

DESIGNING FOR ENVIRONMENTAL AND INFRASTRUCTURE SUSTAINABILITY: ONTARIO CASE STUDIES FOR RETROFITS AND NEW DEVELOPMENTS

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INTRODUCTION

The Low Impact Development (LID) approach has been implemented worldwide for managing stormwater quantity and quality within the context of land development, re-development, and retrofits within an existing development site. Since the inception of the concept in the 1990s, the application of LID has covered different land uses, spatial scales, and environmental objectives, leading to an expanded vision for applying and testing the LID approach. Recently, holistic methodologies and frameworks have linked land planning to key ecological landscapes larger than the previous site scale practice. This new emerging paradigm considers the watershed, subwatershed, and neighbourhood, in addition to the site scale, and consequently, recommends a landscape-based LID and broader Green Infrastructure (GI) solutions (Benedict and McMahon, 2002; Tzoulas et al, 2007; NRDC, 2011).

As part of the holistic understanding of land planning and environmental features and functions within the intended spatial scale, LID and GI measures have been designed and constructed as retrofit measures (i.e., measures implemented within existing development) and as measures implemented within new development areas. Under this new paradigm, the land planning context is linked to environmental objectives to provide end points for environmental conservation and restoration within an ecological landscape such as watersheds, subwatersheds, and stream corridors.

This paper presents three case studies for the design and construction of LID and GI measures within different land use contexts and for providing multiple environmental objectives.

KEYWORDS

Low Impact Development (LID), Green Infrastructure (GI), stormwater management, bioswale, bioretention, permeable pavement, sustainability, climate change adaptation and resiliency, green streets, policy guidelines, Species at Risk (SAR) Act

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OVERVIEW

The basis of the recommendation and implementation of LID and GI measures is founded on the holistic understanding of social, environmental, and economic factors that impact communities and cities. Within the context of the three pillars of sustainability (economic demands, environmental resilience, and social wellbeing), providing sustainable infrastructure that effectively serves the health and wellbeing of urban and environmental landscapes should be based on responsible decisions that aim to protect and conserve environmental features and functions under existing and future conditions.

While the concepts of LID and GI are advancing in theory and practice, the majority of current stormwater management practices still focus on a “business as usual” approach, where advancements in science and adaptive management tools are rarely implemented. More specifically, current practices for new development areas are primarily structural (i.e., engineering-based) with minimal consideration of the environmental and social aspects.

TABLE 1. Key differences between traditional stormwater management measures and LID and GI measures.

Category	Traditional Stormwater Management Measures	LID and Green Infrastructure Measures
System	Based on a minor/major drainage system and managing stormwater runoff.	Based on an ecosystem approach that deals with the ecological landscape and its features and functions.
Treatment	Treat rainwater as a waste that needs to be flushed and removed as fast and efficiently as possible.	Treat rainwater as a resource that should be treated, recycled, and conserved within an overall system that integrates urban and natural features.
Problem/Opportunity	React to problems such as flooding or water quality issues.	Plan and design to prevent problems proactively by providing solutions that are organic to the overall landscape.
Technical Team	Primarily based on an engineer’s input, including structural configurations, calculations, and capacity assumptions.	Based on interdisciplinary input that includes biological, ecological, geotechnical, geomorphological, social, and landscape architecture input.
Priorities	Primarily focus on protecting property from flooding and erosion.	Protect property, habitat, and natural landscape as a whole ecosystem.
Mechanism	Based on a “pipe and convey” approach with basic environmental input related to minimizing stormwater runoff.	Mimic natural processes within urban and natural landscapes. Mimicking natural processes may include surface runoff, infiltration, evapotranspiration, baseflow input, and open channel flow processes.
Rainfall and Climate Change Analysis	Static infrastructure which focuses on historically infrequent and extreme storm events that could cause damage to property and public lands	Adaptive (“elastic”) infrastructure which focuses on historical and predictive storm events including those which could cause damage to property, public lands, and natural features and functions.
Rainfall-Runoff Analysis	Focus on peak flows and propose solutions that are based on decreasing these peak flows to pre-development conditions	Primarily focused on rainfall and runoff volumes including the breakdown of water volumes among the hydrological cycle components (i.e., runoff, infiltration, evapotranspiration, etc.).

Within existing development areas, retrofit measures tend to follow traditional design and construction practices as previously practiced, therefore wasting opportunities to implement innovative solutions that could achieve environmental goals and objectives within a watershed-based context. Key elements that differentiate between traditional (business as usual) stormwater management measures and innovative LID and GI measures are presented in Table 1.

Recent advances and improvements in the policy framework related to land development in Ontario have been progressive and advantageous in regard to proposing and implementing innovative LID and GI measures within new development, re-development, and existing development areas. These advances include the most recent Provincial Policy Statement (MMAH, 2014), which includes items pertaining to LID and climate change adaptation measures. In addition, watershed managers, including the Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation (CVC) Authority, have recently issued stormwater management criteria documents (TRCA, 2012; CVC, 2012) that provide a land-planning context combined with a set of environmental goals and objectives related to the recommendation and implementation of stormwater management measures. For example, among the new requirements is the retention of 3mm of rainfall depth for maintaining water balance and baseflow input to streams, and the detention of 5mm for erosion prevention.

