 – Filter cloth wrapped wooden boards installed at bioretention unit curb cuts

Post-construction

The period of time that immediately follows the completion of construction activities is critical, as it is this time that any issues with the design and construction can be identified and addressed. Techniques for identifying issues include conducting on-site inspections of the practices (during dry periods and, importantly, during precipitation events) and undertaking a performance assessment of the practices to ensure that they are working as intended.

With the Lakeview Project, major construction activities were completed by August 2012. Initial impressions on the functioning of the LID features were positive from both municipal staff and residents. Like most construction projects, a formal inspection took place in September 2012, to identify project deficiencies. The deficiency inspection included the engineering consultant, contractor, landscape contractor, municipal inspector and project manager. A list of deficiencies were identified and provided to the contractor to be addressed.

As-built survey & stormwater bypass

As part of any deficiency inspection, it is recommended that an as-built survey be conducted as it verifies that the final site grading matches that specified in the design. These surveys are valuable for LID practices in particular, as they are often sensitive to very minor changes in grade.

For the Lakeview Project, initially an as-built survey was not completed due to budget constraints and because initial observations had noted positive drainage through the system.

While visual inspection can fall short, performance assessment of any LID site can provide a more comprehensive understanding of site function and performance. An Infrastructure Performance & Risk Assessment (IPRA) was conducted by CVC staff in 2011 to characterize baseline conditions and was initiated again immediately following construction in August 2012.

By examining the performance of the LID practices throughout multiple precipitation events, the IPRA identified an issue with the flow of stormwater through the bioretention units on the north side of First Street. While flow was being observed through the LID features on the south side of the street, little to no flow was observed from those on the north side. For more information on the IPRA conducted at the site, refer to the *Infrastructure Performance & Risk Assessment* section of the case study.

To better understand why there was a discrepancy, a visual inspection of the bioretention units was conducted during a precipitation event. The inspection revealed that several of the inlets were being bypassed. Because of this, insufficient stormwater runoff was able to enter the bioretention units at the curb cuts (shown in the following figure).

Figure 62 – Bypassing of bioretention units during a rainfall event

To better understand this issue, CVC had an as-built survey completed in the summer of 2013. The as-built survey confirmed that at some of the curb cut inlets and grade changes were insufficient to encourage the runoff to enter the bioretention unit. The as-built survey also revealed that grade changes didn't allow for positive drainage within some of the bioretention units, and that the ponding depths were not to that specified in the design.

CVC was able to take the information garnered from the as-built survey and present it to the municipality for the contractor to correct the deficiencies with both inlet grades and ponding depths.

Further investigation revealed that the primary issue with the inlets was that the sod located at the inlets was at too high an elevation, blocking flow into the bioretention cell. This was caused by bioretention soil media not settling as much as expected by the designer and contractor.

To address the issue, the sod was lowered by a minimum of 25 mm below the curb-cut invert to ensure positive drainage into the bioretention unit. Specific activities involved in adjusting the grade within the bioretention units included:

1. Temporary removal of plants
2. Media re-grading - grading, surveys, and string lining by the landscaper
3. Fine grading
4. Re-planting plants
5. Final survey of the start and stop of the planting beds

Figure 63 - Adjusting inlets by removing excess media

Performance assessment to ensure positive drainage through the entire LID feature and appropriate ponding depth is ongoing. Hydrological monitoring does not help only in measuring performance, but can be a key factor in identifying site deficiencies not caught by visual inspection.

Landscaping

After two full growing seasons, a better understanding of plants was also established. Both successful and unsuccessful plants were identified. Resident comments were also taken into consideration as to what plants they liked and didn't like.

During the summer of 2013, residents began voicing complaints to CVC monitoring staff and the City of Mississauga staff about some of the plants in the bioretention units. The Lakeview area had received plenty of rain that year and the plants had healthy growth, especially the green headed coneflower, *Rudbeckia laciniata*, and New England Aster, *Aster novae-angliae*. The green headed coneflower grew to over 6 feet tall. The residents said that they couldn't see when they were backing out of their driveways and that the plants were very unattractive and weedy looking.

In September 2013, contractors removed all the green headed coneflower and New England aster from many of the bioretention units and disposed of the material off-site. Unattractive grasses were also removed. The contractor replaced them with butterfly weed, black-eyed Susan, bee balm, obedient plant, and blue flag iris. These plants were chosen because they were already planted in the gardens, residents liked them, and they had established well. The bioretention units were then mulched and watered. For more information about regular landscaping maintenance that took place during the first two growing seasons see the *Operations and Maintenance* section.

Figure 64 - Overgrown New England Asters that were removed from the bioretention unit.

Figure 65 - Plants chosen to replace green headed coneflower based on this bioretention unit. Irises in the center, black-eyed Susans, and bee balm

Economic (Capital & O&M Costs)

Staff time, external labour, equipment, and materials are obvious factors to consider when evaluating the overall cost of a construction project. A comprehensive analysis of ROW retrofit project costs also includes planning, design, construction overhead, removals and disposal fees. The total cost of the Lakeview Project covering the planning, design and construction phases totalled approximately $892,500. This value includes a contingency of $90,000 as well as consulting fees of approximately $40,000 and $80,000 during the planning and design phases respectively.

Table 7 breaks construction phase costs into ten items. Some important design details to remember when reviewing this cost are:

- The total length of road improvement is 285 m
- The total catchment area of the LID features is 1.6 ha
- Total permeable pavement area is 800 m^2
- Total boulevard bioretention area is 890 m^2

Several of the costs shown in Table 7 are comparable to those of a conventional road reconstruction project. The three items which require additional cost are erosion and sediment control (to ensure LID infiltration is not compromised), drainage and stormwater management (perforated pipe and additional inlets), and landscaping (boulevard bioretention areas).These additional costs can be offset by reduced paving and curbing costs and the lack of costs associated with end-of-pipe stormwater management controls.

The Lakeview Project was one of the first green street residential retrofits in Ontario. As with any demonstration project, costs can be higher than projects using standard design features. The project showcased new design concepts within the residential ROW that incorporated sophisticated monitoring components in order to assess the performance of the LID features implemented. CVC and the City of Mississauga are currently working together to track the operations and maintenance activities taking place on the retrofitted streets to determine their lifecycle costs. For further information, refer to the *Infrastructure Performance & Risk Assessment* section.

Table 8 - Lakeview Project Construction Phase Costs

Item	Cost	Notes
Site Preparation	$14,200	Includes removals, disposal, salvaging of existing asphalt and concrete structures.
Erosion and Sediment Control	$6,500	Includes catch basin controls, silt fencing and dust suppression.
Earth Work	$54,600	Includes all earth excavation and grading.
Paving and Curbing Work	$126,300	Includes granular bedding for roadway and sidewalk, asphalt and concrete curbing.
Drainage and Stormwater Management	$240,200	Includes piping and hydraulic structures.
Driveway Pavers	$137,400	Includes pavers and bedding.
Utility Conflicts	$5,000	Includes design modifications and external consultation.
Parkette	$27,000	Includes all works associated with construction of parkette.
Landscaping	$57,400	Includes trees, grasses and perennials.
Provisional	$13,900	Includes provisional all provisional items.
Total Construction Phase Cost	**$682,500**	Does not include planning, design and contingency.

Operations & Maintenance

Maintenance of Boulevard Bioretention Units

Maintenance is important, particularly during the initial establishment phase, because it enhances the performance, aesthetics, and longevity of the LID practice. In the long run, maintenance will prevent small problems from becoming large ones and improve the overall public acceptance of the practice. Maintenance requirements for most LID technologies are not very different from most turf, landscaped, or natural area and do not typically require new or specialized equipment.

During the establishment period at Lakeview, maintenance has been carried out by the contractor, the City of Mississauga, CVC and the local residents. It is important to follow-up with the contractor throughout the warranty period to ensure that activities specified within the maintenance agreement are taking place.

To date only establishment maintenance is taking place and is not typical of long term maintenance. In the case of the bioretention units and permeable pavement driveway aprons, maintenance includes removing accumulated trash and sediments, weeding, mulching and watering. Long term, maintenance requirements should lessen.

Feedback from PICs indicated that local residents were willing to undertaken 2-4 hours of maintenance per month. However in reality, the level of maintenance done by each homeowner varied. Residents were encouraged to undertake maintenance activities such as weeding, pruning and general clean up. Some residents were renters or away for most of the summer so they maintained their bioretention units and permeable pavement less frequently. The amount of maintenance needed also increased if the landscaped option was chosen instead of turf for the bioretention unit.

Figure 66 - Example of a boulevard bioretention feature that is being well-maintained by the homeowner

Table 9 - Lakeview bioretention unit and permeable pavement establishment maintenance activities (2012-2013)

Task	Frequency
Boulevard Bioretention Units	
Remove weeds	Monthly to every two months during growing season
Remove litter and debris from curb cut inlets and inside the bioretention practice	Monthly
Replace or re-spread mulch	Annually
Replace dead or unattractive plants	June and September
Remove sediment	Annually
Watering	Monthly during growing season
Replace all missing or damaged overflow grates	Annually
Remove all in-grown sod around bioretention units a distance of 150mm (6") from perennial plants planted along the current garden edge.	Annually
Replace all dead sod	Annually
Shovel snow from inlet	As needed
Permeable Pavement	
Remove weeds	Monthly to Annually
Remove sediment	Annually
Add jointing aggregate	Annually

Since June 2012, CVC monitoring staff have been collecting data on maintenance activities performed and inspecting conditions of the bioretention units and permeable driveways at Lakeview on a biweekly basis. A standard site inspection checklist has been created and is used by staff during each site visit. Review of the preliminary data shows that plants are establishing well but that recurring maintenance issues involving weeds, sediment and debris accumulation are occurring. Sediment accumulation in the curb cut inlets can change the grade of the inlets, reducing the flow of water into the bioretention units. Sediment also builds up in between the permeable pavers, encouraging weeds to grow. Leaf debris and trash accumulation within the bioretention unit can also reduce infiltration into the practice. The bioretention units and permeable pavers should be inspected for sediment, trash and debris accumulation and weeds on a regular basis. Going forward, these issues should be addressed and maintained more frequently to improve aesthetics and performance of these LID features.

Figure 67 - Accumulation of debris in the inlets from nearby tree

Figure 68 - Sediment build-up and subsequent weed growth in between permeable pavers

Infrastructure Performance & Risk Assessment

The Lakeview Project provides a unique opportunity to evaluate the performance of LID practices implemented within the municipal ROW in a residential setting. The Lakeview Infrastructure Performance and Risk Assessment Program (IPRA) will directly address several knowledge gaps to elevate confidence in LID technologies within Ontario and provide as-built performance data.

Performance Assessment Locations

Four monitoring stations have been installed for infrastructure performance assessment purposes. Currently, performance assessment efforts have been focused upon First Street only. Two LID performance assessment stations have been implemented at the downstream extents of the LID infrastructure for both the north and south side of First Street. A control site located on a nearby street with a traditional curb and gutter drainage system is being assessed as well as another station monitoring a swale (traditional roadside ditch) system. The individual performance assessment locations are as follows:

- **Location 1 (LV-1):** located on Northmount Avenue north of Fourth Street. The street has curb and gutter drainage and will be used as a control site. Four catch basins collect water from this street and convey it to the sampling manhole.
- **Location 2 (LV-2):** located at First Street and Alexandra Avenue. This manhole receives runoff from both the north and south sides of First Street between Alexandra Avenue and Westmount Avenue. This site was used for pre-construction monitoring and continues to be monitored to provide baseline data for traditional roadside ditches.
- **Location 3 (LV-3):** located on the north side of First Street near Alexandra Avenue. This area drains the north side of First Street between Alexandra Avenue and Meredith Avenue. The monitoring station collects an outflow sample from the downstream extent of boulevard bioretention units and permeable pavement for the north side of the street.
- **Location 4 (LV-4):** located on the south side of First Street near Alexandra Avenue. This area drains the south side of First Street between Alexandra Avenue and Meredith Avenue. Similar to LV-3, the monitoring collects an outflow sample from the downstream extent of boulevard bioretention units and permeable pavement for the south side of the street.

