1-1-2010

A Planning Framework For Low Impact Development (LID) In Stormwater Management - An Ontario Perspective

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A PLANNING FRAMEWORK FOR LOW IMPACT DEVELOPMENT (LID) IN STORMWATER MANAGEMENT – AN ONTARIO PERSPECTIVE

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A Thesis

Presented to Ryerson University

In Partial fulfillment of the requirement for the degree of Master of Applied

Science in the Program of Environmental Applied Science and Management

TORONTO, ONTARIO, CANADA, 2010

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ABSTRACT

A Planning Framework for Low Impact Development (LID) Application in Stormwater Management – An Ontario Perspective

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Environmental Applied Science and Management
Master of Applied Science 2010, Ryerson University

Effective management of stormwater is critical to the continued health of the environment. Progression of stormwater management techniques has evolved to include wider, sustainable objectives, particularly the development of Low Impact Development (LID) methods. Despite the recognition that the application of LID practices is a viable approach to older forms of stormwater management, there exist various challenges and barriers to widespread support. In particular, absent is a methodology to plan for LID practices on a large-scale that encompasses not only technical criteria, but economical, and social aspects as well. To address this need, the objective of this study proposes a framework for LID planning on a watershed level. The LID Planning Framework is comprised of four main components evaluated in a sequential process to support the development of effective management strategies. Specifically, hydrological performance evaluation of LID technologies throughout a watershed; cost-effectiveness analysis; and stakeholders' opinions and acceptance levels of these technologies, are used as input to the final decision-making component. The LID Planning Framework is developed in an Ontario context with a particular focus on the Lake Simcoe Watershed. This study will promote an integrated approach to LID planning, which can be used support the uptake of LID principles and encourage more sustainable methods in stormwater management as a whole.

ACKNOWLEDGEMENTS

I would like to acknowledge the Lake Simcoe Region Conservation Authority (LSRCA), the Canadian Standards Association (CSA), and organizers of the “New Directions ‘09 in Stormwater Management” conference for providing meaningful opportunities to consult with stakeholders for this research study.

I would also like to thank my thesis supervisors, Dr. Darko Joksimovic and Dr. James Li for their knowledgeable input and support in all phases of this study.

A special thanks is extended to the LSRCA who made it possible through their own LID Planning project to support the data requirements and financial resources to carry out the case study conducted in this research.

DEDICATIONS

To my parents James and Rose, and my sister, Carolyn, who always believed in me and supported my every endeavor. To my boyfriend, Leonardo Avila, who was with me at every step in achieving this goal - thank you for your enduring commitment and loving support.

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1.0 Introduction

At the turn of the millennium, a historic milestone was reached when the global population passed the six billion mark, doubling since the late 1950s (Sustainability Reporting Program., 2007). While population increase can be a positive driving force of change, there are also numerous negative effects. As human populations grow and consumption patterns rise, natural resources are becoming more and more depleted and pollution releases are intensifying. This effect of urbanization is becoming an ever growing problem particularly where an increasing amount of humans are concentrating in urban areas. The world population was estimated at approximately 6.8 billion inhabitants in 2009 of which half live in urban areas (Population Division of the United Nations Secretariat., 2009). In Canada, during the last 60 years, Canada's population went from 12.3 million to 32.6 million, an increase of more than 20 million (Statistics Canada, 2008). In 2006, not only did four in five Canadians (81.1 percent) live in a metropolitan area, but one in three Canadian (34.4 percent) lived in one of Canada's three largest metropolitan areas, namely Toronto, Montreal and Vancouver. Metropolitan areas with a population of more than 500,000 accounted for more than half of Canada's population (Statistics Canada, 2008). Consequently, the effects of urbanization are of critical concern due to the unprecedented rate of growth and scope of urban centres.

Among the numerous economical, social, and political consequences of urbanization, environmental impacts have been increasingly significant, demonstrated by the evident signals of change. Noticeable changes has been seen in terms of climate, significant natural resources have been depleted, and increased forms and amount of pollutions are constantly being released into the air, water, and land. Consequently, issues related to urban environmental sustainability are finding their way into top level discussions within many governments worldwide. One such issue is the role of water in urban areas (Marsalek et al., 2006)

In the past decade, a rising number of severe catastrophic weather events, such as Hurricane Katrina, have struck coastal urban areas in a detrimental manner (Novotny, 2007). This brought new attention to the current urban environment, its drainage infrastructure and its inability to survive these hydrologic events and perform its functions. However, these concerns are not only focused on these coastal cities. Some urban centres inland are experiencing the opposite. Insufficient water flows are depleting water supplies as well as impacting the surrounding biota. Due to these occurrences, a paradigm shift is occurring where the principles of sustainability are the driving force for developments, both new and old. The new philosophy is that urban centres will be built in a holistic manner where characteristics such as drainage and transportation infrastructure will be integrated with the natural landscape and habitats. Novotny (2007) describes this vision of “cities for the future” is to make urban centres resilient to extreme hydrological events and pollution, while ensuring there is sufficient clean water to support terrestrial and aquatic life, sustaining humans, and achieving an optimal balance for recreational activities, navigational requirements, and other economic uses. The “cities for the future” vision also focuses on the concept of sustainable developments that controls diffuse and point pollution, and reuses highly treated effluents and urban stormwater for various purposes. It is believed that this goal will achieve benefits such as groundwater recharge that will enhance groundwater resources; environmental enhancement of streams currently challenged with effluents and deprived flow; and, increased water supply for areas that experience shortages. This evolving paradigm shift focuses on the taking an integrated approach to urban water management.

Urban water management in general seeks to manage water resources within the developed areas of human settlement. The focus is commonly on the hydrologic cycle and management of the main water system components of freshwater, wastewater, and stormwater, which correspond to urban water services, such as water supply, drainage, sewage collection and treatment, and receiving water uses. Historically, these components were addressed separately (Marsalek et al., 2006), but a more organic attitude is being adopted. The concept of integrated urban water management demonstrates the connectivity and interdependence of urban water resources and human activities, and stresses the importance of handling aforementioned urban water system components in a sustainable ecosystem approach. For example, water supply generally involves the import of large quantities of water into urban areas. While there are some losses along the distribution networks, most of the water is used within the urban area and turned into wastewater. This collected wastewater is treated at sewage treatment plants for most developed cities, which discharge effluent into receiving waters. In addition, as urbanization increases, so do impervious areas and urban drainage systems to compensate this growth. Consequently, these effects contribute to higher stormwater runoff volumes and flow rates, as well reduced recharge groundwater (Marsalek et al., 2006).

Recently, the degeneration of urban water resources has led to the promotion of a sustainable urban water system. This includes elements such as the preservation of natural drainage, lower water consumption, and protection and enhancement of receiving water ecosystems (Marsalek et al., 2006). One of the principal components of the urban water management system that addresses all these aspects is the urban drainage element. It has been established that the traditional practices of urban stormwater management play a significant factor in the degradation of receiving waterways (Brown, 2005). Runoff from impervious surfaces combined with hydraulic infrastructure produce high flows that affect aquatic ecosystems, stream flow regimes, and water quality. Urbanization also leads to fewer opportunities for infiltration, which leads to reduced groundwater recharge, lowered groundwater tables, and reduced base flows in rivers (Marsalek et al., 2006). As more land is cleared, natural vegetation and depressions that intercept rainfall and temporarily store water are lost, and as a result alter the local hydrologic cycle (Bradford & Gharabaghi, 2004). As societies continue to grow, so does the importance of mitigating the effects on receiving waters. Stormwater management is referred to as the knowledge to “understand, control and utilize waters in their different forms within the hydrologic cycle” (Wanielista & Yousef, 1993). This practice and the technologies that are implemented are not expected to be able to eliminate these impacts, but play a key role in alleviating the effects of urbanization. As a result, the objectives of stormwater management have evolved accordingly with the growth of societies.

In Europe, a movement towards sustainable methods in urban planning is underway. This is demonstrated through changes in proposed planning regulations and developments of European wide frameworks, such as the European Union (EU) Water Framework Directive (WFD) (European Parliament, Council, 2009). The mandate of WFD requires a more holistic approach in the decision-making process for water management by all EU member states. The framework obliges members’ commitment to achieve good qualitative and quantitative status of all water bodies, and take prescribed steps to reach common goals. One mandate of the WFD is the production of key documents. This includes River Basin Management plans that must integrate a number of objectives with respect to the protection of the quality of water for each river basin in the EU boundaries. Other directives prescribe steps to achieving goals related to the marine environment, water quantity, water impacts on health (i.e., drinking and bathing water), and water pollution. In terms of urban water management, the EU Council co-funded an action research programme called SWITCH aimed to support a paradigm shift in urban water management (SWITCH Central Management Unit, n.d.). The objective is to change the focus from existing ad hoc solutions towards a more coherent and integrated approach. The vision of SWITCH is for sustainable urban water management in the “City of the Future”. One of the six research themes of SWITCH focuses on stormwater management. The objective is to develop sustainable stormwater management strategies and decision making processes, which will contribute to the achieving the requirements of the WFD.

In the United States (U.S.), the Environmental Protection Agency (EPA) has the overall governing responsibility for developing standards, criteria, guidelines and limitations under the Clean Water Act and Safe Drinking Water Act (U.S. EPA, 2008). The U.S. EPA manages stormwater under their National Pollutant Discharge Elimination System (NPDES) Stormwater Program. This program regulates the discharges related to stormwater from three potential sources: municipal separate stormwater sewer systems, construction activities, and industrial activities. These discharges are considered to come from point sources, and operators must receive a permit before they can discharge. This regulatory framework for stormwater management was developed for the intention of preventing runoff from carrying harmful pollutants into local surface waters such as streams, rivers, lakes, or coastal waters. Most states are authorized to administer the NPDES Stormwater program, where only a few exceptions are under the permitting authority of the EPA. One key aspect of the NPDES program is the implementation of Total Maximum Daily loads (TMDLs). The Clean Water Act mandates all states to identify impaired waters and establish TMDLs for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards. It has been recognized that stormwater sources emit pollutants such as sediment, pathogens, nutrients, and metals into impaired waters. It is therefore required under the NPDES program that all point and non-point stormwater sources are allocated a pollutant loading.

In Canada, water management primarily is handled within each province except for matters related to fisheries, navigational waters, federal lands, and international waters (particularly responsibilities involving boundary waters shared with the United States) (Environment Canada, 2007). For the Province of Ontario, water governance falls under broad legislative frameworks of the Ontario Water Resources Act (R.S.O. 1990, c. O.40), Clean Water Act 2006 (S.O. 2006, c. 22), *and* Environmental Protection Act (R.S.O. 1990, c. E.19). Each Act addresses particular aspects that contribute to the overall governance of Ontario's waters. For example, the purpose of the Ontario Water Resources Act is "to provide for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use, in order to promote Ontario's long-term environmental, social and economic well-being" (Ontario Water Resources

Act, 1990*)*, whereas the Clean Water Act (2006) is in place to protect drinking water at the source requiring the preparation of locally developed, terms of reference, science based assessment reports and source protection plans. The actual management of water is primarily driven by watershed management. A watershed is a natural unit of land defined by the area that drains into a river and its tributaries (Conservation Ontario, 2009). Watershed management is the process of managing human activities with watershed boundaries to support the protection and rehabilitation of land, water, aquatic, and terrestrial resources, while recognizing the benefit of sustainable growth and development (Conservation Ontario, 2009). The administration of watersheds is done by conservation authorities as created and legally mandated by the Conservation Authorities Act *(R.S.O. 1990, c. C.27)*. Their purpose is to ensure the conservation, restoration and responsible management of Ontario's water, land and natural habitats through programs that balance human, environmental and economic needs. It is through watershed planning that stormwater is managed. While at the provincial level guidelines do exist for stormwater management, it is at the local agency level that requirements exist (Bradford & Gharabaghi, 2004). These stormwater management requirements are developed at the local level in the context of broader watershed plans. Depending on the municipality, “guidance” is made mandatory through incorporation into by-laws and other tools available to these local governments. Permits and authorizations are issued by government agencies such as conservation authorities.

The practice of managing stormwater is continuing to evolve in Ontario as the science of watershed management grows. It has been recognized that effective management of stormwater is critical to the continued health of our streams, rivers, lakes, fisheries and terrestrial habitats. Traditionally, the philosophy of stormwater management was to dispose of water from cities as quickly as possible (Gilroy & McCuen, 2009). During the past three decades, the practice of stormwater management has changed significantly. In the 1970s, the primary focus was on flood control (Bradford & Gharabaghi, 2004). This evolved into controlling the quantity of runoff and then to the inclusion of stormwater water quality treatment requirements by the 1990s. Currently, the practice of stormwater management has expanded to include broader issues such as prevention of stream channel erosion, maintenance of groundwater flow and stream baseflow, and protection of aquatic habitats and species.

Techniques to manage stormwater have kept paced with the evolution of objectives. Previous methods typically included end-of-pipe solutions where water was removed from a site and stored in an off-site, downstream facility (Gilroy & McCuen, 2009). This mainly focused on the control of peak discharge. Storage facilities such as detention ponds, wet ponds, and infiltration basins were commonly used methods to address discharge. While these end-of-pipe solutions achieved the objective of controlling downstream peak discharge rates, they did not address other important issues such as increased runoff volume, and preservation of aquatic life (Gilroy & McCuen, 2009). By the 1990s, it was recognized that the traditional designs and systems of stormwater management was out of touch with the environmental values of society. As Brown (2005) expresses, in order for broader, sustainable goals to be achieved, significant changes were needed.

Progression of stormwater management techniques to include wider, sustainable objectives has included the development of Low Impact Development (LID) methods[1] (Gilroy & McCuen, 2009). First implemented in Prince George's County, Maryland (Prince George's County Government, 1999), the LID approach moves beyond the typical stormwater design and encourages more careful site design in the planning phases. The intention of LID practices is to preserve the predevelopment hydrology of a site (Dietz, 2007) by controlling rainfall on-site (Gilroy & McCuen, 2009; Prince George's County Government, 1999). Achieving this objective has included targeting the reduction of volume and rate of surface runoff from development or redevelopment sites. Practices that target control of stormwater at-source and on conveyance systems that discharge to downstream watercourses are typically focused on in implementation of LID methods (Graham et al., 2004).

In the recent years, it has been recognized by governments and developers that the application of LID practices is a viable approach to older forms of stormwater management (Graham et al., 2004). However, incorporating the approach into existing frameworks and providing guidelines for implementation have been slow despite the increased awareness and knowledge (Elliott & Trowsdale, 2006). The practice is still considered to be fairly new since the first formal application occurred in 1999 (Prince George's County Government, 1999). In the past few years, over 30 stormwater management manuals and guidelines have been released in locations such as British Columbia (Government of British Columbia, 2002), Michigan (SEMCOG, 2008), the United Kingdom (UK) (CIRIA, 2007), and Australia (South Australian Government, 2009). All these manuals are considered to be the most up-to-date with the current approaches and practices. Subjects such as modelling concepts, the use of the treatment train

[1] Appendix A provides examples and descriptions of LID practices considered throughout this study.

approach and the application of LID practices have emerged within these manuals (CVC & TRCA, 2010). However, majority of these guidelines are more technically focused where aspects such as economic, social and cultural criteria are only touched upon and not included extensively in the planning framework. Some manuals produced by governments recognize the need for taking a more holistic approach and integrating some of these other factors into the planning process (SEMCOG, 2008; Ellis et al., 2006; Lai et al., 2009).

In addition to the challenges associated with the limited holistic planning frameworks, there exists a shortage of LID drainage design tools that operate at the necessary range of scales (Elliott & Trowsdale, 2006; Elliott et al., 2009). Since traditional stormwater structural Best Management Practices (BMPs) are commonly implemented, the existing conventional stormwater models are typically oriented to facilitate design and implementation of these centralized BMPs (Cheng et al., 2004). Therefore, there is currently a lack of models that are developed specifically to address LID hydrology (Graham et al., 2004). With the models that do exist, simulation of LID systems is more challenging than simulating traditional stormwater systems (Heaney & Sansalone, 2009). The availability of effective LID modelling software is essential to the selection, design and application of LID practices (Elliott & Trowsdale, 2006). The existence of these tools will not only allow for the evaluation of LID drainage measures at a range of scales applicable to urban management, but could act to encourage wider uptake of LID principles (Elliott & Trowsdale, 2006). Currently there are over 40 models for urban stormwater (Elliott & Trowsdale, 2006) where many allow for the modelling of these complex decentralized systems (Heaney & Sansalone, 2009). However, each model handles important processes differently and the implications and effectiveness of each of these models in determining LID performance is still being determined (Wright et al., 2000; Heaney & Sansalone, 2009).

Another issue that is connected to LID implementation, as well as integrated urban stormwater management as a whole, is recognizing the importance of stakeholder participation from the initial planning process. Organizations, such as the Credit Valley Conservation (CVC) and the Toronto and Region Conservation Authority (TRCA), both in Ontario, have acknowledged the integrated design process and the requirement to involve a range of disciplines into the planning and design team for LID projects (CVC & TRCA, 2010). This recognition of a need for an integrated approach in planning, design and implementation of LID practices also extends worldwide (Government of British Columbia, 2002; Brown, 2005; Ellis et al., 2006). Some groups, such as the Southeast Michigan Council of Governments (SEMCOG), has taken this concept one step further and have identified that sustainable stormwater management needs to involve not just the traditional stakeholders of stormwater management, but a wider group (SEMCOG, 2008). Individuals such as elected officials, landscape architects, and representatives from the community, should be included in the planning stages. Without the support of all affected groups, other issues can arise such as jurisdiction complications, lack of participation, and ineffective implementation. While incorporating various stakeholders, both from public and private domains, into the selection process of LID practices has been recognized as being necessary for effective and sustainable implementation, the process can also be complex and cumbersome (Ellis et al., 2006). Each group holds differing opinions, where significance of technical, environmental, economic, and social criteria ranges. Research and development into creation of broader planning frameworks and decision support tools are currently underway (i.e., Ellis et al., 2006; Makropoulos et al., 2008; Lai et al., 2009); however, these methods are still in their development phases. Therefore, until these broader frameworks and decision support tools that incorporate other criteria into the planning process exist, municipalities will continue to experience challenges in the involvement of wider stakeholder groups into the planning process of LID systems (Ellis et al., 2006).