In order to address the current gap in infrastructure sustainability within new development and re-development and provide a way forward to address the most recent policy frameworks and environmental goals and objectives, the presentation and analyses of three LID and GI case studies within different land use and environmental contexts provides a means to test and validate innovative techniques and tools. Each case study presents problems and challenges, design criteria and objectives, functional pathways, and performance. The case studies are illustrated in such a way that can help practitioners to holistically address stormwater infrastructure design issues while addressing the myriad of urban and environmental requirements.

DESIGN CONTEXT: THE DUAL NATURE OF LID AND GI

Design for the Environment

A primary element in the planning and designing of LID and GI within the environmental context is providing a set of goals, objectives, and targets that need to be addressed. Recent research and practice have proven that urban development can cause negative impacts to environmental features and functions within different spatial scales ranging from a subdivision to a watershed.

Addressing environmental objectives within the context of restoration, preservation, or improvement of a landscape feature where development exists may differ from project to project. Key environmental goals and objectives that present areas of concern for stormwater management in Ontario include:

1. *Water quality concerns:* including Total Suspended Sediment (TSS) and phosphorus loading from urban and rural areas, heavy metals from urban areas, *E.coli* loading from agricultural landscapes.
2. *Water quantity concerns:* including flooding, erosion, decreases in groundwater recharge and baseflow input to streams and rivers.

3. *Terrestrial ecology concerns*: including the fragmentation of ecological landscapes, limited stream riparian zones, and impacts to wetland hydroperiods.
4. *Aquatic ecology concerns*: including lack of necessary streamflows to maintain fisheries habitat at different times of the year (Zaghal, 2010), and lack of baseflow input.

The relative importance of the above-mentioned objectives will vary from project to project depending on many factors including:

1. The policy and legislation driving the study.
2. The overall goals and objectives of a watershed study or a master plan where the development area is located.
3. The location within the watershed.
4. Proximity to a watercourse (i.e., downstream or upstream of a certain feature or function).
5. The nature of the project: reactive or pro-active.

For example, the recommended stormwater management measures for a new development area within the habitat of an endangered species (e.g., Redside Dace) might be different in terms of design requirements and implementation than recommended measures for a retrofit within an existing development area with phosphorus loading issues. More specifically, Redside Dace habitat requirements include specific physical parameters that must be achieved through stormwater management. Particularly, Redside Dace prefer temperatures of less than 24°C and dissolved oxygen (DO) of at least 7 mg/L. In addition, spawning occurs when the temperature reaches 16–18°C. In order to achieve such instream temperatures, special attention should be paid to the temperature of stormwater draining into a watercourse where Redside Dace population inhabits. Moreover, recommendations should also be considered with respect to stream restoration features (e.g., riparian buffers and trees) that may allow more shading and cooling along the watercourse of interest.

Competing environmental objectives must be addressed when proposing an LID measure within an area where trade-offs based on consultations and discussions among stakeholders might be needed. Expert input at a preliminary phase of the design process may be required to understand key limiting environmental variables that need to be addressed and restored or improved through stormwater management (Booth and Jackson, 1997; Allan, 2004).

Design for Efficient and Sustainable Infrastructure

Municipal planning objectives are critical to the success of the implementation of any LID and GI measures within a town or a city. Accordingly, municipal planning objectives need to be integrated into the suite of environmental objectives addressed throughout the design. These objectives may include:

1. Integration with existing infrastructure
2. Operation and maintenance procedures
3. Cost
4. Durability and life cycle
5. Social acceptance

Since the implementation of LID and GI measures is still in its infancy, the majority of municipal standards and engineering guidelines are not yet in sync with the advances in the theory and practice of LID and GI systems. It is essential when planning and designing LID and GI measures within a new municipal landscape to provide context for LID implementation, namely an environmental context and a planning context. For example, addressing environmental objectives by building a bioretention unit may be presented in terms of how effective it is in removing pollutants such as Phosphorus or TSS. Municipal objectives may be addressed in terms of how a bioretention unit may be integrated within an existing storm sewer system, how much less it would cost to build, and what would be the technical and managerial effort in addressing operation and maintenance issues.

Understanding the functionality of the landscape plays a major role in designing efficient and sustainable infrastructure. Specifically, site investigations are foundational in examining the site-scale soil properties and groundwater levels and fluctuations, which have important implications on the design of infiltration-based LID and GI measures. In addition, analyzing functional drainage pathways plays a key role in evaluating the overall performance of the stormwater management system, including:

1. Natural processes within pervious areas, including parks, depression storage areas, and vegetation communities
2. Conveyance mechanisms within storm sewer systems including minor and major systems
3. Retention, detention, and conveyance mechanisms within an LID/GI measure as part of the overall stormwater management system.

