Low Impact Development within Integrated Water Management Systems: Barriers, Opportunities, and Risks

A white paper prepared for the Canadian Water Network research project:
"An Integrated Risk Management Framework for Municipal Water Systems"

The Centre for Water Resource Studies
Dalhousie University
Nova Scotia, Canada
2015

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overview

Municipalities face many challenges in the management of drinking water, wastewater, and stormwater systems. Within these challenges, the aging of our water related infrastructure and the effects of continuing urbanization on these systems have been identified as key risk drivers across all municipal water systems. Going forward, the integration of municipal water systems represents an option to promote holistic, cost effective management of these systems. Within integrated water systems, stormwater has significant linkages to both drinking and wastewater systems. Adopting technologies and approaches that promote the preservation of pre-development hydrologic conditions, such as Low Impact Development (LID) features, can reduce risks within both stormwater and integrated water management systems. Through implementation of LID features and approaches, risks to drinking water and wastewater systems can be reduced through (i) improvements to groundwater recharge and availability, (ii) improved surface water quality and watercourse assimilative capacities, and (iii) reduction of flows to be managed in combined sewer networks, among others.

Where conventional stormwater management approaches are primarily focused on the management of low frequency, extreme storm events, considerations for impacts related to frequent events have typically not been addressed. In addition, concerns related to the performance, maintenance, and overall effectiveness of typical conventional end-of-pipe stormwater management features (e.g., dry and wet ponds) have been raised in literature. Stormwater management solutions incorporating LID features and approaches, which include infiltration-promoting structures and development methodologies that work to mimic pre-development hydrologic conditions, can provide effective management of these events while providing benefits to both existing infrastructure and downstream environments.

Several barriers exist to increasing adoption of LID features and approaches, including ineffective and outdated regulatory support, lack of synergy between involved departments, lack of guideline documents and design support, design and construction inexperience, concerns regarding maintenance and performance variability, and economics, among others. With a significant quantity of stakeholders involved in LID implementation, establishment of new policies is challenging and slow-moving.

Stormwater regulations and guidelines in Canada have been trending towards increased promotion of LID approaches and features, including considerations for water quality, runoff volume, and water balance criteria and analysis, but the implementation of these guidelines varies countrywide. A more consistent message for municipalities related to LID's importance within stormwater management is required to ensure effective promotion and implementation. Designing effective LID features is dependent on several project specific variables (e.g. site conditions, local design criteria, local approval requirements, costs and availability of materials, etc.), and the level of design and construction experience is not as comprehensive or extensive as with conventional stormwater systems. Many support documents have been recently produced to aid in the proper design and construction of LID features. Long-term maintenance and performance of these systems still have a level of uncertainty, although research has shown continued effectiveness in cases where monitoring data is available. The perception that LID features are more expensive to implement represents another barrier to their adoption, although there are many studies that highlight its affordability when compared against conventional systems.

Three case studies with focuses on LID integration within drinking water and wastewater systems are presented to illustrate how a holistic approach to water management, with a specific focus on implementation of LID features and approaches, can reduce risks within integrated municipal water management systems. In all of these cases, the implementation of LID features and approaches provided significant benefits to the communities while reducing risks within several municipal systems. Additional research was completed into smaller case studies of LID feature implementation within different climatic regions in North America to highlight successful approaches across a wide range of environmental conditions, with links to additional resources provided. A general summary of how these case studies affect risk is presented to illustrate how smaller-scale LID implementation can lower risk to drinking and wastewater systems. A large quantity of case studies illustrating effective implementation of LID features and approaches are available and illustrate that these such technologies can be successful in a variety of different design scenarios.

As steps toward integration of municipal water systems are made, increased LID implementation can function to reduce risk across all municipal water systems. In order to ensure the continued and increased adoption of LID features and approaches throughout Canada, a more consistent cross-Canada approach to promoting alternative stormwater management approaches would allow for more effective discussion, collaboration, and implementation of LID technologies. Additional demonstration projects focused on mitigating concerns related to long-term maintenance, the effects of road salt and de-icing chemicals on features, and effects of LID on infiltration and inflows to sanitary systems will help in mitigating uncertainties in their application. As these and other lessons are learned, the continued development of design support information is recommended, with efforts to promote these features within the previously existing municipal stormwater guidelines.

In order to further push LID adoption, there are several examples of successfully incentivizing lot-level scale LID implementation in order to promote applications in previously existing developments. Through the separation of stormwater into a distinct rate within municipal water utility billing, opportunities exist to both educate the public about the overall importance of stormwater and provide rate incentives for homeowners that install LID features. Although questions regarding maintenance are ongoing, this represents a method to both promote adoption and reduce risks in existing developments.

As the effective implementation of LID features and approaches crosses many departments within municipalities and governments, increased education on their function, importance, and applications throughout the various connected departments is recommended. By incorporating LID requirements into typical maintenance and retrofits within other municipal departments, these projects can provide multiple benefits to municipalities. Through earlier integration of LID considerations into project planning, the effectiveness of these approaches can be maximized – among other options, this can be accomplished through earlier inclusion of stormwater designers into municipal planning and development processes.

A more simplified, unified website that collects information related to LID features, approaches, case studies, and support documentation would allow for more effective dissemination of LID knowledge collected to date. This would allow for increased collaboration and removal of barriers related to inexperience and uncertainties. In order to ensure the ongoing development of LID within Canada, additional government support related to LID initiatives, demonstration projects, support for municipalities, and updates to policy and guidance documentation are recommended.

pt 1. introduction

There are many risks municipalities and provincial authorities face relating to the management of stormwater in Canada. As the infrastructure in our towns and cities ages, climate change influences the frequency and magnitude of high intensity rain events, and the development of Canada continues through growth in urbanized centres and suburban areas surrounding major city centers, the risks to these systems will only continue to increase. Integration of the management of municipal water systems (i.e., drinking water, wastewater, and stormwater) represents an option that can encourage a holistic, cost-effective approach to managing these systems and their related risks. Stormwater, whose importance is often placed behind wastewater and drinking water systems, represents a key component within integrated water management, with important linkages to risks in each of the other water systems.

1.1 KEY DRIVERS IMPACTING WATER SYSTEMS

In order to understand the critical drivers that impact municipal stormwater systems, various stakeholders and stormwater experts were engaged through surveys at the following locations: 1) Canadian Water Resources Association Conference (July 2014); 2) Federation of Canadian Municipalities Conference (June 2014); and 3) Online. Members of the academic, consulting, and governmental sectors completed these surveys, which asked responders to identify critical drivers in each municipal water system. Through analysis of the results, the three most critical drivers impacting municipal stormwater systems were identified as (in no particular order):

- Aging Infrastructure;
- Climate Change and Increased Extreme Weather; and
- Increased Urbanization.

These results were compared against the survey responses for both drinking water and wastewater systems, with aging infrastructure and increased urbanization consistently representing two of the top three critical drivers identified. As a result, addressing these two drivers of risk is the focus of this study. The effects of climate change on stormwater systems, including the updating of stormwater design criteria (e.g., Intensity-Duration-Frequency curves), is the subject of significant research both available and ongoing from a myriad of sources (Peck et al., 2012; Solaiman et al. 2011), and thus is not explicitly addressed in this document. Aging infrastructure and increased urbanization are elaborated in further detail below.

1.1.1 AGING INFRASTRUCTURE

Aging water management infrastructure in Canada presents many challenges to municipalities. These challenges are expected to increase as additional strain is placed on these systems. As outlined in the Canadian Infrastructure Report Card, which assesses the four main categories of municipal infrastructure (i.e., roads, wastewater, drinking water, and stormwater infrastructure), approximately 30% of municipal infrastructure has been ranked as being in 'fair' condition or worse, with 'fair' being defined as '...requires attention, with some elements exhibiting significant deficiencies'. The estimated cost required to update the infrastructure in these categories is in the range of $171.8 billion dollars (CA, 2012).

Stormwater considerations related to aging infrastructure include not only the maintenance required to effectively manage the collection and conveyance of stormwater runoff through existing infrastructure, but also the capacity of these systems in light of both changing design criteria and site conditions. It is important to note that while the Canadian Infrastructure Report Card gives stormwater features an overall rating of 'very good: fit for the future', only 14.5% of responders were reported to base their assessment off of complete and reliable assessment data. With stormwater management design being primarily based on management of low-frequency rainfall events, a system reported as 'very good' could be one significant rainfall event away from a 'very poor' rating. As design guidelines continue to evolve beyond just conventional peak flow management and towards incorporating water quality and water balance considerations (Section 2.2), existing infrastructure may become increasingly inadequate.

Where combined sewer systems are in place, combined sewer overflows (CSOs) are a large issue related to aging and undersized infrastructure. In the United States, between 23,000 and 75,000 CSOs are estimated to occur annually, discharging approximately 3 to 10 billion gallons (approximately 10 – 40 billion litres) of untreated wastewater into rivers, lakes, and oceans. The consequence of these CSOs is extensive in both taxation on existing infrastructure, and in impacts to public health and receiving water environments (Montalto et al., 2007; US EPA, 2004). In addition to environmental concerns related to CSOs, stormwater inflows into combined sewer systems also represent additional treatment volumes to be managed by the wastewater treatment system (City of Seattle, 2010).