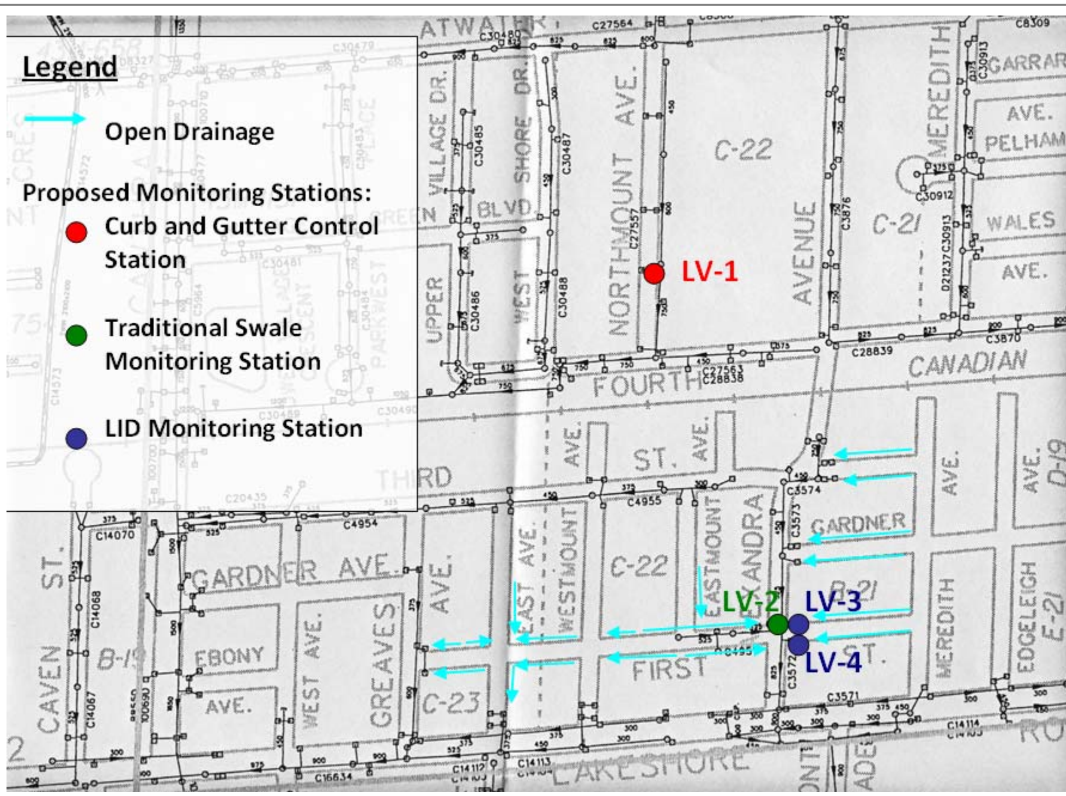


Figure 69 - Performance assessment locations within the Lakeview neighbourhood

Table 10 – Details on ongoing performance assessment activities

Monitoring station	Stormwater management system	Performance assessment activities	Priority pollutants	Continuous monitoring	Sampling interval
LV-1	Control site (curb and gutter drainage)	Water quality sampler and flow measurement in manhole receiving runoff from Northmount Avenue.	• General chemistry • Total suspended solids • Total dissolved solids • Total metals • Nutrients • Polycyclic aromatic hydrocarbons	Temperature	10 min
LV-2	Traditional ditches	Water quality sampler and flow measurement in manhole receiving runoff from the north and south sides of First Street between Alexandra Avenue and Westmount Avenue.	• General chemistry • Total suspended solids • Total dissolved solids • Total metals • Nutrients • Polycyclic aromatic hydrocarbons	Temperature	10 min
LV-3	Boulevard bioretention units and permeable pavement	Flow measurement in manhole receiving flow from bioswales and permeable pavement driveways on the north side of First Street between Alexandra Avenue and Meredith Avenue.	N/A	Temperature	10 min
LV-4	Boulevard bioretention and permeable pavement	Water quality sampler and flow measurement in manhole at outlet of bioswales and permeable pavement driveways on the south side of First Street between Alexandra Avenue and Meredith Avenue.	• General chemistry • Total suspended solids • Total dissolved solids • Total metals • Nutrients • Polycyclic aromatic hydrocarbons	Temperature	10 min

Objectives

Fifteen overarching objectives were selected for this program to meet the priorities of stakeholders. These objectives were structured to address top stakeholder priorities. These priorities include long-term maintenance and subsequent performance, lifecycle 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 (MOE); Building Industry and Land Development Association (BILD); Credit Valley, Toronto and Region and Central Lake Ontario Source Protection Region; as well as developers.

The overarching objectives of this project are presented in **Table 11** along with details on how the goals are being met.

Table 11 – Objectives of Infrastructure Performance & Risk Assessment

Objective	Details
Evaluate whether LID stormwater management systems are providing flood control, erosion control, water quality, recharge, and natural heritage protection as per the design standard.	The Lakeview performance assessment will provide data for the evaluation of water quality (hydrologic measurements and water quality samples), and recharge (monitoring wells/infiltration measurements). Outflow volumes from the bioretention units will be compared with the control and ditch outflow volumes. This shall provide a frame of reference to compare the runoff reduction benefits of LID practices to conventional approaches.
Evaluate and refine construction methods and practices for LID projects.	Performance will be assessed over time to determine if there are any construction characteristics that cause the facility to operate differently than intended. Documentation of maintenance will also be informative in the long-term assessment of the project.
Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance.	Details including costs and history of maintenance and repair activities will be established for each of the sites over the short and long term through detailed maintenance inspections. Inspections include documenting vegetation health, debris or sediment accumulation, and a photographic log.
Assess the performance of LID designs in reducing pollutants that are dissolved or not associated with suspended solids (i.e. nutrients, oils/grease, and bacteria)	Dissolved parameters such as chloride, nitrates and total dissolved solids will be assessed for loading reduction.
Assess the water quality and quantity performance of LID designs in clay or low infiltration soils and those that do not use infiltration.	Given the predominance of clay soils in the lower part of the CVC watershed, many LID practices will be located over these soils. To accurately determine the pollutant load capture and volume reduction, runoff will need to be monitored at the inlet and the underdrain and overflow outlet(s). The Lakeview LID sites are constructed with underdrains and provide examples of water quality control systems that are suitable for application in areas with soils with low to marginal infiltration capacity. The LID performance assessment program will evaluate volume reduction and flow attenuation from permeable pavement and bioretention units overlaying clay soils.
Determine the life cycle costs for LID practices.	The Lakeview performance assessment allows for long term monitoring and documentation of maintenance, repair and eventual rehabilitation costs. CVC staff, in collaboration with the City of Mississauga, will establish lines of communication to keep track of maintenance activities, and when monitoring or site observations indicate maintenance may be needed. To assess life cycle costs, documentation of maintenance activities shall be conducted.
Evaluate how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity as a whole.	The monitoring stations downstream of the LID sites monitor the outflow from a treatment train of practices - permeable pavement and boulevard bioretention units. Effluent data will characterize the overall performance of the system as a whole. The traditional swale site may demonstrate some benefits of disconnected impervious area relative to the control site.
Develop and calibrate event mean concentrations (EMCs) for total suspended solids, phosphorous, chloride, copper, zinc, nitrate/nitrite, total nitrogen, and E-coli.	The control site characterizes event mean concentrations (EMCs) from a typical medium-density residential neighbourhood. The inflow EMCs from the control site are expected to be representative of inflow conditions for the other stormwater practices that are being assessed. These values will allow any reductions in pollutants to be documented for future use.
Demonstrate the degree to which LID mitigates urban thermal pollution	Temperature loggers were installed at each of the Lakeview monitoring stations in 2013. The data collected at the Lakeview sites will provide side-by-side comparisons of thermal benefits, improvements in thermal loading and event mean temperatures for streets retrofitted with LID versus conventional curb and gutter.
Assess the potential for soil contamination for practices that infiltrate	Sampling of sediments captured in the roadside ditches, bioretention surface sediment deposits and shallow soil samples will aid in assessing possible contamination. In addition, a sample of sediment collected in the control catch basin will be collected and analyzed for contaminants of concern.
Evaluate effectiveness of soil amendments and increased topsoil depth for water balance and long-term reliability	The bioretention soil media installed in the bioretention units is amended media designed for efficient infiltration. Infiltration testing over time will assess this reliability.
Assess performance assessment data to determine potential rebates on development charges, credits on municipal stormwater rates and/or reductions in flood insurance premiums	The performance assessment provides comparisons of three street drainage strategies for residential areas, demonstrating the strengths and weaknesses of each system. Data on runoff reduction, lag in peak flow and other performance criteria can be used to determine the appropriate credit to award LID practices.
Assess the potential for groundwater mounding in localized areas	The piezometers installed in the boulevard bioretention units will provide data that will characterize how long water levels remain elevated following precipitation events.
Assess the ancillary benefits, or non-SWM benefits	CVC has interacted with residents throughout the construction of the LID practices at the Lakeview site and continues to do so while collecting performance assessment data. Continued interaction with residents and assessment of changes on private property are important and will provide a sense of how the residents perceive the LID practices.

Data Collection Methods & Equipment

In order to evaluate the performance of LID systems, staff collects climatic data (precipitation and temperature), hydrologic data (inflow, water level, soil moisture) and water samples for water quality analysis. The following sections provide an overview of the methodology used to monitor these parameters.

Climate

Precipitation is measured using a City of Mississauga-managed rain gauge located less than one kilometre from Third Street. Further precipitation data is collected via a CVC climate station installed on the roof of the Cawthra Community Center.

Water Quantity Monitoring

Outflow from the underdrains of the bioretention units and permeable pavement driveways are measured using a stage-based method with weirs and water level loggers.

A compound weir plate has been installed and calibrated by a consultant at all four performance assessment stations. An ISCO 4150 or Hach FL900 flow meter was installed in each manhole with the probe secured to the weir to make certain that accurate water level measurements are recorded. The flow meters are set to record water levels at 10-minute intervals.

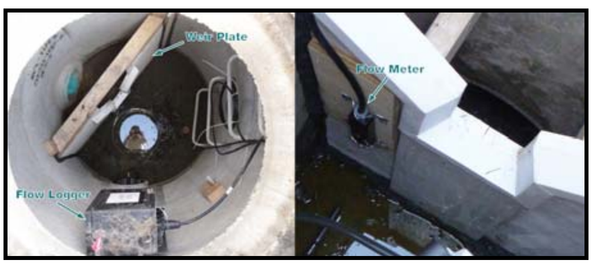


Figure 70 - Flow monitoring equipment and compound weir

Temperature Assessment

Three of the performance assessment locations record the water temperature in the manhole on a continuous basis. A HOBO UA-002-64K temperature logger was installed at stations LV-1 and LV-4 in 2013. The flow meter at station LV-3 also records temperature.

Water Quality Assessment

Stormwater quality is monitored with flow proportioned composite samples collected by automatic samplers and analyzed for a variety of common stormwater runoff constituents. These measurements are made in accordance with the provincial water quality objectives (PWQO), with priority given to pollutants of concern for the Cooksville Creek watershed.

Constituents

The collected samples are analyzed for the following constituents:

- Chloride
- Turbidity
- Conductivity
- pH
- Total suspended solids (TSS)
- Total dissolved solids (TDS)
- Nutrients:
  - Total phosphorus
  - Orthophosphate
  - Total kjehldahl nitrogen (TKN)
  - Total ammonia
  - Nitrate and nitrite
- Total metals
- Polycyclic aromatic hydrocarbons (PAHs)

Water quality parameters were chosen to include parameters that have been commonly analyzed in published literature. This will allow the performance assessment data from the Lakeview project to be interpreted and discussed in context with other LID projects in Canada and the United States. Water quality parameters were also selected to ensure pollutants of concern as identified in the CVC *Impact Monitoring Program 2007-2011 Report* were included in the monitoring program.

Sampling Frequency

A minimum of ten precipitation events will be sampled per year from three of the performance assessment locations (LV-1, LV-2, & LV-4) with an ISCO 6712 Automatic sampler. The samplers are connected to the water flow loggers and triggered when a predetermined water level is recorded by the flow logger. The monitoring program will continue until a minimum of thirty precipitation events have been collected.

Figure 71 - Water quality sampling

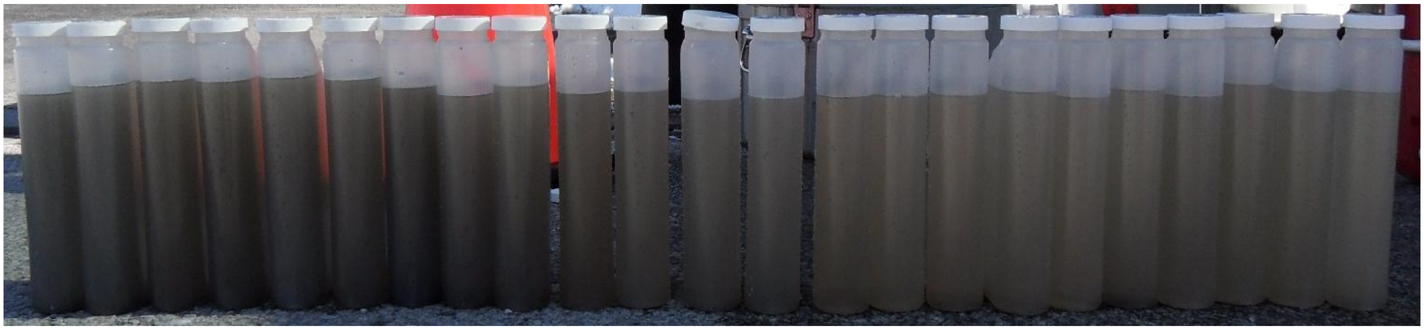


Figure 72 - Sampling bottles depicting the first flush, first six bottles from left and composite samples

Sampling Methodology
During water quality monitoring event sampling is conducted using the following procedures:

- Two samples are submitted per surface water quality monitoring station per event.
- One composite grab sample is collected from the first six bottles sampled by the ISCO sampler and submitted for analysis to analyze the initial first flush of the storm event.
- The remaining eighteen bottles are used to collect a flow-weighted composite sample. The length of time between bottle fills may be lengthened or reduced depending on the event forecasted. This will either shorten or lengthen the sampling program in order to get a sample that best represents the event.
- Water quality samples are brought to Maxxam Analytics for laboratory analysis.