Despite the existing challenges associated with LID planning, jurisdictions and organizations are making progress in mitigating them. Various test studies have been initiated (Wossink & Hunt, 2003; Banting et al., 2004; CALTRANS, 2004; TRCA, 2007; Farahbakhsh et al., 2008; TRCA, 2008), particularly on the local level. Implementing LID practices on a larger scale, however, have been fewer in numbers, as discussed further in Chapter 3. One organization seeking to resolve some of these issues of large-scale LID planning is the Lake Simcoe Region Conservation Authority (LSRCA).

Due to numerous water quality and quantity issues in the Lake Simcoe Watershed, several initiatives, such as the Government of Canada's Lake Simcoe Clean-up program (Environment Canada, 2009), are currently underway. The purpose of these programs is to encourage watershed stakeholders to not only apply conventional techniques of stormwater management, but to apply alternative practices as well. In addition, the Lake Simcoe Protection Plan (Government of Ontario, 2009) has stated that municipalities should consider source and lot-level controls before proposing traditional stormwater treatment facilities (OMOE, 2009). As a result, the LSRCA is currently engaged in a study to plan for the implementation of LID technologies at selected areas throughout the watershed. It is a desired outcome by the organization that the study will provide guidance to watershed municipalities for incorporating LID technologies into their stormwater management master plans (Li et al., 2009).

The data in the LSRCA LID Planning Project are used in this thesis as a case study to support the research goals. This thesis proposes a framework for LID planning on a watershed level, as there is a recognizable lack in this area, particularly in a Canadian context. The LID Planning Framework establishes four components to developing effective management strategies to apply in initial stages for wide-spread LID implementation. As such, the proposed Framework begins with an evaluation of the hydrological performance of implementing LID technologies throughout a watershed, followed by determining the cost-effectiveness of that application. Finally, through the use of stakeholder participation methods, the acceptance of these technologies can be included in the decision-making process to optimize management strategies. The three components of the LID Planning Framework are developed in an Ontario context with a particular focus on the Lake Simcoe Watershed. This study will promote an integrated approach to LID planning, which can be used support the uptake of LID principles and encourage more sustainable methods in stormwater management as a whole. In addition, the concepts discussed throughout the study and the methodologies that are developed may have potential applicability to watersheds and jurisdictions outside of Ontario's borders. The specific objectives, scope, and organization of the thesis are discussed in the remainder of the chapter.

1.1 Objectives

As a result of these deficiencies in a holistic approach to LID selection and performance assessment discussed above, a need has been identified for an approach that would assist with the transition to a more sustainable approach to urban stormwater management. Specifically, it has been identified to assist with closing the gaps in LID planning methodology on a watershed level. The main objective of this thesis is to develop a planning framework (hereafter referred to as "The Framework") for LID implementation on a watershed level in Ontario. Through the creation of this framework, additional study objectives will be satisfied:

1. To develop a modelling approach for the evaluation of benefits of LID implementation on a watershed basis.

2. To apply cost-effectiveness analysis for the purpose of developing optimal management strategies.
3. To develop a methodology for collecting stakeholder opinions and an analysis approach that can be applied in LID planning.
4. To integrate all methodologies from the previous three objectives to optimize management strategies for LID planning.

1.2 Scope

Based on the above objectives, the scope of the study is:

1. To describe the function of each component of the proposed Framework, where each section will be developed from an Ontario perspective.
2. To apply the components of The Framework in detail through a case study for the Lake Simcoe Region Watershed that will demonstrate the effectiveness of the approach to plan for the implementation of five lot-based LID technologies that accepts roof-top runoff, throughout the study area. The five LID practices are green roofs, soakway pits, downspout disconnection, dry well, and rainwater harvesting.

1.3 Organization of thesis

The thesis is comprised of eight chapters. Chapter One begins with an introduction of the research needs, as well as the objectives and scope for carrying out the study. It also provides a brief overview of the watershed used in the case study. Chapter Two provides an overall description of the Framework that establishes the structure of the thesis. Chapters Three to Six describes the function of each component in the Framework. Each of these chapters includes a literature review to appropriately describe the component's purpose in the framework and any existing studies to support the methods proposed. Chapter Seven is the case study. Data from the Lake Simcoe Watershed was used to demonstrate the usefulness of the proposed LID Planning Framework. Chapter Eight highlights the conclusions of the research study, and provides recommendations based on the findings.

2.0 LID Planning Framework

Legislative and administrative frameworks are used in all societies to provide a systematic process to handle complex issues. It ensures quality and capability of meeting goals such as those related to the environment. As described previously, urban water management in general is handled under a broad regulatory framework. Depending on the country, the degree in which specific water management aspects are controlled vary widely. As seen in Ontario, stormwater management falls under a number of broader legislative frameworks. While direction does exist under these frameworks, explicit guidance is limited or outdated. For example, to date, the most current stormwater management guidance issued by the Ontario Ministry of Environment (OMOE) is the 2003 OMOE Stormwater Management Planning and Design Manual (OMOE, 2003). Even though the guidance document reflects current technology, such as the use and design of BMPs, the information is becoming rapidly out of date. Most of the material reviewed is dated prior to1999; climate change factors and methods of adaption are not discussed; and newer philosophies and practices are not included (CVC & TRCA, 2010; Environmental Commissioner of Ontario., n.d.). In the last five years, jurisdictions worldwide have released stormwater management manuals and guidelines that are considered to be the most up-to-date with technologies and concepts. Objectives such as maintaining predevelopment hydrology, the use of the treatment train approach, and LID methods form the bases of these documents (CVC & TRCA, 2010). These concepts are all applicable in Ontario's watersheds. Incorporating LID principles into existing frameworks and providing guidelines for implementation have been slow despite the increased awareness and knowledge (Elliott & Trowsdale, 2006). The first Ontario-based LID Stormwater Management Manual was issued early 2010, where other jurisdictions such as Prince George's County, MD have been implementing LID concepts since 1999 (Prince George's County, 1999). Despite this slow process of providing provincial stormwater management guidance, local agencies such as the LSRCA, and municipalities such as the Regional Municipality of Waterloo, and City of Toronto are championing the movement by engaging in LID projects within their jurisdictions (Li et al., 2009; WESA, 2007, Banting et al., 2005).

Users of LID practices include a broad range of parties that includes various levels of government and private consulting engineers, scientists and planners, members of the research community, NGOs and other local agencies, as well as concerned citizens. Each group of stakeholders would benefit from the LID implementation and design knowledge to some level of degree. However, it is often traditional stakeholders of stormwater management, which include representatives from governments and agencies, engineers, scientists, and watershed planners that would benefit the most from the existence of LID planning frameworks and design guidance. One major challenge facing users of LID practices is the selection of technologies for specific locations to support large-scale watershed planning. Existing manuals issued by governments and other institutions provide guidelines for application of LID methods on primarily a lot-level. In addition, the focus is primarily on design of LID technologies, where relevant site, development, and hydrological characteristics are detailed. For example, Prince George's County LID manual provides a step-by-step design approach that uses the definition of hydrological control goals and evaluation of site constraints to screen for LID practices (Prince George's County Government, 1999). Likewise, manuals produced in Michigan (SEMCOG, 2008) and Ontario (CVC & TRCA, 2010), use a similar process. The use of fact sheets and checklists are also employed to ensure the LID designer includes all important design criteria relevant to planning and performance (SEMCOG, 2008; CVC & TRCA, 2010). While these guidelines are useful, the task of selection and placement is still a challenging task for many planners working beyond the lot-level. For example, planners working on a master (watershed) level, other aspects need to be taken into consideration such as jurisdiction issues, social concerns, and economic impacts. The challenge for developers of these manuals is to produce guidelines that targets all types of groups, as well as presents a more integrated approach to LID implementation, regardless the spatial scale. Despite the recent issues of some manuals (i.e., SEMCOG, 2008) providing some consideration of these broader aspects such as legal matters, costs, and social concerns, a more appropriate, all encompassing framework for LID planning and implementation is needed.

2.1 Existing frameworks that support LID principles

The need for an integrated approach to LID planning and stormwater management as a whole has not gone unrecognized within the scientific and public community. There has been some work in the incorporation of LID principles into existing frameworks and even the development of new decision-support tools to allow planners and stormwater managers to consider the use of LID practices. In the U. S., the System for Urban Stormwater Treatment and Analysis (SUSTAIN) was developed by the U.S. EPA to act as a decision-support tool to assist agencies in the creation of strategic management options and placement of BMPs in urban watersheds based on cost and effectiveness (Lai et al., 2009). The BMP/LID options that are provided are done so with the consideration of significant water quantity and quality factors in urban watersheds (Lai et al., 2007). SUSTAIN is intended for users who have a fundamental watershed knowledge and BMP modeling processes. This includes various levels of government and private consulting engineers, scientists and planners, federal and state regulatory reviewers, and members of academia. The concept behind this framework takes into account “watershed-based placement scenarios” and “tiered analysis”. The idea is that a relatively large watershed can be sub-divided into several smaller sub-watersheds. For each sub-watershed, users can select suitable and feasible BMP technologies based on type, configuration, and cost to be placed at deliberate locations. SUSTAIN provides the platform to predict the quantity and quality of stormwater runoff with these BMPs placed at strategic points. In addition to assisting watershed and stormwater practitioners to develop, evaluate, and select optimal BMP combinations at regional and local levels, the tool can be used for a number of planning activities. For example, as shown in Figure 2-1 at various points throughout the watershed planning process, SUSTAIN can be used to define various decision options.

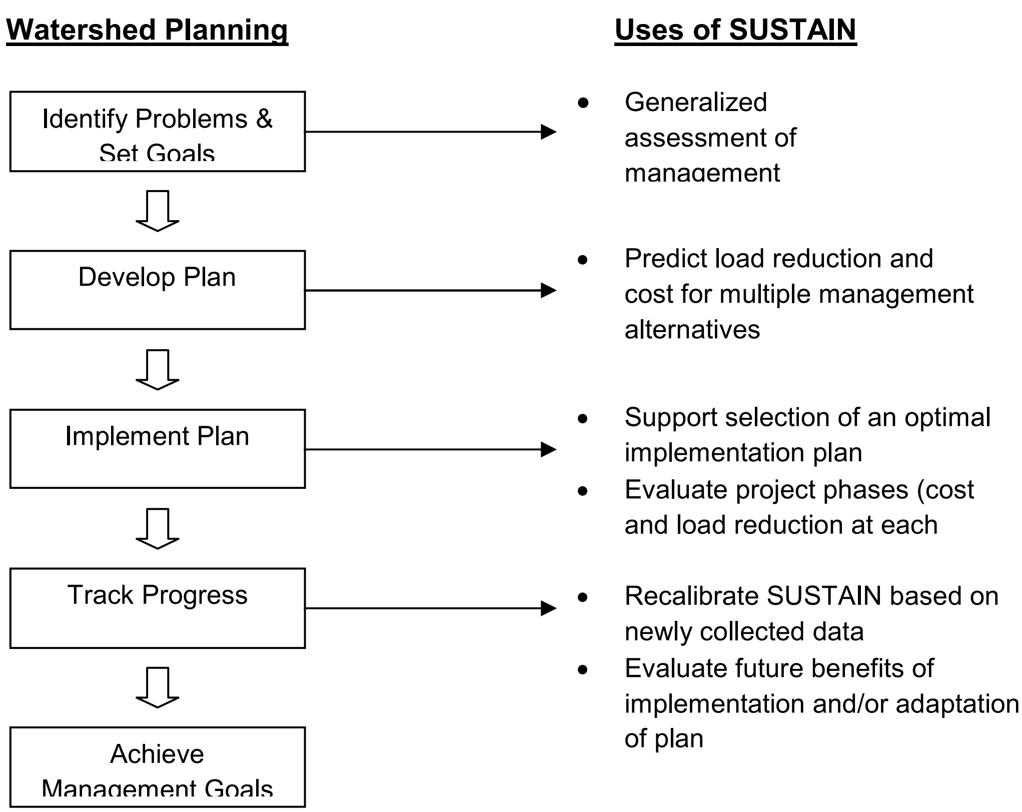

Figure 2-1: Uses of SUSTAIN in U.S. Watershed Planning Process (adapted from U.S. EPA, 2009)

In addition to these applications, SUSTAIN can be used to: develop TMDL implementation plans, identify management practice to achieve pollutant reductions, determine optimal green infrastructure strategies for reducing volume and peak flows to combined sewer overflow (CSO) systems, quantify benefits of implementing "green" infrastructure on water quantity and quality in urban streams, and develop a BMP installation plan using the cost effectiveness data.

The Australian developed Model for Urban Stormwater Improvement Conceptualisation (MUSIC) offers a different approach for stormwater-related decision-making. As indicated in its name, the decision-support tool is intended to assist organizations plan and design at the conceptual level appropriate urban stormwater management systems for their catchments. MUSIC allows users to simulate both quantity and quality of runoff from catchments ranging from a single house block up to many square kilometres. The tool also allows for the prediction of the effect of a wide range of treatment facilities on the quantity and quality of runoff downstream. The concept of the simulation framework employs the "treatment train" approach, which seeks to evaluate the performance of a group of stormwater management measures configured in series or in parallel. The effectiveness of the whole system is based on a risk-based approach, which considers the assessment of

1. "the long-term frequency in which receiving aquatic ecosystems is subjected to exposure of pollutant concentrations above a pre-specified threshold level and/or
2. the long-term mean annual pollutant load delivered to the receiving waters" (Wong et al., 2005)

The product is a flexible decision-support system that assists in the conceptual design for the most efficient and cost effective urban stormwater system that meets water quality standards for local catchments, as well as monitor and assist with the development of guidelines for the urban water management industry. Despite its widespread use in Australia, particularly to support LID initiatives, the application cannot be used as a detailed design tool. As a result, it must be used in combination with other analysis methods. The current version of MUSIC does not incorporate all aspects of stormwater management that must be considered by the decision-maker. LID design and stormwater management in general is based on factors other than stormwater quality. Aspects such as hydraulic analysis for stormwater drainage, indicators of ecosystem health, and integration of facilities into the urban landscape are not included in the framework.

Research in the area of integrated planning tools for water management has increased substantially in Europe over the past decade, signalling significant movement towards sustainable methods in urban planning. The EU WFD demonstrates this progress (Ellis et al., 2006). The mandate of WFD requires a more holistic approach in the decision-making process for water management (Ellis et al., 2006). One decision-support tool to assist in stormwater management, specifically, is the web-based Adaptive Decision Support System (ADSS) called Hydropolis that was developed under the DayWater EU 5th Framework Programme project (Ellis et al., 2006). This program assists with the process of identifying possible BMP solutions for urban stormwater management taking into account development location and community aspects. The framework employs a Multi-Criteria Analysis (MCA) approach that ranks the BMP alternatives to include structural and non-structural controls in a performance matrix. This provides the means to reducing the alternatives to a short list that can assess in further detail, as well as identify solutions that are not possible. The Hydroplis decision-matrix is based on seven principal Areas of Concerns (AoCs). These AoCs include site characteristics, technical, environmental, economic, operation and maintenance, social and urban community benefits and legal and urban planning criteria. Site characteristics are used for initial characterization and screening of suitable BMP alternatives. For example, infiltration practices would be eliminated as options for sites that have high groundwater levels. The other remaining six AoCs are further divided into indicators which each have benchmarks of reasonable threshold values and units. The performance matrix is displayed online, allowing users to connect at anytime. Following completion of the matrix score, weightings can be applied to reflect the importance placed on each criterion and/or indicator by all stakeholders. The advantage of using Hydropolis and its capability to incorporate stakeholders' viewpoints and strategies allows for it to be used as a "negotiating tool" that highlights areas of agreement and a means of maintaining focus among various stakeholders. However, similar to MUSIC, Hydropolis is not intended to be a BMP drainage design approach and other hydraulic and water quality tools will have to be use for aspects such as sizing of individual technologies.

In Canada, the development of integrated decision-support systems for stormwater management has lagged behind the rest of the world considerably. To date, British Columbia has the most "state-of-the-art" decision-support tool in Canada with the Water Balance Model powered by QUALHYMO (WBM). WBM assists decision makers by bridging the objectives of engineering design and planning to create sustainable communities (British Columbia Inter-Governmental Partnership, n.d.). Two previously separate existing rainfall-runoff simulation models were merged to create a tool that integrates continuous hydrologic simulation capabilities of QUALHYMO with built-in databases of land use, low impact system, and soil and local climate information contained within the previous Water Balance Model. The decision-support tool allows users and reviewers to compare multiple development and land use scenarios, as well as focus on a multitude of design details available to achieve the desired objectives. The tool can also be used for planning on a site level to a watershed level. On a site level, users can evaluate the effectiveness of source controls to achieve performance targets for rainfall volume capture and runoff rate control based on various combinations of land use, soil and climate conditions. On a watershed level, engineers and local governments can use WBM to achieve desired urban stream health and environmental protection objectives.

The framework currently used in stormwater management in Ontario is not as developed and current as that followed in British Columbia. As described earlier, the OMOE Stormwater Management Planning and Design Manual (OMOE, 2003) provides overlying guidance document for the implementation of stormwater management facilities within Ontario. It describes the accepted planning and approval process and the required environmental studies that must be completed. The OMOE manual provides design criteria for "conventional" end-of-pipe stormwater management practices such as wet ponds and constructed wetlands but provides only limited information about lot level and conveyance controls. The OMOE manual does, however, emphasize the use of a treatment train approach to reduce the impacts of stormwater runoff. A treatment train approach employs lot-level, conveyance, and end-of-pipe stormwater management practices in combination. This type of approach is usually required to meet the multiple objectives of stormwater management, which include maintaining the hydrologic cycle, protecting water quality, and preventing increased erosion and flooding. A treatment train approach supports the principles of LID and its methods. Recognizing the need to continuously support the evolvement of stormwater practice in Ontario, conservation authorities have taken it upon themselves to improving management strategies. They believe that an improved understanding of the requirements for stormwater management will lead to improvements in management practices and an increasingly standardized and streamlined approach to addressing stormwater throughout their watersheds (CVC & TRCA, 2010). These organizations are currently in the process of developing guidance material for LID design and implementation. One key document, the LID Stormwater Management Planning and Design Guide (LID SWM Guide) (TRCA & CVC, 2010) has been issued with the intention to augment the OMOE Stormwater Management Manual. Drawing on a number of published resources and local studies, the guidance document provides planning and design direction to users of LID practices for a number of lot-level and conveyance stormwater management practices currently used world-wide. The LID SWM Guide should be seen as a technical design guideline in that the inclusion of broad decision-making criteria is not included extensively. While some costs estimates are provided for the LID practices addressed in the manual, it is left to the user of the manual to consider other aspects, such as social elements that may impact effective implementation.