The total estimated cost of replacing only the water-related municipal infrastructure in Canada is reported to be approximately $80.7 billion, or $6,508 per household (CA, 2012). As mentioned above, these issues are not isolated to Canadian infrastructure – the United States have ranked the state of existing water and sewer infrastructure as the number one issue in the water industry in 2014 (AWWA, 2014). The AWWA estimation of the cost required to address these deficiencies exceeds $2 trillion.

1.1.2 INCREASED URBANIZATION/DEVELOPMENT

The 2006 census reported that 'Almost 90% of the total population growth in Canada since 2001 has occurred in the country's 33 census metropolitan areas' (StatCan, 2008), confirming the general trend in Canadian migration from rural areas to urban centres. As urban populations grow, so does the need for new developments and infrastructure, which typically increases impervious surfaces and decreases green space. Balancing the need for new developments to allow for population and economic growth with the environmental effects due to this urbanization is an issue faced by many Canadian municipalities.

Through the construction of housing developments using conventional stormwater approaches, pre-development hydrological regimes are disrupted by the conversion of vegetated, porous soil surfaces to impervious surfaces (e.g., roads, driveways, and parking lots). In doing so, the previously existing infiltrative properties of an area are reduced or eliminated, leading to the generation of more stormwater runoff following rainfall events. In engineering, stormwater runoff has traditionally been considered and managed as a risk to persons and property, with primary considerations on the management of extreme predicted rainfall events. In conventional stormwater systems, stormwater management features have been designed to convey stormwater runoff away from buildings and into roads and subsurface stormwater piping infrastructure, where flows are typically conveyed to the receiving water environments as quickly as possible. Traditionally, no considerations were made in maintaining the previously existing hydrological water balance regime. Environmental effects resulting from this design approach include: decreased lake levels and stream base-flows, reduced wetland sizes due to reduced groundwater recharge, as well as increased erosion and pollutant loadings in receiving water systems due to increased velocities and reduced natural filtration (American Rivers et al., 2012; Dietz, 2007; IFC Marbek, 2012; Stephens et al., 2012). These effects carry both environmental and human consequences, from loss of fisheries habitat to reduced and impacted drinking water reserves (Akan & Houghtalen, 2003).

According to the US EPA, 44% of total river miles and 64% of lakes in the United States that were assessed were rated as 'impaired', or 'not clean enough to support their designated uses' (US EPA, 2009). Habitat alterations, organic enrichment, and nutrients were identified as several of the leading causes of this impairment, with urban stormwater accounting for between 5 – 10% of these effects. The effects of urbanization on stormwater discharges could also be linked to several other identified sources of this impairment in the report (e.g., unspecified non-point source, hydromodification, habitat alteration, etc.; US EPA, 2009). Lastly, stormwater runoff was identified as the #2 source of pollution resulting in public beach advisories and closings (US EPA, 2003).

1.1.3 STORMWATER CONSIDERATIONS WITHIN INTEGRATED MUNICIPAL WATER SYSTEMS

As previously mentioned, the management of stormwater has several linkages to risks in both drinking and wastewater management systems, in addition to risks related to overall ecosystem health.

By changing pre-development soil conditions to predominantly impermeable surfaces through development and urbanization, the area available for stormwater runoff to infiltrate is significantly reduced. The effects of these reductions can be wide ranging from both drinking and wastewater management perspectives, and can include (Konrad & Booth, 2005):

- Reductions in the available community surface drinking water supply systems (e.g. reservoirs, lakes);
- Reductions in groundwater availability within drinking water wells;
- Reductions in receiving water wastewater assimilative capacities due to streamflow reductions; and
- Loss of aquatic habitat due to streamflow reductions resulting in damages to overall ecosystem health.

In addition to groundwater related considerations, the transport of pollutants in urbanized catchments represents a concern to downstream environments, as well as drinking and wastewater systems. Common stormwater contaminants found in developed and developing watersheds include (Klein, 1979; Hamel et al., 2013; Wenger et al., 2009; WSA, 2014):

- Total Suspended Solids (TSS);
- Nutrients (i.e. nitrogen, phosphorus);
- Organic pollutants (e.g., pesticides, hydrocarbons);
- Rubber and automotive fluids;
- Particulate matter;
- Trace metals (e.g., zinc, copper, lead); and
- Increased temperatures.

The transport of stormwater-related pollutants to receiving waters is a great risk in stormwater management, and can cause significant damage to downstream environments. Ultimately, the transport of these and other pollutants can result in eutrophication, fish kills, pollutant bioaccumulation in the food chain, and pathogen contamination leading to loss of recreational areas (US EPA, 2003). These receiving water impacts also have the potential to affect risk and management of drinking and wastewater systems, including:

- Additional treatment requirements within drinking water systems as a result of reduced surface water quality; and
- Reduced assimilative capacity of receiving waterbodies, resulting in greater wastewater treatment requirements prior to discharge.

Conventional stormwater management approaches can also lead to additional receiving water concerns. Studies suggest that even minimal additions of impervious surfaces within a watershed have consequences to stream health (Klein, 1979; Tillinghast, 2012). Urbanized streams have been reported to have several differing characteristics when compared against non-developed watercourses, including 'flashier' responses to rainfall events, increased variability in flow rates, reduced base-flows, and increased frequency of higher discharge events (Klein, 1979; Konrad & Booth, 2005). These differences lead to several consequences: high discharge velocities within receiving water environments causing significant downstream erosion and scour and mobilization of additional sediment, destruction of downstream fisheries habitats and ecosystems, and others.

Lastly, the increases in runoff flows and volumes due to urbanization of catchments and the use of conventional stormwater management techniques lead to additional inflows to combined sewer systems. These additional inflows have impacts on both receiving water environments and wastewater management systems, including:

- Additional treatment volumes to be managed by wastewater treatment plants;
- Additional taxation on existing conveyance infrastructure; and
- Significant downstream ecosystem effects due to additional discharges to watercourses from CSOs.

1.2 PROJECT SCOPE

The implementation of Low Impact Development (LID) designs within stormwater management has been identified as an approach with the potential to mitigate some of the risks associated with the critical drivers identified as affecting not only conventional stormwater systems, but also integrated municipal water systems.

The scope of this document is to summarize the role LID can have in mitigating the risks associated with the critical drivers identified across municipal water systems in Canada. The benefits of LID implementation have been widely reported, but adoption of LID in Canada remains a work in progress. The barriers, challenges, and risks in implementing LID features and approaches are summarized, and success stories and case studies outlined to provide municipalities and other interested parties with additional background into the LID techniques have been successful. Lastly, recommendations to improve adoption of these features are outlined.

pt 2. stormwater management approaches and risks

Management of stormwater within both rural and urban developments has been a key responsibility of municipalities in Canada for over 100 years. As time has progressed, combined sewer systems, although still in operation in several municipalities across Canada, have been supplanted by dedicated stormwater management infrastructure. To systems both new and old, risk, as defined by the design considerations related to both probability of input phenomena and consequences to these inputs, is of main concern in the design and implementation of any engineered stormwater management system. The approaches of both conventional and LID stormwater management approaches are outlined below.

2.1 CONVENTIONAL STORMWATER MANAGEMENT

The traditional approach for mitigating stormwater management related risks has been to minimize consequences to persons and property driven by significant, low probability design storm rainfall events. By taking this approach, consequences related to the rainfall events with the highest levels of catastrophic risks to people and property can be addressed. However, the design of these systems have little consideration for the risks associated with frequent storm events that have to be handled throughout the year, which can create other issues if not managed effectively.

Updated stormwater management and design guidelines prepared by some municipalities within Canada have shifted to address both quantity and quality concerns within stormwater management. With this being said, the typical focus of these documents rely on design criteria related to management of extreme precipitation events using a dual drainage stormwater management approach consisting of piped infrastructure in conjunction with overland flow management. In typical dual drainage systems, piped infrastructure is designed for design storm events of moderately high occurrence (e.g., 5 – 10 year return period), with runoff from larger storms (e.g., 100 year return period) managed by a combination of both piped and overland flow management features. These systems typically convey stormwater flows to various end-of-pipe management features, such as wet and dry stormwater ponds, with the end goal of discharging at a predefined rate. These permitted discharge rates are typically based on values developed from pre-development conditions, or to rates defined by watershed/regional analysis, among other similar approaches.

Where water quality concerns have been incorporated into stormwater management guidelines, wet and dry ponds have been adopted as an end-of-pipe solution (Drake & Guo, 2008; WSA, 2014). These ponds are typically designed to both achieve pre-determined discharge limits, while wet ponds are also designed to meet pre-determined water quality discharge criteria. Dry ponds have been reported to fail in mitigating changes to pre-development hydrology (Konrad & Booth, 2005), while wet ponds are typically specified to be constructed with compacted clay liners, which limits any potential infiltration from these ponds. In addition, several other concerns related to wet ponds have been identified (Drake & Guo, 2008; IFC Marbek, 2012; LSRCA, 2011):

- Wet ponds require periodic intensive maintenance to function as designed (e.g., dredging of accumulated sediment), a task that has been difficult and costly to execute;
- Loss of storage capacity due to sediment build-up;
- Reduction in treatment performance;
- Eutrophication from nutrient inputs; and
- Increased discharge temperatures, representing a risk to sensitive downstream environments.