The following case studies represent three LID and GI projects within Ontario, Canada, where considerations such as the ones presented above have been addressed. For each case study, the following is examined:

1. **Project context:** describes the location of the case study and explains triggers of the case study, including policy/legislation (Endangered Species Act in Case Study 1), water quantity improvement objectives (providing water quantity infiltration-based solutions in Case Study 2), and water quality improvement objectives (improving water quality upstream of a Provincially Significant Wetland (PSW) in Case Study 3)
2. **Problems/Challenges:** provides a brief summary of challenges at different spatial scales (site, watercourse, and watershed)
3. **Site investigations:** explains investigations that were carried out as part of the case studies, including geotechnical investigations, vegetation surveys, and in-situ infiltration testing
4. **Design objectives and criteria:** explains municipal and environmental objectives and criteria
5. **Overall design and functional pathways:** shows key components and layout of the design concept for each case study
6. **Performance:** discusses how the performance for each system within each case study is monitored and assessed.

CASE STUDY 1—UPPER MIDDLE ROAD BIORETENTION FACILITY

Project Context

This case study details an innovative bioretention design used to mitigate aquatic habitat impacts in response to Species at Risk Legislation as part of a roadway expansion/reconstruction, stream realignment, and culvert extension project in Oakville, Ontario, Canada (Figure 1). Initiated by the Region of Halton, Delcan, and Aquafor Beech, the 1,600m² facility was constructed in 2011. The bioretention facility is being monitored through a comprehensive five-year monitoring program.

In 2007, the Canadian Federal Government enacted the Endangered Species Act (ESA). This act provides broader protection for species at risk and their habitats. In general, the purpose of the act includes the preservation and rehabilitation of habitat and the enhancement of other areas so that they can become habitat. Under the act, habitat may be described by specific boundaries, features, or “in any other manner,” and may prescribe areas where species live, used to live, or are believed to be capable of living and beyond. The act provides greater support for conservation organizations; a stronger commitment to recovery of species; greater flexibility; increased fines; more effective enforcement; and greater accountability, including government reporting requirements.

FIGURE 1. Bioretention facility protected during plant establishment and contributing area stabilization (off-line condition). Photo courtesy of Joseph Choi, Region of Halton.



In response to the ESA, traditional stormwater management techniques are being evaluated against newly-developed ESA stormwater management criteria. Imposed as a condition of approval, stormwater management facilities are required to limit maximum TSS loads above background levels in the receiving watercourse, preserve stream baseflow, minimize thermal enrichment, and reduce chloride levels below acute and chronic exposure levels. As a result, traditional stormwater management techniques are being replaced with innovative LID techniques such as bioretention.

Problems/Challenges

To address stormwater impacts to the habitat of Redside Dace—a fish species provincially designated as “At Risk” and protected under the ESA—Ontario’s largest bioretention facility, accepting drainage from approximately 4 hectares of newly-constructed roadway, was constructed.

The innovative bioretention design goes beyond current provincial and Canadian design guidance with respect to maximum suggested contributing drainage area (max. suggested 0.5 hectares) and impervious drainage area to facility footprint ratio (33:1 ratio, with suggested maximum being 15:1) by utilizing a unique four-stage treatment process, with each successive stage providing an increasing level of water quality improvement and thermal mitigation. The use of a bioretention infiltration facility to provide water quality enhancements represents a state-of-the-art approach to stormwater management in response to sensitive species and their habitats.

Concerns over water quality and thermal impacts, as well as baseflow contributions in regards to the habitat of the Redside Dace related to the road widening and culvert replacement in the provincially protected watercourse, were largely the drivers for the project implementation. This project was constructed in 2011 and is being monitored through a comprehensive five-year monitoring program.

Site Investigations

As this bioretention design was a component of a larger infrastructure project, numerous field investigations and site investigations were undertaken by the project team and others. These investigations were utilized to characterize the site, scope, and additional site assessment requirements for the bioretention design. The site investigations included the following and are summarized in Table 2:

- A hydrogeological study to understand the surface and groundwater interactions; and
- Geotechnical investigations in 2005 and 2007.

FIGURE 2. Redside Dace. Source: Department of Fisheries and Oceans (DFO).



FIGURE 3. High hydraulic conductivity sand & gravel overlain by low hydraulic conductivity silty clay.



TABLE 2. Summary of site sub-soil conditions.