All other existing decision support tools are primarily modelling tools that use mainly technical criteria to analyze the placement of stormwater management strategies. To date, there are no planning frameworks similar to SUSTAIN (Lai et al., 2009), Hydropolis (Ellis et al., 2006) and WBM (British Columbia Inter-Governmental Partnership, n.d.) in Ontario.

2.2 Framework Overview

The proposed LID Planning Framework is aimed at providing a structured approach in applying sustainable technologies for the management of stormwater. Generally the LID planning framework will facilitate the identification of LID systems that are appropriate for implementation based on the conditions to which each LID is suited and the geographic extent of these conditions across the study area. At the conclusion of a LID planning study, a planner should be able to identify the appropriate LID practices that should be used for a given area within a watershed and the performance of placing the LID practices at that specific site. In addition to these aspects, it is necessary for planners to take into consideration cost information. This should be evaluated against the goals of the study (e.g., cost of reducing phosphorus entering the lake with the application of LID methods). Analyzing the cost-effectiveness of LID practices occurs typical in planning studies and is an important decision factor for selecting LID technologies. Lastly, the success of applying LID practices relies on the acceptance and support of stakeholders implementing the systems. Watershed planners are therefore required to understand and evaluate the opinions and concerns of those who will apply LID technologies in order to eliminate any barriers and to ensure effective implementation. The conceptual framework includes four main components, which should be evaluated in a specific sequence. An overview of the function of the LID planning framework, as well as a brief description of the role and function of each component is described in the next few sections.

The proposed sequence of the LID planning process along with a brief description of the aspects addressed in this study is shown in Figure 2-2. As shown highlighted in a grey background, the first major component of the framework evaluates the hydrological performance of LID practices implemented within the watershed. The evaluation methodology consists of applying screening criteria based on site and development characteristics to select LID systems to be placed within areas that are hydrologically similar. The performance of these LID systems are then determined for these hydrologically similar areas, termed Hydrological Response Units (HRUs), using a modelling approach developed through this thesis research. Once all the HRUs are modelled, the performance of each can be aggregated over the watershed.

The second component, the cost-effectiveness analysis, is performed to understand what types of costs will be associated with the placement of LID systems within the study area. The objective will be to determine the balance that can be achieved between the total cost (e.g. implementing, operating, and maintaining) and the goal (e.g., improved water quality) being sought on a watershed level.

The third component of the LID planning process takes into account the interests of stakeholders. Involving stakeholders' preferences in the decision-making process is an important factor for successful LID implementation. Currently LID practices can be applied in two scenarios, new development or retrofit opportunities. For new developments, the implementation of LID practices is simplified significantly where the main factors relate to site-specific screening criteria. Furthermore, these new developments are only a fraction of the urbanized land. If broader, sustainable objectives in urban water management are to be achieved, proposed stormwater management initiatives need to account for presently existing developments, which are majority of the cases. For retrofit opportunities, implementation is more difficult, particularly on a large-scale level. Retrofit application of LID practices requires watershed planners to understand who will be implementing these systems and how to gain their support for implementation. Considering their concerns will allow for more effective program and policy development, as well as the provision of directed guidance to ensure acceptance and uptake of LID principles. Engaging in stakeholder consultation on this final step will allow the watershed planners the capability to give advice and guidance to the various types of stakeholders within a watershed that represent a possible diverse range of areas.

The final component in this framework is the application of decision-making theory. It is at this point in the process that all the results from the previous three components are integrated to form possible LID planning solutions. Various theories and approaches can be applied to develop these solutions.

Upon application of the framework, it is believed a useful tool to facilitate LID planning will be created. The framework described in this chapter forms the core of this study. Each component is described in further detailed in the subsequent four chapters.

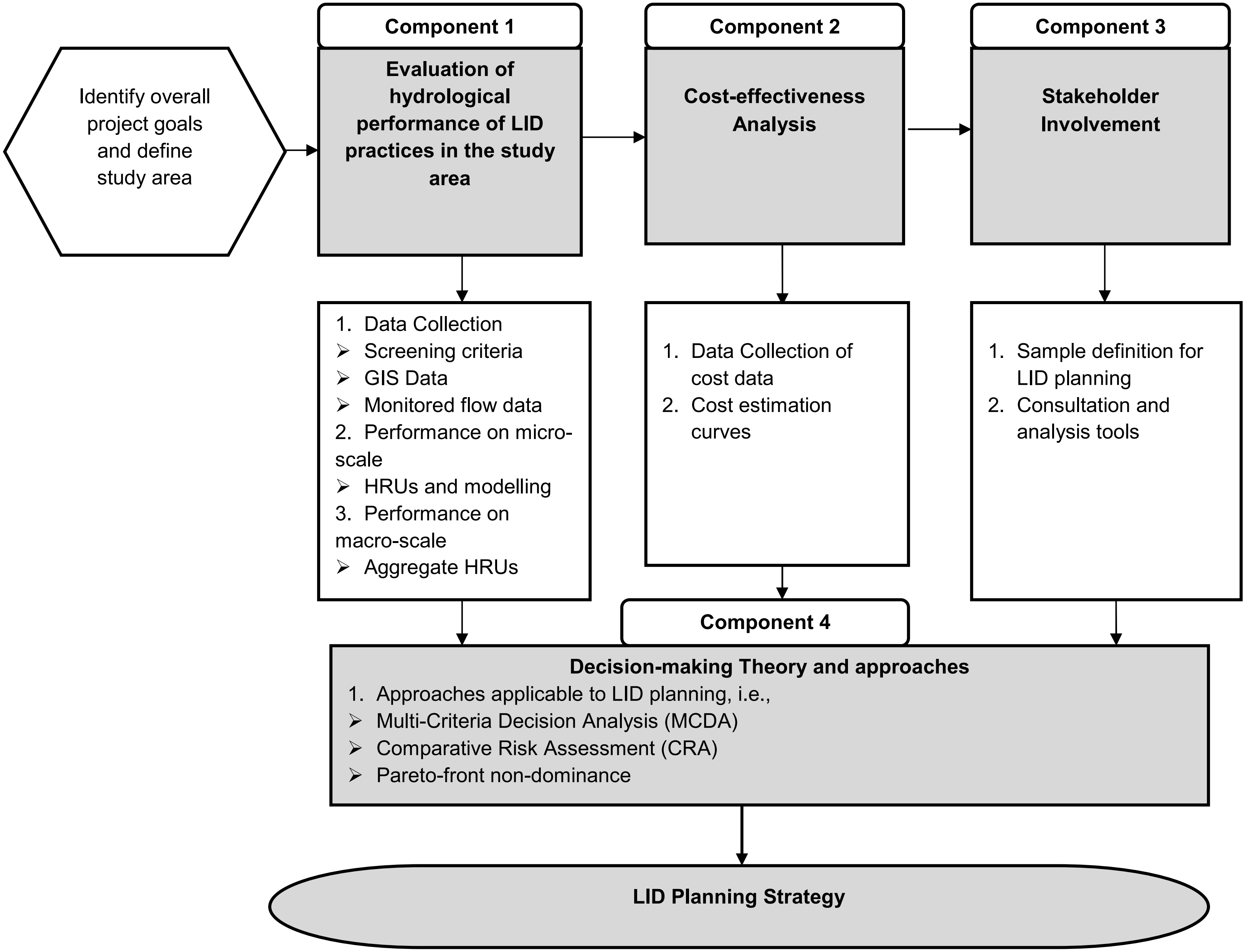

Figure 2-2: LID planning process

3.0 Evaluation of Hydrologic Performance in LID planning

3.1 Introduction

Watershed management in generally is a complex process that requires maintaining a balance among various technical, social and economic elements within the watershed boundaries. A major component of watershed management is predicting the effects of urbanization on all aspects of the hydrologic cycle (OMOE, 2003). Analysis approaches within jurisdictions focus on evaluating the sensitivity of the watershed system to hydrologic impacts such as reduced groundwater recharge, issues regarding water quality and quantity, and the affect on aquatic habitats. Traditionally, such analyses have concentrated on evaluating the hydrological performance of conventional stormwater practices. However, due to the emergence of LID practices and their technical nature, establishing an approach to evaluate their performance has been challenging. This has been seen as a particular issue for planning on a watershed level. Existing research studies centered on this large-scale objective are limited particularly within a Canadian context. The cases that do exist are typically demonstrated at the source or local scale, which do not experience the same number of challenges as planning on a larger scale, such as accounting for the variability of the land or the increased number of stakeholders.

While the advantages of LID implementation are generally known and have been accepted of its possibility to improve watershed health (Duram & Brown, 1999; Li et al., 2009; Farrell & Scheckenberger, 2010), only a limited number of studies have been conducted to evaluate the potential performance of these technologies on a large scale. In addition, a major component to making the appropriate selection of LID practices for desired locations within a watershed is having the appropriate drainage design tools that can operate at the necessary range of scale (Elliott & Trowsdale, 2007). Since LID applications in stormwater management are still a relatively new concept, the availability of effective LID modelling software is still limited (Heaney & Sansalone, 2009). While many of the current tools will allow for the modelling of these decentralized systems (Heaney & Sansalone, 2009), the specific characteristics of majority of these practices are not built into the software and many assumptions are required. This framework component aims to address some of these issues that have risen regarding the evaluation of hydrological performance of LID technologies throughout a watershed. Specifically, an approach will be outlined to select appropriate LID practices that can be used for a given area within a watershed, as well as determine the overall benefit achieved for placing the technologies at those specific sites.

3.2 Review of Literature on Existing LID Performance Studies and Models

3.2.1 Existing research studies for the evaluation of LID hydrological performance

While limited in number, there are a few existing studies that evaluate hydrological performance of LID-type technologies over a large scale. One of the first studies of this nature in Canada occurred in Ontario as part of the Toronto Wet Weather Flow Study (WWFS) (City of Toronto, 2003). This study applied the concept of developing unit models for generic land use conditions. Each unit model represented one hectare of development for a specific land use condition, characterized by soil type, topography, connectivity to minor systems, as well as the presence of LID stormwater management practice (City of Toronto, 2003 as cited in Farrell & Scheckenberger, 2010). The approach that was developed aimed to produce the hydrographs that described the surface runoff and groundwater recharge responses for each generic land use. These Unit Response Functions (URFs) were generated by applying the U.S. EPA Hydrologic Simulation Program – Fortran (HSP-F) for a continuous simulation using four years of meteorological data. Each URF was multiplied by the areal composition of the respective generic land use and was used to quantify the impacts of implementing the LID practices on groundwater recharge. It also provided the means to determine the effects on peak flow response and flood risk that could result from a land use change. While the study demonstrated an approach to assess the overall benefits of applying LID practices at the subwatershed scale, the process was quite time intensive, requiring several hours to carry out one simulation to generate the URF. In addition, the simulation period of four years was insufficient to conduct a thorough frequency analysis to quantify flood risk. Typically, a continuous simulation period of 20 years is used (City of Toronto, 2003 as cited in Farrell & Scheckenberger, 2010) is used for modelling.

Applying the approach taken in the Toronto WWFS, the Credit Valley Conservation (CVC) carried out a Flow Management Study (FMS) (Phillips Engineering Ltd., 2007). The objective of this study was to recommend stormwater management practices for flood control to be implemented at main branch Flood Damage Centres throughout the watershed. Building upon the experiences of the Toronto WWFS, the CVC FMS utilized a continuous simulation of 40 years of meteorological data using the HSP-F method. Instantaneous peak flow rates were determined at key locations along the Credit River through a Water Quality Study. The Water Quality Study applied a version of the WWFS HSP-F model (Phillips Engineering Ltd., 2007). As part of the overall study, a simulation approach was developed to evaluate LID practices at the sub-catchment scale. It included applying the HSP-F model for larger catchments of mixed land use (Phillips Engineering Ltd., 2007). To determine the simulation techniques for the LID practices, specific information was required as well as methods incorporated from the Water Quality Model. The result was an approach to adequately simulate the hydrologic effects of implementation of the LID practices, particularly related to reduction of runoff volumes that could be applied at the sub-watershed scale.

Recognizing the need to conduct hydrologic analyses before the Stormwater Management and Site Plan stages (typical to Ontario (OMOE, 2003)), Farrell and Scheckenberger (2010) developed an approach to apply a “generic” storage routing element to represent infiltration techniques, which could be used at the Subwatershed Study stage. Studies such as Site Plans occur at the final stages in the stormwater management planning process, which focus on the requirements of the specific development area (Farrell & Scheckenberger, 2010). It was reasoned that it is necessary to evaluate the performance of LID practices on a wider scale in order to incorporate the broader objectives of these governing higher-level studies, as well as understand their impacts with respect to the overall environmental system. The approach developed assessed LID practices that promote infiltration of urban runoff. Using a generic design concept to represent the various infiltration technologies, the HSP-F hydrologic model was applied along with a long-term continuous simulation methodology. The result of the study produced a methodology of evaluating the long-term effectiveness of LID practices that promote infiltration at the subwatershed stage for new development areas. It was also demonstrated that the developed method could be used to provide direction related to maintaining the water balance within the study area, as well as determining required efficiencies for the sizing of end-of-pipe facilities (Farrell & Scheckenberger, 2010).

Among the existing studies attempting to evaluate the benefit of large-scale LID practices in general, there are a few cases that focus solely on the widespread implementation of just one practice, particularly green roofs. In 2005, the TRCA contracted a study to determine the effectiveness of implementing green roofs within the Highland Creek watershed by assessing its impact on water quality, flooding, water balance and erosion (Aquafor Beech Limited, 2005).

The approach utilized the HSPF model and the concept of URFs applied in the Toronto (2003) WWFS. These URFs developed in Toronto (2003) was redefined to represent the percentage of land uses where flat roofs could be used for green roof implementation in the Highland Creek Watershed. Assuming that the minimum roof area available for application was 100 m^2 and only 75 percent of each roof would be used, 50 and 100 percent implementation of suitable land use scenarios were modeled to evaluate the hydrologic benefit (Aquafor Beech Limited, 2005). Among the conclusions from the study, it was found that while Highland Creek is a good candidate to consider green roofs since approximately 30 percent of the land uses have flat roofs, the results show that only a fairly small runoff volume reduction of approximately 4 percent can be obtained at the mouth of Highland Creek assuming a 100 percent implementation (Aquafor Beech Limited, 2005). It was found, however, that the percent reduction does vary on subwatershed level depending on land use and suitability for implementing green roofs (Aquafor Beech Limited, 2005).

Following this study, a research team from Ryerson University working on behalf of the City of Toronto, applied the concepts and results produced from the Highland Creek green roof study to determine the environmental benefits of green roof application throughout Toronto (Banting et al., 2005). The study aimed to evaluate these benefits by taking into account specific land uses using the Geographic Information System (GIS) environment. The purpose of using the GIS tool was to produce a methodology that took into account the characteristics and distributions of actual rooftops across Toronto. Similar to the methodologies applied in Highland Creek Green Roof Study (Aquafor Beech Limited, 2005), Banting et al. (2005) applied the URF concept to assess the ability of the green roofs to divert stormwater from sewers. Similarly, HSP-F was used for modeling and specific URFs were adopted directly from the study (Aquafor Beech Limited, 2005) if there was a corresponding land use category. If the model was not available, then URFs were averaged from the Highland Creek study if there were a few similar land use categories (Banting et al., 2005). The URFs that were used represented the annual runoff from one hectare of drainage area of certain land use category (Banting et al., 2005). Based on the assumption that the runoff process is linear, total runoff is predicted by multiplying the area by its corresponding URF. Applying this concept, the URFs to estimate runoff with and without green roofs application was established for various land use categories that typify Toronto. These results were then used in combination with GIS to assign predicted runoff to suitable roof areas for each land use in the study area. The roof areas that were assumed suitable for green roof application were at least 350 m^2 on buildings with low sloped roof surfaces and the green roof would occupy 75 percent of the area. GIS also provided the means to aggregate the stormwater reduction obtained by green roof application across the whole city, demonstrating the hydrological benefits of implementing this LID technology.

Among the studies reviewed, there are some noteworthy elements that can be applied in the development of a methodology to evaluate the performance of LID technologies on a watershed level. The Toronto WWFS the process provides an initial basis for evaluating LID practices at the sub-watershed scale, particularly the cumulative impacts. The concept employed of using generic unity models that was characterized by aspects such as land use condition, soil type, topography, and LID type suitability, proved to be very useful for LID performance evaluation. In the CVC FMS, the cumulative impacts of LID practices were not evaluated. However, it was shown that the current approach of representing the cumulative hydrologic impacts of stormwater management systems using a single routing element at the sub-catchment outlet is still appropriate. One aspect the CVC FMS also pointed out that should be considered in developing a LID performance evaluation methodology is the need for specific information regarding the types of LID practices. It is important for this information to be established in the context of future land use condition, as well as in order to generate the storage-discharge relationship for the model routing element. The study by Farrell and Scheckenberger (2010) introduced the concept of generic storage elements to represent infiltration techniques. The approach applied consisted of practical aspects for an evaluation method applied in the context of sub-watershed planning. However, the study addressed several LID practices and it was developed for application in new developments. The final two studies reviewed both looked at evaluating the benefit of large-scale green roof implementation. The study focusing on the Highland Creek watershed (Aquafor Beech Limited, 2005) defined appropriate assumptions for modelling green roofs in Toronto, which can be used in any further development of hydrological performance evaluation methodology. The Toronto Green Roof Study (Banting et al., 2005) demonstrated the usefulness of the GIS tool in producing a method for assessing the benefit of green roof application in Toronto. GIS as a means of forming the basis of the performance evaluation methodology is relevant to the development of a method to evaluate numerous LID technologies. The tool provided the means of taking into account the characteristics and distributions of actual rooftops across a large study area, which can be applied in here for the case of numerous LID evaluation over a watershed.