Guidelines across Canada appear to be slowly incorporating additional considerations and criteria related to stormwater quality. For example, the City of Calgary has adopted criteria relating to TSS reductions, with additional criteria potentially upcoming (City of Calgary, 2011). With this being said, the majority of stormwater systems in service within Canada are based on conventional stormwater approaches, which are focused on mitigating a single aspect of the overall stormwater related risk – peak flow management. As outlined in Section 1.1.3, this approach carries risk not only to stormwater systems, but drinking and wastewater systems as well.

By further incorporating water quality considerations into stormwater management requirements, updated stormwater guidance documents provide considerations towards minimizing environmental impacts associated with the addition of impervious surfaces and pollutant sources related to site development. However, considerations related to the additional volume of runoff generated through site development are less widely considered and applied – the preference of conventional stormwater approaches is to collect and convey, not to store and infiltrate. As a result, pre-development hydrologic regimes typically are significantly altered post-development through reducing the quantity of runoff able to infiltrate throughout the area.

2.1.1 BENEFITS

The benefits of conventional stormwater systems relate to the level of collective experience that both stormwater professionals and contractors have in the design, implementation, and construction of these systems. Extensive design guidelines based on years of experience are available, and these systems have been in place and successful in reducing risks from extreme precipitation events for decades or longer. Contractors are comfortable with the construction requirements associated with these projects, and this knowledge from similar previous construction projects is applied for additional checks against designs during the construction phase (Olorunkiya et al., 2012).

2.2 LID APPROACHES AND DESIGNS

Low Impact Development (LID) refers to the design and implementation of stormwater management systems and features in developed areas that emphasize drainage and conveyance characteristics that mimic pre-development conditions. Though LID has been defined separately by several different levels of government, academia, developers, and others, the following key points are considered in this document:

- Identification of stormwater as a resource rather than nuisance;
- Maintaining natural hydrologic regimes;
- Implementing infiltration based stormwater management and source control features; and
- Minimizing site disturbances.

Strategies that utilize the same core concepts as LID or that fit within LID systems have been referred to by different names in other studies, such as Green Infrastructure (US EPA), Best Management Practices (BMPs), Source Control Practices (SCPs), Sustainable Urban Drainage systems (SEPA, 2014), and Environmentally Sensitive Design (US EPA, 2010). Many of these other definitions either overlap the key concepts of the definition of LID given above, or represent components of the LID approach. Several common LID features and designs for the management of stormwater runoff include:

- Reduction of impervious surfaces through reduction of lane widths, the use of alternative construction materials (e.g., permeable pavement), and greening of minor traffic areas (e.g., residential back lanes);
- Implementation of infiltration-promoting bioretention and biofiltration areas, such as rain gardens, vegetative swales, and street runoff collection features (e.g., curb cuts to depressed traffic medians);
- Lot-scale stormwater management features, such as infiltration galleries and rain barrels;
- Sub-dividing watersheds into smaller subcatchments with smaller stormwater management features; and
- Reducing disturbances in new developments, keeping existing forests and vegetation.

LID features can be both implemented on a large scale at a site development level with a more integrated approach, but also implemented as supplemental features to existing stormwater management systems. If more information about specific features within LID is desired, these features are outlined and described in great detail by several documents, such as 'Managing Stormwater Runoff to Prevent Contamination of Drinking Water' (US EPA, 2010), 'National Menu of Stormwater Best Management Practices' (US EPA, 2014), and 'Effectiveness of Low Impact Development Practices: Literature Review and Suggestions for Future Research' (Ahiablame et al., 2012).

2.2.1 BENEFITS

The benefits of LID are well described in several documents published by both governments as well as in academia, such as US EPA (2012), City of Edmonton (2011), and ICF Marbek (2012). In general, LID features have been shown to reduce overland flows and stormwater quantity, improve stormwater quality, as well as benefit the health of downstream receiving waterbodies. In this document, we will briefly outline the benefits of LID with a specific focus on those issues within integrated water systems (e.g., drinking and wastewater) previously covered in Section 1.1.3.

2.2.1.1 STORMWATER QUALITY AND QUANTITY

As an approach that includes features and planning with a focus on the promotion of infiltration, the reduction of stormwater runoff generated by frequent storm events is a significant benefit of LID implementation. By storing and infiltrating these frequent storm events, a large percentage of the overall annually generated stormwater can be managed without the need for conveyance, reducing the burden on aging infrastructure systems. Although LID features are not intended to replace engineered flood-control structures designed for extreme weather events (US EPA, 2007), these design features have been shown to help reduce the severity of less extreme flood events due to the distributed conveyance methods used in many integrated water management programs. Some additional benefits associated with increased infiltration of precipitation include maintenance of base flow levels in urbanizing streams, as well as a potential reduction in particulate loading associated with bed scour (Finkenbine et al, 2000).

In addition, one of the most significant improvements to stormwater quality as a result of implementation of LID practices relates to the corresponding reduction in stormwater quantities within this approach. Increased infiltration can be correlated to a decrease in the amount of overland flow, resulting in decreased opportunity for pollutants to be collected and transported to receiving waters (US EPA, 2007). Studies have also shown a reduction in common stormwater pollutant loadings (such as those outlined in Section 1.1.3.2) is observed in stormwater collected after exiting vegetative swales, permeable pavement areas, and other LID features (US EPA, 2007). These and other water quality benefits allow for a reduction in risk to downstream environments and potentially provides benefit in the protection of drinking water sources.

There are many other positive impacts to stormwater quality and quantity associated with LID, including increased groundwater recharge, pollution abatement, and greater availability of water to terrestrial flora and fauna within the watershed. However, risks regarding performance variability, site requirements, and others do exist, and are further detailed in Section 3.

2.2.1.2 ECOSYSTEM HEALTH

As a potential approach to be used in mitigating the risks to streams in urban environments outlined in Section 1.1.3.2, the implementation of LID practices has been shown to minimize negative impacts to stream health, and also to be potentially applicable in retrofits and redevelopments in heavily urbanized watersheds (Bernhardt and Palmer, 2007).

pt 3. risks and challenges in LID implementation

As previously mentioned, LID designs and concepts have been studied extensively for approximately 15 years. A significant amount of information and research relating to the benefits of proper implementation of LID features into stormwater management system designs has been produced and made available by conservation groups, academia, and other invested stakeholders, yet the widespread adoption of these approaches and technologies across Canada has been slow. A survey of literature indicates that the barriers to LID implementation are fairly wide ranging, with no one conclusive barrier restricting their adoption. Several potential barriers to the selection, design, and implementation of LID features have been identified in literature (CWAA, 2011; Olorunkiya et al 2012; Primeau et al, 2009; etc.), and generally include:

- Approvals and regulations not suited to implementing new technologies;
- Minimal incentives for developers, from both lack of information and awareness in general public and minimal government pressure;
- Uncertainty surrounding long-term maintenance requirements, including defining responsible parties;
- Lack of supporting information in design guidelines to aid designers and streamline approvals;
- Construction and design inexperience;
- Minimal municipal resources available for proper research/promotion of best LID features; and
- Lack of case studies to demonstrate successful tools that can be used.

In addition, several municipal stakeholders within Canada were given a survey in order to attempt to better understand the approach, state of LID implementation, and barriers facing LID implementation in Canada. Through an analysis of the survey results, the barriers identified were generally consistent with those stated above. The results of this municipal LID survey are referenced throughout the sections that follow.

3.1 APPROVALS AND REGULATIONS

As described in Section 2.1, stormwater approvals in Canada are trending towards incorporating recommendations and requirements for more alternative, LID style approaches in their stormwater design guidelines. Various governmental bodies have identified the need to adopt LID style stormwater features into policy making in order to mitigate the water-based challenges facing municipalities both today and in the future. It has been noted that due to the multi-disciplinary nature of stormwater management, obtaining a commitment from all invested parties to change the existing policies and management direction of stormwater resources has proven difficult. For example, In Ontario, five different ministries have been identified with stormwater responsibilities: The Ministries of Environment, Municipal Affairs and Housing, Natural Resources, Transportation, and Infrastructure (ECO, 2014). With additional stakeholders involved, such as watershed groups, conservation authorities, NGOs, and municipalities, establishing new policies is a complex and complicated procedure.

Stormwater plans have evolved to include collaboration and considerations from a variety of different levels of governments and organizations, from River Basin Councils through to Watershed Planning Groups, with varying levels of involvement of both municipal and provincial governments. There exist several watershed-level water management plans that have been prepared in regions within Canada (Alberta Watershed Partnerships, B.C. Integrated Stormwater Management Plans, Ontario Conservations Authorities, etc.), with the goal of improving water quality and ensuring the protection of the surface and groundwater systems within these watersheds. Examples of some of the stakeholders who are involved with stormwater approvals can include:

- Provincial;
- Conservation authorities;
- Regional river basin partnerships;
- Local river and watershed protection partnerships; and
- Several municipal departments (e.g., water resources, parks, public works, transportation)

With a variety of stakeholders involved, which is especially prevalent in urban settings, approvals for stormwater management require a great deal of planning and communication. When innovative technologies are proposed whose approvals are not clear, there is the potential for uncertainty, delays, and additional expenses. This uncertainty represents a significant barrier to the implementation of these innovative technologies. In contrast, conventional end-of-pipe solutions represent a more straightforward approvals process, with better defined design criteria (IFC Marbek, 2012). It has also been noted that due to the interdisciplinary nature of LID, previously existing specifications for municipal infrastructure that are not flexible to LID feature designs (e.g., road widths, green space drainage, etc.) may represent barriers to effective implementation of LID (US EPA, 2009b).