Soil Stratigraphy	>8m of unsorted sand & gravel, overlain and confined within the valley slopes by 5–10m of silty clay (Halton Till)
Hydraulic Conductivity	Silty clay till characterized as low conductivity (10^{-7} to 10^{-10} m/s) Sand & gravel unit characterized as high conductivity (10^{-5} to 10^{-6} m/s) <ul style="list-style-type: none">• 2–3 orders of magnitude difference• Using a sensitivity analysis, 15 mm/hr was determined using hand-driven piezometers & sharp response to rainfall events and rapid drainage as baseflow
Seasonally High Groundwater Table Elevation	$\pm 122.5\text{m}$
Groundwater Table Fluctuation	0.2–0.5m

The bioretention design exploited the high hydraulic conductivity of the native sand and gravels by ensuring the bioretention gravel storage reservoir made a hydraulic connection. Design drawings required that the native sand and gravels be exposed and verified by the supervising engineer prior to backfilling.

Design Objectives and Criteria

The design objectives and criteria included:

- Water quality control for a 25mm rainfall event to ensure 80% long-term total suspended solids (TSS) removal. Control of the 25mm event represents approximately 90% of the total annual rainfall events for southern Ontario;
- Thermal impact mitigation through the infiltration of runoff;
- Maintenance of baseflow conditions (shallow infiltration) to the adjacent Redside Dace-occupied watercourse;
- Complete integration of bioretention plantings within the surrounding vegetation and natural environment of the existing watercourse valley feature (Figure 4); and
- Low long-term operation and maintenance costs and extended life expectancy.



FIGURE 4. The bioretention facility plantings were chosen to disappear into the existing valley features.

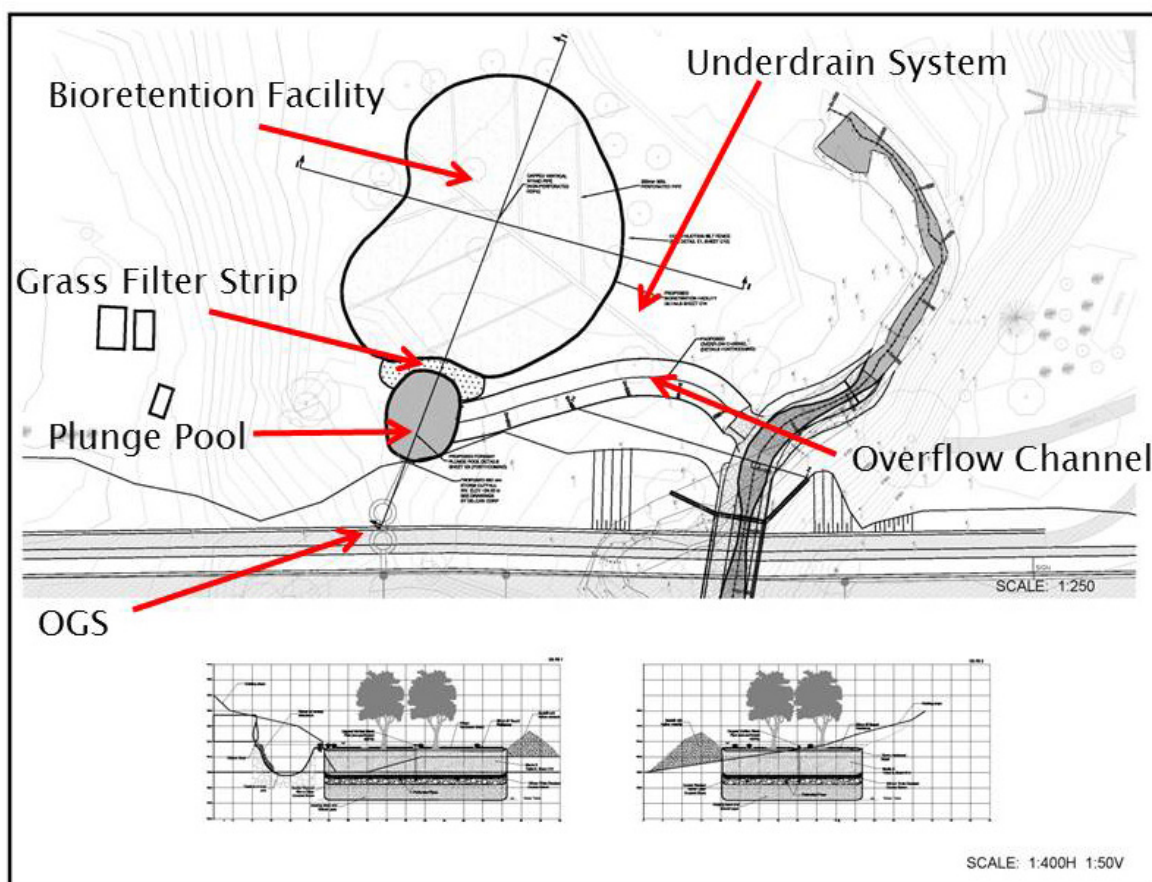
Overall Design and Functional Pathways

The overall design includes a four-stage treatment process, including three pre-treatment mechanisms prior to treatment within the bioretention facility, and an overflow channel to divert major events (Figure 5).