3.2.2 Review of existing models appropriate for LID evaluation

As mentioned previously, an important aspect of selecting suitable LID practices for large-scale study application is having the appropriate drainage design tools. Elliot and Trowsdale (2007) analyzed and compared ten models commonly used in the evaluation of urban stormwater systems. While these models were typically used in application to conventional stormwater drainage systems, an emphasis in this study was placed on assessing the simulation capabilities of LID practices. The review of models included a comparison of attributes such as intended use of the model (i.e., research, public, education, catchment planning, etc.), temporal resolution and scale, catchment and drainage network representation, hydrology abilities (i.e., runoff generation, routing to and within the drainage network, groundwater movement, etc.), containments included in the model, capability of explicit representation of LID devices, and user interface. The results of the comparison for each model will not be discussed and can be found in the review (Elliott & Trowsdale, 2007); however, a number of gaps that were identified will be highlighted. One significant gap identified was the ability for these models to comprehensively predict the effects of LID implementation on hydrology, water quality, and the ecosystem (Elliott & Trowsdale, 2007). It was noted specifically that these models did not address some key quality parameters such as temperature and only one of the models reviewed (MOUSE) addressed dissolved oxygen depletion, but the emphasis is on wastewater discharges rather than stormwater (Elliott & Trowsdale, 2007). It was identified as a gap that the models are not integrated with ecosystem effect models (Elliott & Trowsdale, 2007). As a result, their ability to predict the benefits of LID on the stream ecosystem is limited, which is one of the key motivations of LID implementation. Another major gap that was identified was the limited number of documented tests demonstrating the ability of stormwater models to predict the actual effect of LID at a subdivision or catchment scale (Elliott & Trowsdale, 2007). It was recognized that this was due to the difficulties in setting up a suitable study site with the required spatial control (Elliott & Trowsdale, 2007). Numerous other deficiencies of the reviewed models were identified in terms of their use in LID implementation. Recommendations were made to address these limitations including more research into flow and contaminant generations to improve the processes used in the models, testing the performance of existing or new devices, and simply refining existing models (Elliott & Trowsdale, 2007).

The gaps in LID modelling identified by Elliott and Trowsdale (2007) effectively highlighted the primary areas in need of research and development. While the transition has been slow in LID implementation, since then, there has been some work in the development of new models and refinement of existing models to allow planners and stormwater managers to consider the use of LID practices (U.S. EPA, 2009; Wong et al., 2005; Cheng, 2007; Lai et al., 2007). The following section is a review of six currently available proprietary and public hydrologic modelling tools. The evaluation of the models is based on their ability to simulate LID technologies. A summary of their computational process capabilities, as well as any distinctive features regarding system and operation will be also given. The assessment is based on versions of the models available in April 2010.

Storm Water Management Model (SWMM)

Storm Water Management Model (SWMM) was developed by the U.S. EPA in 1971 (Rossman, 2009). This dynamic rainfall-runoff simulation model is used for planning, analysis and design related to stormwater runoff, sewer systems, and other drainage systems used in both urban and non-urban areas. Currently, in Version 5.0 the model provides an integrated environment for editing study area input data, running hydrologic, hydraulic, and water quality simulations, and presenting results in a variety of formats (US EPA, 2009).

The SWMM system relies on conceptualizing a drainage system as a series of water and material flows between components considered to be major environmental compartments. There are four major compartments in total. The Atmospheric Compartment is from which precipitation falls and pollutants are deposited onto the Land Surface Compartment. The Land Surface Compartment receives precipitation from the Atmospheric Compartment in the form of rain or snow. Outflow is sent to the Groundwater Compartment in the form of infiltration and to the Transport Compartment as surface runoff and pollutant loadings. The Groundwater Compartment receives infiltration from the Land Surface compartment and transfers a portion of the inflow to the Transport compartment. Finally, the *Transport Compartment* contains a network of conveyance elements (i.e., channels, pipes, pumps and regulators) and storage/treatment units that transport water to outfalls or to treatment facilities. The environmental compartments are used in conjunction with “SWMM objects” to simulate a drainage system. The “SWMM Objects” include elements such as rain gauges to represent rainfall, subcatchments that correspond to the Land Surface Compartment, and conveyance elements such as channels, pipes and pumps. In a particular model, it is up to the user to determine which compartments are used. If desired, for example, only the Transport compartment with a user-defined hydrograph could be used.

In terms of simulation methods and processes, SWMM uses a physically-based, discrete-time simulation model that employs principles of conservation of mass, energy, and momentum wherever appropriate. Major processes that are simulated are surface runoff, infiltration, ground water, snowmelt, flow routing, surface ponding, and water quality routing. Infiltration can be modeled by using Horton's equation, the Green-Ampt Method, or the Curve Number Method. Flow routing is modeled within a conduit link by applying conservation of mass and momentum questions for gradually varied, unsteady flow. Steady-flow, kinematic wave, or dynamic wave, routing can be applied to solve the questions. The model is also capable of simulating the impacts of pollutants. Pollutants can be introduced into the nodes of drainage systems through user-defined time series of various flows such as dry weather inflows or groundwater inflow. In addition pollutant build-up, pollutant wash-off, and the effects of street sweeping can be incorporated into the models.

The ability of the traditional version of SWMM to simulate LID practices is quite limited. The current version cannot explicitly simulate the most-used practices, and must be evaluated using a variety of approaches. This is summarized in Appendix B.

Storm Water Management Model Version 5.0 – BMP/LID Extension (SWMM 5.0-BMP/LID)

To address the strong desire to evaluate the hydrological processes of LID practices, the U.S. EPA is in the process of developing methods to assist with these analyses. In October 2009, the U.S. EPA released the Beta version of the SWMM 5.0 with BMP/LID extension modules (Rossman, 2010). The SWMM 5.0 runoff engine and graphical user interface have been extended to explicitly model the following generic types of LID controls:

- Infiltration trenches,
- Porous pavement,
- Vegetative swales,
- Bio-retention cells which include rain gardens, green roofs, street planters,
- Rain barrels and cisterns.

Each generic type of LID control is represented by a different combination of vertical layers whose properties are defined on a per-unit-area basis (Rossman, 2010). During a simulation, a moisture balance is performed that keeps track of how much water moves between and is stored within each layer (Rossman, 2010). As an example, consider the street planter shown in Figure 3-1.

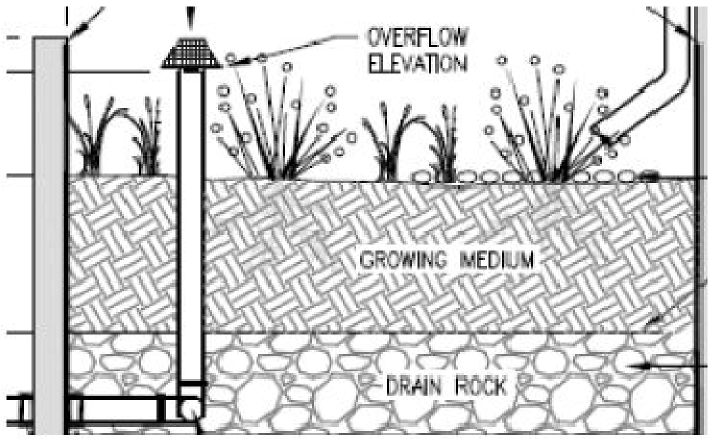

Figure 3-1: Conceptual design of a street planner bio-retention cell (As adapted from Fig. 11.2 of Rossman 2010)

In the SWMM model, the street planter would be conceptual represented by layers and flow processes as shown in Figure 3-2.

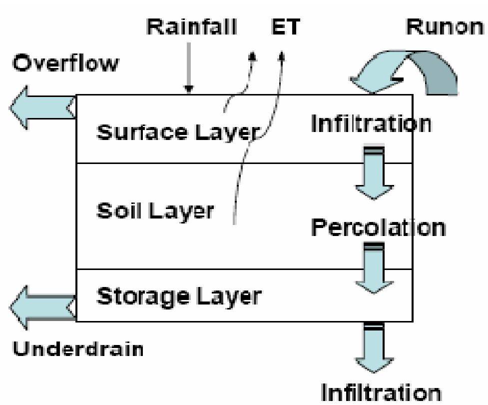

Figure 3-2: Layers used to model a bio-retention cell (As adapted from Fig. 11.32 of Rossman, 2010)

The ability of the SWMM-LID/BMP model to explicitly simulate the most-used practices is summarized in Appendix B. As shown, the tool can explicitly model a number of point and linear based LID practices.

Model for Urban Stormwater Improvement Conceptualisation (MUSIC)

As described in Chapter Two, MUSIC is an Australian developed model currently in its fourth version (eWater, 2010) MUSIC provides the ability to simulate both quantity and quality of runoff from catchments with a spatial resolution that ranges from 0.01 km^2 (i.e., single house block) to a watershed level. It also allows for the simulation of a wide range of treatment facilities and their effect on the quality and quantity of runoff downstream. MUSIC is used mainly as a conceptual design tool where application is mainly to evaluate and support conceptual designs of stormwater management systems to ensure the suitability in a catchment.

MUSIC is based on the “treatment train” approach, which assesses the performance of a group of stormwater management measures that is arranged in a series or parallel configuration. The treatment train concept used in this tool to connects a set of treatment devices together to treat all the contaminants associated with the stormwater flow. The three main types of models to create the treatment train is the *Catchment*, which consists of a number of nodes that represents the entire urban catchment; *Nodes*, which acts as a connection point for drainage links; and, *Drainage Link*, which links the flow between nodes (eWater, 2010).

The simulation methods utilized in MUSIC is known as the Universal Stormwater Treatment Model (USTM). Treatment devices such as grass swales, wetlands, ponds, and infiltration systems are considered to be single continuum of treatment based on flow attenuation and detention and particle sedimentation. The unified model adopts three main principles: hydrologic routing, which represents the simulation of water movement through the treatment system; a first-order kinetic model, which corresponds to the removal of pollutants within the treatment system; and, the concept of the Continuously Stirred Tank Reactor (CSTR), which characterizes the physical storage of elements such as ponds and tanks (Wong et al., 2005).

The current version of MUSIC can only explicitly simulate some LID practices such as rainwater harvesting, bioretentions, filter strips, grass channels, and dry swales (Wong et al., 2005). MUSIC's capabilities to simulate the most-used LID practices are summarized in Appendix B.

BMP/LID Decision Support System (BMPDSS)

The BMP/LID Decision Support System (BMPDSS) (Cheng et al., 2007) is another existing model that can be used for urban stormwater management planning and design at the watershed level. This GIS-based tool was co-developed by the Prince George's (MD) County Department of Environmental Resources Programs and Planning Division and Tetra Tech Inc. (Cheng et al., 2007). Currently in its first version, the objective of this tool is to assist with the decision-making process for the placement of BMPs at strategic locations in the urban watershed based on integrated data collections and hydrologic, hydraulic, and water quality modeling. Specifically, the system uses GIS technology and integrates BMP process simulation models and applies the system optimization techniques for planning and selection. The computational system is made up of several components. The ArcGIS interface is the main user platform for BMP placement and configuration and establishment of a routing network. This interface also requires ArcView and Spatial Analyst components. The database component contains all relevant data and files needed to begin implementing BMP options. The BMP Simulation Module is the component that characterizes the function and pollutant removal efficiency of the BMPs. This module simulates many of the major process associated with BMP function using the same process-algorithms described in SUSTAIN (described in the next section). The Routing/Transport Module is based on SWMM 5.0 transport algorithms. The final two components are the Optimization Component, which indicates the most cost-efficient BMP selection and placement strategies, and the Post-processor, which assist users with the analysis of the output data. The result is a system that takes into consideration the benefits of choosing a particular practice, the difference in management options, costs, environmental goals, and other factors for a comprehensive analysis (Cheng et al., 2007). Figure 3-3 shows the main components in the system and their connections.

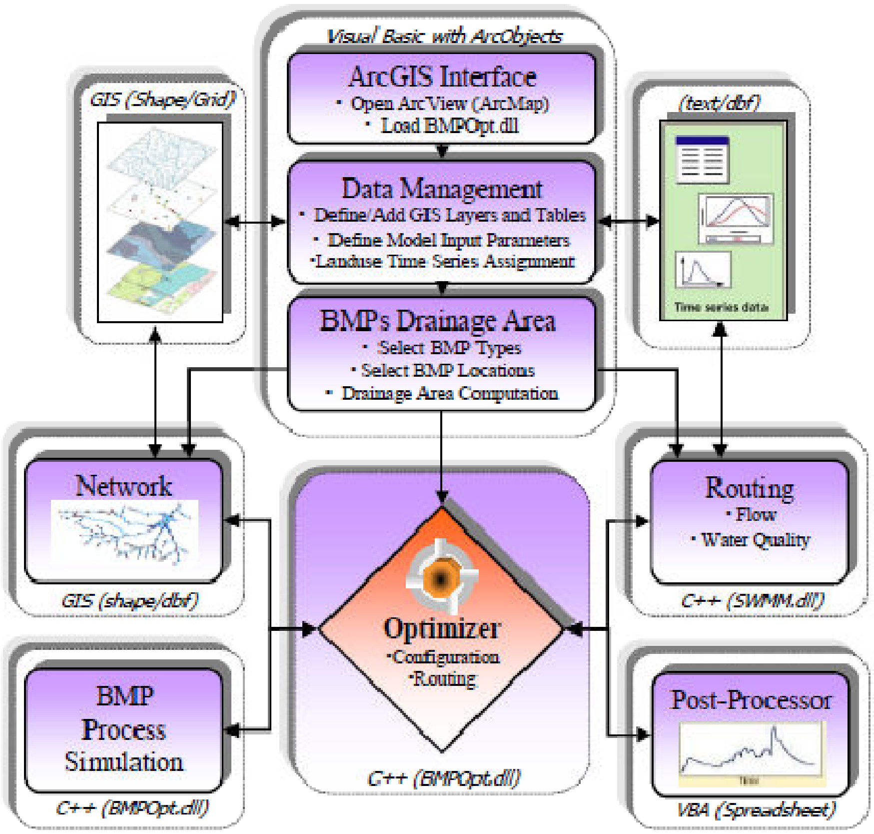

Figure 3-3: BMPDSS system (adapted from Figure 2-1 from Cheng et al., 2007)

Currently, BMPDSS can directly simulate a number of LID practices as shown in Table B-4 in Appendix B. LIDs that cannot be explicitly simulated to date are soil amendments, tree clusters, and filter strips (Cheng et al., 2007).

System for Urban Stormwater Treatment and Analysis (SUSTAIN)

As introduced in Chapter Two, SUSTAIN was developed by the U.S. EPA to act as a decision support system to assist in the strategic placement of BMPs in urban watersheds based on cost and effectiveness (Lai et al., 2009). The BMP/LID options that are available were included for their capability to address significant water quantity and quality factors in urban watersheds. Due to the comprehensive scope of the model, SUSTAIN was developed in phases. Phase 1 was built on the BMP module developed by Prince George's County (BMPDSS) (Lai et al., 2009). The focus of Phase 2 was on expanding the capabilities and functionalities of the system such as expanded cost estimating functions, including additional

BMP types, and improving BMP simulation processes. Phase 2 was completed in September 2009 and has been released for commercial use.

The SUSTAIN system has many operating system requirements, including ESRI's ArcGIS 9.3 and the Spatial Analyst extension. There are six modules, many of which are similar to BMPDSS. The Framework Manager module serves as the main user interface. The Land Module generates runoff and pollutant loads from the land through internal land simulation. The BMP Module performs process simulation of flow and water quality through BMPs. The Conveyance Module simulates routing of flow and water quality in a pipe or a channel. The Optimization module evaluates and identifies cost-effective BMP placement and selection strategies for a preselected list of potential sites, applicable BMP types, and ranges of BMP size. Finally, the Post-Processor perform analysis and summarization of the simulation results for decision making.

In terms of the simulation processes, SUSTAIN's capabilities are rooted in three modules: land, BMP, and conveyance (Lai et al., 2009). These modules are used in combination to support the range of watershed processes. The land simulation module is supported by two other existing models. The surface runoff and water quality components are provided through the SWMM 5.0 system or from an external linkage to a previously calibrated watershed model (Lai et al., 2009). The sediment erosion process is simulated using HSPF where the particle size distribution for eroded sediment is represented as fractional distribution of sand, silt, and clay (Lai et al., 2009).

The BMP simulation module uses a combination of process-based algorithms such as weir and orifice control structures, flow routing and pollutant transport. Infiltration, evapotranspiration, and pollutant loss/decay processes are also included in the simulation (Lai et al., 2009). The core of the module is based on the Prince George's County BMP Module developed in 2001 for the Low-Impact Development Management Practices Evaluation Computer Module (Tetra Tech Inc., 2001 as cited in Lai et al., 2009). Additional enhancements of this module include the concept of the CSTR in series; pollutant removal based on the ki-C* model developed by Kadlec and Knight (1996, as cited by Lai et al., 2009); and dynamic simulation of evapotranspiration. Stream buffer strip simulation is supported by the process-based algorithm applied in the VFSMOD (Lai et al., 2009).

The final simulation module is associated to conveyance. This module represents the movement of water and pollutants among the physical parts of the watershed (land, BMP, conduit, etc.). The kinematic wave and CSTR approach used in the SWMM Transport compartment is applied to model flow and pollutant routing. The sediment transport component utilizes the associated algorithms found in HSPF and Loading Simulation Program in C++ (LSPC) models (Lai et al., 2009).