In this period of transition to more water quality and water balance based stormwater planning approaches, barriers exist in the form of the lag time for policies to adapt to new and innovative ideas. The reviewing and updating of existing stormwater approvals processes and documents has been identified as a requirement by those parties responsible in Ontario (MOE, 2010), but critics have pointed out that the resulting documents have instead represented 'supplementary and voluntary' LID design guides (ECO, 2014). As a result, there has been a call to update approvals and policy in a way that allows for municipalities to have the tools available to effectively promote and require LID implementation going forward (ECO, 2014).

Highlighted in the survey results was the difference in LID presence within regulations across municipalities in Canada, from areas where high-level LID approaches (e.g., water balance targets) are expected, to areas where LID implementation is still in its infancy. The trend observed in the majority of the responses received was that while LID was encouraged, it was not specifically required. Concerns were also raised as to when LID considerations were first mentioned in the planning process; this typically occurred too late in the planning stages to allow for effective considerations for wide scale implementation. If LID approaches were incorporated earlier in the planning stages of development, there would be more opportunity to ensure designs incorporate LID features effectively, instead of trying to fit them in at later stages when spaces within the development have already been allocated. Additional concerns were raised regarding municipal guidance on LID implementation – the need for a more comprehensive strategy, supported by policy, guidelines, and a framework for implementation were reported as barriers to LID implementation.

An additional barrier to the approval and regulation of LID features and technologies relates to the definition of the terms used. As previously discussed, LID designs and features can also be referred to by other names within approvals, guidelines, and regulations, leading to a level of uncertainty when such designs are proposed.

3.2 MAINTENANCE AND LIFESPAN

Appropriate maintenance of LID features is critical in order to ensure they continue to function as designed, and to limit potential risks. Each potential LID feature has different maintenance requirements, which are typically required on a more frequent basis than their conventional stormwater counterparts, but can also be less costly than repairs to conventional systems (IFC Marbek, 2012). With these additional maintenance requirements comes a level of risk, as some form of inspection and maintenance program would have to be implemented that could focus on the increased number of smaller facilities that encompass the LID approach (Montalto et al., 2007).

From survey results, recommendations for maintenance and inspection of LID features is observed to be in its infancy, with a noted absence of data to allow for general rules to be created. Maintenance and monitoring was identified as an area that required further thought and considerations, as well as additional resources going forward. At this time, the maintenance and inspections of LID features must be determined through engineering judgment and through research into similar LID features in order to have a feasible and effective maintenance and operation plan in place. There also exists an opportunity to design LID features that involve minimal maintenance requirements.

There are several reports providing guidance with respect to how to best approach the maintenance requirements of LID features (City of Seattle, 2010; CVC, 2010). When community involvement is required, the following recommendations have been proposed:

- Neighbourhood involvement starting at the earliest stages possible to foster homeowner buy-in;
- Development of aesthetically pleasing designs that promote a sense of homeowner pride;
- Clear definition of homeowner responsibilities before project execution; and
- Clear communication between all stakeholders (e.g., different municipal departments, homeowners, contractors).

LID features also must be designed with maintenance and lifespan considerations in mind, as features with increased maintenance demands carry more risk. If maintenance requirements are not effectively performed, features may not function to designed specifications. For example, prioritizing vegetation that requires minimal maintenance allows for more flexibility in these requirements. Additional considerations regarding enforcing homeowner maintenance requirements, including rights to inspect private property and leverage fines, and a summary of approaches taken in several municipalities, are discussed further in additional support documents (CVC, 2010b; IFC Marbek, 2012).

3.3 ENGINEERING DESIGN AND CONSTRUCTION

As LID approaches and features represent stormwater management technologies that are best suited to the management of frequent runoff events, there are some inherent risks involved with the design and implementation of these features - especially in how they relate to extreme event stormwater management. As a result, it is likely that these features will have to be designed to work in conjunction with conventional stormwater management approaches in order to ensure limited liability and risk for damage to persons and property. Through LID survey results, an approach that uses a combination of conventional and LID approaches was identified as an effective stormwater management approach going forward.

3.3.1 DESIGN GUIDELINES

As an approach that has slowly been adopted into guidelines, the relative experience level associated with LID designs is still limited when compared against conventional design knowledge in many areas within Canada. In general, stormwater management guidelines and supporting documentation have offered design criteria and prescriptive design approaches relating to conventional stormwater management features, and little information related to the design and implementation of LID features. Recently, and in particular in the last five years, guidelines across Canada have been updated to include additional references to LID features and their role and importance within stormwater management. That being said, the representation of LID within current design guidelines still represents a barrier to LID implementation.

As an example, designing effective LID features offers challenges in determining appropriate rainfall design criteria (e.g., return period, storm duration, storm distribution, etc.). Typically, the Chicago rainfall distribution (or similar) is recommended when determining appropriate design storm temporal distributions, as this storm represents a conservative distribution for designing peak flow related management systems in urban environments. The design of management features more related to volume and smaller storm management, such as LID features, might require other storm distributions (e.g., Huff or SCS storm distributions). Some design guidelines (City of Calgary, 2011) have been updated to include design storm recommendations specific to LID features, but this example illustrates how variable design input parameters could represent barriers to LID implementation. To provide another example, computer modeling is typically required in the calculation of peak flows and volumes. The input of LID related features into these models requires a level of judgment and interpretation that is not required when simulating conventional stormwater features. Without additional guidance and support comes uncertainty, additional challenges, time requirements, and costs – all of which representing barriers to LID adoption.

LID survey responses indicated that the majority of those surveyed were asked to provide support in the design and implementation of LID features, including providing inputs into designs, approving proposed approaches that may not yet be included within guidance documents, and others. By updating stormwater management guidelines to better incorporate LID features, the design and approval process for these features could be streamlined, allowing for less uncertainty in planning for their implementation. As a lack of support in promoting, managing, and reviewing LID features was listed as a barrier in several of the LID survey results, having more extensive support documentation for designers would help to ease the time commitment required to properly assess these systems.

It must be stated that while, in general, LID approaches have had a slow adoption rate across much of Canada, there have been exceptions. In B.C., provincial stormwater guidance has outlined the need for considerations of changes to landscape water balances and establishment of runoff volume targets, and have been available for over 10 years (BC MoW, 2002). These guidelines represent a strong template for an approach that has been adopted throughout guidelines in several municipalities in B.C. (City of Chilliwack, 2002; District of North Vancouver, 2006; etc.).

In addition, there are several resources available related to the proper design and implementation of LID style features in new developments (City of Calgary 2007; City of Edmonton, 2011; CVC & TRCA, 2010; etc.). There are also several examples of guidelines being updated to include additional focus and attention on the most applicable LID features in particular environments (City of Calgary, 2011).

Ontario's Conservation Authorities have developed several design guidance documents referred to within this document, and have also been responsible for the preparation of one of the most comprehensive LID-style stormwater management criteria found through this study (TRCA, 2012). Under the approach outlined in this document, the following criteria are given (TRCA, 2012):

- Prevent any increases in flood risk potential;
- Maintain runoff volume, frequency, and duration from frequent storm events;
- Protect water quality;
- Preserve groundwater and baseflow characteristics;
- Prevent undesirable geomorphic changes in watercourses; and
- Maintain appropriate diversity of terrestrial and aquatic life and opportunities for human uses.

These key high-level goals are not only important within the management of stormwater, but have positive benefits to integrated water systems as well (see Section 2.2). However, the language related to these and other guidelines referencing LID features uses soft language, such as 'encouraged', 'should', and 'recommended'. As these features are not yet a hard requirement in these cases, there will be a lack of adoption of an approach that is perceived to carry more uncertainty.

The remaining issues associated with LID guidelines is that there is a lot of discussion regarding the importance of including LID considerations, but the design criteria and available information in these guidelines is still very heavy on conventional end-of-pipe options (e.g., design information relating to dry and wet ponds, etc.). Additional resources related to LID feature designs and specifications is typically available under separate covers, but until LID design details are consistently located within the main stormwater guideline documents as a requirement, there will be perceived barriers to its implementation. As an example, where TSS reduction design criteria could be met with or without LID implementation (e.g., through end-of-pipe wet ponds instead), designers will choose to include those options where they have more design experience and where design specifications and standards are more readily available.

3.3.2 CONSTRUCTION INEXPERIENCE

As further described by Olorunkiya et al. (2012), highly skilled and experienced contractors are able to point out parts of a prospective design that does not conform to the practices and standards of previously completed works. When working in an LID project construction environment, this level of familiarity with designs, standards, and practices is not yet established, and the ability of contractors to identify potential risks in construction does not exist. As LID projects may include the use of new products, non-standard materials and construction techniques, among other differences from conventional drainage construction projects, there are risks related to improper materials and construction practices being used. In a study of 72 LID-type features, it was reported that 47% deviated from provided design specifications (CVC, 2012). With these risks comes the potential for LID features to not function as designed and represent a liability within the drainage system.

In addition, intensive erosion and sediment controls are required at the onset of any LID related construction activity in order to ensure minimal initial sediment clogging of infiltration-based features. Some features (e.g., pervious pavement) require special considerations pertaining to ensuring the pores of the material remain in good condition, such as considerations for sanding and salting. Other considerations relating to the minimization of material compaction during construction activities need to be explicitly communicated to the contractors on site.