Surface Water Infiltration
To assess surface water infiltration, two piezometers were installed within the First Street bioretention units during construction. The piezometers are located near monitoring stations LV-3 and LV-4. HOBO U20 continuous water level loggers were placed in the piezometers to measure variations in water level throughout the profile of the bioretention units. Level readings are then compared to rainfall amounts to calculate surface water infiltration in the cells and determine the drawdown time required for stormwater to fully infiltrate through the bioretention units.

An additional logger is located at Green Glade Sr. Public School (approximately nine kilometres from the site) to record barometric pressure. These measurements are used to normalize the water level measurements for barometric pressure. All loggers recorded water level readings in 10 minute intervals.

Figure 73 - Manual level measurements are taken to verify the accuracy of readings and level logger is calibrated as needed

Sediment/Soil Sampling
Sediment is a very important stormwater pollutant, because it carries many hydrophobic pollutants and creates potentially toxic conditions in receiving environments. LID practices capture sediments by design. These deposited sediments have the potential to become an in-situ source of pollution, which may be released by changes in the ambient water quality. Routine maintenance of LID practices, including removal and disposal of sediments can help to control the in situ pollution potential of captured sediments.

Monitoring data will be collected to characterize captured sediments and associated stormwater pollutants. This component of the performance assessment program will be important for evaluating frequency of maintenance and for quantifying pollutant load reductions when maintenance is performed.

At the Lakeview performance assessment sites, sediment samples will be collected annually at each of the monitoring stations to characterize stormwater sediments and pollutant accumulation. For LV-2, LV-3 and LV-4, two sediment/soil samples will be collected each year:

- One sample will consist of surficial deposits of sediments remaining in the facility after runoff events. If deposits are visible, they can be sampled using a clean spade. Multiple deposits may be sampled to create a composite sample. If there are no visible sediment deposits, a soil sample consisting of the top 1 to 2 cm of soil in the cells near an inlet (soil separated from vegetation) shall be used.
- The second soil sample will be collected in each swale near the outlet and will consist of soil from the top 10 cm of the cell (surface sediments and top 1 - 2 cm excluded). Comparison of this sample result with the sediment deposit/surface sample will provide an idea of whether or not pollutants are migrating into the soil column over time. For LV-1, sediments collected in the catchbasin will be collected and analyzed. These samples will be collected in the fall after summer precipitation events but before the ground freezes. Samples will be analyzed for total metals (same that are being monitored in water samples), nutrients and pH. Depending on results, CVC may increase the frequency or extent of this type of sampling in the future.

Quality Assurance and Quality Control

The sites are visited at minimum every two weeks by CVC staff to inspect equipment, check battery power and verify that all systems were operational. Data is downloaded in person using ISCO Flowlink 5 or Hoboware software. The software automatically summarizes and plots the data graphically, which is then easily exported to a program like Microsoft Excel.

Field and lab data management follows CVC's *Data Storage, Organization, and QA/QC Protocol*. Unaltered data that has been downloaded in the field or acquired from the lab is stored on an external drive and backed up regularly. Files that are undergoing review are organized by site, date and employee initials to ensure raw data is not manipulated or adjusted. Each file is subject to a quality assurance and quality control review to ensure any inconsistencies are noted and to determine possible reasons for the inconsistency.

Maintenance Monitoring

Maintenance needs for the boulevard bioretention units and the permeable pavement is currently being evaluated by CVC and the City of Mississauga. CVC staff conducts bi-weekly maintenance inspections and completes an inspection checklist documenting obvious visual maintenance needs. Checklists include documenting common issues such as sediment deposition, trash accumulation, vegetation health, and a photographic inventory. This log of maintenance needs will not only assist the City and residents with maintenance of these LID practices, but also provide an indication for maintenance requirements for future LID projects across Ontario.

Landscaping

Maintenance logs also include communication with residents in the Lakeview neighbourhood. Through the visual logs and communication with residents, concern regarding one of the plant species selected for the boulevard bioretention units was brought to the attention of the City of Mississauga. The boulevard bioretention planting plan included shorter species in front of the swale with larger species in the back. One species, *Rudbeckia laciniata*, grew much larger and taller than expected. To resolve this issue, the plants were removed and replaced with more appropriate species. For more details, refer to the *Post-construction* section of the case study.

Damage to Overflow Grates

Each boulevard bioretention unit incorporates an overflow that allows excess water to directly enter the underdrain. The grates for the overflow pipes at Lakeview are made of plastic, and the maintenance monitoring program has identified issues with the long term suitability of this material type for this application. Several of the grates have broken since the completion of construction, likely due to the weight of snow piled on the overflows, and during summer months, damage from lawn mowing equipment. A photograph of a broken overflow grate is shown in the following figure.

Based upon these findings it is recommended that overflows for landscaped bioretention practices utilize a heavy-duty metal grate to ensure they do not break shortly after construction.

Stormwater Bypass

An important finding of the Infrastructure Performance & Risk Assessment program at Lakeview was that several of the boulevard bioretention cells were being bypassed – stormwater not was entering the cells, and instead traveling along the curb to a downstream catchbasin. As this significantly affects the performance of these LID stormwater management practices, steps were taken by the project team to address this issue as soon as it was identified. For further details on what actions were taken to address the stormwater bypass issue, please refer to the *Post-construction* section of the case study.

Long Term Assessment

Performance assessment results will be summarized in a technical report in the spring of 2014.

The Infrastructure Performance and Risk Assessment program at Lakeview is currently ongoing and will provide a long-term assessment on the performance of LID practices within the road ROW in a residential setting. Long-term assessment activities at the site will continue to include, water quantity and quality performance as well as detailed site inspections to identify maintenance requirements and lifecycle costs. Further information on the performance of the Lakeview Project will be posted on CVC's website in 2014. Refer to bealeader.ca for updates.

Acknowledgements

Credit Valley Conservation would like to sincerely thank the following companies, organizations and individuals for their support in the development of this case study:

- Aquafor Beech Ltd.
- City of Mississauga
- Pacific Paving
- Schollen & Company Inc.
- Region of Peel
- Ontario Ministry of the Environment

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Version 1.0, Released April 2014

Case Study

George Richardson
Stormwater Management Pond Retrofit

Location: Newmarket
Constructed: 2010 - 2012

Public Lands

Project Objectives, Design and Performance

- Reduce phosphorus loadings to Lake Simcoe in accordance with the Lake Simcoe Environmental Management Strategy.
- Construct a demonstration site incorporating innovative red sand filtration to evaluate its effectiveness at reducing and trapping phosphorus.
- Improve water quality by reducing annual phosphorus loading into Lake Simcoe by 23 kilograms per year.

Overcoming Barriers and Lessons Learned

- Careful consideration had to be put into the design, including how to preserve fisheries, maintain the creek's base flow, and capture the majority of rain events through the treatment train.
- Proper planning to include appropriate buffer time in the project for unexpected issues such as delays in the permit approval process, weather conditions, and funding partner's time constraints is key to success.
- Challenges of consturction in a park were discussed and addressed at the beginning of the project.
- To avoid interrupting use of the adjacent soccer fields construction was completed outside soccer season.

Practices Implemented

Innovative SWM

Pollution Prevention

Barriers & Issues Encountered

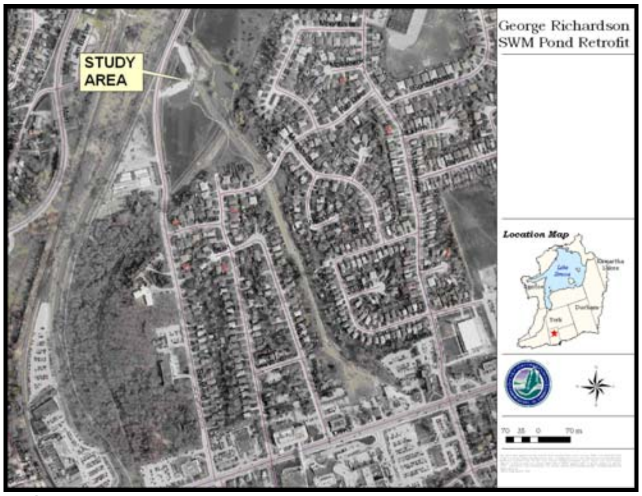
Planning & Regulations

Design

Construction & Comissioning

Overview

The George Richardson Stormwater Management Pond Retrofit is located in George Richardson Park, Newmarket. Eastern Creek traverses through the pond, and is a tributary of the East Holland River. The East Holland River is the most populated and polluted river in the Lake Simcoe watershed.



George Richardson stormwater management pond location

Prior to the retrofit, the George Richardson stormwater pond was negatively impacting cold water fish habitats, water quality and oxygen levels. It was also a major source of pollutants (including phosphorus and suspended solids) entering through Cook's Bay at Lake Simcoe.

The George Richardson SWM pond was chosen as an ideal retrofit site as water quality was not incorporated into the original design. An innovative red sand filter was installed to capture the soluble phosphorus in the system as part of the treatment train.

Goals and Drivers

There were several goals and drivers that prompted the retrofit of the George Richardson stormwater management pond. These included:

- Improving stormwater management within the East Holland River watershed using innovative technologies.
- Providing a low maintenance system.
- Improving the existing natural riparian buffer around the pond to discourage edge disturbance and waterfowl access.
- Creating a demonstration site using innovative technology and educate the community through signage.
- Creating a by-pass channel to have base flow provide a means to create functional fish habitat and avoid creating a fish barrier with an online stormwater management (SWM) pond.
- Cleaning out the existing online pond to create a functional SWM pond but limit intrusion into the other park functions.
- Creating a berm to allow for extended detention of a small runoff event and minimize flooding in the park.
- Monitoring the performance of the red sand filter as a pilot project for removal of phosphorus.

Successes

The successes achieved through this project include:

Innovative technologies – The George Richardson Stormwater Management Pond Retrofit project is the first retrofit in Ontario to incorporate a red sand filter system.

Reduced phosphorus loading – This retrofit is aimed at improving stormwater quality by reducing phosphorus loading by 23 kg/year. Improvements were also made to water quality in overland flow through the installation of the enhanced riparian buffer.

Multi-partner collaboration – Lake Simcoe formed many partnerships to ensure the success of this project, including: the Regional Municipality of York (Landowner Environmental Assistance Program), the Lake Simcoe Conservation Foundation, R.J. Burnside and Associates Ltd, the Town of Newmarket, Environment Canada and the RBC Blue Water Program.

Overcoming Barriers and Lessons Learned

A number of barriers were encountered over the course of this project. They included:

- Obtaining approval from some review agencies was difficult as innovative retrofits did not follow the typical guideline criteria.
- Because this project was an on-line pond, the design needed to include a fisheries component. Coming up with an ideal concept that would recognize the creek systems' base flow, while trying to capture the majority of rain events through the treatment train was challenging.
- Working under various weather conditions was problematic and involved dewatering the site frequently.

The following approaches were used to overcome these barriers:

- Ensuring that all partners worked together to address any issues was key to the success of this project.
- Installing a rock flow splitter to accommodate creek base flow while diverting storm events through the treatment train system (addressing the fisheries component of the project).

Lessons learned:

- It is critical to include appropriate buffer time for unexpected issues such as delays in the permit approval process, weather conditions, and funding partner's time constraints, to ensure the project's success.

Planning & Regulations

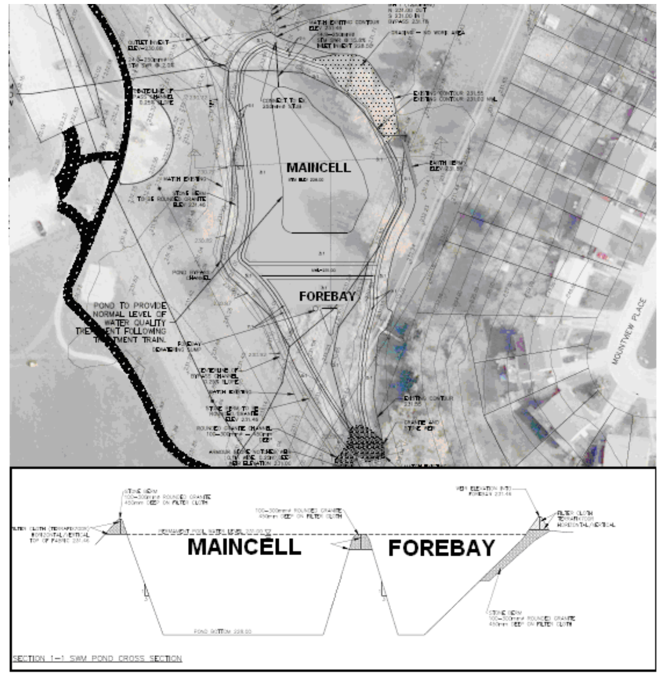
A consulting firm was retained to assist in creating a Feasibility Study. This study was used in the Environmental Assessment and public consultation process. The consulting firm also assisted in creating the final report and plans that were circulated to all approval agencies for review. All project partners provided input in the report and final design drawings. Some of the review agencies found the application to be challenging as it was a retrofit project using new technologies (red sand filter). Additional meetings were required with stakeholders to deal with these challenges. Proper planning and communication allowed these concerns to be addressed and resolved in a timely manner.

Design

The SWM pond retrofit was designed to capture stormwater runoff through a treatment train system, while recognizing the potential environmental impacts on the adjacent watercourse, Eastern Creek. A naturalized by-pass channel with flow splitter was constructed in order to maintain fisheries in the pond. As part of the treatment train, a forebay and main cell were created. After travelling through that part of the system, the storm water would then go through an oil/grit separator and finally through a polishing agent, the red sand filter.