Due to the large drainage area and the associated high sediment loads, all incoming stormwater is pre-treated via three mechanisms—a Stormceptor™ STC-14000 hydrodynamic separator (OGS), a 150m² plunge pool, and a 3.0m-wide grass filter strip—prior to entering the bioretention facility.

The functional pathway or conceptual flow path of the incoming stormwater can be characterized by the nature of the rainfall event. Smaller, frequent, low-intensity and long-duration events represent the majority of the annual rainfall. These smaller events enter the bioretention facility after pre-treatment and are filtered, infiltrated, and released either as shallow baseflow or via the designed underdrain system. Larger, infrequent, high-intensity and short-duration events enter the bioretention facility like the smaller events until such time as facility capacity is surpassed, at which time the water levels allow the stormwater to bypass the facility via the overflow channel. The bioretention design ensures that during all rainfall events the 'first-flush' is accepted and treated.

FIGURE 5. Bioretention design elements.



Performance

The monitoring program began pre-construction with the evaluation of soil media as compared to specifications and the effect on in-situ infiltration rates, with the comprehensive monitoring program initiated in 2012. The program includes

- Continuous flow monitoring at three locations;
- Four season water quality sampling of both influent and effluent (from the system underdrain) and groundwater for general chemistry, including oil and grease, heavy metals, total suspended solids (TSS), dissolved oxygen, pH, conductivity and nutrients;
- Continuous groundwater level monitoring (upstream, downstream, and within the bioretention facility);
- In-situ infiltration testing using the Guelph Permeameter equipment and methodology; and
- Soil chemistry of bioretention media grain size, organics, cation exchange capacity (CEC), pH, phosphorous content, and organics.

The results are intended to show the effectiveness of the facility given the high impervious to pervious (I/P) ratio. Specifically, the effectiveness is manifested in the use of a treatment train approach to better protect surface and groundwater quality (Figure 6), reduce storm-water volumes, preserve baseflow (groundwater mounding and transmission), reduce thermal impacts, and reduce chloride concentration peaks to the receiving streams.

The monitoring program includes intensive monitoring in years 1 and 2, reduced monitoring in years 3 and 4, and reassessment through intensive monitoring in year 5 to confirm the continued function as seen in years 1 and 2.

Preliminary results from the first year of monitoring revealed that:

- peak storm sewer inflow and peak bioretention outflow were recorded as 122 L/s and 20 L/s respectively, representing a peak flow reduction of more than 80%
- the bioretention system response for a 24 hour, 36mm event which produced a peak storm sewer inflow and a peak bioretention outflow of 112L/s versus 2.73 L/s respectively, and a bioretention peak flow lag time (vs. the storm sewer peak) of 17hrs
- the bioretention system demonstrated seasonal variation in removal capabilities, but in general exhibited high pollutant removal capabilities for many parameters. In many cases removals exceeded 90%.

Turbidity – 1 hour after event



FIGURE 6. Post rainfall, bioretention effluent (underdrain) exhibits significantly lower turbidity than the receiving watercourse.

- All outflow temperatures from September to January 2013 were below 24°C and generally below 18°C
- Infiltration testing demonstrated that the saturated hydraulic conductivity of the bioretention media has marginally increased over time and is supported by previous findings from Pitt et al. (2004), Hsieh & Davis (2005a), Brady & Weil (2002), Hillel (1998), and Denich et. al. (2014).

CASE STUDY 2—LAKEVIEW

Project Context

This pilot project in the Lakeview Community of Mississauga, Ontario was initiated by the City, Aquafor Beech Ltd., and Schollen & Company, with support from Credit Valley Conservation. Two streets, First St. and Third St., were selected for retrofit in 2012 (Figure 7). Both streets are characteristic of the Lakeview neighborhood, an older area of the city bordering Lake Ontario, established originally as cottages in the 1930s. The neighborhood was built before current provincial SWM standards were developed and is primarily serviced by ditched drainage systems, has standing water issues, flooding, poor water quality, and a road surface scheduled for repair (Figure 8).

FIGURE 7. Completed bioswales on Third Street. Photo courtesy of Credit Valley Conservation.

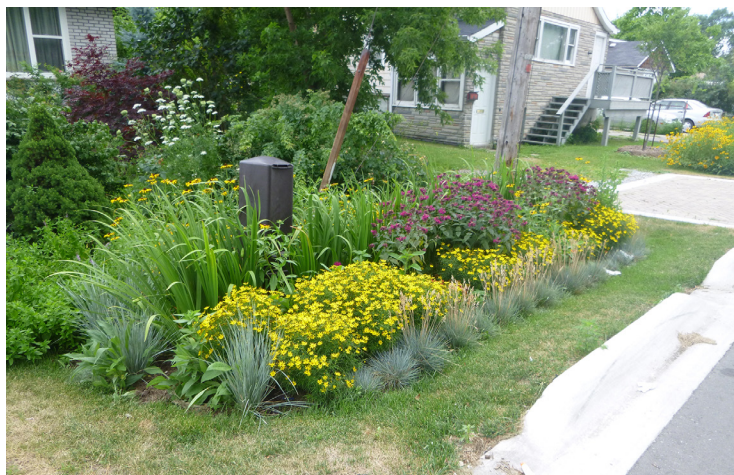


FIGURE 8. Lakeview is an older established neighbourhood of Mississauga, ON. Source: Google Earth.