In constructing LID features, it is important to have discussions with the anticipated landscape architect on the project (where applicable). It has been noted that differences in material characteristics exist between what is desired from an engineering perspective, and what is desired from a vegetation, appearance and aesthetics perspective (ALIDP, 2014).

Documents outlining specifics related to proper LID construction are available for details on proper construction techniques, inspector tools, and other additional information (CVC, 2012, 2014).

3.3.3 SITE CONDITIONS

In order to ensure proper function, several site-specific considerations must be taken into account in the planning and design of LID approaches and features. In general, the following should be considered:

- Site soil conditions;
- Groundwater table levels;
- Near surface geology;
- Site development plans; and
- Drainage area characteristics (e.g., drainage area size, site topography).

With several site-specific conditions to consider, LID features typically cannot take a 'one size fits all' approach to meeting required design criteria. The underlying soil type has been commonly referred to as a barrier in implementing LID approaches and designs. For example, typical stormwater guidelines specify a maximum time allowance for water from a storm event to be drained and managed by a system. This particular criteria can prove challenging if slow draining soil conditions exist on site, and may require additional considerations. There have been examples of LID designs that successfully compensate for these soils, be it through the installation of sub-drainage systems, or the use of a larger quantity of coarse infiltration material in designs (Dietz, 2007). While requiring additional design considerations, having a large percentage of clay-based underlying soils can still allow for LID feature implementation.

Geotechnical concerns have been raised regarding LID implementation. In particular, risks related to potential increases to Inflow and Infiltration (I&I) due to LID feature implementation have been identified. Additional points of concern include the effects of increased infiltration volumes on nearby infrastructure (e.g., road bases and other structures). Geotechnical studies are recommended to mitigate these potential concerns, which can potentially represent a significant amount of extra work, time, and investment on the part of prospective developers and designers. In addition, some of the considerations mentioned are very difficult to quantify and determine without related case studies and supporting documentation. From LID survey results, additional tools have been examined to aid in standardizing solutions for homeowners looking to implement their own technologies, as geotechnical studies can prove too overwhelming for homeowners to understand and apply.

While there are methods to ensure that LID features can be effectively implemented in most design cases, there are some design cases where LID implementation has been deemed potentially unsuitable. They include (City of Seattle, 2010; Dietz, 2007; TRCA, 2012):

- Areas where contamination of groundwater through infiltration is a concern (e.g., gas stations, industrial sites, etc.);
- Sites with steep topographic conditions;
- Sites with limited infiltration capacity (e.g., shallow bedrock depths or high water table levels);
- Floodplains; and
- Within close proximity to drinking water wells (<30 m).

Lastly, there are concerns that the increased groundwater recharge resulting from implementation of LID systems may impact subsurface infrastructure. For example, in a study into the groundwater effects of bioretention facilities, it was shown that groundwater levels were raised by the implementation of these LID devices leading to potential risks to nearby infrastructure. This study concludes that considerations for bioretention facility proximity are required in sensitive areas (e.g., floodplain areas) and where existing infrastructure is vulnerable to groundwater table fluctuations (Endreny & Collins, 2008). It should be noted, however, that these increases in groundwater levels are sometimes desired; in Boston, reduction in groundwater levels was observed to deteriorate untreated timber piles supporting the foundations of several buildings in the City, leading to studies on how LID type features and approaches could aid in increasing groundwater levels in the study areas (Thomas & Vogel, 2010).

3.3.4 PERFORMANCE VARIABILITY

The installation of LID features in areas where pollutant loads exceed the natural capacity of vegetative systems is also a risk. Additional considerations are required in areas that may require additional stormwater treatment (e.g., industrial sites, gas stations, etc.; CRD, 2014), as increased pollutant loads can lead to LID feature failure.

There is potential for bioretention features to function as a source of nutrients (nitrogen, phosphorus) into stormwater systems (Dietz, 2007; TRCA, 2008). It has been inferred, however, that the increased nitrogen loading may be a direct result of fertilizers applied to plants in those areas, and would likely be reduced if application of chemical fertilizers was limited. In addition, features that promote infiltration in areas with heavy road salting have been identified as representing potential risks to groundwater systems. A connection between de-icing chemicals and increased metal mobility in groundwater systems has also been made, with lead and cadmium identified as potential parameters of concern (TRCA 2008). This subject requires additional research and consideration.

In addition, there are concerns regarding winter operation and effectiveness of LID features when implemented within the climates experienced across Canada. However, several studies report that LID features are still effective through the winter months (Dietz, 2007; IFC Marbek, 2012; TRCA, 2008).

The continuous loading of contaminated stormwater to subsurface soils has been identified as a potential risk to soil quality in LID feature areas, but studies with several years of data suggest that the build-up of contaminants within these systems is not a concern (TRCA, 2008). As studies that include the measurement and monitoring of the performance of LID features continue, some of the uncertainty and risk related to the variability observed in feature performance can be better understood.

3.3.5 ECONOMICS

Though it represents a perceived barrier in LID implementation, there are several documents available that provide conclusions relating to the affordability of LID projects when compared against conventional stormwater systems (CVC, 2014b; IFC Marbek, 2012; Shaver et al., 2009; US EPA, 2007; US EPA, 2009b;). Other documents also include the risks to receiving water systems to provide additional decision-making insight (American Rivers et al., 2012). A comparison made by the City of Seattle of conventional vs. LID street design illustrated a large difference in estimated total project costs, with LID streets (estimated at $4.6 million) representing ~52% of the cost of traditional street designs achieving the same level of service (estimated at $8.8 million). It should be noted, however, that there was estimated to be a minimal increase in the cost of required maintenance when compared against conventional systems ($4,800 annually; City of Seattle, 2010).

It has been reported that when uncertainty and risk are involved in a project, a premium to the cost of the project should be included to cover this risk (Olorunkiya et al., 2012). Due to the level of uncertainty and risk in LID projects, it has been observed that cost for these projects is much more than anticipated. This is further outlined in Olorunkiya et al. (2012).

3.4 LID IMPLEMENTATION IN EXISTING SYSTEMS

The City of Calgary proposed retrofitting a section of street in the community of Lakeview to incorporate LID features, including bioswales and a reduction in lane width. This was met with 'strong opposition' by the majority of the community residents, and as such was not completed (City of Calgary, 2010). With this example in mind, the need for additional education of the importance of stormwater management is highlighted. Through analysis into several case studies (see Section 5), it has been shown that homeowners have generally been very satisfied with the implementation of LID into neighbourhoods, illustrating that this apprehension in LID adoption can be overcome. As noted in the LID survey results, continuing education of the public, levels of government, and developers/designers is required in order to ensure continue adoption of LID features and approaches.

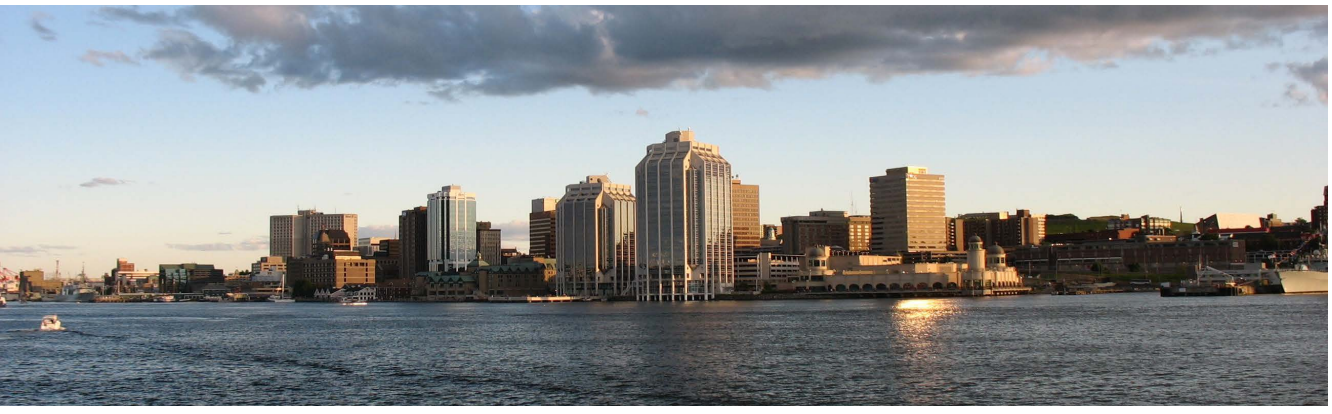
When considering LID approaches to retrofits in existing areas, municipalities that have had success have shown that identifying suitable locations and having an extensive selection process (including public consultation) prior to construction was critical (City of Seattle, 2010; Transport Canada, 2004). The most typical concerns raised by communities have been related to potential changes to street parking through street narrowing and LID feature construction (City of Canmore, 2014; City of Seattle, 2010;).

pt 4. case studies in LID within integrated water management

Three case studies, with a focus on high-level integration of LID approaches and features, have been summarized below. Case studies were chosen to illustrate LID integration within drinking water, wastewater, and retrofit systems. The three case studies provide examples of risk mitigation within integrated municipal water systems.