Forebay and Main Cell

Both the forebay and main cell were excavated from an existing depth of 30cm down to 3 metres. The excavated soil was considered contaminated and had to be transported to a licensed treatment facility at a cost of $250,000, which was included in the contruction costs.



Stormwater management pond forebay and main cell

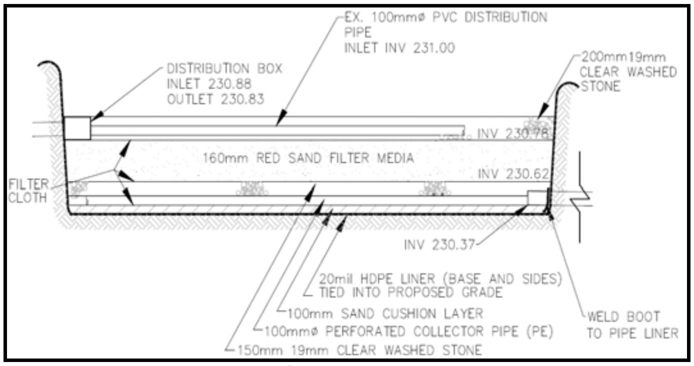
Oil and Grit Separator

This unit is downstream of the forebay and main cell to capture the smaller particulates before water enters the red sand filter for extensive phosphorus removal.

Red Sand Filter

By testing numerous sand mixes, the red sand was found to have adequate percolation and phosphorus retention capability, allowing it to reduce greater than 99% of total phosphorus and other minerals. This technology was installed as the last part of the treatment train to function as a final polishing unit. The underground system was first lined with a Bentonite liner to minimize groundwater exchange, with various layers of clear stone and red sand sandwiched between nonwoven geotextile fabrics.

The water is distributed via a system of perforated piping covering the top layer of the underground system just above the red sand filter media. Collector pipes are located near the bottom. The cross section of the underground system with the red sand filter is shown below. The system is estimated to reduce 23 kg of phosphorus per year.



Red sand filter cross-section

Design Issues

A key component in the design was to recognize the existing features surrounding the pond. All large trees remained untouched and were incorporated into the design.

Also considered during design was the very slight grade change at the site. Using gravity to maintain flows without having to rely on a pumping system, final grading needed to follow the plans exactly, allowing little tolerance.

Key Facts

Issues

- Delays in construction due to weather conditions and continuous dewatering.

Solutions & Lessons Learned

- Frequent on-site meeting with all partners was key to the success of this project.
- Continuing to look one step ahead of the project with possible solutions available for any upcoming issues.

Construction and Commissioning

Construction took place over a two-year period in two separate phases causing several issues for the contractor.


Excavating the main cell of the SWM Pond

Construction Phases

The first phase of this project was finished in March 2010 and included installation of a red sand filtration system. The final steps involved retrofitting the stormwater management facility on town-owned lands. In September 2011, construction began on creation of a sediment forebay (permanent pool) and main cell, creation of a flow splitter to connect the by-pass stream channel, and extensive landscape restoration.


Excavated Underground System

Construction Drawings

Several minor changes were made to the drawings in reference to the rock flow splitter and final berm elevations in order to address some fisheries issues and backflow concerns. These changes were fairly minor in nature and simple for the contractor to accommodate.


Creating a stone covered berm between sections of the pond

Sediment and Erosion Control

Sediment and erosion control measures were monitored daily and repaired when required. These measures included:

- Reducing topsoil stripping as much as possible and seeding individual lots as soon as possible.
- Placing silt fencing downstream of all excavated material to prevent sediment transport.
- Maintaining the existing grassland vegetation/wooded areas along the development limits to provide a natural barrier to filter potentially sediment loaded overland flow.
- Providing conveyance protection by placing rock check dams and straw bales at intervals along constructed ditches and at the outlet culvert prior to construction.

- Using a mud-mat that consists of large diameter rip-rap at the entrance to control mud tracking from construction traffic.

Protection of existing grassland vegetation/wooded areas during construction

Dewatering

The pond area was dewatered during excavation while maintaining base flow of the creek system. The discharge was connected to filter bags which were replaced on a weekly basis.

Economic (Capital and O&M Costs)

The approximate capital costs for this SWM pond retrofit are as follows:

Item	Approximate Costs
Design/consultant fees	~$70,000
Construction final grading and riparian buffer installation	~$1,000,000

The cost of hauling the contaminated soil to an appropriate facility was a key factor influencing the price of the project, accounting for approximately $250,000 of the $1 million spent on construction.

Proper planning and the ability to foresee potential problems is key to a successful project. Creation of detailed site plans and obtaining soil samples assisted in determining how much fill material needed to be taken off site, and depending on soil results, where the material could go. Through the Environmental Assessment process, the public was invited to an open house. The open house was advertised in local papers and an invitation was delivered to all homes within a one kilometer radius of the subject project. Every effort was made t to be cost effective. This included the project partners providing both cash and in-kind contributions and the community assisting with an Earth Day event, planting over 1,000 trees and shrubs at the project site.

Operations and Maintenance

With proper monitoring, operation and maintenance times should be kept to a minimum. The project was designed to be low maintenance, allowing long time intervals between any clean out or dredging.

Installing native plants around the perimeter of the project requires no maintenance or watering, reducing staff time at the park for the municipality. Regular inspections will be performed to remove any accumulated litter or debris by hand.

Grass cutting is not recommended in order to maintain a natural environment and increase water quality benefits. Weed control is not anticipated or recommended for this facility. Using herbicides and insecticides is prohibited because of potential water quality concerns in the downstream areas. Fertilizer use is limited to prevent nutrient loading to downstream areas.

Long-Term Performance

As the George Richardson Stormwater Pond retrofit project was completed in 2012, long-term performance data is currently unavailable.

Pre- and post-construction monitoring is in place and early data indicates a reduction in total suspended solids and phosphorus after going through the system. The monitoring program will operate for three years in non-winter months, during and after typical rain events. Six samples will be collected annually to get comparative seasonal readings, dry weather flow and several wet weather flow conditions. The water quality samples will be collected from the upstream and downstream manholes of the red sand filter as well as at the inlet of the SWM pond forebay and downstream of the extended detention outlet.

Acknowledgements

Credit Valley Conservation would like to sincerely thank the following companies, organizations and individuals for contributing to this case study:

- Lake Simcoe Region Conservation Authority
- R.J. Burnside & Associates Limited
- North Gate Farms Limited

IMAX Parking Lot Retrofit

Location: Mississauga
Constructed: 2013

Case Study

Business and Multi-Residential

Project Objectives, Design and Performance

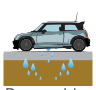
- Design and construct a better functioning parking lot that upgraded stormwater management infrastructure with modern low impact development (LID) features.
- Benefit from project partnerships to enable a variety of innovative stormwater management technologies to be integrated into the IMAX parking lot including permeable pavers, Jellyfish® Filter, bioswales and Sorbitive® Media.
- Conduct infrastructure performance assessment to 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 provided sufficient drainage infrastrucutre 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. They act as a resource and liaison between the contractor, client and other stakeholders.

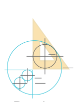
Practices Implemented


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 (SWM) technologies. These technologies collect, absorb 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 Ontario Ministry of the Environment's Showcasing Water Innovation (SWI) program. The SWI program funded leading edge, innovative and cost-effective solutions for managing drinking water, wastewater and stormwater systems in Ontario communities.

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 (should the City of Mississauga decide to implement a stormwater utility)

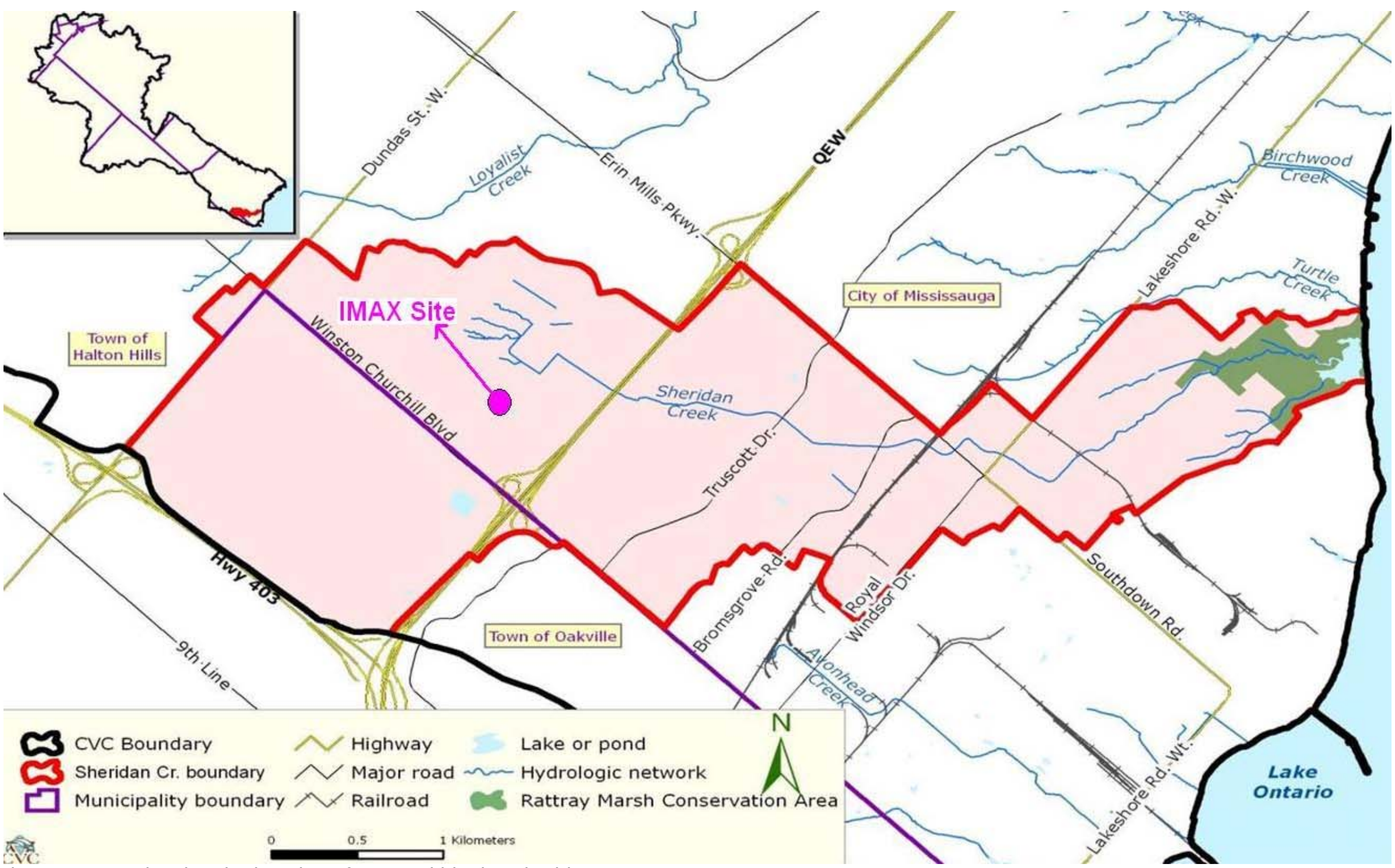


Figure 1: Map showing the location of IMAX within the Sheridan Creek watershed.

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 rapidly urbanizing 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 and mitigate impacts of combined sewer overflow.
- 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 contaminates and nutrients into waterways and natural areas. These technologies also reduce the quantity of stormwater runoff from the site.

Figure 2: Groundbreaking ceremony

Expanded and more efficient parking lot – The new parking lot has improved drainage and aesthetics, reduced maintenance requirements, and increased space to accommodate anticipated employee growth.

Demonstration showcase –Numerous presentations, events, articles, and site tours have helped IMAX and its partners to educate others about the benefits of LID.


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

Extended infrastructure lifespan –The use of drainage infrastructure and permeable pavers will increase longevity of parking lot surfaces.

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 and building market capacity for innovative technologies – The use and promotion of specialized stormwater management systems at IMAX encourages growth of Ontario's green jobs sector.

Operation and maintenance (O&M) savings – Permeable pavers have less O&M costs than asphalt surfaces. For instance, in winter conditions, pavers will require less de-icing than traditional asphalt.

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: Field monitoring team collecting samples

Overcoming Barriers and Lessons Learned

Table 1 outlines this project's barriers and issues and the lessons the project team learned when addressing them.

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 proposed 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
Monitoring	Discharge from LID practices can be very low since these systems are effective means of absorbing, 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.
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.
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 (Figure5). It also includes some of the surrounding natural area.

Figure 5: IMAX retrofit 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. Grades to the east slope toward Speakman Drive. A naturalized wetland area at the northeast corner of the site drains to a concrete weir structure. From there it drains 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.

Through discussion with the Ministry of the Environment it was determined that an ECA would not be required. This exemption occurred because the

IMAX site is a single parcel of land and is not zoned as industrial land.

Proposed 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. Proposed parking stall configurations vary and included motorcycle, compact car, and priority angled parking.

The proposed 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.