FIGURE 9. Third Street, Mississauga, ON. Before (L): ditched system had poor conveyance, failing headwalls, standing water, and poor aesthetics. After (R): bioswales and permeable pavement driveways provide improved water quality and aesthetics.



Using a “green street” concept as part of scheduled road reconstruction activities, the project represented a first attempt to address stormwater quality and quantity flowing into Lake Ontario using bioswales with perforated pipe systems and permeable pavement driveways in the city of Mississauga. This project is a template for the retrofit of more than 200 streets within the city’s urban core which retain a rural cross-section (i.e., are ditched).

The Lakeview “green street” retrofit project was an opportunity to work with the community to develop exciting new approaches to treating stormwater. By introducing boulevard infiltration systems, rainwater is directed primarily to the soil along the roadway, allowing beautifully landscaped street edges (Figure 9), while simultaneously addressing water quality in Lake Ontario.

Problems/Challenges

This project is in essence a study on the dual objectives, perspectives, and expectations of both the municipality and the local residents.

From the Municipalities Perspective—The objective of the Lakeview “green street” retrofit project was to implement environmentally-responsible LID practices on both First and Third Streets to:

- Improve conveyance and eliminate standing water;
- Improve the overall streetscape aesthetic;
- Minimize the ditch profile for improved maintenance;
- Ensure emergency vehicle and snowplough access;
- To pilot new LID concepts as part of road reconstruction projects;
- To reduce road reconstruction costs; and
- Improve water quality being discharged to Lake Ontario.

From the Residents Perspective—A series of engagement initiatives were utilized including a series of three Public Information Centers (PIC) and websites, each with follow-up questionnaires. The objectives of the Lakeview ‘green street’ retrofit project, were to:

- Address on-street parking issues;

- Improve water quality;
- Create overall environmental benefits;
- Prevent flooding;
- Integrate any design elements into the existing neighborhood aesthetic and character;
- Improve conveyance and eliminate standing water; and
- Improve the overall streetscape aesthetic.

Other objectives identified by the residents included: no new sidewalks as part of the reconstruction; project cost was not a factor in their evaluation or mindset; the desire to maintain their existing driveway width; more than 50% of the respondents wanted perennial plantings; and that residents were willing to undertake maintenance of the plantings once completed.

Site Investigations

Site investigations included:

- General site reconnaissance;
- Vegetation and tree survey;
- Geotechnical investigation; and
- In-situ infiltration testing of the native soils.

The site reconnaissance identified numerous encroachment issues (parking, old infrastructure, fences, and driveways), existing surface and sub-surface utilities, existing traffic safety issues, and failing municipal infrastructure (Figure 10). The following tree survey identified only a small number of mature trees which had the possibility of being impacted as part of the retrofit.

The geotechnical investigation included eight borehole investigations of the sub-surface soil conditions and stratigraphy, and the analysis of selected representative soil samples in conformance with Ministry of the Environment (MOE) “Soil, Ground Water and Sediment Standards for Use” under Part XV.1 of the Environmental Protection Act (March 9, 2004). In-situ infiltration testing of the native soils was completed using the Guelph Permeameter Apparatus and Testing Methods in conformance with the Low Impact Planning and Design Guide (TRCA/CVC, 2010 v.1). Results are summarized in Table 3.

FIGURE 10. Failed culvert and unapproved parking encroaches on the municipal ROW and blocks drainage.



TABLE 3. Summary of site sub-soil conditions.

Soil Stratigraphy	<ul style="list-style-type: none"> • 5–30cm of topsoil • 0.2–1.5m of Clayey Silty Fill with some sand & gravel • Clayey Silt Till deposits at depth
Hydraulic Conductivity	<ul style="list-style-type: none"> • At 1.0–1.2m depth below surface, design infiltration rate was determined to be 5mm/hr (when applying a 2.5 Safety Factor)
Groundwater Table Elevation	<ul style="list-style-type: none"> • Groundwater observed in boreholes ranged from dry to at ground surface. (GW observed at surface in some locations—attributed to water perched in the ditches and fill stratum)
Groundwater Table Fluctuation	<ul style="list-style-type: none"> • Seasonal fluctuation in groundwater were anticipated

Design Objectives and Criteria

The design objectives and criteria included:

- Provide minor system conveyance for all flow up to the 10-year event per city standards;
- Water quality control for a 17mm rainfall event to ensure 80% long-term total suspended solids (TSS) removal;
- Reductions in stormwater volume and peak flows through detention, retention, and infiltration;
- Groundwater recharge;
- Improved streetscape aesthetics; and
- Minimal long-term operation and maintenance.