4.1 HALIFAX REGIONAL MUNICIPALITY, NS LID INTEGRATION WITHIN DRINKING WATER SYSTEMS

Halifax, Nova Scotia is an amalgamated municipality of the governments of the former cities of Halifax and Dartmouth as well as the town of Bedford and the County of Halifax. Covering approximately 5500 square kilometers, the municipality consists of more than 200 individual communities with the bulk of its 413,710 (as of 2013) residents centred in the urban areas (Halifax, 2014). Residents within the core service boundary are serviced by Halifax Water, the local integrated water, wastewater and stormwater utility. Halifax Water is a private, publicly traded utility with all its shares held by the municipality (Halifax Water, 2014). Outlined below are two case studies that illustrate the potential risks (Case Study 1), and benefits (Case Study 2) of integrated water management planning, with a specific focus on LID impacts on drinking water systems.



4.1.1 CASE STUDY 1 - APPROACH

Beaverbank is a small suburban residential area located outside the defined core water service area of Halifax. Due to its location outside the core service boundary, developments in Beaverbank must be planned with private drilled wells for drinking water supply, and are not serviced by Halifax Water. Beginning in 2008, residents of two rapidly expanding residential subdivision developments, Monarch Estates and Rivendale, began running out of water (HRM, 2010). They lost the ability to water their gardens, launder their clothes, and even flush their toilets with regular frequency (CBC News, 2010). As per the minutes of a Halifax Community Council meeting related to this issue (2010), one resident drilled a secondary well at a depth of over 700 feet, only to experience the same water shortages again not long after. At the time there was no provision by the Halifax Regional Municipality (HRM) or Halifax Water in place to require a study of groundwater availability for residential developments in suburban and rural areas not serviced by municipal water, and no such study was conducted (HRM, 2010).

4.1.2 CASE STUDY 1 - RESULTS

Residents petitioned the city to extend municipal water service to their subdivision, and there was significant negative media attention related to the problem. Residents won their battle to have municipal service extended, but at a cost of over $5M to Halifax Water, and an average cost of $20k to each homeowner for lateral connection fees (HRM, 2010). It must also be noted that this project drew resources and attention away from growth areas as directed by the Regional Municipal Planning Strategy (Regional MPS), and that installation of water infrastructure after construction has been completed is dramatically higher than installation prior to completion (Davis, 2014). While the residents of Monarch and Rivendale Estates now enjoy the benefits associated with municipal water service, they will experience a faster failure of their asphalt surfaces due to the disturbances associated with open trenching to lay water service pipe (Davis, 2014).

The Beaverbank case study is an example of what can go wrong when an integrated approach to water management is not considered in the planning stages of a residential development. There have, however, been some positive outcomes as a result of this situation. The Government of Nova Scotia passed legislation allowing municipalities to require groundwater planning studies prior to development approval. While HRM has not enacted this legislation, they do now require groundwater planning studies for new developments on a case-by-case basis (CBC News, 2010b). The groundwater planning studies consider how alterations to the landscape will influence groundwater recharge and availability. A relevant take-home message from this situation is that an understanding of how a development will impact all water resources and systems is imperative, and integrated management plans can help identify and reduce risks.

4.1.3 CASE STUDY 2 - APPROACH

The Seven Lakes development is a phased suburban residential development proposed to consist of 634 units located in an area known as Porters Lake within the municipality of Halifax (HRM). It is proposed as an Open Space design to be constructed in seven phases over 10 years in an area of approximately 256 ha. In HRM, Open Space design means that a portion of the lands are to be conserved as open space and specific to Seven Lakes 60% of the 256 ha must remain as common Open Space. Housing, services, and public and private parkland are to be located in the remaining 40% of the area. The development is proposed to be owned by one owner who will be responsible for water and septic systems, common open space and common accessory buildings (HRM, 2013).

Phase 1, which consists of 103 units, is currently under construction. This phase is serviced by a decentralized wastewater system and shared and/or individual groundwater wells. A stormwater plan is required for each phase of development and the first phase has been approved to include LID features such as retaining 60% of the original vegetation on each lot, bioswales and the construction of a stormwater wetland (HRM, 2013).

The Seven Lakes Developers, in corporation with Dalhousie University, the Department of Natural Resources (Provincial Government) and the Ecology Action Centre (NGO), received a grant to explore the effect of LID stormwater management techniques on groundwater recharge. The objectives of this research are to provide information to government and developers about LID stormwater management and its integration into drinking water supply management. This study was initiated, in part, due to the situation described in Case Study 1.

4.1.4 CASE STUDY 2 - RESULTS

The first phase of development is currently under construction. Groundwater wells were drilled at the site as part of the required Level 2 Hydrogeological Assessment (now a municipal requirement). This assessment is completed to characterize the groundwater aquifer and estimate a sustainable yield. Four wells have been designated as monitoring wells and loggers have been recording groundwater levels prior to and during construction. Recorded data was used to calibrate a groundwater model designed to test the sensitivity of both groundwater pumping and recharge rates on the groundwater level. Preliminary results show that groundwater levels are sensitive to pumping and recharge rates (Centre for Water Resources Studies, 2014), and that the incorporation of LID features has a positive impact on drinking water availability.

Dalhousie University continues to monitor groundwater and surface water flows and is developing water balance models of the development. Identifying potential risks to drinking water supplies as a result of facilitated recharge will be monitored and addressed in the study.

4.2 PORTLAND, OREGON, USA LID INTEGRATION WITHIN WASTEWATER SYSTEMS

The city of Portland, Oregon, has a combined sewer for wastewater and stormwater which discharges into local streams and rivers. As in most cities with combined sewer systems, large rain events overwhelm the treatment plants and untreated wastewater is discharged directly to the environment. In 2004 after investing billions of dollars to upgrade the sewer system, approximately 50 rain events caused overflows of polluted water into local waterways (CCAP, 2011). The city of Portland commissioned a financial valuation to determine the costs to upgrade the conventional system (e.g. the cost of increasing the pipe sizes) compared to the costs of implementing LID (from keeping trees to installing green roofs) across the city. The valuation accounted for the multiple benefits of LID including the cost of avoided damages and increases to property values in addition to the stormwater management value. Once the numbers were in, it was obvious that the role LID can play was not insignificant and the city began to invest in this approach (CCAP, 2011).

It launched a campaign named "Grey to Green" focused on shifting the "grey" stormwater to "green" infrastructure. The city offers stormwater management fee discounts to property owners to include LID on their property, incentives for disconnecting downspouts and building green roofs in addition to investing millions of dollars into city owned LID projects (CCAP, 2011).

4.2.1 RESULTS

As of 2007, more than 44,000 homes have disconnected their downspouts, which has resulted in an estimated reduction of 1 billion US gallons of stormwater per year from the combined sewer system (US EPA, 2007). In 2011 alone, 288 green roofs, covering almost 14 acres, were installed (American Rivers et al., 2012). It is estimated that Portland's LID projects retain and infiltrate about 43 million gallons (163 million L) of water per year accounting for approximately 40% of annual runoff (CCAP, 2011).

All told, Portland was able to achieve $250 million in hard infrastructure cost reductions by investing $8.5 million in green infrastructure (US EPA, 2007).

The ability to compare the financial costs of LID with those of conventional stormwater management upgrades, and acknowledging the multiple benefits of LID implementation with a price, helped the city launch and evaluate the effectiveness of its LID campaign. Downspout disconnections do not come without risk, however. In order to minimize risks to individuals and property, homeowners are encouraged to anticipate where the disconnected downspout will flow to and direct them to gently sloped pervious areas, where possible.

4.3 SEATTLE, WASHINGTON, USA LID INTEGRATION WITHIN DEVELOPMENT RETROFITS

The City of Seattle has become a leader in the design and implementation of LID features and approaches, which are a part of their Natural Drainage Systems city strategy. This strategy was born out of concerns related to downstream environmental impacts (including impacts on sensitive fisheries streams), lack of municipal funds for installation of standard stormwater infrastructure, and an aging stormwater management system (including combined sewer systems).

As part of updating an outdated housing development, the City of Seattle took the opportunity to retrofit the area's stormwater management approach (which included a previously constructed dry retention pond) to incorporate LID features and approaches. The development was designed to standards above those typically set for developments, with additional requirements relating to reducing the overall quantity of runoff generated by the development area. This case study represents an approach that can be taken to retrofit systems that have existing end-of-pipe solutions in place (e.g., wet and dry ponds).

Features implemented include: street systems that are sloped towards gutters with curb cuts, allowing stormwater to collect in bioretention swales for infiltration of typical runoff events, disconnected downspouts which flow towards amended soil infiltration features, porous sidewalk surfaces, narrowed streets, and a conventional piped stormwater system which directs larger event flows to a dry pond for storage and release.

4.3.1 RESULTS

Through the combination of LID and conventional management features, a reduction in the size of the pond required was achieved. It was reported that if only conventional approaches were used, the dry pond would have required an addition 5x the volume of that of the combined system. In addition, it is reported that the project is meeting water quality related goals.