The current version of SUSTAIN assists in the planning of most LID practices by direct simulation. The LID practices that can be explicitly simulated by the program are shown in Appendix B. Some practices that are not included are soil amendments and tree clusters (Lai et al., 2009).

Water Balance Model (QUALHYMO)

The Water Balance Model (WBM) was developed in 2002 as an extension to British Columbia's Stormwater Planning Guidebook (Government of British Columbia, 2002). WBM is an on-line tool that assists with the potential assessment for new development and retrofit opportunities in communities by taken into account hydrological conditions. As a result, users can quantify the effectiveness of various stormwater source control strategies subject to a range of situations. The WBM is powered by the QUALHYMO model. This proprietary model was developed over 20 years ago for the Ontario Ministry of Environment as a research tool with the purpose of rapidly testing various water algorithms related to the performance assessment of BMPs (British Columbia Inter-Governmental Partnership, n.d.). The WBM provides users with an easy to use, visual interface that is supported by QUALHYMO's computational engine capabilities.

The QUALHYMO system functions on a continuous simulation methodology that includes rainfall/runoff and snowmelt processes. The simulation process relies on time series files significantly to perform the analysis. Required files to run models include rainfall, temperature, evaporation, and flow/pollutant series. Used in combination with a number of commands, BMPs and surface runoff processes on impervious and pervious areas can be simulated. In addition to simulating water, QUALHYMO can allow the user to add sediments and dissolved constituents to the analysis process.

The current version of WBM assists in the planning of a number of LID practices by direct simulation. The LID practices that can be explicitly simulated by the program are shown in Appendix B.

The above review provided insight into the present technical capabilities of existing drainage models to simulate LID technologies. A few conclusions can be made regarding the models that were discussed regarding their strengths and weaknesses. SWMM is a popular used model worldwide due to the numerous advantages that it offers. As a result of being about three decades old, it is well documented, the interface is well developed, and it is open source. In terms of its technical capabilities, it is designed to handle continuous simulation, various levels of available data, and the hydraulics engine is strong. The newest version also allows for various infiltration methods (i.e., Horton, Green-ampt, and curve number) which is important for modelling for LID practices. Although SWMM has been used in various studies evaluating LID technologies, it is still fairly new application. As a result, approaches to simulation techniques are variable and a sufficient base of knowledge is required by the user to capture the various hydrological processes of individual LID technologies.

As discussed previously, the U.S. EPA is currently undergoing the development to expand the existing SWMM model to include LID-specific modules. Once the full release of this expanded version of SWMM has occurred, many of the deficiencies highlighted above with this tool will be addressed.

The MUSIC model, while based in Australia, provides the means to model a wide range of LID technologies. The strongest feature of this tool is its ability to simulate the pollutant removal efficiencies. These values are supported by many document studies In addition to these advantages, it has a user-friendly interface and sufficient supporting documentation. Its greatest weakness is its intended purpose of conceptual planning. As a result, design of LID practices and evaluating their performance cannot be achieved with application of this tool.

BMPDSS and SUSTAIN both possess notable attributes as decision-support tools where they provide the ability to incorporate aspects other than technical criteria into the planning process for a number of LID technologies on a large-scale. These tools, however, operate within their own planning framework, rather than as a separate model focused on hydrological performance evaluation. As a result, in the case of this study, a standalone model would be more effective for LID hydrological performance evaluation. Lastly, WBM-QUALHYMO, while developed in Canada, is not as well documented as the other modelling tools. However, it is an internet-based tool, which allows flexibility for the user in access. Depending on the scope of the study, this feature can be a disadvantage since it will not allow spatial analysis tool such as ArcGis to be integrated into the planning process.

3.3 An approach for evaluating the hydrological performance of LID practices implemented on a watershed scale

The planning stage for LID implementation over a watershed involves identifying areas where LID practices are appropriate based on understanding the conditions to which each technology is suited and the knowledge of the geographic extent of these conditions across the study area. The following sections describe an approach that can be applied to determining the benefit of LID application for retrofit cases throughout a watershed.

3.3.1 Outline of approach

Based on the literature review of existing cases that evaluate the benefit of applying LID methods across a watershed (City of Toronto, 2003; Aquafor Beech Limited, 2005; Banting et al., 2005; Phillips Engineering Ltd., 2007; Farrell & Scheckenberger, 2010), the concept of assessing the response to hydrologically similar areas has been indicated to be the most favourable direction for developing an approach. In addition, due to the nature of these technologies to be designed at the lot-level scale, applying this concept of conducting the hydrological analysis on a micro scale and then aggregating each unit model's performance to the watershed scale would be appropriate and relevant. This widely used practice, termed evaluating Hydrologic Response Units (HRUs), can be found in a variety of areas related to water resource management (Brilly & Vidmar, 1993; Rinaldo & Rodrigues-Iturbe, 1996; Cooper & Naden, 1998; Legesse et al., 2003; Devito et al., 2005). Application of this theory is based on the idea that drainage areas that have similar hydrological dynamics and runoff generation can be identified and used in the evaluation of larger drainage areas composed of these entities (Flugel, 1997). The concept of HRUs has been used extensively in modelling of large, river and drainage basins (Flugel, 1995; Cooper & Naden, 1998; Heuvelmans et al., 2004) and rural watershed areas (Salama et al., 2002; Merritt et al., 2004; Cammeraat; 2004), and more recently, in more urbanized settings (Fohrer et al., 2001; Rodriguez et al., 2003; Easton et al., 2007). It is this concept of HRUs that will be applied in the development of a methodology to evaluate the hydrological performance of LID practices implemented in a watershed. A visual representation of the sequence of the intended approach is shown in Figure 3-4.

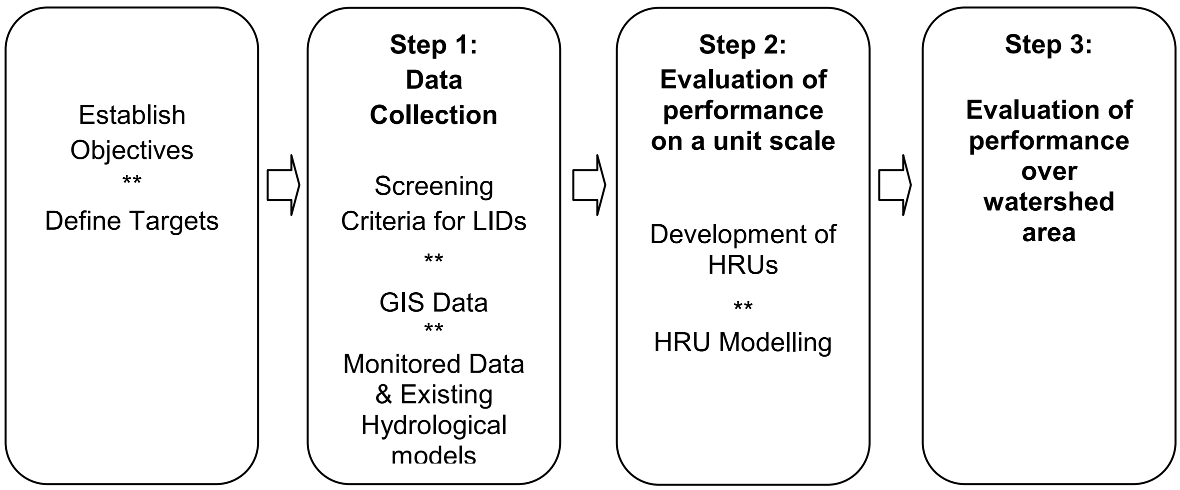

Figure 3-4: General outline of evaluation approach

3.3.2 Description of Evaluation Approach

Establish Objectives and Define Targets

At the start of any watershed planning study, it is necessary to establish an appropriate range of environmental, social and functional objectives to guide the evaluation process. A similar perspective can be adopted in the case of LID planning. The objectives and targets should be established with consideration to background information, existing conditions, and linkages to the surrounding natural and built systems. Any key issues driving the study should also be outlined. Establishing this information will assist the relevant agencies and stakeholders steering the study to develop the appropriate goals and objectives. Evaluation of this step can also be used as a basis to developing alternative strategies for the project or for subsequent studies (OMOE, 2003). This step is shown in Chapter Two (Figure 2-3) outside of the "evaluation of hydrological performance component." The purpose is to show that these objectives and targets should be established for the whole project and not solely the technical component of hydrological evaluation.

In terms of the priority of these objectives, it is up to the planners and officials of the project to determine each items importance. For example, if the goal is the reduction of phosphorus loading to the receiving water body, then the appropriate LID methods chosen and their performance in relation to this parameter will be evaluated. Since LID technologies are supposed to emulate the predevelopment hydrologic conditions of a site (i.e., temporary storage (detention) and infiltration (retention) functions), the parameters that are commonly looked at are (Prince George's County, 1999):

- runoff volume control,
- peak runoff rate control,
- flow frequency/duration control, and
- water quality control (e.g. TSS).

Step 1: Data Collection

To characterize all HRUs that will be developed in Step 3, the appropriate data needs to be collected. Specifically, the following is required to be identified:

1. Data properties that can be used as a screening criteria to characterize hydrologically similar areas (e.g. land use, slope, soil, etc), as well as locate suitable opportunities for each LID practice in the watershed;
2. Monitored data and existing hydrological models for calibration (e.g. rainfall data, evapotranspiration data, models created by municipalities)

To identify the areas that are suitable for LID practices in hydrologically similar areas within the watershed, a spatial analysis data tool is required. Geographic Information System (GIS) is a tool that provides the capability to compile spatial data from various sources (ESRI, n.d.). It also allows the ability to screen potential sites for each of the LID practices and the derivation of parameters that can be used in HRU modelling. The focus of this thesis is to describe the methodology in evaluating the hydrological performance of LID practices across the watershed. While GIS will be applied as a tool to collect the data and assist in the aggregation of HRU performance over the watershed, no detailed description of the data modelling methodologies or the solutions to overcome challenges experienced with the application of the GIS tool is provided here. There are several literature sources (i.e., Brimicombe, 2010; Johnson; 2009) that the reader can refer to for any detailed explanation of the application and operation of GIS.

Data Group 1: Screening criteria to identify LID practices in the watershed

In order to identify the HRUs, and ultimately the locations within the watershed suitable to each LID practice, a screening criterion must be used. The screening criterion can be developed based on the properties that determine an LID technology's ability to be implemented on a lot. Existing stormwater management and LID manuals (Government of British Columbia, 2002; SEMCOG, 2008; CIRIA, 2007; South Australian Government, 2009; CVC & TRCA, 2010) suggest that the main constraints in implementation on a lot-level are site and development characteristics. Site and development characteristics are defined in this thesis as the physical conditions of the area that must be in place in order for the project to occur. Based on a literature review (Government of British Columbia, 2002; SEMCOG, 2008; CIRIA, 2007; South Australian Government, 2009; CVC & TRCA, 2010), the physical constraints that could be included as a screening criterion to assess the suitability of an LID technology on a particular lot is shown in Table 3-1. These properties are categorized under three broad groups based on their geometry: point, linear, and area based LID practices. Point-based LID practices capture drainage at a specific location upstream and through a combination of techniques, manage flow and removes pollutants (Lai et al., 2007). Typical practices that are applied in point-based LID approaches are detention, infiltration, evaporation, settling, and transformation. Linear-based LID practices are characterized by their narrow linear shapes adjacent to stream channels and roads (Lai et al., 2007). This type of practices provides benefits such as filtration of runoff, nutrient uptake, and aesthetic value. Area-based LID practices are land-based management practices that address impervious area, land cover, and pollutant inputs (Lai et al., 2007). In application, multiple LID practices are typically implemented on a site (CVC & TRCA, 2010). Appendix A describes some common LID approaches within each category. Any analysis or discussion in this study will be centered on the definitions of these LID technologies.

Table 3-1: Examples of site and development characteristics to be included in a screening criterion used for LID planning

Point –based	Linear-based	Area-based
• Soil Infiltration (mm/hr) • Separation from water table/ Bedrock (m) • Slope (%) • Typical Drainage Area (m2) • Setback from Building (m) • Utilities, Overhead wires, Wells • Parking Lots, Roads, Sidewalks • Trees	• Soil Infiltration (mm/hr) • Separation from watertable/ Bedrock (m) • Slope (%) • Setback from Building (m) • Utilities, Overhead wires, Wells • Parking Lots, Roads, Sidewalks	• Soil Infiltration (mm/hr) • Separation from watertable/ Bedrock (m) • Slope (%) • Setback from Building (m) • Utilities, Overhead wires, Wells • Parking Lots, Roads, Sidewalks

The number of properties included in the developing of the screening criteria will depend on the goals of the study and type of LID technologies that will be considered for the assessment. For example, if the study aims to implement only green roof technologies across the watershed, properties such as the separation to water table/bedrock and a setback from building requirement can be excluded from the screening criteria. It is important for the appropriate number of properties to truly determine the suitability of a particular LID practice on a lot is included.

Data Group 2: Properties used to characterize HRUs (GIS data)

The data to develop the HRUs requires a variety of information to be collected using GIS. HRUs are typically defined based on their physiographic parameters (e.g. precipitation, soil, land use, topography, geology, etc) (Fugel, 1997), although other parameters such as stormwatershed characteristics (drainage structure, building-to-lot area ratio, etc) have also been considered (Devito et al., 2005; Li et al., 2010). Table 3-2 provides examples of the type of data that could be needed in order to create the desired GIS layers to collect the necessary data to develop the HRUs. Since the concept of HRUs will be applied in the case of LID planning, the HRUs will be defined further by identifying the LID technologies that can be implemented in each unit area. Table 3-1: indicates the type of spatial data required to identify areas suitable for LID practices in the watershed. As shown, the specific site conditions, such as soil permeability, slope of land, and relationship to roads and other impervious areas, can restrict the placement of LID practices. Therefore, it is necessary to include this information in the characterization of HRUs. Collection of this type of data can typically be acquired from conservation-authority databases and municipal data. Other sources, such as commercial suppliers may need to be used depending on the gaps in the data.

Table 3-2: Examples of GIS spatial records required for HRU development in LID planning (Li et al., 2009; Li et al., 2010)

GIS Data Layer	Required Data
Sewersheds	Land providing runoff to each storm drain
Stormsewers	Network of drains, pipes, ditches and outfalls
Landuse	Detailed land uses categories by type and density (e.g., High density residential, commercial, industrial, parks, protected spaces, etc.)
Roads	▪ Rights-of-way extent ▪ Density ▪ Presence or absence of ditches ▪ Surface material ▪ Paved area
Trees	Cover and drip lines
Soils	▪ Permeability/Infiltration, ▪ Drainage class, ▪ Hydrologic Soil Groups (HSG) ▪ Depth to watertable/bedrock
Land Parcels	Area, permeable area per lot, drainage area
Topography	Slope steepness, upslope drainage areas, downslope, drainage ways, locations of active erosion
Buildings	▪ Building height ▪ Building and roof age ▪ Building area ▪ Type (flat or sloping) ▪ Storm-sewer connectivity
Utilities	Setbacks, right-of-ways, locations for buried and overhead utilities (e.g., telephone, TV, gas, water, electricity, locations (buried or poles)
Aerial Photography	Images of the natural and built landscape

Data Group 3: Monitored data and existing hydrological models

To develop accurate models in the tool selected to describe each HRU, monitored flow data is required. Rainfall input data are typically required in any modelling tool and can be obtained from a number of climate data sources local to the study area. Due to the nature of the LID practices, other data should also be obtained to appropriate calibrate the models. Evapotranspiration data will give meaning to the models created for the implementation of LID practices such as bioretention and green roofs. Also, existing hydrological models may be obtained from local municipalities within the study area. Obtaining these data that would assist in calibration of the HRU models. Additional data that would fall in this group may be related to pollutant loadings. For example, if the goal of the study is to estimate pollutant loading reduction with implementation of LID practices, information such as Event Mean Concentrations would need to be obtained appropriate to the study area.

Step 2: Evaluation of hydrological performance on a unit scale

The process of evaluating the performance of LID practices on a HRU level consists of two stages:

1. Identification of HRU types; and
2. Modelling of HRU types.

Identification of HRU Types

The identification of HRUs is carried out with the data that are collected in Step 2. The output from this previous step should include physiographic and stormwatershed properties, as well as the areas amenable to LID technologies. Manipulating the data to group areas with similar hydrological characteristics is then carried out. An example of an approach to distinguish the HRUs is shown in Table 3-3. The example assumes the unit area of each HRU is a whole stormwatersheds, however other sizes can be used appropriate to the study area. Based on Table 3-3: Hypothetical Identification of HRUs , stormwatersheds MUN – A1 and MUN – A3 can be grouped together. Various methods can be used in identifying the HRU types. For example, clustering theory (Luxburg & Ben-David, 2005) can be used to group the similar types of HRUs.

Table 3-3: Hypothetical Identification of HRUs

Stormwatershed ID #	Land Use	Soil Type	Slope*	Ratio of Building to Lot Area	LID 1 suitability	LID 2 suitability	LID 3 suitability
MUN – A1	Commercial	B	Flat	High	X	X	
MUN – A2	Residential	A	Flat	Low		X	X
MUN – A3	Commercial	B	Flat	High	X	X	
MUN – A4	Industrial	C	Flat	High	X		
MUN – A5	Park	A	Steep	Low		X	
MUN – A6	Industrial	B	Flat	Low	X		
MUN – A7	Residential	A	Steep	High		X	

*Flat = < 5%, Steep = > 5%

While it is encouraged to identify and evaluate all parameters for HRU characterization during the data collection stage, it should be recognized that it may not be until this stage that it is made clear that additional characteristic information is needed. As a result, Step 1 and 2 may be an iterative process. At the conclusion of the process, a sufficient amount of data should be collected to meaningfully identify an adequate amount of HRU types, each possessing a reasonable level of uniqueness depending on the goals of the planning study. For example, an alternative means of identifying HRUs can be based on land suitability according to specific LID technologies and various physiographic properties. In addition, the base unit area could be on a parcel level rather than on the stormwatershed basis. Regardless of the definition of the HRU used, it should be certain that sufficient data has been collected to achieve the goals of the study.