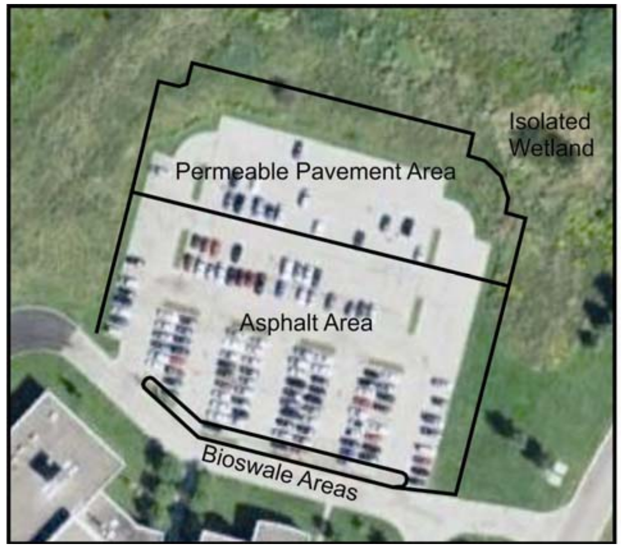


Figure 9: IMAX Retrofit Site – Retrofit Concept

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 proposed 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 Infiltratio n 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.

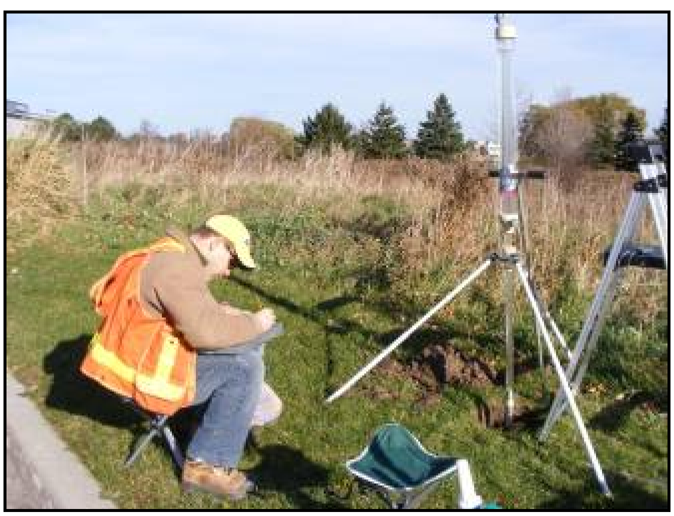


Figure 10: Infiltration testing conducted at IMAX.

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 does 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 proposed parking lot. The project budget refined the ultimate boundary line and proportions of permeable pavement versus asphalt used.

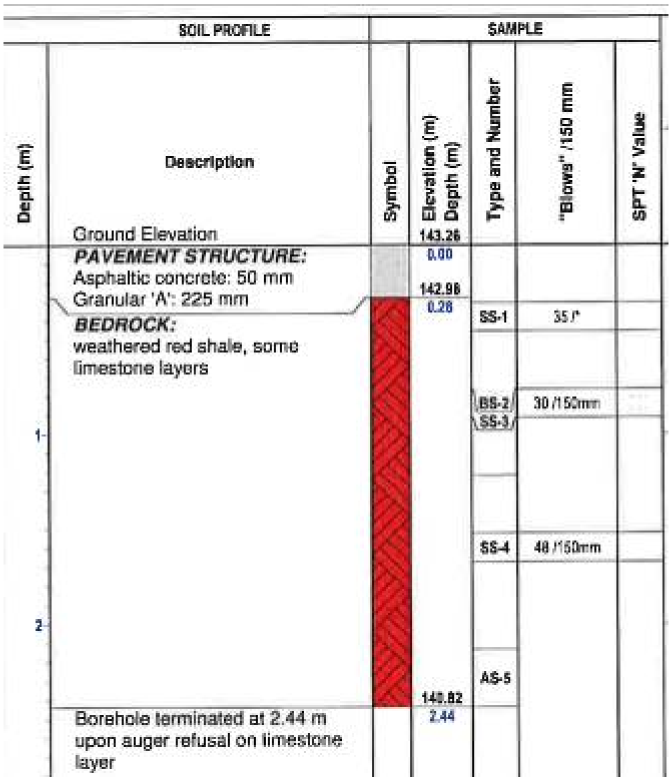


Figure 11: Borehole stratigraphy used to determine bedrock constraints at the site

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 proposed 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 of 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 proposed 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 proposed 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.

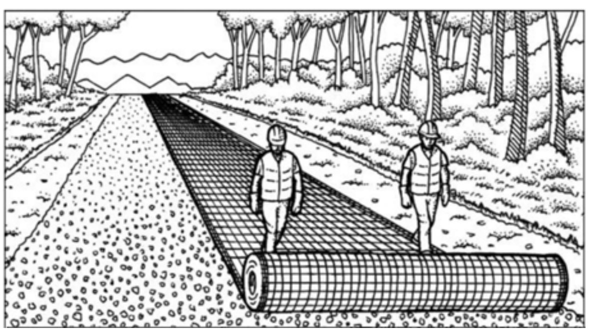


Figure 15: Roll geotextile onto flattened subgrade surface.

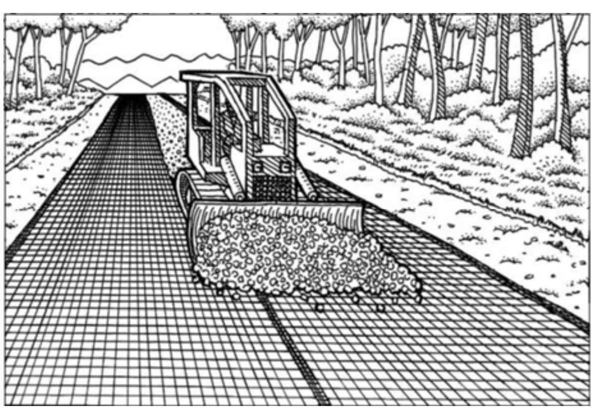


Figure 16: Base material placement onto geotextile.

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.

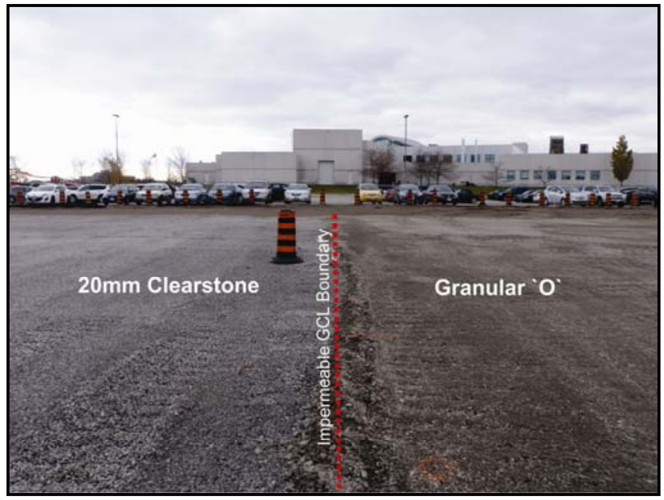


Figure 18: 20 mm ø angular clearstone and Granular "O".


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.

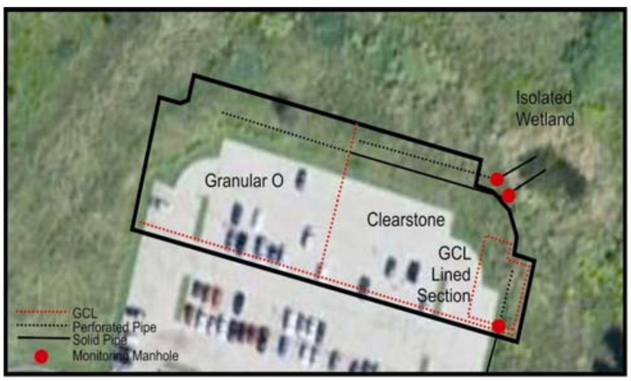


Figure 21: Permeable pavement underdrain layout

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: West end, upstream of the Sorbtive® Vault polishing unit.
- Bioswale #2: Between the other bioswales and downstream of the Jellyfish® Filter pre-treatment system.
- Bioswale #3: 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 #3 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/

Component	Percentage by weight
Sand (2.0 to 0.05 mm Ø)	85 – 88%
Fines (<0.05 mm Ø)	8 – 12%
Organic matter	3 – 5%
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	

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 will be 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 proposed bioswales designs.

Table 9: General dimensions of the bioswales

System component/ parameter	Bioswale #1	Bioswale #2 Jellyfish® Filter	Bioswale #3 Sorbtive® Vault	Bioswale #4
Top width	3.5 m	3.5 m	3 m	1.5 m
Bottom width	1-1.5 m	1-1.5 m	1-1.5 m	0.5 m
Side slopes	5:1	5:1	5:1	2:1
Long. slope	0.50%	0%	0.50%	0.50%
Total length	14.5 m	19.5 m	22 m	65 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 proposed 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	Bioswale #2 – Jellyfish® Filter	Bioswale #3 – Stand Alone
Contributing drainage area	1125 m^2	1350 m^2	1566 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 proposed 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 proposed parking lot area.

As mentioned in previous sections, the grass channel proposed 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.

Table 11: Proposed 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 for the 25 mm storm event 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.

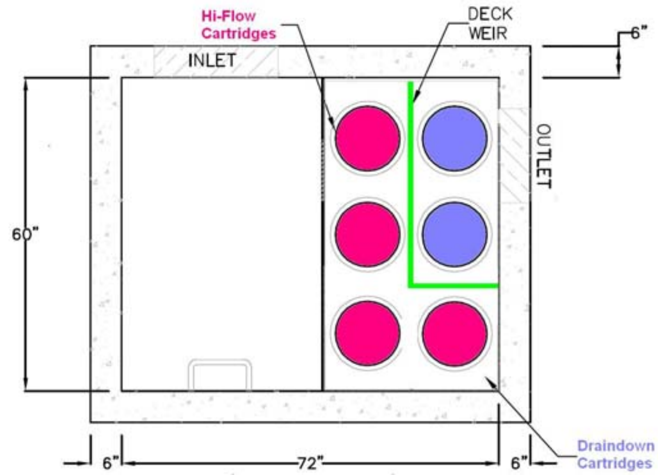


Figure 33: Jellyfish® Filter Plan View (Hi-Flow and Draindown cartridges).

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® Filer 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 absorbing 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 will be 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 shall be distributed to the treatment bay and Sorbtive® Media. Figure 35 shows the various components of the Sorbtive® Vault.

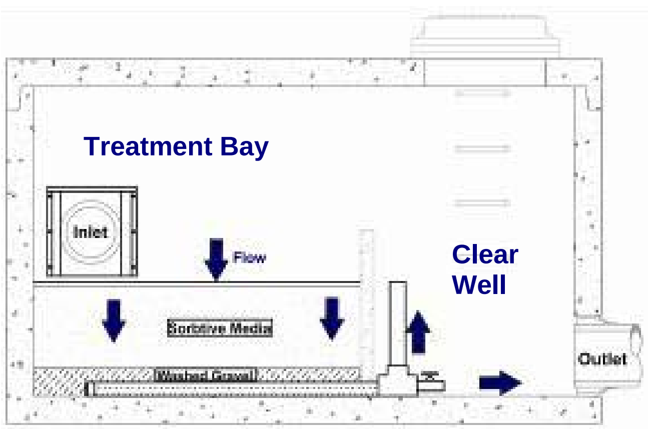


Figure 35: Conceptual of the Sorbtive® Vault installed at IMAX.

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.

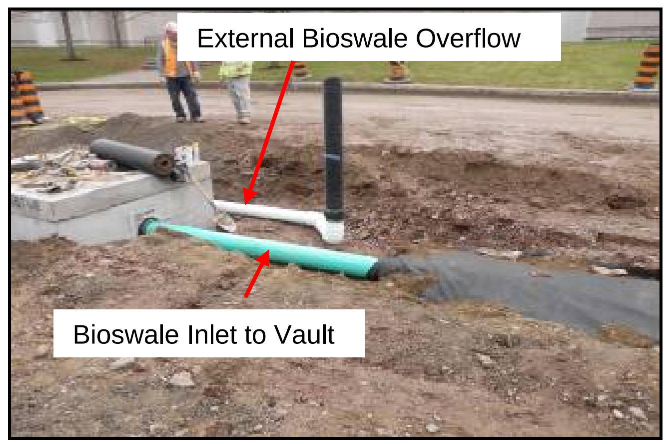


Figure 36: Sorbtive® Vault installed at IMAX and upstream bioswale.

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.

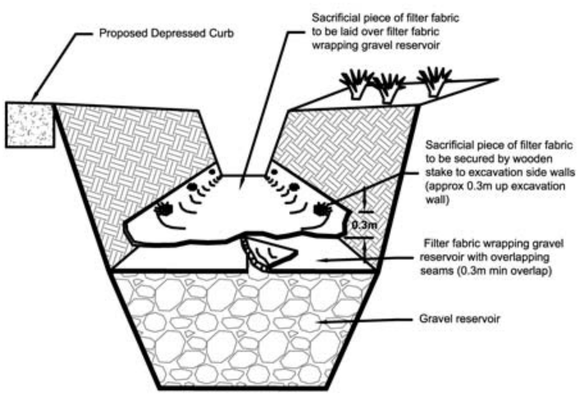


Figure 42: Conceptual of the sacrificial piece of filter cloth used to protect bioswales.

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.

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.

proprietary technologies have their own maintenance requirements.