Applied Technologies and Functional Pathway

The Lakeview “green street” retrofit project included the use of bioswales with subsurface perforated pipe systems and permeable pavement driveways within the municipal ROW (Figure 11). The bioswales and permeable pavement structures are underlain by perforated HDPE pipe, sized to municipal standards, and connected to existing ditch-inlet catch basins (DICB). Two curb-cuts within the “roll-curb” of each bioswale unit allow runoff to enter and exit should the capacity be surpassed. Overflow structures are included within each bioswale and are connected to the subsurface perforated pipe system. Flat curb banding is used to restrain the permeable paver driveways. Bioswales are planted with either a mix of perennial grasses, flowering plants, or turf. Through the public involvement process, plant material within each bioswale unit was selected by the individual homeowners.

Construction

Construction of both First and Third Street commenced in April 2012 and was completed in September 2012. Figure 12 illustrates the installation of the perforated pipe system (geotextile, open-graded granular, and the HDPE pipe) and the finished permeable pavement driveways and bioswale overflows awaiting the installation of the bioretention media—shredded hardwood mulch and plantings.

During the construction of LID infiltration practices, the adherence to the specified erosion and sediment control plan is of utmost importance. With many phases of construction, multiple contractors, and activities taking place within a confined roadway that must remain

FIGURE 11. Schematic of the bioswale with the perforated pipe system and the permeable paver driveways at the Lakeview “green street” retrofit project.

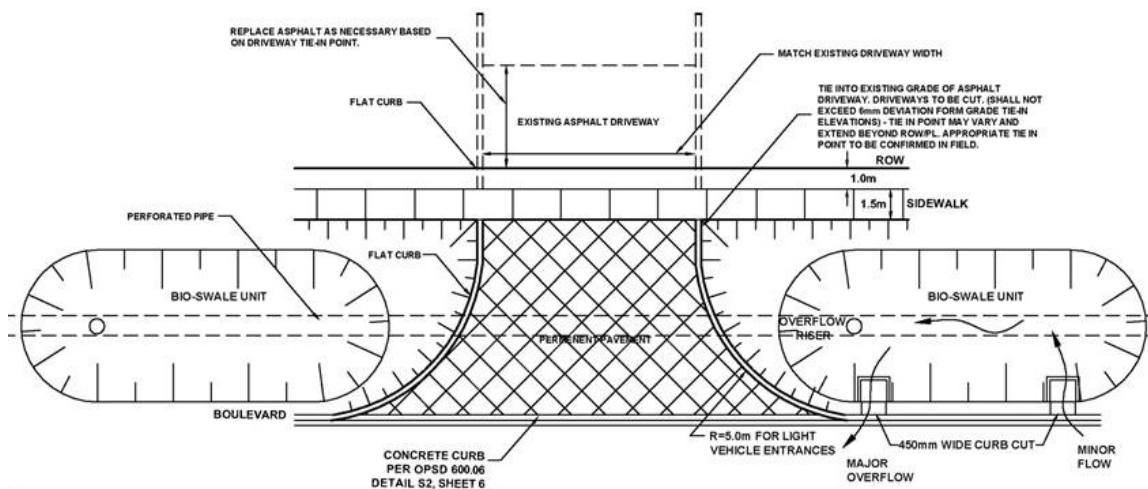


FIGURE 12. Schematic of the bioswale with the perforated pipe system and the permeable paver driveways at the Lakeview “green street” retrofit project.



open at all times during construction, erosion and sediment control is often neglected. The construction staging plan for the Lakeview “green street” retrofit project minimized the areas of exposed soil, ensured construction materials were stored downstream of infiltration practices, performed pre-installation material testing and verification, and utilized sacrificial geotextiles to protect infiltration practices from construction sediments and unwanted damage (Figure 13).

Performance

Performance is being monitored as part of the Lakeview Infrastructure Performance and Risk Assessment Program (IPRA) by the Credit Valley Conservation (CVC) as part of the Ministry of the Environment (MOE) Showcasing Water Innovation (SWI) program. The monitoring will directly address several knowledge gaps to elevate confidence in LID technologies within

FIGURE 13. Inlet sediment barrier protects from sediment contamination prior to media placement (R) and sacrificial geotextiles area used to protect the granular material from slumping and atmospheric deposition of construction sediment.



Ontario and provide as-built performance data including flow, water quality, operations and maintenance, infiltration rate, and sediment and soil sampling.

CASE STUDY 3—GREEN GLADES PUBLIC SCHOOL

Project Context

The Green Glades School is located immediately adjacent to the Rattray Marsh—one of the last remaining baymouth bar coastal wetlands in the GTA. Much of the upstream drainage area is highly urbanized and built prior to SWM management.

Initiated by the Credit Valley Conservation Authority (CVC), in cooperation with Aquafor Beech Ltd. and Fernridge Landscaping and Eco-Consulting, this project has endeavored to improve the water quality of the contributing area through this rain garden (bioretention) retrofit. Identified as a “watershed opportunity site”; the project’s vision became a public space where educators, students, and the community could learn about LID, their link to watershed management, and its connection to the protection of Rattray Marsh.