Modelling of HRU types

Once the HRU types are identified, the next step is to model each type. Various scenarios can be evaluated depending on the number of LID practices to be implemented on a unit area. The number of configurations that are evaluated should be based on the goals of the study. For example, models could be set up to determine the performance of each LID practice implemented solely on the area, as well as combination of LID technologies. Regardless of the scenarios, existing conditions should be modelled as a base condition for comparative analysis.

In addition to defining the number of scenarios to be assessed, an appropriate modelling tool should be selected. Section 3.2.2 provided a review of currently available modelling software and their ability to simulate LID technologies. Selection of the modelling tool is based on a number of factors including the goals of the study, the LID systems to be evaluated, resources available and even the location of the study area. For example, previously described SUSTAIN tool offers a comprehensive decision-support tool in selecting a number of LID practices to be implemented over a large area. However, the software necessitates certain, potentially constraining, operating system features such as the ArcView GIS platform. The following are aspects that can be taken into consideration when selecting a modelling tool.

- Goals of the study
- LID practices to be evaluated
- Study area
- Versatility
- User interface
- Documentation
- Open vs. Proprietary source
- Known cases studies demonstrating application to LID practices
- Ability to explicitly simulate LID systems
- Additional operating system requirements (i.e., GIS components)

Upon selection of an appropriate modelling tool, a sensitivity analysis should be conducted to understand the limits of the model in simulating LID technologies in the context of the study objectives.

The number of HRU models will depend on the amount of HRU types that were determined from the identification step described above. To provide meaning conceptually, representative lots within each HRU type can be chosen. A variety of methods can be applied to select these representative lots including examining orthographic photographs and applying a selection criterion (i.e., producing histograms of the characteristic (e.g. roof/lot) selected as indicator of hydrologic similarity and analyzing its distribution over the lots in the study area). An adequate number of lots should be chosen to produce detailed models. At the minimum, three lots should be selected to produce the HRU performance curve, which is the main output of this stage.

Specifically, two curves will be developed from the detailed modeling of the lots to assess the HRUs:

1. A curve to describe the runoff volume for existing conditions; and
2. A curve to represent the performance parameter being measured for each LID technology. For example, a function to describe the volumetric reduction in stormwater runoff for a defined area resulting from an application of a specific LID technology or a combination of technologies (treatment trains).

It is these functions that will be used to obtain the benefit of implementing the LID practices over the watershed.

Step 3: Evaluation of performance over watershed using GIS

The last step in the modelling strategy will be the integration of HRU modelling results. The functions derived from the above two curves can be applied to all areas in the watershed that fall in that HRU type. This will allow for the calculation of the overall impacts of LID implementation in these areas. Integrating the result is best done using a spreadsheet; however, this can also be done in the GIS framework.

4.0 Cost-Functions for LID planning

As with any activity involved in watershed management, the planning of LID technologies must take into account aspects other than just technical criteria, particularly on such a large scale. While evaluating options from a scientific perspective may form the basis of any decision, it is typically economics that becomes the driving factor in prioritizing management strategies. Understanding the costs associated with implementing LID practices is central to the successful, long-term application in a watershed. However, a limited number of studies have been documented that quantifies the financial impacts of large-scale LID implementation, particularly in a Canadian setting. As cost associated with LID implementation is identified as a significant barrier among traditional stakeholders of stormwater, it is critical that the financial impacts and benefits connected to LID application be investigated.

This chapter aims to provide further insight into these issues and should be viewed as a strong component of the LID planning framework that can be used to optimize management strategies. The approach presented here focuses on applying results from existing research and case studies to develop planning-level capital and operating and maintenance (O&M) cost-estimate functions for using LID practices. The intended outcome is to determine the cost-effectiveness of implementing LID practices.

4.1 Existing Research of Economic Performance of LID Technologies

A very limited number of research studies have been conducted to thoroughly assess the economic performance of LID technologies. Existing case studies typically focus on the technical process and benefits of LID implementation. There are few documented cases that provide estimates of capital or initial costs, and even a smaller amount that report the long-term operating and maintenance costs. The U.S. EPA (2007) carried out a review of costs associated with LID application. The report examined seventeen case studies of developments in the United States and Canada that applied LID methods for managing stormwater. The sites of the projects varied in land uses and LID technologies implemented. While the results of the studies showed that in twelve of the cases studies, total capital cost savings ranged from 15 – 80 percent with LID application, it was made clear that more research is needed to quantitatively estimate and compare whole life costs, as well as identify the additional economic benefits that could be received (U.S. EPA, 2007).

In the context of this discussion, costs associated with individual LID technologies are of most value. However, the availability of reported costs related to specific methods varies widely, as well as the scope of values reported. A literature review was completed to collect cost estimates for individual LID practices. While most studies provided estimates for single moments in time and are focused solely on capital costs, a few key studies aimed to evaluate the whole life costs. In the U.S., some jurisdictions have attempted to investigate life-cycle costs associated with the implementation of LID and BMP stormwater practices. The California Department of Transportation (CALTRANS) (2004) initiated a study to assess the technical feasibility and costs of applying these devices for retrofit cases. While the cost data gathered reflected the land type in their possession, primarily highways, the life-cycle costs obtained for infiltration trenches, swales, and biofiltration strips provide valuable information in the context of linear applications. In addition, as pointed out, despite the variability of costs reported for BMP retrofit applications, obtaining life-cycle cost data can be used as a means to rank technologies as part of a selection process (CALTRANS, 2004). Other U.S. studies aimed to establish approaches for estimating the total economic impacts of LID practices. Wossink and Hunt (2003) used the Present Value of Costs approach to develop an economic decision making tool to choose structural BMPs in North Carolina. The selection process focused on four devices, which included one LID practice (bioretention). Choice of each practice is based on size of watershed, curve number that describes watershed, soil type, and pollutant type. Weiss et al. (2007) expand the number of stormwater BMPS study to six, which included the two LID practices of bioretention filters and infiltration trenches. Again, the total present cost of each storm-water BMP was reported, but as a function of the water quality design volume, and both to a 67% confidence interval (Weiss et al., 2007). A more recent study carried out by Vanaskie et al. (2010) developed cost estimates for implementing various LID technologies within several land use types. While the analysis was limited to determining just construction and annual O&M costs, it was demonstrated that for large-scale urban watershed planning purposes, normalizing these values to directly connected impervious tributary areas is sufficient.

The brevity of studies performing whole-life economic analysis for LID practices is even more severe within Canada. A few recent studies have been initiated in Ontario for specific LID technologies. The Toronto and Region Conservation Authority (TRCA) (2007) carried out a study to estimate the life-cycle costs and savings associated with the implementation of green roofs in the GTA. Life-cycle cost comparison was conducted for various application scenarios, including a conventional green roof system, incorporation of a municipal incentive program, and the establishment of a green-roof market to drive costs. While it was concluded further research is needed in this area, the study highlighted key points related to costs associated with green roof design. Similarly, Farahbakhsh et al. (2008) conducted an economic analysis of the implementation of rainwater harvesting in the residential sector of Ontario. As part of a two-year and half research and development project, Farahbakhsh et al. (2008) evaluated capital and O&M costs, expected water savings, and stormwater reduction for individual rainwater harvesting systems. The study found that while homeowners bear the costs of these systems, municipal governments experience significant savings as a result of reduced operating costs and delayed infrastructure investment. Both studies from Canada, as well as the limited number of studies in the U.S. show the grave need for further economic analysis studies to be conducted for LID implementation.

4.2 Total-Cost Functions for LID practices

The objective of this component within the framework is to determine the cost-effectiveness of implementing LID practices, which can be applied in optimizing planning strategies on a watershed scale. The intention of the final compilation of cost information is to be in a uniform format that can be applied appropriately to LID planning studies. The collection of data mainly involved a review of existing cost studies for BMP/LID technologies. Where needed, information was obtained from manufacturers and tools developed to determined the whole life costs of BMPs and LID practices. A list of those studies and the information that was collected according to each LID practice is shown in Appendix C.

The scope of cost-effectiveness analysis was limited to point and linear based LID practices due to the lack of data available for area-based LID methods. Costs were also obtained for whole LID practices rather than a breakdown of individual components that the technology is composed of. While it is recognized that an LID can be designed in a variety of methods, it is believed that a commonly used design for each practice is sufficient to be assumed for cost estimating since the application is for planning purposes.

The cost information collected for each LID practice is summarized in tables located in Appendix C. The basic approach was that all costs were indexed and updated to 2010 Canadian dollars. If the data was presented in another currency, the amounts were first updated to the 2010 value in the same currency and then converted to Canadian dollars. All studies that utilized cost equations or tools were solved for common boundary conditions specific to the LID to obtain a cost range. For example, in applying the *WERF BMP and LID Whole Life Cost Models V2.0* (WERF, 2009) in the cost evaluation of swales, the only value that was varied was the drainage area. All other criteria remained the same. Variables that were modified for each tool are specified in the cost summary tables found in Appendix C. Finally, if a range of costs was given in the original source, the average was used in the cost curve that was developed.

Due to the constraint in the non-uniformity in which available cost information is reported, the values that were obtained were converted to unit costs. A sufficient amount of data was available to develop curves associated with capital costs. However, a limited amount of annual O&M costs were available for each LID practice. Separate cost curves were developed to estimate the O&M costs using only the relevant existing data. In most cases, the amount of data shown was much less than the data used to develop curves for capital cost estimates. These curves are shown in Appendix C and a summary of cost functions for each LID practice are shown in Table 4-1: Capital and O&M cost-estimate functions determined for various LID practices . Where insufficient data was available to develop a function to estimate O&M costs, a percentage of the capital costs is assumed based on literature. The final total cost of implementing an LID practice can be estimated for planning purposes by summing the capital cost and the present value worth of the annual O&M costs. This is expressed by the following equation (CalculatorSoup, n.d.):

Total cost = capital cost + present value worth of annual O&M expenditures *(4- 1)*

where present value worth of annual O&M expenditures =

$$\frac{\left[-pmt\times(1+rate\times type)\times\left[\frac{((1+rate)^{nper}-1)}{rate}\right]-fv\right]}{(1+rate)^{nper}} \quad (4\text{- }2)$$

pmt is the payment made each period and does not change over the life of the payment, rate is the interest rate per period, fv is the future value that is desired to be attain after the last payment is made, type = is the number 0 or 1 and indicates when payments are due. If the value is 0, the payments are at the end of the period. If the value is 1, the payments are at the beginning of the period.

A total life span of 25 years can be assumed for each LID practice based on the cost-assessment for LID practices conducted by Fairfax County (2005). Application of these functions should also assume that there is no salvage value at the end of life for each technology (Future Value (FV) = 0) and that payments are made at the end of each period.

4.3 Application of Total-Cost Functions

The cost-estimate functions described in Table 4-1: can be used by LID planners in combination with knowledge of the performance of LID practices to develop management strategies. Since the cost curves are developed as a function of impervious area from which they receive runoff, the HRUs developed according to the method described in Chapter 3 can be assess directly for their cost-effectiveness. The appropriate cost function can be applied to all areas applicable for LID implementation that fall into the HRU type within the watershed. Using Equations 4-1 and 4-2, the total cost of implementing a particular LID practice on a suitable area can be estimated, which provides the means of determining the cost of LID application on each HRU type. This is illustrated in Table 4-2.

Table 4-1: Capital and O&M cost-estimate functions determined for various LID practices

LID Practice	Capital Cost-Estimate Function	O&M Cost-Estimate Function (Annual)	Assumptions
Rainwater Harvesting	$y = 0.0007x^2 + 15.174x$	$y = 0.1585x + 1343.4$	----
Downspout Disconnection	$y = 0.0201x^2 - 2.6386x$	Insufficient data available.	As specified by Fairfax County (2005), this practice does not have O&M costs as with other LIDs. Related maintenance activities are primarily focused on the areas designated to receive stormwater runoff. Annual inspection may be required to ensure that the stormwater is still directed to the desired location.
Dry Well	$y = -0.0005x^2 + 11.452x$	5-10% of capital cost	Annual maintenance costs estimated by Pennsylvania Department of Environmental Protection (2006).
Green Roof	$y = 258.1x$	$y = 25.005x^{0.84}$	----
Permeable & Porous Pavements	$y = 62.188x^{1.0434}$	$y = 0.1333x^{1.3379}$	----
Bioretention	$y = 100.91x^{0.6745}$	$y = 0.0031x^2 - 1.6649x$	Some outlying data was removed to produce good fit
Filter strips and level spreaders	$y = 6.357x^{1.055}$	$y = -26.298x + 107021$	Filter strips and level spreaders were assumed to have similar costs (CWP, 2007).
Grass Channel	$y = 9.6052x^{1.002}$	$y = 0.8156x - 0.3091$	----
Dry Swale	$y = 18.813x^{0.7799}$	$y = 0.0003x + 269.61$	----
Soakaway pits and infiltration trenches	$y = 10876e^{0.0002x}$	$y = -1E-05x^2 + 0.4015x$	Soakaways are similar in construction to infiltration trenches (TRCA, 2007) so the cost data obtained will apply to both practices.

Note: y = cost in 2010 $CDN, x = impervious area treated (m^2)

Table 4-2: Evaluating costs for each HRU

HRU Types	Area in HRU Type	Capital cost	O&M cost	Total estimated cost
1	x_{11}	Apply appropriate capital cost-estimate function from Table 4-1: Capital and O&M cost-estimate functions determined for various LID practices	Apply appropriate O&M cost-estimate function from Table 4-1: Capital and O&M cost-estimate functions determined for various LID practices	Apply Total Cost Function (eqns. 4-1 and 4-2)
1	x_{12}			
1	x_{13}			
1	x_{14}			
1	X_{15}			
1	X_{16}			
. . .	. . .	. . .	. . .	. . .
---	**Sum of treated area for HRU Type 1**			**Sum of cost for HRU Type 1**

5.0 Stakeholder Involvement in LID planning

5.1 Introduction

In the past few decades, a strong emphasis has been placed on involving stakeholders in environmental planning, decision making, and policy development (Beers, 1973, as cited in Adams, Dove, & Leedy, 1984; Beierle & Konisky, 2000; Larson & Lach, 2007). It has been recognized that in order for effective solutions to be applied to achieve sustainable development, policies should reflect the needs and desires of the local community (Tran, Euan, & Isla, 2002). Achieving an integrated approach to sustainable planning requires a full understanding of public attitudes with regards to environmental and social issues. While the benefits of carrying out effective stakeholder consultation and public participation are recognized throughout various environmental disciplines, the process can be very lengthy and complex (Mustajoki, Hamalainen, & Marttunen, 2004,). Numerous studies have been conducted to understand the ideal conditions to support the inclusion of and representation of interested groups (Maguire & Lind, 2003; Irvin, & Stansbury, 2004). This has led to a broad range of participatory practices available to decision-makers for constructing successful participation schemes (Beierle, 1999; Irvin & Stansbury, 2004). It has been found that application of these strategies in an effective manner can lead to better policy and implementation decisions (Irvin, & Stansbury, 2004).

The practice of stormwater management has also evolved accordingly to include the concepts of stakeholder participation into the planning and decision-making process. It has been recognized that sustainable solutions to stormwater pollution are only achievable with the involvement of all affected parties. (Lloyd, Wong, & Chesterfield, 2002; Ellis, Deutsch, Mouchel, Scholes, & Revitt, 2004; Apostolaki, Jefferies, & Wild, 2006; Brown & Farrelly, 2008; Roy et al., 2008) As Beers (1973, cited in Adams et al., 1984) pointed out, "the success of any program to manage runoff as a water resource in the suburban environment is highly dependent upon the support of the people in that environment. Such a program may be technically feasible, may make sense from a resource management perspective, and may have the full support of all the 'experts,' but will still fall short of implementation if the people do not accept the program". This point of view holds true in the case of LID planning. Due to the nature of these technologies to control stormwater at-source and/or through conveyance systems, the requirement to involve a range of groups representing various interests, socially, technically, ecologically, and politically, is essential for effective LID application. Governments and organizations worldwide have acknowledged the integrated planning and design process and the requirement to involve a range of disciplines into the planning and design team (CVC&TRCA, 2009; Brown, 2005; Ellis et al., 2006; Government of British Columbia, 2002; SEMCOG, 2008). In order to achieve long-term support for a stormwater management scheme, commitment to the project by key stakeholder groups such as local government, the local water authority and community is required. In addition, beyond the traditional stakeholders of stormwater management, successful LID implementation requires the inclusion of a wider group such as elected officials, landscape architects, and representatives from the community, should be included in the planning stages (SEMCOG, 2008). Without the support of all affected groups, other issues can arise such as jurisdiction complications, lack of participation, and ineffective implementation (SEMCOG, 2008).

5.1.1 Why it is needed on a watershed level

Gaining the support of all affected groups is of particular importance when planning for LID implementation on a watershed level. Several papers have documented the existing challenges to widespread LID adoption (Lloyd et al., 2002; Ellis et al., 2004; Brown 2005; Roy et al., 2008). In particular, Roy et al., (2008) provides a discussion on impediments associated with LID implementation on a watershed-scale, such as uncertainties in performance and cost and insufficient engineering standards and guidelines. It is believed by Roy et al., (2008) that in order to achieve sustainable stormwater management, one fundamental element is that it must be planned and applied on a watershed scale. To attain effective implementation, consistent institutional, legislative, economic, and social arrangements must be applied across an entire watershed. In the context of this discussion, impediments such as “resistance to change” will continue to remain a barrier that proponents struggle to overcome if a consistent approach is not taken to engage and educate stakeholders across other jurisdictions.