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 to see if phosphorus is down to the 30 um/L concentration.
- To maintain the stringent removal rate/discharge guideline, the media may need to be replaced every year at a cost of $3.00/lb. The total media required is 1,300 lbs. ($4,325/year).

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 (six-inch high kidney-shaped or oval-shaped weir) for standing water in the pool. 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.

Winter operations

The 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 will be monitored during this study. Site operators will 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 will 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:

- o 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

- o 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.

As-built survey

Post construction survey of the as-built structure will provide reference elevations of the pavement and bioretention soil media. If settlement is experienced it will be possible to track and measure elevation changes.

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 Assessment Program (IPAP) will directly address several knowledge gaps to elevate confidence in LID technologies within Ontario. The IPAP 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 15 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 16.

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

<table>
<tr><th>Hydrologic questions</th><th>Water quality questions</th></tr>
<tr><td>• 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.)?</td><td>• 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)?</td></tr>
<tr><th>Design questions</th><th>Long-term questions</th></tr>
<tr><td>• 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?</td><td>• 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?</td></tr>
<tr><th colspan="2">Operation and maintenance question</th></tr>
<tr><td colspan="2">• 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)</td></tr>
</table>

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 will allow for winter measurements. A heated rain gauge was selected and installed on site to collect precipitation data (Figure 46). Precipitation data is logged at a five-minute interval.

Figure 46: Heated rain gauge installed on-site.

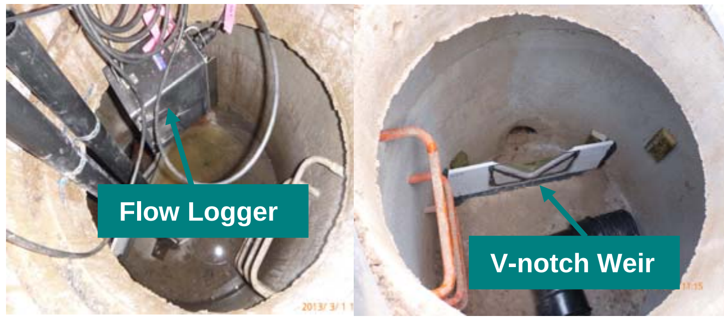


Figure 47: Water quantity monitoring set-up.

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 44).

The consultant experimented and developed a stage-discharge curve for the V-notch weirs in a lab setting. As shown in Figure 48, the IMAX rating curve is used to convert field measured water level data to discharge (L/s).

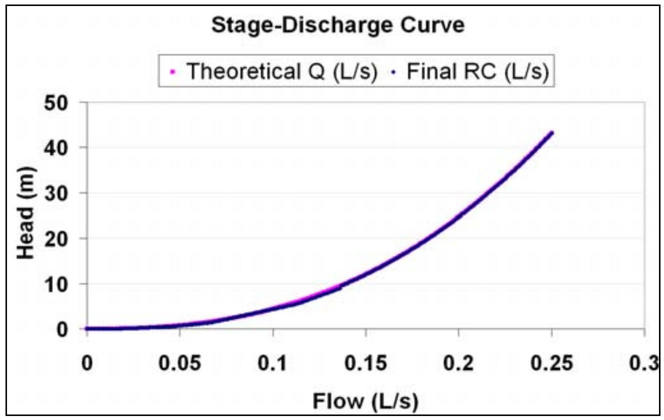


Figure 48: Stage discharge curve from IMAX

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 will 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 will be 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 Quality Data

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.

The metals monitored in this study will depend on available funds. Preferably samples will be analyzed for a complete suite of metals but testing may be limited to key metals if needed. 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 will be analyzed for the following constituents:

- General Quality
    - Total Suspended Solids (TSS)
    - Total Dissolved Solids (TDS)
    - Hardness
    - Chloride
    - Temperature
    - pH
- Nutrients:
    - Phosphorus (particulate, dissolved and orthophosphate)
    - Nitrogen
- Metals
- Oil and grease
- Hydrocarbons (tested using indicator parameter such as extractable solvent (or similar) instead of testing for specific polyaromatic hydrocarbons)

Winter salt monitoring

Road salting and snow removal activities will be monitored during this study starting in December 2013. Working with site operators, the volume of road salt applied on the asphalt and permeable pavement will be recorded. Winter performance monitoring will be conducted on the control site (IX-1), bioretention areas (IX-2, IX-3, and IX-4), and permeable pavement (IX-5, IX-6, and IX-7). However, winter salt monitoring of permeable pavement will be limited to Catchment 7 as Monitoring Stations IX-5 and IX-6 are not operational during the winter months due to loss of equipment as a result of 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 will be used to continuously measure conductivity, which can be used to determine chloride concentrations. A laboratory test will be 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 will be sampled per year. For the first year of monitoring, water quality samples were collected for rainfall events (or snowmelt events) greater than 5 mm. Using an adaptive management approach, the monitoring frequency will be 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 settings are different for the control site versus the LID sites. The Autosampler consists of 24 bottles, each with the capacity to hold 950 mL of sample water (Figure 49).

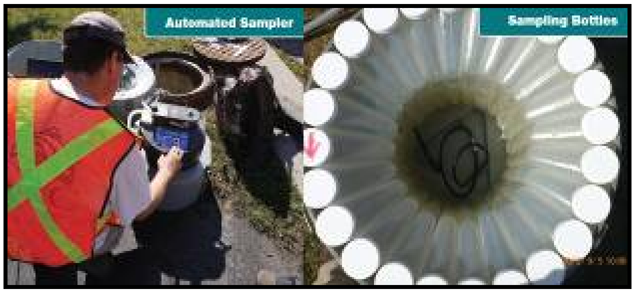


Figure 49: Water quality sampling.

For the Control site, IX-1, the Autosampler collects samples in a two-part program, Part A – Grab Sampling and Part B – Composite Sampling. The length of the program for the Control site is 12 hours and the two-part program works as follows:

- Part A fills the first six bottles as the grab sample
- Part B fills the remaining 18 bottles (950 mL) at 20-minute intervals for the flow-weighted composite sample.

For the LID sites, the Autosampler runs a one-part where the AutoSampler collects a composite sample by filling a bottle up to 500 mL (half a bottle) every hour for a total of 48 hours.

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 either remotely or by CVC staff from each piece of equipment using ISCO Flowlink 5 or Hoboware software (or equivalent). Field and lab data management will follow the 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 50 shows the layout of the retrofit parking lot and outlines the various stormwater management systems. Table 17 summarizes the monitoring tasks for all systems and is followed by a detailed description of each drainage area.

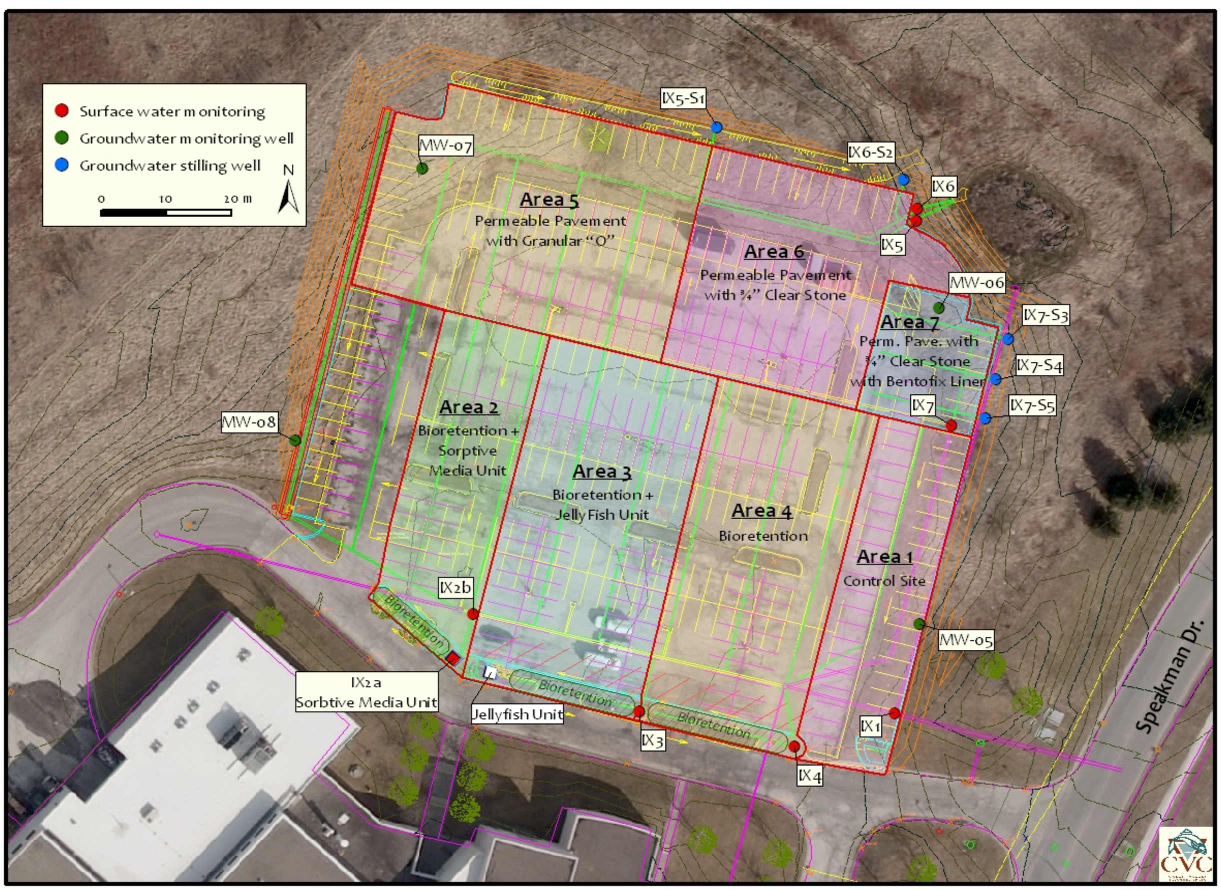


Figure 50: Retrofitted IMAX parking lot, LID systems and monitoring stations.

Table 17: Monitoring stations and associated monitoring tasks.

SWM system	Area (monitoring station(s))	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	20 min
Bioretention + Sorbtive® Media unit	Area 2 (IX-2a, IX-2b)	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	1 hr
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, Hydrocarbons, Total Phosphorus, Dissolved and Particulate Phosphorus, Orthophosphate	Temperature	1 hr
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	1 hr
Permeable pavement with Granular "O"	Area 5 (IX-5, IX-5S1)	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	1 hr
Permeable pavement with ¼" clearstone	Area 6 (IX-6, IX6-S2)	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	1 hr
Permeable pavement with ¼" clearstone and Bentofix liner	Area 7 (IX-7, IX7-S3, IX7-S4, IX7-S5)	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*	1 hr*
* IX-7 will replace IX-5 and IX-6 during the winter time to address equipment freezing issues. * Given that IX-6 has a large storage capacity and to-date no samples have been collected. To compensate for water quality sampling, IX-7 will be in affect all year round to represent water quality results with 20 mm clear stone similar to IX-6.					

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) = 1714 m^2), shown in Figure 50, 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 which discharges to the municipal stormsewer, as shown in figure below. Area 1 reflects a conventional stormwater conveyance system and serves as the control treatment for the site.

Figure 51: 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 will provide when maximum surface ponding depth is reached and runoff is now entering the overflow riser pipe directly with no LID treatment.

Stormwater from Area 2 (DA = 1125 m^2) is infiltrated through Bioswale 1, collected in an underdrain and routed to a Sorbtive® Vault. Currently, there are two monitoring stations used for Area 2 including (Figure 50):

- IX-2a, located within the clear well of the Sorbtive® Vault
- IX-2b 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 53, 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 will 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)

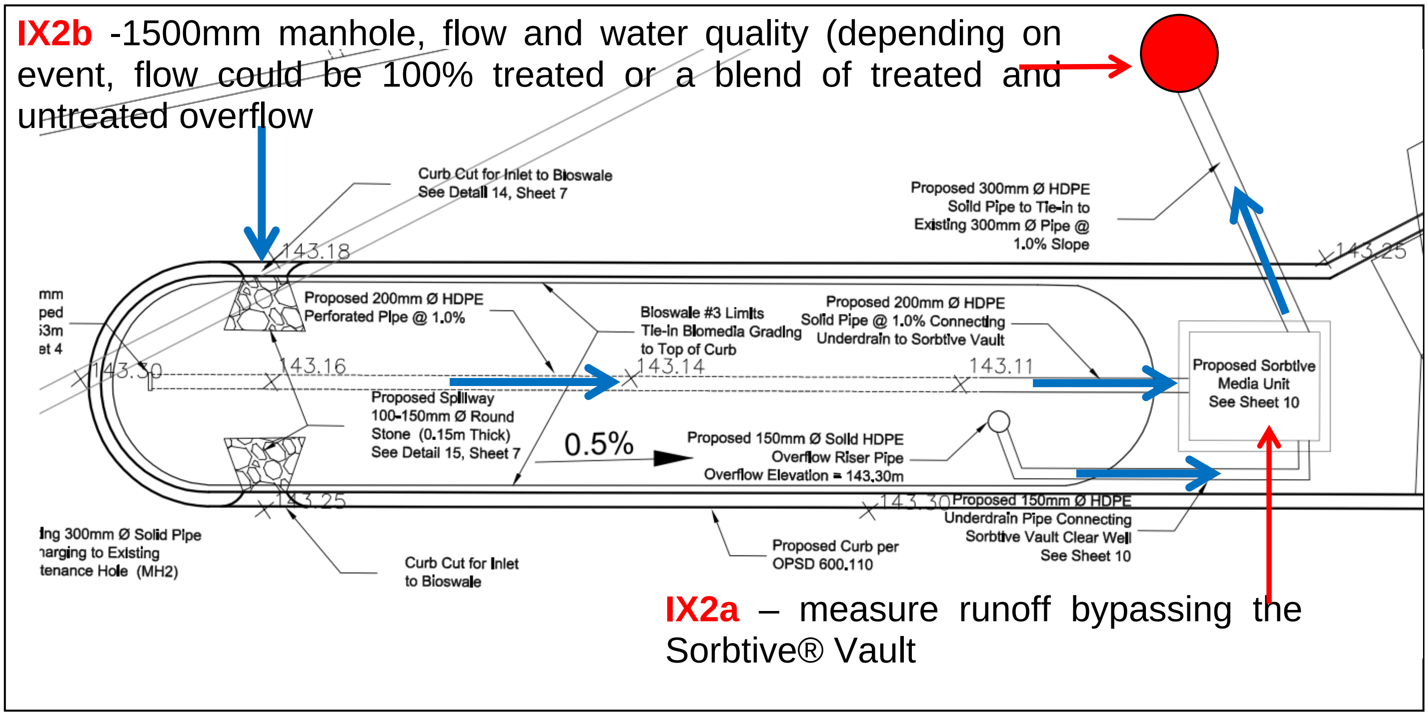


Figure 52: Bioswale Cell 1 Layout (Aquafor Beech, 2012).