The reasoning for the initiation of this project correlates well to those issues previously outlined in Section 1.1 (e.g., extensive infrastructure costs and receiving waters concerns), and as such represents an applicable analog for future implementation across Canada. A loan from a fund developed by the Washington State Department of Ecology (in place to promote such technologies and approaches) ensured the project could be completed, and illustrates how investment into these technologies can push forward adoption (City of Seattle, 2010).

pt 5. case studies in LID implementation

In addition to LID approaches on larger scales such as those outlined in Section 4, there are opportunities to implement LID features on a smaller scale within both retrofit and renewal projects. Retrofitting systems to incorporate LID features allows for improvements to stormwater quality and reductions in stormwater runoff quantity, which can provide benefits in reducing risks within integrated water management systems. Summarized in Appendix A are several examples of smaller LID implementation projects across Canada and North America, with the approaches, lessons, and risk considerations summarized for each case study. In these cases, LID features supplement existing conventional drainage networks and systems. References to supporting documents have been included if additional details are desired.

The case studies summarized in this document represent a very small sample of the total amount of information that is available on LID case studies through several sources in Canada and the USA. Notable online resources with additional case study information include:

- Innovative Stormwater Management Practices website (Online database of LID practices in Ontario, TRCA, 2014);
- Stormwater Case Studies website (US EPA, 2014b); and
- Showcasing Water Innovation website (CVC, 2014c).

Results from the completed municipal LID survey identified that LID systems with absorbent landscaping approaches were being adopted and implemented effectively. Other common LID features currently implemented in municipalities throughout Canada included permeable pavement, bioretention areas and bioswales, rain gardens, and green roofs.

Information relating to feature sizing is becoming increasingly available through published documents by government agencies in both Canada and the USA (CVC & TRCA, 2010; CVC, 2014d; City of Edmonton, 2011). Comprehensive guides to sizing particular features have been developed as experience with these features increases (e.g., bioretention features, WI DNR, 2014). With this experience come additional examples of typical LID design drawings and specifications (City of Portland, 2008). As outlined in Section 3.3, effective LID implementation accounts for site-specific conditions and considerations. As such, it is difficult to recommend one solution for all design scenarios. Learnings from these and additional case studies will allow for the collective growth of the knowledge of stormwater professionals with respect to LID implementation.

pt 6. recommendations

This section summarizes recommendations related to the implementation of LID. They include the development of new stormwater regulations and policies, continued development of updated design guidance and support documents, incentivizing lot-level LID adoption, and promoting LID synergy within different levels and departments of government in order to promote the adoption of LID approaches and features.

6.1 GUIDANCE DOCUMENT DEVELOPMENT

A consistent, clear, and focused goal pertaining to the role of LID within stormwater management is required in order to reduce uncertainty regarding its implementation throughout Canada. These goals could be achieved through the development of an extensive policy that reflects the importance of mitigating risks related to conventional stormwater approaches. Across Canada, there have been varying levels of adoption of LID criteria into stormwater management requirements. Going forward, working towards a consistent urban stormwater approach across Canada would allow for more effective collaboration, learnings, documentation, and design experiences to occur. In turn, this consistency would allow for more effective integration of stormwater systems into holistic municipal water system management.

Larger Canadian municipalities (e.g., City of Toronto, Metro Vancouver) have implemented design guidelines that incorporate LID approaches with a specific focus on ensuring pre-development hydrologic conditions are preserved. It is recommended that municipalities work towards implementing a similar approach, including considerations for extreme event, frequent event, and water balance criteria.

On a smaller scale, as LID features and approaches become integrated into stormwater management design criteria, the availability of design support documentation will continue to grow. In order to support this growth, it is recommended that demonstration facilities on public lands continue to occur. Within these demonstration projects, a focus should be on establishing proper maintenance criteria for future inclusion within design guidelines. Further investigation into the effects of infiltrating runoff containing road salt and de-icing chemicals on the potential mobilization of metals within these systems would help to mitigate uncertainties encountered with these considerations. In addition, the effects of increased infiltration from LID features and their potential impacts on inflows & infiltration in sanitary systems is a source of additional uncertainty. Further research into these and other remaining areas of concern will help remove the remaining technical barriers to LID implementation.

6.2 INCENTIVE STRATEGIES

As shown through the significant amount of research and literature related to barrier in LID implementation, the economics of implementing these strategies is perceived as a significant obstacle to implementation. Through the potential integration of wastewater, water, and stormwater utilities on a municipal scale, the opportunity exists to introduce stormwater credit incentives for homeowners to choose developments that include LID features, or to push for retrofits. The Portland, OR "Grey to Green" campaign represents a successful example in the use of incentives to push LID approaches for mutual homeowner/municipality benefits, including the mitigation of risks to both stormwater and wastewater systems.

In Halifax, a distinct stormwater charge was implemented in order to provide the revenue required to maintain and operate the stormwater system. This charge has been implemented as a lump rate for residential customers, with multi-residential, industrial, commercial, and institutional customers charged based on quantity of impervious surface specific to the property (Halifax Water, 2014b). Stormwater charges also have begun to be implemented in other municipalities across Canada in order to more effectively (and transparently) support the stormwater management infrastructure.

Within this and similar structures comes the increased ability to offer incentives for rate reduction through homeowner action. In Kitchener-Waterloo, a stormwater charge based on both impervious area and total lot size was implemented in order to fund stormwater management in those municipalities. This approach helps in both educating homeowners about stormwater and runoff, while opening discussions about potential incentives to lower stormwater charges through implementing LID features. Under this system, Kitchener-Waterloo allows for reductions to this stormwater charge through the application for credit related to the installation of LID features (e.g., green roofs, rain barrels, etc.; City of Kitchener & Waterloo, 2010; ECO, 2014).

Other opportunities exist to push adoption of lot level LID implementation through incentives. The City of Guelph offers rebates to homeowners who install seasonal or full year rain barrels on their property (City of Guelph, 2011), and Richmond Hill and Mississauga have also implemented incentivized rate structures. The City of Edmonton follows a similar approach in that a calculation based on area, an 'Intensity of Development Factor', and a runoff coefficient based on zoning is in place. In this system, however, residential lots cannot as of yet reduce their bill by applying for credits where developments are shown to contribute less stormwater to the City's systems (City of Edmonton, 2014). Additional information in the form of a detailed overview of stormwater financing is available through Credit Valley Conservation (CVC, 2008).

For systems where an incentivized rate structure is implemented, there is a risk related to lack of maintenance being performed after credits are received. It must be well communicated that the maintenance of these LID features on private property remain the responsibility of the homeowner, and that continuing credit for these features hinges on the required maintenance taking place.

The key to this and other implementation strategies hinges on the continued education of the public on the importance of stormwater systems in urban environments. By identifying stormwater as a distinct charge within integrated water utilities, its profile can be raised and opportunities to further educate the public regarding its importance, and of effective strategies for its management, can be created.

6.3 INCREASED GOVERNMENT SYNERGY

An important issue identified in the literature, and the LID survey, is the need for future open communication between the various departments of interest within municipalities to ensure that (i) the need for LID is understood and (ii) how and where it can be implemented throughout municipalities. Collaboration in teams has been identified as an approach to LID implementation that may allow for reducing the perceived risks in LID projects. In addition, the dissemination of LID knowledge on a peer-to-peer level has been cited as an effective method of helping to reduce barriers and the risks perceived in implementing new technologies and approaches. While documents from municipalities indicate that we are moving in this direction, future efforts are required.

If LID implementation as a tool in reducing risk in integrated municipal water systems is to occur, relationships between both departments within governments, and between these governments and stormwater management designers, planners, and developers must be further developed. In doing so, several suggestions have been put forward by the US EPA, and are briefly summarized below (US EPA 2009):

- Earlier inclusion (pre-concept stages) of planners, stormwater designers, and stormwater managers in meetings regarding potential development projects;
- The use of demonstration projects on public lands to both act as proof of concept and connect the parties identified above. This can also act in educating stakeholders in several departments of government (e.g., Parks if on parks land, Public works/transportation if on roads projects, etc.) about the use, importance, and role of LID going forward;
- Integrate stormwater management professionals in municipality planning processes to ensure effective considerations for watershed and hydrology based goals are included; and
- Encourage cross training of municipality staff with LID and stormwater training sessions to further knowledge within all areas of municipalities.

Due to the interconnected nature of not only the municipal water systems but their related infrastructure (e.g., specifications for roads, parking lots, green spaces), efforts into ensuring methods for more effective collaboration between departments would help in removing barriers to LID implementation and adoption. In addition, by removing interdisciplinary design boundaries, opportunities for planned maintenance to aging infrastructure to act as both maintenance and stormwater upgrades exist, providing benefits to multiple areas of municipal infrastructure.

There is an overwhelming quantity of information regarding benefits, case studies, design approaches, etc., for LID available within Canada. This information is spread across countless websites developed to aid in LID education, but instead presents a barrier in itself, as there are too many places to find similar information. It is recommended that an overarching website to collect and effectively disseminate this information be created in order to more effectively provide this information to the end users.

Lastly, to ensure that resources are available to municipalities across Canada, various levels of government will need to commit to long-term support of LID initiatives. The implementation of LID approaches and features into design guidelines across Canada has made significant strides in the past 5 – 10 years, and additional funding commitments would both allow for the expansion of demonstration projects and provide the support required to ensure adoption and implementation of these technologies and approaches continues.

It has been shown through our research that the proper implementation of LID features not only provides improvements to stormwater management systems, but can be used in reducing risks to both drinking and wastewater systems as well. As considerations for integrating municipal water management become more developed, further implementation of LID should be considered within these systems.