5.1.2 Frameworks to Incorporate stakeholder’s opinions

Despite the recognized benefits of incorporating various stakeholders from public and private domains, the process can also be complex and cumbersome. Each group holds differing opinions, where significance on technical, environmental, economic, and social criteria ranges (Ellis et al., 2006). Research and development into the creation of broader planning frameworks and decision support tools do exist particularly for urban water management in general (i.e., Lundie et al., 2005, and Taylor et al., 2006, and Hall & Lobina, 2007, as cited in Pearson et al., 2010; Hellstrom et al. 2000; Ellis et al., 2006; Makropoulos et. al, 2008). For example, Makropoulos et al. (2008) carried out research for the development of a decision-support tool to assist with water management in new residential developments. The Urban Water Optioneering Tool (UWOT) was developed within the Water Cycle Management for New Developments (WaND) Project in the UK (Makropoulos et al., 2008). UWOT was created to facilitate the strategic planning of sustainable water management systems (Makropoulos et al., 2008). The tool adopts a holistic approach by taking into account the three main components of the urban water cycle: water supply, wastewater disposal, and stormwater drainage (Makropoulos et al., 2008). Application of UWOT provides decision-makers with the ability to select site-specific water saving practices that can be incorporated in the design of water management systems of new residential developments in a single modelling framework. The advantage of this tool is that it not only considers technical criteria, but takes into consideration social, environmental and economic associated factors (Makropoulos et al., 2008). Specifically, the components of the tool consist of a water mass balance model, a large technology library, and a set of user-defined sustainability indicators associated to the above mentioned factors (Makropoulos et al., 2008). The result of the process is a comparison of water management strategies with and without the incorporation of these factors. In addition, UWOT provide the user with a holistic view of the entire urban water system within the new development, including water supply, wastewater collection and disposal, and drainage. The study confirmed the effectiveness of the tool on a case study site in the UK (Makropoulos et al., 2008).

One decision-support tool to assist in stormwater management, specifically, is the web-based Adaptive Decision Support System (ADSS) called *Hydropolis* that was developed under the DayWater EU 5th Framework Programme project (Ellis et al., 2006). This program assists with the process of identifying possible BMP solutions for urban stormwater management taking into account development location and community aspects. The decision support tool also uses a multi-objective approach which incorporates stakeholders' viewpoints and strategies. Other aspects that are included in the matrix-based evaluation are site characteristics, technical criteria, environmental objectives, economic criteria, operation and maintenance outcomes, social and urban community benefits, legal issues, and urban planning criteria (Ellis et al., 2006).

5.1.3 Existing cases of stakeholder involvement in LID planning

Despite the complexity of stakeholder involvement in LID planning, governments have applied various strategies to include various groups into the decision-making process. In Australia, there are numerous examples in which it can be demonstrated that stakeholder involvement in LID planning can lead to widespread support (Roy et al., 2008). Due to prolonged drought conditions, Australian officials have had no choice but to seek out the best methods to address issues of water shortage. As a result, this increased public awareness and acceptability of LID practices (Roy et al., 2008). It was recognized early on that in order for this to be a successful solution, the social aspect of water reuse technologies would need to be considered along with the economic and environmental benefits (Marks, Martin, & Zadoroznyj, 2006; Roy et al., 2008). Several studies have been carried out in Australia in relation to water-reuse in general (Sydney Water 1996; Roseth 2000; ARCWIS 1999; Dolnicar & Schafer, 2009; Marks et al., 2006) and public acceptance of LID technologies specifically (Eadie 2002, and Mongard 2002 as cited in Roy et al., 2008; Lloyd et al., 2002; Brown & Clarke 2007; Brown & Farrelly, 2008). Lloyd et al., (2002) reported a survey of 300 homeowners and prospective buyers at one of the first WSUD demonstrations (Lynbrook Estate in Melbourne). The results of the survey showed that over 90% of respondents were supportive of the incorporation of at-source treatment systems (such as biofiltration systems) into right-of-ways along streets. Most of the respondents (66%) found these systems to be attractive. Other studies have also shown significant landscape amenity benefits through the incorporation of LID practices (Eadie 2002; and Mongard 2002, as cited in Roy et al., 2008). Major land developers in Australia have also reported that the incorporation of LID practices can increase the market value of developments (Lloyd et al., 2002; Brown & Clarke 2007).

As described in Chapter Two, Europe is engaged in numerous research studies investigating sustainable methods in urban water management and planning. Despite the increase in these activities, similar to other regions of the world, minimal research has been conducted to assess the attitudes, perception, and involvement techniques associated to LID implementation. The studies that have been carried out to investigate the opinions of stakeholders regarding issues involving LID practices such as amenity, landscape, restoration, safety, and biodiversity

(McKissock et. al., 1999, and Hjerpe & Krantz, 2000, as cited in Apostolaki et al., 2006; McKissock et. al., 2003, Apostolaki, 2006). For example, one study in the UK (Apostolaki et al., 2006) compared the public and professional attitudes toward LID techniques. Through the application of social perception surveys applied to various areas in England with ponds, the attitudes of public stakeholders were assessed. It was found that improvement of the aesthetics of the area, the attraction of wildlife, and the creation of new habitats were the primary perceived advantages. The main concerns indicated through the surveys were associated to safety particularly in the case of children. The results obtained were site specific and highly dependent on aesthetics and amenity value in the area (Apostolaki et al., 2006). Similarly, the attitudes of the professionals that were surveyed considered LID practices to be of a high value when constructed and maintained according to the design requirements and to sustain a natural look. Compared to the issue of safety, the professionals recognized potential risks that the public concluded, but believed that the actual risk was low or insignificant. It was the opinion of the professionals that if the LID schemes were designed with safety in mind, and proper impact assessments were conducted, then safety was not an issue for LID practices located in an urban area.

In France, a case study was performed by Ellis et al., (2004) that investigated a technique to involve a variety of stakeholders in the selection of sustainable urban drainage systems (SUDS) (i.e., the European accepted term for LID practices) in the control and treatment of urban and highway runoff. The study aimed to develop a multi-criteria analysis methodology to be used in an overall decision-support framework to evaluate LID structures. The methodology was based on the concepts that in order to assess long-term cost-effective drainage options, technical, environmental, social/community, and economic-cost factors become prime sustainability criteria that must be considered (Ellis et. al., 2004). The multi-criteria analysis methodology developed was applied to the French case study that intended to select a construction site for a county retention basin in Blanc-Mesnil (Seine Saint-Denis, Paris, France) (Ellis et. al., 2004). Principal stakeholders associated to four choice sites were included in the decision-making process. Applying the multi-criteria analysis methodology, the officials of the project were able to present and explain the advantages and disadvantages of the four site variants to the local inhabitants and to the local commercial representative groups (Ellis at al., 2004).

In Canada, the research into stakeholder attitudes and involvement in issues related to stormwater management, much less LID practices, have been very limited. In 2006, a research study (Hwang et.al, 2006) was completed to assess the public perception and attitudes of stormwater recycling for park irrigation purposes in the City of Calgary. Distributing a questionnaire to patrons of the park as well as residents of the surrounding area of a park located in southeast Calgary, an assessment was completed to evaluate objectives such as respondents' perception of water quality and their willingness to implement a stormwater recycling program in the area. It was found that public perceptions of stormwater recycling in Calgary range from unsure to supportive, with only rare instances of negative feedback. The results also indicated little resistance by the survey participants to adopting a stormwater recycling program as long as agencies monitor stormwater quality and make the public aware of health risks. Research studies related to stakeholders, assessment of their opinions or involvement in LID planning are even more limited that studies for stormwater management in general. One known study that has been carried out for the practice of rainwater harvesting was completed by the Canadian Mortgage and Housing Corporation (CMHC) (Farahbakhsh et al., 2008). The overall objective of the study was to evaluate the feasibility of large-scale use of rainwater harvesting in Ontario, as well as develop design requirements (Farahbakhsh et al., 2008). One aspect of the study was to conduct a policy analysis to assess the ability of the existing regulatory framework to facilitate the support of rainwater harvesting, as well as to identify barriers and opportunities for widespread implementation (Farahbakhsh et al., 2008). Various stakeholders within the Guelph area were consulted by semi-structured interviews to evaluate these objectives. The process resulted in a number of key findings, including the existing level of interest in rainwater harvesting; significant barriers such as liability and limited end uses permitted for rainwater; proposed solutions such as increased technical education for the building sector; and aspects that must be included in a regulatory framework for rainwater harvesting such as the restructuring of the building code (Farahbakhsh et al., 2008).

Despite the limited studies that have investigated the opinions and involvement of stakeholders related to planning and implementation of LID, it has been recognized that the success of this concept as a sustainable stormwater management technique relies on parameters in addition to technical factors. The social impacts of new stormwater management schemes and technologies cannot be ignored if wide-spread implementation is to be achieved particularly on a large scale such as a watershed.

5.2 Approaches for Stakeholder involvement in LID planning

There are numerous consultation tools that can be applied at various stages of the planning or decision-making process for an LID project. In the case of stormwater management and LID planning, it has been recognized by governmental organizations that this process of stakeholder inclusion should occur in the early stages of an evaluation (Government of British Columbia, 2002; Brown, 2005; Ellis et al., 2006; SEMCOG, 2008; CVC&TRCA, 2010).

Involving stakeholder consultation in the initial planning stages generally serves the purpose of:

- eliciting stakeholders' preferences and priorities,
- identifying common ground and differences in what stakeholders' want from the evaluation, and
- determining a manageable set of priorities, preferably through consensus (European Commission, 2009).

As a result of this purpose, the evaluation process is able to move in a direction that includes the needs and interests of relevant stakeholder groups, evokes a sense of ownership, as well as increases the likelihood that evaluation findings will be implemented and acted upon (European Commission, 2009).

There are numerous sources (e.g., OMOE, 2007; European Commission, 2009; Government of Canada, 2009; Groves et al., 2009) available to those engaging in stakeholder consultation activities. Typically, a framework is available by the industry, government, or agency in which a project is carried out. In many jurisdictions, the requirement of public participation is embedded within the legal framework where criteria are specified. For example, in Ontario, the *Ontario Environmental Policy Act 1990* (*Environmental Protection Act*, R.S.O. 1990) exists as an overall comprehensive piece of legislation that was put in place “for the protection and conservation of the natural environment” (*Environmental Protection Act*, R.S.O. 1990, S. 3(1)). This framework governs a range of activities including those related to waste management, water, motors and motor vehicles, and renewable energy (*Environmental Protection Act*, R.S.O. 1990) that occur within borders of Ontario. Throughout an EA study, affected stakeholders must be given an opportunity to participate and provide input on a proposed project. To assist with meeting consultation requirements, the OMOE has developed a *Code of Practice* for proponents

(OMOE, 2007). The methods described in this document outline appropriate two-way communication techniques to achieve effective participation throughout the planning, implementation, and monitoring phases of a project. Consequently, proponents engaging in environmental project in Ontario have an established legal framework to guide their stakeholder consultation activities.

Building upon the frameworks for general inclusion of stakeholders' opinions for environmental planning and decision-making, the following is a method that can be applied to specifically LID planning on a watershed level:

1. Establish the goals of the project
2. Determine the sample
3. Choose consultation technique(s) and methodology
4. Develop consultation questions
5. Data Collection - Conduct consultation process
6. Analyze the data and produce the reports

This method is a synthesis of literature reviewed on this topic (i.e., OMOE, 2007; European Commission, 2009; Groves et al., 2009; Government of Canada, 2009). The following is a detailed description of each step and examples of the type of information to be included within each step.

1. Establish Objectives and Goals

The purpose of this step is to determine the direction in which the stakeholder involvement process will take. It essentially is what the planner would want to learn. When planning for LID implementation on the watershed level, the objective is to assess the appropriateness and feasibility of placing types of LID practices in a type of area and to evaluate their hydrological performance over the watershed level. Currently LID practices can be applied in two scenarios, new development or for retrofit opportunities. For new developments, the implementation of LID practices are simplified significantly where the main factors relate to lot-level screening criteria (i.e., site and development characteristics). For retrofit opportunities, implementation, particularly on a watershed level is more difficult. Application of LID methods for large-scale retrofit opportunities, it is important for watershed planners to understand who will be implementing these technologies and how to gain their support for implementation.

Understanding their concerns will allow for more effective program and policy development, as well as the provision of directed guidance to ensure acceptance and uptake of LID principles. Some examples of objectives and goals for involving stakeholders in LID planning are the following:

Objectives:

- To identify who the affected stakeholders are in terms of LID planning.
- To identify each group of stakeholder's main concerns for LID implementation
- To identify the barriers that are preventing each group of stakeholders from possibly implementing LIDs
- To identify the aspects need to be included to address the concerns of each group of stakeholders. (e.g., if municipalities identify a concern to be costs of implementation, watershed planners can recommend different strategies and financing models)
- To identify the areas that will need to be investigated in further studies at a sub-watershed level
- To identify what aspects and infrastructure need to be in to be place to encourage implementation at a smaller scale. (e.g. tax credits, rebates, etc.)
- To identify the drivers of LID implementation

Goal of surveying stakeholders on a watershed level

- To provide insight into the challenges ahead for each stakeholder group.
- To provide direction for subsequent sub-watershed plans in terms of LID implementation
- To understand how implementation can be planned at a sub-watershed effectively
- To ensure the inclusion of appropriate stakeholders and to understand their capacity in which facilitate broader and effective LID implementation

2. Design and select sample

The purpose of this step is to identify the affected stakeholder groups, the number of groups to include, and the distribution of the sample. In the case of LID planning, it has be acknowledged that the planning and design process must be integrated in nature and include groups beyond the traditional actors in stormwater management. Traditional stakeholders of stormwater management are individuals, groups or organizations that are commonly identified and consulted in a stormwater related project. Typically these groups will play an active role in the decision making process of stormwater related projects (i.e., governments, conservation authorities, associations, contractors, etc), as well as anyone who can affect the outcome of the project. Depending on the nature of the project, this latter criterion can extend to other non-traditional stakeholders, such as non-profit organizations, community groups, and private homeowners. In the case of LID planning and the type of implementation that has to be carried out for these types of technologies, these non-traditional stakeholders should be included in the planning process. Some examples of traditional and non-traditional stakeholders that should be included are shown Table 5-1.

Table 5-1: Examples of Stakeholder Groups of Stormwater Management

Traditional Groups	Non-Traditional Groups
▪ Municipal government ▪ Provincial or Federal government ▪ Conservation Authority ▪ Land Developer ▪ Scientist (i.e., geoscience, aquatic, biology, botany, ecology) ▪ Planning professional (i.e. architect, landscape architect, urban planning consultant) ▪ Private consulting firm (environmental, construction) ▪ Storm water professional (i.e., manager, engineer, hydrologist, modeller)	▪ Member of local NGOs ▪ Member of School Board ▪ Local Business Owner (i.e., restaurant, supermarket, real estate, etc) ▪ Private landowner

In addition to identifying the stakeholder groups that will be included in the planning process, the role which they play in the decision-making process should be acknowledged. This assists in determining the extent to which they will affect the implementation of LID technologies. Combined with the results of the consultation process, effective policies and methods to gain support can be developed appropriately. Finally, the sample size should be determined. This discussion is limited to a conceptual level since the focus is confined to planning purposes.

Specific sites (i.e., location) and structural aspects will not be determined at this point. However, the sample should be representative of all proposed areas.

3. Choose stakeholder involvement technique(s) and methodology

There is a wide range of techniques that can be used to involve stakeholders in the LID planning process. Stakeholders' views can be gathered in isolation using various tools and procedures to analyze the gathered responses, or through more participatory forms of facilitated face-to-face discussion and dialogue. Weiss (1998) provides a discussion of the various techniques that can be applied. For example, the application of Multi-Attribute Utility Theory (MAUT) methods will rank the priorities of participants on a set of elements in a manner that allows for the combinations of results (Fulop, 2005). Another type of method commonly used is the application of surveys. Surveys are an effective means to gather the opinions of a large number of participants which can be then be analyzed and applied in a manner useful to the project. Additional techniques include focus groups, interviews, roundtables, and task forces (Government of Canada, 2009). The Government of Canada (2009) provides a comprehensive list of techniques that can be used to elicit stakeholders' opinions. Selection of the consultation technique should be done appropriate to the nature of the issues. For example, depending on the goals of the study, an iterative process may be required in order to get a good feel of the important issues prioritized by the affected stakeholders. In such a case, distribution of surveys rather than interviews may be a more suitable choice of method if cost is a strong factor in the project. Other factors, as outlined by the European Commission (2009), such as the distribution and number of stakeholder groups; as well as time and budget should be considered by project officials selecting the appropriate consultation method.

In addition to these factors, it should be remembered that at the planning stage of the LID project, the purpose of involving stakeholders should be for scoping. Detailed and more intense consultation methods can be applied later in the project based on the results of the planning phase. For example, if the results of the consultation process in the planning stage indicate that all stakeholder groups will be accepting of one type of LID technology, more detailed investigations can be conducted into the economic or technical options that will support implementation of that specific LID practice.

4. Develop consultation questions

The questions that are developed to collect the views and opinions regarding LID planning should be based on the goals of the study, the technique selected to gather the opinions, and the types of stakeholder groups that will be consulted. For example, if an open forum is selected to gather qualitative responses, the questions that should be asked should encourage elaboration of opinions. Essentially, open-ended questions should be used. Conversely, if an internet survey is the technique of choice, a more valuable type of question may be multiple choice or numeric rating scale type questions. Numerous discussions and resources on survey design are available (e.g., Groves et al., 2009; Fowler, 2009) and appropriate for application to LID planning.

Appendix D.3 provides examples of questions that can be used in assessing the opinions of stakeholders for LID planning. The questions follow the following set of objectives that focuses on identifying:

1. Types of stakeholder groups represented within a watershed;
2. Current knowledge of LID practices possessed by stakeholder groups represented;
3. LID practices survey participants would likely be interested in implementing;
4. Perception of benefits for implementing LID practices;
5. Concerns for LID implementation;
6. Drivers required for effective LID support;
7. Types of incentive programs required for effective implementation;
8. The perception of costs associated with LID implementation and maintenance.