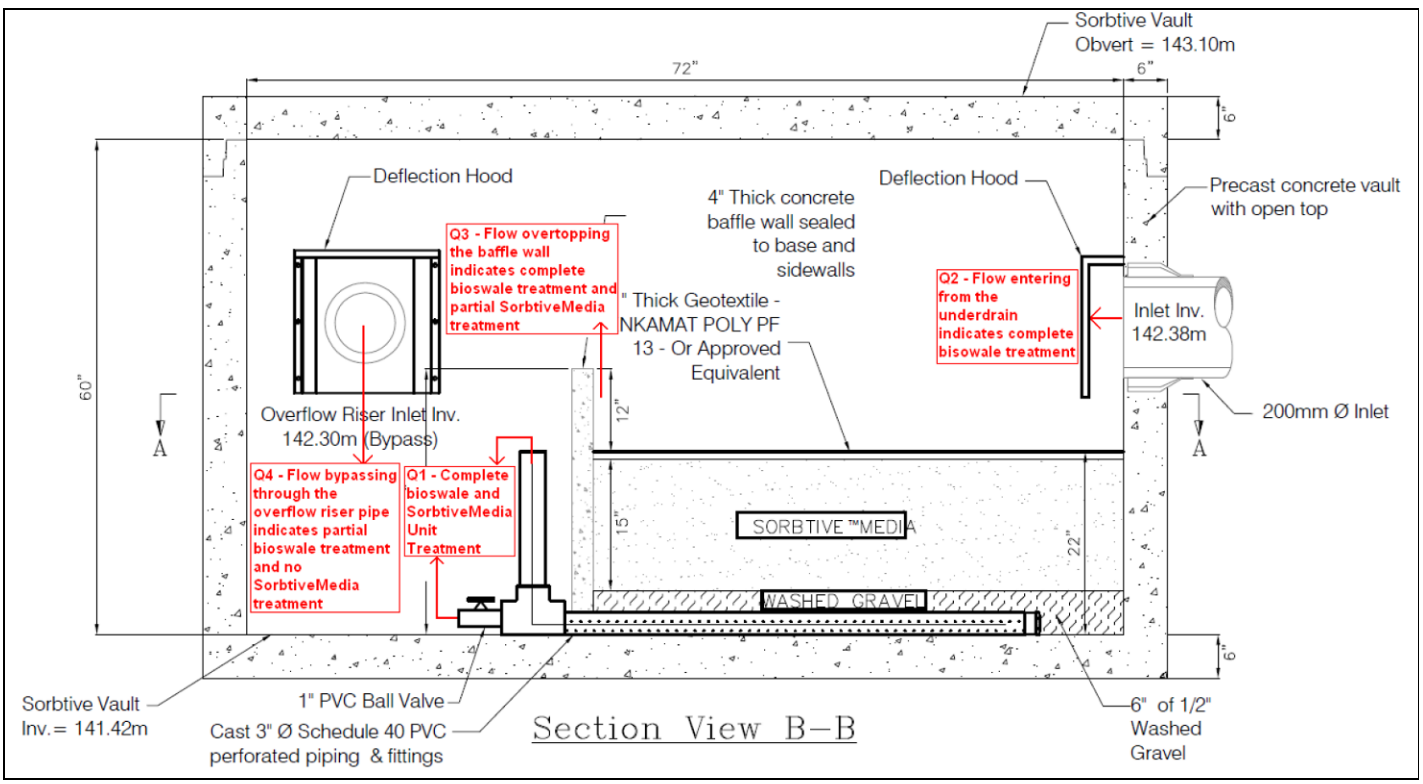


Figure 53: Sorbtive Media Bypass (Aquafor Beech, 2012).

Stormwater from Area 3 (DA = 1350 m^2) is pre-treated by a Jellyfish® Filter unit before discharging to Bioswale 2 (Figure 54). 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 will be assumed and accounted for when interpreting water quality data measured downstream at IX-3. When the Jellyfish® Filter surcharges, runoff will be diverted to the bypass channel and flow directly into the bioswale (Figure 55).

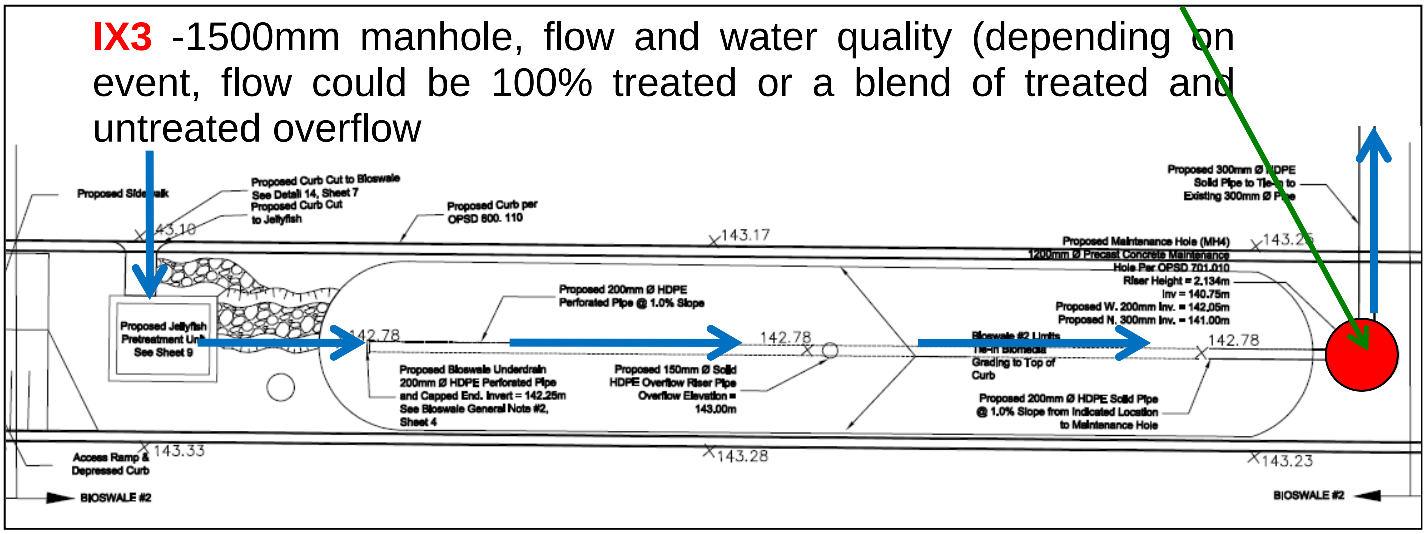


Figure 54: Bioswale Cell 2 layout (Aquafor Beech, 2012).

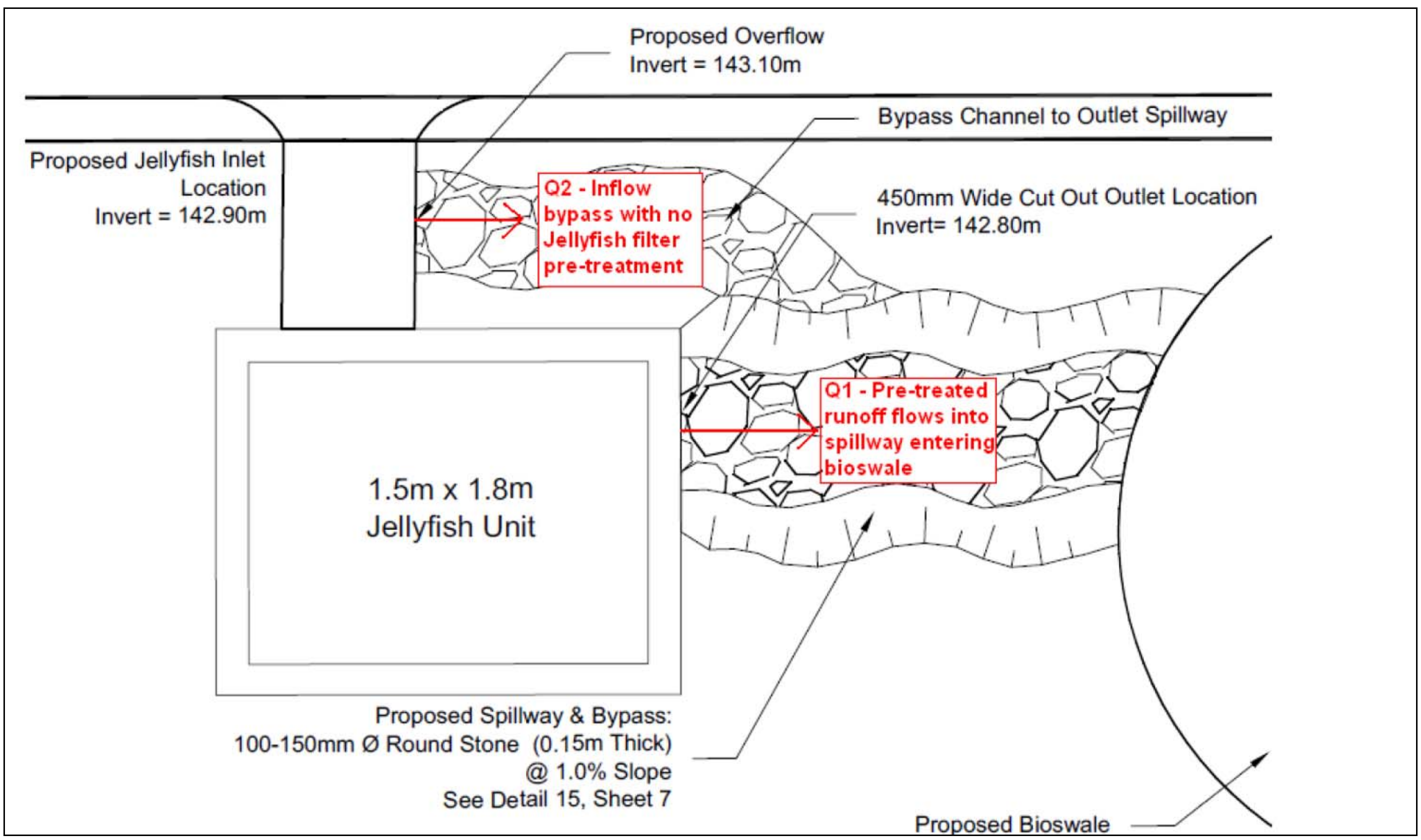


Figure 55: Jellyfish® Filter bypass.

Stormwater from Area 4 (DA = 1566 m^2) is filtrated by Bioswale 3 (Figure 56). 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.