Problems/Challenges

Watershed Challenges

Rattray Marsh is a sensitive environmental feature which is experiencing the effects of the lack of stormwater management within the established contributing urban area. Rattray Marsh Conservation Area is a unique and environmentally sensitive area. It is one of the last remaining baymouth bar coastal wetlands in the GTA/Golden Horseshoe Areas (from Burlington to Toronto). Opened as a public park in 1975, Rattray Marsh as a whole is designated as a Provincially Significant Wetland and an Area of National and Scientific Interest (ANSI). Rattray provides various microclimates and a wide range of diverse habitat features. Rattray Marsh habitats include beach, marsh, swamp, meadow, and upland forest. These habitats support rare plant species and provide refuge for various wildlife including more than 200 hundred bird species.

FIGURE 14. Completed rain garden at the Green Glades Public School, Mississauga, ON.



Much of the upstream drainage areas, including the Green Glades Public School, were largely built prior to current SWM management requirements; as such, the area can be characterized as an uncontrolled urban pollution source for Rattray Marsh, delivering high levels of nutrients and sediments. These urban pollutants, coupled with a channel morphology that is largely straightened and channelized along its length, and a flow regime characterized as “flashy”, have all contributed to the ongoing ecological degradation of Rattray Marsh.

Site Challenges

Site drainage from a small flat roof above the building’s front entrance, as well as a portion of the parking lot area directly in front of the main entrance, was creating nuisance flooding and standing water in student pedestrian areas, including the local cross-walk areas (Figure 15), sidewalk, and front entrance. During the winter season, the nuisance ponded water created substantial ice formation and unsafe conditions for students which necessitated the application of excessive deicing salts.

FIGURE 15. Nuisance flooding creates unsafe conditions for students in winter months. Source: CVC.





FIGURE 16. Student art integrated into the rain garden design.



Design Objectives and Criteria

Constructed in 2011, the 11m² rain garden (bioretention) facility objectives and criteria included:

- Acceptance of both roof and parking lot drainage to alleviate ponded water and unsafe ice conditions;
- Improved school aesthetics;
- Creation of an educational opportunity for students (outdoor classroom) and the community to create awareness for watershed management, stormwater management, and protection of Rattray Marsh (Figure 16);
- Improved water quality control for stormwater discharging to Rattray Marsh. (water quality control criteria—25mm rainfall event to ensure 80% long-term total suspended solids (TSS) removal);
- Thermal impact mitigation through the infiltration of runoff;
- Reductions in stormwater volume and peak flows through detention, retention, and infiltration;
- Groundwater recharge.

Site investigations

Site investigations at Green Glades Public School included:

- General site reconnaissance;
- Sub-surface soils investigation (hand auger); and
- In-situ infiltration testing of the native soils.

In-situ infiltration testing of the native soils was completed using the Guelph Permeameter Apparatus and Testing Methods (Figure 17) in conformance with the Low

FIGURE 17. In-situ infiltration testing using the Guelph Permeameter Apparatus and Testing Methods.



TABLE 4. Summary of Site Sub-soil Conditions.

Soil Stratigraphy	<ul style="list-style-type: none"> • 10–15cm of topsoil • 0.8–1.0m of silty, fine sand (approx 10% silt) • >2m of fine sand
Hydraulic Conductivity	At 1.5m depth below surface—hydraulic conductivity of native soils = 2.03×10^{-3} cm/s, or 73mm/hr
Groundwater Table Elevation	No water table encountered at depths greater than 2.5m throughout testing (June–August)
Groundwater Table Fluctuation	n/a

Impact Planning and Design Guide (TRCA/CVC, 2010 v.1). Results are summarized in Table 4.

Functional pathways

Rainwater from the roof area is directed to the rain garden via a rock channel lined with an impermeable barrier. Parking lot runoff is conveyed through the existing sidewalk via a grate inlet. A second grate retrofitted into the existing sidewalk outlets stormwater to an existing storm sewer catchbasin when the facility has reached the maximum ponded water level and design capacity (Figure 18). This facility was designed as a full infiltration system (i.e., without an underdrain system) due to the high infiltration rate of the native sandy soil.

CONCLUSIONS

LID and GI measures are innovative solutions for stormwater management within new development and redevelopment areas. Three real-world case studies of the design and implementation of these measures, their implementation challenges, functional pathways, and performance were presented. Moreover, environmental goals and objectives achieved from the implementation of these measures were discussed. The discussed case studies would provide practical and process-based guidance to municipal engineers and watershed restoration practitioners in their quest to provide sustainable and healthy urban ecosystems.

FIGURE 18. Rock channel lined with an impermeable liner (L), grate inlet retrofitted into the existing sidewalk (center), and overflow/outlet grate (R).



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