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APPENDIX A

CASE STUDIES IN LID IMPLEMENTATION

Project Description	Approach	Results & Lessons Learned	Risk Considerations
Rear alleyway Retrofit Pacific Climate (Vancouver, BC) Reference Documents: Transport Canada, 2004 Hutchinson, 2013	• Removal of the previously existing asphalt alleyway • Installation of concrete/gravel driving strips, integrated with a 'structured grass' product, placed on an appropriate subgrade material • The structured grass is included to provide additional structural support and allow for turning off of the driving strips with minimal damage to the existing vegetation • Additional design considerations were made for driveway connections and lane entrances in order to ensure minimal loss of alleyway functionality.	• Selection of an appropriate subgrade reported as a key design parameter • Careful consideration to the grading of the lane is required in order to ensure proper drainage away from households, which was observed to be more challenging than with using conventional construction and materials • Reported that mowing would be the responsibility of the City, though many homeowners have become accountable for mowing with time, and are invested in its aesthetics and function. Smaller maintenance activities (i.e. weeding and watering) would be the responsibility of the connected homeowners • Design lessons mostly relate to the recommended replacement of the concrete/gravel driving strips with the structural grass product as well as the uniform placement of the structural soil throughout the width of the country lane. Newer structural grass products that have been developed since project initiation may offer better performance • The project has been deemed a success, with high homeowner satisfaction and benefits for surrounding real estate prices. In addition, feedback from residents surveyed shows that the majority of residents are willing to pay more to have these country lanes instead of the typical asphalt lanes • It was also reported that the cost of implementing these country lanes was approximately double that of a traditional asphalt lane.	Risk Decrease: • Reduction of runoff from previously pervious surface, reducing burden on aging systems • Nutrient uptake by vegetated areas, decreasing runoff pollutant concentrations Risk Increase • Due to challenges in grading, risk to proper drainage • Structured grass product not typical, has set lifespan – must be monitored to ensure still functioning adequately • Homeowner adoption required for best lifespan and functionality

Project Description	Approach	Results & Lessons Learned	Risk Considerations
Three Sisters Drive & MacDonald Place Street Rehabilitation Foothills Climate (Canmore AB) Reference Documents: Brock White, 2014 City of Canmore, 2014 Invisible Structures, 2014 Primeau et al., 2009	• Project initiated to rehabilitate aging and under-designed roadway and infrastructure. Project goals were to both improve transportation and minimize stormwater effects on downstream Bow River • Paved street lane widths were reduced to limit impervious surfaces • Traffic management features to both manage the speed of traffic and allow for additional reduction of impervious areas • Gravel has been used as an alternative to asphalt in the areas surrounding the paved lanes, with gravel street parking and driveway entrances offering increased permeability over typical asphalt.	• A product called 'Gravelpave2' by Invisible Structures was used for these gravel areas. According to Invisible Structures, this product minimizes compaction concerns, and is applicable in cold climates • Grassy roadside swales have also been implemented to manage runoff in lieu of a conventional subsurface piping system, allowing for reductions in runoff velocity and potential settling of TSS and removal of pollutants • Narrower street provides challenges, from new requirements to yield to large vehicles (e.g., snow plows), and changes to available on-street parking • The aesthetics of the roadway have been improved, as has pedestrian safety through installation of walking paths and reductions in vehicle speeds in the area • Through decreasing 50% of the pre-construction impervious areas, a 50% reduction of the runoff in the area is reported • Total project cost was reported as approximately $5.5 million	Risk Decrease: • Reduced impacts to receiving Bow River watercourse (both water quality and quantity) Risk Increase: • GravelPave2 is a fairly new product therefore there is uncertainty in the lifespan and long-term effectiveness of GravelPave2 • Monitoring and maintenance required

Project Description	Approach	Results & Lessons Learned	Risk Considerations
Bioretention System Eastern Climate (Vaughan, Ontario) Reference Documents: TRCA, 2014b	• Bioretention area implemented to manage runoff from parking lot • Bioretention area comprised of landscaped vegetation and rock features, with permeable soils and perforated subdrains • During large events, overflow considerations are in place to direct flows towards nearby catchbasin • Monitoring of water quantity and quality related to feature installation occurred for 2 years postconstruction • Underlying soils are reported to be silty clay glacial till	• Results related to water quantity include a 90% reduction in outflows as a result of infiltration and evaporation from the bioretention facility • Reduction levels were similar through all seasons of study, although infiltration rates were reduced in the winter months • Surface ponding occurred during larger intensity storm events in summertime, but rarely ponded for greater than a 20 minute period. Infrequent ponding was observed in winter, but lasted longer • Results of ongoing post-construction monitoring show reductions of 65 –92% of the total mass of pollutants when compared against typical parking lots • Bioretention feature was observed to increase nitrate nitrogen levels • Vegetated areas of the bioretention area showed potential for greater runoff reduction effects over non-vegetated • Effluent temperature was significantly reduced • Regular maintenance of the feature was estimated at $1500 annually	Risk Decrease: • Decreased runoff volumes • Decreased contaminant loading • Decreased effluent temperatures Risk Increase: • Increased nitrate nitrogen level through bioretention area • Uncertainty regarding long-term maintenance requirements and timing
Low Impact Development Pilot Project Naval District Washington, DC Reference Documents: Low Impact Development Center (A and B)	• Single bioretention cells and strips implemented between parking areas • Sand filter gutters • Permeable pavement with slow release cisterns and rain barrels to control flow to river • Street tree boxes • Downspout disconnects • Retrofit storm drain inlets to filter and trap sediments • Open area soil amendments for water retention	• Still underway • Street tree filters and soil amendment areas helping trees and plants survive drought periods with less watering • Soil amendments provide reduction in peak runoff flows and filtering pollutants from stormwater • Stormwater inlets reducing grease, oils and other debris from stormwater	Risk Decrease: • Not quantified, but general opinion that less water used for grounds maintenance • Reduction in peak flows • Reduced rainwater into sewer system due to downspout disconnects Risk Increase: • Oil/water separators require ongoing monitoring and maintenance. • Monitoring underground cisterns for release requires training and consideration • Cleaning of sediments from drain inlets

Project Description	Approach	Results & Lessons Learned	Risk Considerations
100 Domain Drive Parking Lot Corporate Campus Retrofit (Exeter/Stratham, New Hampshire) Reference Documents: American Society of Landscape Architects, 2014	• Bioretention rain garden facilities implemented within new parking lots replacing previously existing, aging parking lot • Project included installation of rain garden, bioswale, and implementation of curb cuts	• Construction began March 2011 • 85% of stormwater is now being captured, retained and infiltrated • Enhanced aesthetics	Risk Decrease: • Less maintenance of paved surfaces for lot owner • Reduced runoff Risk Increase: • Stormwater management (not previously managed) • Education of grounds keeping staff for maintenance of rain gardens
SEA Street Street Rehabilitation Western Climate (Seattle, Washington) Reference Documents: City of Seattle, 2010	• A street without dedicated stormwater piping infrastructure was retrofitted to manage stormwater through a combination of LID approaches • Features include narrowing paved streets, installing bioretention facilities, additional landscaping and 'greening' of streetways, and extensive public consultation/education regarding on-going maintenance	• It was noted that due to the dramatic differences in design vs. conventional streetway stormwater management, extensive public consultation and education was required to ensure project success • Results have shown that most residents consider the changes to be positive, and believe that their property values have in turn increased • The study notes that changes to street designs required extensive collaboration between several departments within the municipality, and was met with resistance prior to project success • By making changes to typical street width requirements, impervious area was reduced 11% over typical street designs • Reported monitoring results have shown a high level of project success relating to reduction in site runoff, with post-project measurements representing 1 – 2% of pre-project levels	Risk Decrease: • Significant reduction in site runoff • Extensive public consultation and education to mitigate maintenance risks • Stormwater now managed where previously no form of stormwater infrastructure was in place. Risk Increase: • Maintenance required where none was previously (due to no infrastructure in place)

Project Description	Approach	Results & Lessons Learned	Risk Considerations
Seneca College Permeable Pavement Eastern Climate (King City, Ontario) Reference Documents: TRCA, 2008	• Parking lot of Seneca College, consisting of permeable interlocking concrete pavers (PICP) • Monitored over 3 years to understand long-term performance • Native underlying soils are clay loam, with groundwater table >3m below installation base	• Only one of 71 reported runoff generating events during the monitoring period showed a related surface flow in the PICP system. This event correlates with the largest precipitation event in the study monitoring period (72 mm in 5.5 hours) • Peak flows from the PICP system were 5% from similar asphalt systems • The base coarse material installed was of greater depth than necessary (see reference document for details) • Performance in winter conditions was reported to be satisfactory, with the PICP feature reported to function to temperatures up to -25°C • PICP was observed to reduce concentrations of Zn, P, TSS, and oil and grease over typical asphalt, reduce temperatures, and have no significant effect on the underlying soil quality over several years of monitoring • The infiltration of runoff laden with de-icing chemicals was listed as a concern, as this may increase the mobility of metals in the infiltrated water • Durability tests showed similar strength characteristics as typical asphalt • Design and maintenance recommendations given in reference document	Risk Decrease: • Significant reduction in site runoff • Reduction in several water quality parameters Risk Increase: • Infiltration of de-icing chemicals a concern, especially related to metals concentrations • Sand inputs significantly decrease performance • More frequently required maintenance (3-4 years)

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