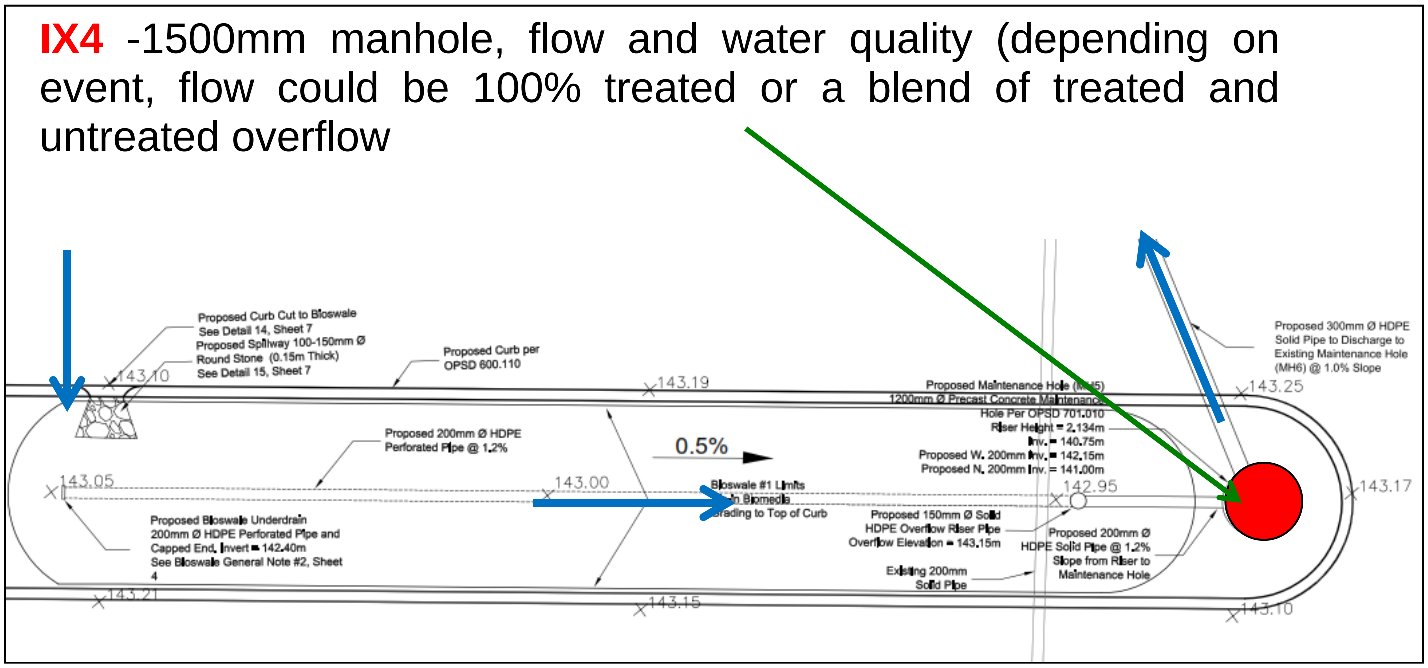


Figure 56: Bioswale Cell 3 layout (Aquafor Beech, 2012).

Permeable pavement (Areas 5, 6 and 7)

Areas 5 and 6 represent the permeable pavement portion of the parking lot (DA = 3133 m^2). The parking lot grading is such that the permeable pavement will 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 will be collected separately and performance comparisons between the different materials will be possible. As shown in Figure 50, stormwater from Areas 5 and 6 will be 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 which is adjacent to the IMAX property before entering 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 57) which will allow researchers to control the water levels beneath the permeable pavement. Elbows will initially be 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).

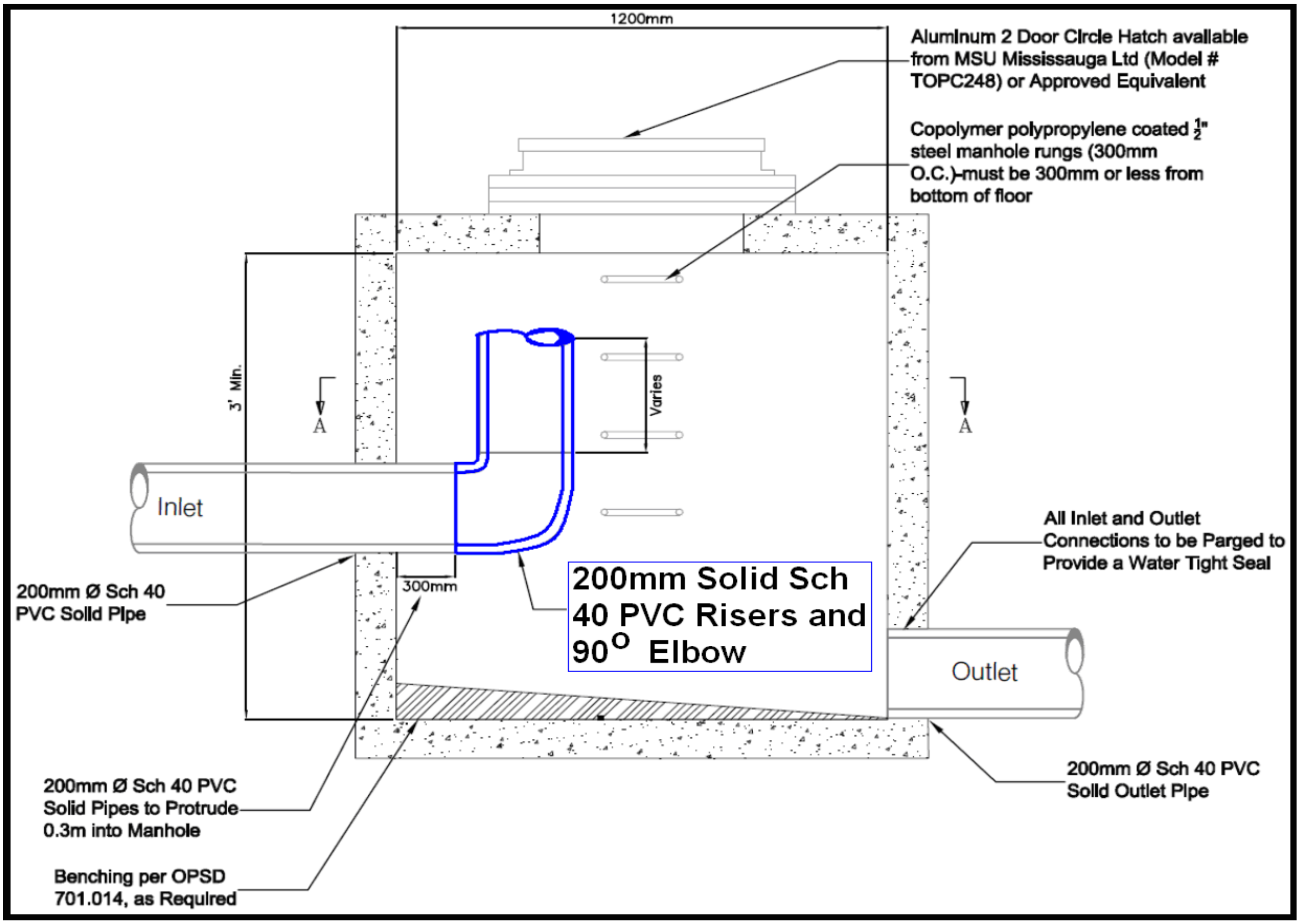


Figure 57: Moveable 90° elbows (Aquafor Beech, 2012).

Area 7 is fully lined with an impermeable geosynthetic clay liner (GCL). The lined area will be 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 58). 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.

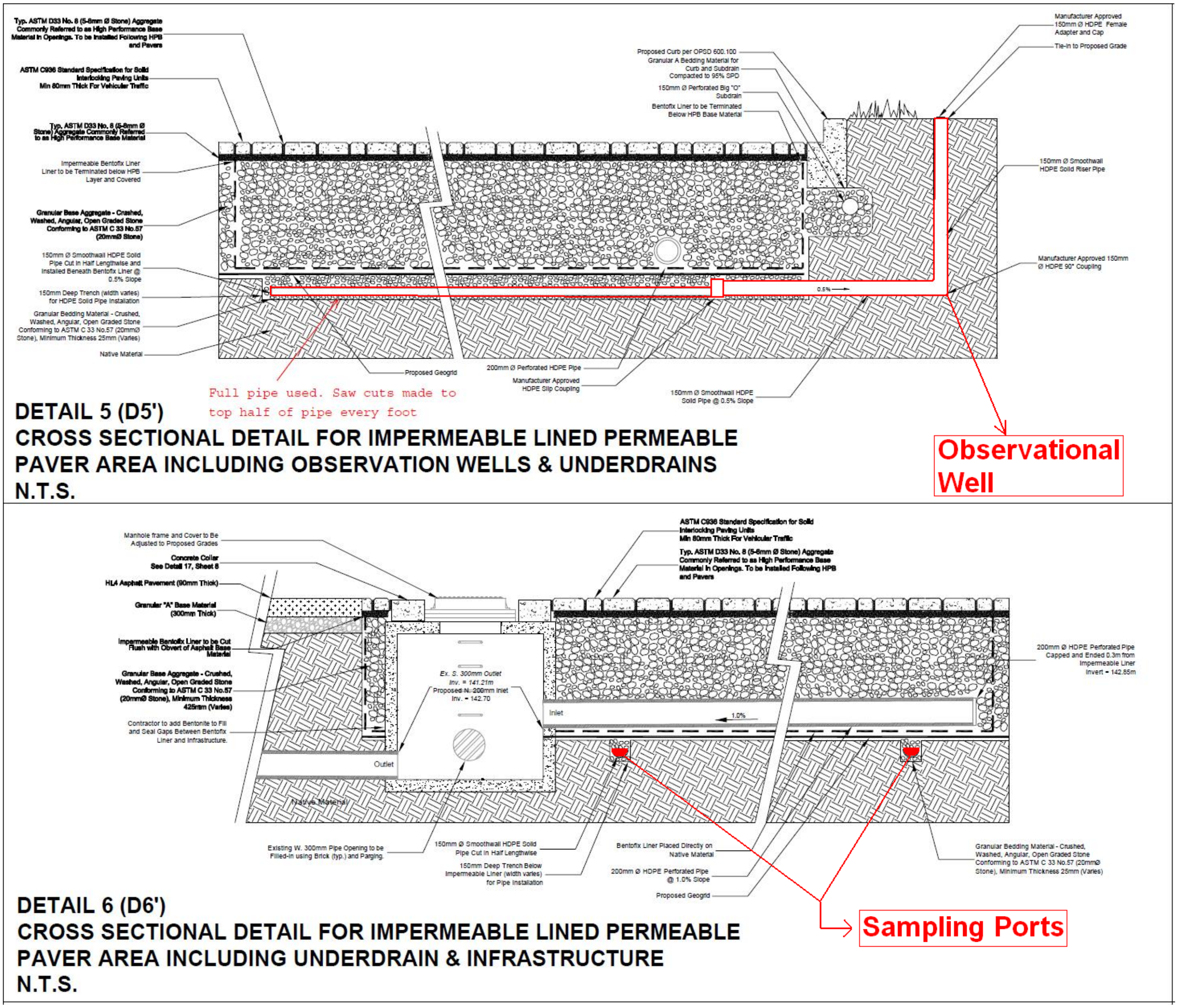


Figure 58: Sampling ports and observational wells for subcatchment 7 (Aquafor Beech, 2012).

Monitoring challenges

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

- Need for a control site
- Missed rain events
- Accommodation of monitoring equipment

Need for a control site

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

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

Missed flow events

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

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

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 59: 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 60) in a low traffic landscaped area near the wetland posing no obstructions on the daily use of the parking lot.

Figure 60: Steel box to accommodate Autosamplers.

Permeable pavement infiltration test results

University of Guelph and CVC staff completed infiltration testing of the permeable pavement systems at subcatchments IX-5, IX-6, and IX-7 on June 14, 2013 and August 2, 2013. 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.

There are two different kinds of sub-base material used in the permeable pavements systems at the IMAX property: Granular “O” in IX-5 and ¾” clearstone in IX-6 and IX-7. As IX-6 and IX-7 share the same granular material they are assessed as one area when comparing infiltration rates based on sub-base material.

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

The total average infiltration rates for IX-5 and IX-6/IX-7 are 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. Infiltration rates range from 804.5 mm/hr to 10140.9 mm/hr for IX-5 and from 1982.1 mm/hr to 10288.8 mm/hr for IX-6 and IX-7. 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 61). These infiltration tests will be performed on a yearly basis and changes in infiltration capacity will be tracked overtime.

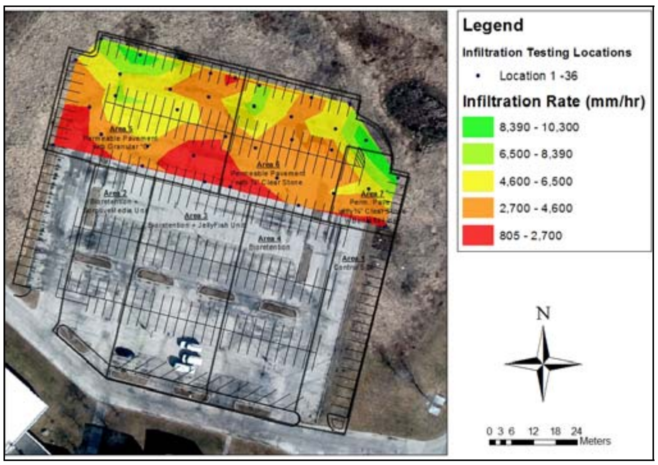


Figure 61: Infiltration rate contour map.

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 average infiltration rate based on parking area location was found, as expected, within the centre of the parking stalls with an average of 5334.0 mm/hr. The lowest average infiltration rate based on parking area location, however, is located on the lines dividing parking spaces. The average infiltration rate in these areas is 3735.1 mm/hr. This is likely due to the build-up of sediment along the lines that washes off of vehicles within the parking spaces, as well as due to the accumulation of debris left in these areas by people entering or leaving their vehicles. The average infiltration rate for laneways fell between those for parking stalls and paints lines, with an average of 4499.1 mm/hr. Infiltration rates within laneways, however, varied significantly; both the lowest (804.5 mm/hr) and highest (10288.8 mm/hr) individual infiltration rates were found in laneways. The lower infiltration rates within the laneways are located in the entrances to the permeable pavement area as well as in the row closest to the entrance to the building. This reflects the areas of the parking lot that are most commonly used by IMAX staff.

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

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