The intention of investigating these objectives can put into perspective the current LID implementation capacity and support within the watershed, as well as direction in the creation of programs and strategies. The first objective seeks to identify all stakeholder groups for the purpose of determining which groups to develop the planning strategies. The second objective establishes the knowledge capacity for each stakeholder group. This information is important to gauging the current situation of the watershed in terms of LID implementation and deficient areas of knowledge depending on the group. When connected with the responses to the third and fourth objectives, an understanding can be established as to which LID practices would be supported based on the current knowledge capacity. If the hydrological and economic benefit is there for specific LID practices, then the appropriate educational strategies can be focused on these areas where the LID knowledge is weak to gain stronger support. The fifth objective of understanding the concerns of stakeholders is very important in LID planning. Identifying these concerns will highlight the major barriers preventing each type of group from full LID support. The sixth and seventh objective will provide an understanding as to the type of assistance each stakeholder group would like to be in place to overcome their concerns and increase their support for LID principles. Finally, the last objective recognizes that associated LID implementation costs are a major concern for all parties. The responses from this objective can assist with overcoming this strong barrier and the development of strategies. Overall, the goal of including the opinions of all affected stakeholder groups will provide the basis of an effective LID planning strategy that will ensure long-term success.

5. Data Collection

To eliminate any unanticipated problems with questionnaire design, some preliminary tests should be done if possible. This can be as extensive as conducting the consultation process on a subset of the intended sample of stakeholders to just having a few people, other than the developer to test the questions. Undergoing this step can reveal if the stakeholders will understand the questions and if useful answers will be expected. Upon completion of the testing, the full consultation process and data collection can proceed as planned.

6. Analyze the data and produce the reports

This final step involves the processing of the responses received by participating stakeholders and analyzing it for application in the project. There are various methods, including statistical analytical methods that can be applied to data to draw meaningful conclusions. A few methods that are commonly employed in environmental planning studies are multi-objective analysis (e.g., Merrick et al., 2005), weighting of responses (e.g., Anagnostopoulos et al., 2005), and the popular multi-criteria methods (e.g., Ellis et al., 2004; Martin et al., 2004, Mustajoki et al, 2004, Linkov et al., 2006, etc.). In the case where surveys are chosen as the technique for involving stakeholders, existing software packages are a simplified way to analyze the data. Selection of the survey analysis software tool should include, but is not limited to, the following criteria:

- Easy to use with an appropriate and well-developed user interface
- widely used and reputable (i.e., examples demonstrating use in research studies)

- well-developed statistical computation and analysis capabilities
- relatively inexpensive
- allows for the use of different medias for gathering data (i.e., can combine online research with paper distribution)
- strong support services available including customer service, online assistance, appropriate documentation of tools
- secure source
- reliable
- web-based

There are numerous survey software readily available (i.e., QuestionPro Survey Software, 2009; SawTooth Software, 2010; Survey Monkey, 2010) that can be fit many of the above characteristics and are appropriate for use in LID planning.

The output of this exercise is a collection of stakeholders' opinions that can be incorporated into a LID planning project. This component should be viewed as an iterative process, in which mechanisms for ongoing stakeholder involvement should be established. Adopting a philosophy such as this will as a result strengthen the chance of effective widespread, long-term LID implementation.

6.0 Decision-Making for LID planning

Selection of the best course of action is an important step in any project. Decision making theory and models are routinely applied to solve a problem and achieve desired objective(s). The process of selecting the most appropriate solution not only includes identifying the various possible alternatives, but also incorporates balancing criteria such as technical, economic, ecological and social elements to reach the most effective outcome. A variety of decision-making approaches exists which can be applied depending on the situation. In the case of decision-making for stormwater management, there are numerous documented instances (i.e., Ellis et al., 2004; Brown, 2005; White & Howe, 2005, Ellis et al., 2006) stressing the need to move beyond typical technical and economic criteria and apply a more holistic approach in identifying solutions. The following section describes some decision-making approaches in the context of environmental planning and their relevance and application to LID planning.

6.1 Literature Review

As described in Chapter Three, the initial process for decision-making begins with defining the problem, objectives, goals and conditions. Once this has been established, the general process proceeds to identifying objectives, defining criteria to classify the alternatives, and applying a decision-making approach to evaluate alternatives against the criteria (Baker et al., 2001). It is the selection of the decision-making methodology that is of interest at this point in the LID planning framework. Evaluation of the three preceding framework components (i.e., LID hydrological performance assessment, cost-effectiveness analysis, and stakeholder involvement) has provided the basis in which the management strategies will be developed. There are numerous decision-making models that can be applied, but choice of one will depend on the type of problem being solved. If the case has a single criterion, the decision-making process is simplified in that the alternative selected is determined based on the best value achieved for the single criterion (Fulop, 2005). The process becomes more complex when more than one criterion is used and there exist a number of feasible alternatives. This latter type of decision-making problem belongs to the field of multiple criteria optimization and is the most relevant in the case of LID planning. Multi-Criteria Decision Making (MCDM), sometimes referred to as Multi-criteria Decision Analysis (MCDA), is a set of tools to support decision makers faced with problems that are under numerous decision criteria (Linkov et al., 2006). When employed, this type of approach assists with comparing options and tradeoffs related to project objectives, technical solutions, as well as synthesizing the various input information (Linkov et al., 2006). The advantage of applying an MCDM approach is that it does not rely on the availability of measurements. The measurements in MCDM are derived or based on value judgement formed as indicators of the strengths of various preferences. These tools are useful in the decision-making process not only for individual decision makers, but also decisions involving multiple stakeholders. As Kiker et al., (2005) pointed out, taking an MCDA approach in group decisions is highly beneficial since it provides the means for clarifying the similarities or potential areas of conflicts between stakeholders with separate views. As a result, a better understanding of all values held by all participants can be achieved. The discipline of MCDM is commonly seen as the broad class of decision models. This class can further be divided into Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM). The rest of the literature review focuses on commonly used decision-making models within each sub-class of MCDM tools.

6.1.1 Multi-attribute decision-making (MADM) methods

MADM techniques are commonly employed for problems of a discrete nature (Schinas, 2007). Specifically, the number of criteria is finite and the alternatives are outlined explicitly (Fulop, 2005). In general, the methodology scores the performance of alternatives against the existing criteria, typically in a decision table (Fulop, 2005). For example, using the decision shown in Figure 6-1, a problem can have m criteria (C_1, ...C_m) and n alternatives (A_1, .., A_n).

		x_1	•	•	x_n
		A_1	•	•	A_n
w_1	C_1	a_{11}	•	•	a_{m1}
•	•	•	•	•	•
•	•	•	•	•	•
w_m	C_m	a_{m1}	•	•	a_{mn}

Figure 6-1: Example of decision table adapted from Fulop (2005)

Each row corresponds to a criterion in which weights, w_1, ...,w_m are assigned. The weights, assumed to be positive, indicate the relative importance of the criteria to the decision. The weights are usually derived on a subjective basis, where they represent either the opinion of a single decision maker or an amalgamated view of a group of stakeholders (Fulop, 2005). The columns describe the performance of the alternative. The score a_{ij} represents the performance of alternative A_j against the criterion C_j. The values $x_1,...,x_n$ associated with the alternatives in the decision table are the final ranking values of the alternatives. The selection of alternative is based on the highest value of x_n, which typically signifies a best performing alternative.

Development in MADM methods has been ongoing for the past 30 years. This sub-class of MCDM models contains more than thirty types (Zhen et al., 2007), and as a result can be categorized further. Two main families under MADM methods are Multi-attribute Utility Theory (MAUT) and Outranking (Bernard and Daniel, 1997; Guitouni & Martel, 1998, Fulop, 2005, Zhen et al., 2007). These two categories of approaches are described briefly below along with techniques that fall under their definition.

MAUT Methods

The family of MAUT methods is based on the aggregation of the various decision criteria into a function that is maximized. The overall objective of this technique is to find a simple expression to represent the decision-maker's preferences (Linkov et al., 2004). Commonly used MAUT –based approaches employ the concept that the weights, as shown in Figure 6-1 above, reflects the importance of the criterion if the scores (a_{ij}) are from a common, dimensionless scale. To obtain these scores on a dimensionless scale, utility functions are applied to transform the raw performance values of the alternatives against the criterion (Linkov, 2004; Fulop, 2005). These utility functions can be applied to both factual (objective and quantitative) and judgmental (subjective and qualitative) criteria that represent areas such as costs, risk, benefits and stakeholders (Linkov, 2004; Fulop, 2005). Once transformed, the preferred performance is given a higher utility value on a scale ranging from 0 to 1 (or 0 – 100). Therefore, the goal of the decision-maker is to maximize the utility value.

Simple Multi Attribute Rating Technique (SMART)

The SMART method is a simplified approach under the MAUT classification. Generally, the performance of each alternative is represented as ranks on a numerical scale, which are evaluated through a direct-rating procedure (Makowski, 2001). The ranking values (x_j) for alternative A_j is determined as the weighted algebraic mean of the utility values associated with it. Fulop (2005) describes an approach as being represented by the following function:

$$\boldsymbol{x_j = \sum_{i=1}^{m} w_i\, a_{ij} / \sum_{i=1}^{m} w_i, \qquad j = 1, \dots, n.} \qquad \textit{(6- 1)}$$

This simple additive model is one of several other methods to assess the weights for each criterion (Fulop, 2005). In addition to the simplified approach, another advantage of using this method is that it allows for the application of a smaller scale range if alternatives, which are not significantly different for a particular criterion, can be given an equal score (Linkov et al., 2004). It has been shown that this simplified MAUT method is quite valuable in decision analysis (Linkov et al., 2004)

The Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was developed by Thomas Saaty in 1980 (Fulop, 2005). The AHP falls under the MAUT family of methods because it is a compensatory optimization approach that aggregates various factors of the decision problem into a single optimization function called the objective function. The goal is to select the alternative that results in the greatest value of the objective function (Linkov et al., 2004). The distinguishing element of this method is that rather than using utility and weighting functions, AHP uses pair-wise comparisons of decision criteria. For example, how important is criterion C_j relative to another criterion. The weights for criteria are established this way using a nine point scale, as well as to assess the performance scores for alternatives on the subjective criteria (Fulop, 2005). Further description on the methods of developing these weights is described by Linkov et al. (2004). All individual criteria are paired against all the others, and the results are compiled in matrix form (Linkov et al., 2006). AHP is one of the more widely applied multi-attribute decision-making methods.

Outranking decision-making approaches

The concept of outranking was defined by Roy in the 1970s (Linkov., 2004). It is based on the premise that one alternative has a degree of dominance over another rather than the presumption that a single best alternative can be isolated. This is the main difference from MAUT and AHP. However, similar to the MAUT methods, outranking assumes data availability, such as the alternatives and criteria must be specified, and the data in the decision table (i.e., a_{ij} and w_{ij} in Figure 6-1 above). The outranking concept developed by Roy is briefly described by Linkov et al. (2004) as the performance of alternatives on each criterion is compared in pairs. For example, alternative A1 outranks alternative Ai if it performs better on some criteria Cj and at least as well as Ai on all the other criteria. An alternative that is "dominated" is one that is inferior in some respects and no better than equal in others. In contrast, a "dominant" alternative is superior or equal in all respects (Linkov et al., 2004). Outranking is considered a partially compensatory method that does not rely upon optimization. The emphasis is on acknowledging the trade-offs and providing a structured means of comparing the strengths and weaknesses in a quantitative manner. In addition, outranking methods permit identifying the relationships in criteria weightings and for alternatives that are typically not considered comparable (Linkov et al., 2004). Further description of the outranking method is provided by Vincke (1992), Figueira et al. (2004), and Linkov et al., (2004).

6.1.2 Multi-objective decision-making (MODM) approaches

Multi-objective decision-making (MODM) is used with the intent of finding the most optimal solutions given a number of different objective functions, each subject to a set of system constraints (Sadjadi et al., 2008). Problems that would fall under this approach typically have an uncountable set of solutions, which can be evaluated to produce vectors whose components represent trade-offs in decision space (Van Veldhuizen & Lamont, 1998). As cited by Coello (1999), applying MODM to a problem is defined by Osyczka (1985, as cited by Coello, 1999) determining a vector of decision variables which satisfies constraints and optimizes a vector function whose elements represent the objective functions. The result is a set of functions that mathematically represent the performance criteria which are usually in conflict with each other. Coello (1999) formally defines the MODM approach as the following mathematical expressions:

Determine the vector $\vec{x}^* = [x_1^*, x_2^*, \dots, x_n^*]$ that satisfies the *m* inequality constraints;

$$g_i(\vec{x}) \geq 0,\ i = 1,2,\dots,m \quad (6\text{- }2)$$

The p equality constraints;

$$h_i(\vec{x}) = 0,\ i = 1,2,\dots,p \quad (6\text{- }3)$$

and, will optimize the vector function

$$\vec{\boldsymbol{f}}(\vec{\boldsymbol{x}}) = [\boldsymbol{f_1}(\vec{\boldsymbol{x}}), \boldsymbol{f_2}(\vec{\boldsymbol{x}}), \dots, \boldsymbol{f_{1k}}(\vec{\boldsymbol{x}})]^{\boldsymbol{T}} \qquad (6\text{- }4)$$

The key in deciphering the optimization problem lies in finding the solution that give the values of all the objective functions acceptable to the decision maker. Essentially, the goal is to find the vector solution that is a good compromise, or optimum values, of all objective functions determined from among the set *F* of all numbers which satisfy (6-2) and (6-3) (Coello, 1999).

There are various models under the practice of MODM which can be applied to solving problems of this nature. Many methods make use of the concept of Pareto Optimality in determining a set of solutions. A brief description of this theory is focused on for the remainder of this literature review.

Pareto Optimality

The concept of optimum in MODM was formalized by V. Pareto in 1896 (Coello, 1999) and is considered the origin of multi-objective optimization research. Continuing from the discussion above, Coello (1999) defines that "$\vec{x}^*$ is Pareto optimal if there exists no feasible vector $\bar{x}$, which would decrease some criterion without causing a simultaneous increase in at least one other criterion. Therefore, it is not possible to improve one objective without deteriorating at least one of the other. The Pareto optimum always gives a set of solutions that are non-dominated (Coello, 1999). The set of Pareto optimal solutions, which is the plot of the objective functions whose non-dominated vectors are in the Pareto optimal set, comprises the Pareto front (Coello, 1999; Legrie et al., 2010)

Some important terms worth stating explicitly in a mathematical context are Pareto dominance, Pareto optimality, and Pareto front:

- Pareto dominance- A vector $\vec{u} = (u_1, \ldots, u_k)$ is said to dominate a vector, $\vec{v} = (v_1, \ldots, v_p)$ if an only if $\vec{u}$ is partially less than $\vec{v}$ (Van Veldhuizen & Lamont, 1998; Coello, 1999)

- Pareto optimality – A solution x_u Є U is said to be Pareto optimal if and only if there is no x_v Є U for which v = $f(x_v)$ = (v_1, ..., v_p) dominates u = $f(x_u)$ = (u_1, ..., u_p) (Van Veldhuizen & Lamont, 1998)

- Pareto front - For a given multi-objective optimization problem $\vec{f}(x)$ and Pareto optimal set P^*, the Pareto front (PF^*) is expressed as (Coello, 1999):
- $PF^* := \{\vec{u}\} = \overrightarrow{f =} \big(f_1(x), \ldots, f_k(x)\big) | x \in P^*$

An example of Pareto dominance is provided by Van Veldhuizen & Lamont (1998), which states the optimization problem to be as such:

- Minimize $f(x_u), u \in \{a, b, c, d\}$, where
  - $a \triangleq f(x_a) = (3.25, 1.76, 4.67)$
  - $b \triangleq f(x_b) = (3.25, 1.76, 4.67)$
  - $c \triangleq f(x_c) = (3.15, 1.76, 4.67)$
  - $d \triangleq f(x_d) = (3.15, 1.76, 4.22)$.

Based on this problem, *a* and *b* are dominated by both *c* and *d; c* is dominated by *d*, and *d* dominates all other vectors Van Veldhuizen & Lamont (1998). The solution x_d is therefore considered the Pareto optimal solution of the set {x_a, x_b, x_c, x_d}. Pareto optimal solutions are non-inferior, efficient solutions. Their corresponding vectors are termed non-dominated (Van Veldhuizen & Lamont, 1998). Selecting a vector(s) from this non-dominated vector set indicates acceptable Pareto optimal solutions (Van Veldhuizen & Lamont, 1998).

As described before, when the non-dominated vectors of the Pareto optimal solutions are plotted in criterion space, we produce the Pareto front. An example of producing this Pareto front for a general case is described by Van Veldhuizen & Lamont (1998) for one variable, two-objective problem, $\mathcal{F}1$. The problem's two objectives are defined as:

Minimize $f_{11} = x^2$ (6- 5)

Minimize $f_{12} = (x-2)^2$ (6- 6)

Rudolph (1998b, as cited by Van Veldhuizen & Lamont, 1998) showed that given,

Minimize $f_{11} = \|x^2\|$ (6- 7)

Minimize $f_{12} = \|(x\text{-}2)^2\|$, with $0 \neq z \in R$ (6- 8)

The Pareto optimal set for this general multi-objective problem is $X^* = \{x \in R | x = rz, r \in [0,1]\}$. When the values of function f_{11} is plotted against those of function f_{12} for the same value of the independent variable (shown in Figure 6-2), a graphical display of the non-dominated vectors for this problem as points in criterion space is produced. This plot forms the Pareto front.

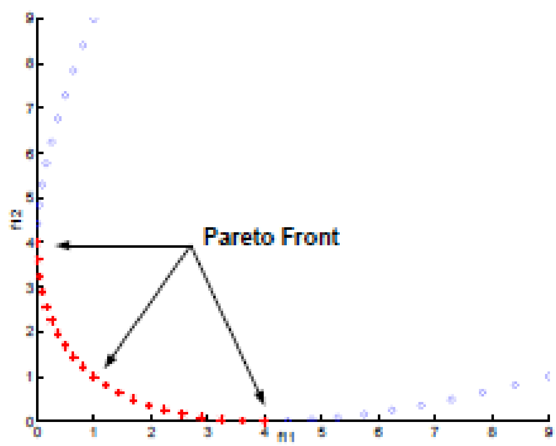

Figure 6-2: Functions F1's Pareto Front (f11 plotted against f12) (Source: adapted from Figure 2 in Van Veldhuizen & Lamont (1998))

6.1.3 MCDM approaches in existing environmental case studies

The application of MCDM approaches in environmental decision-making has been recognized as a useful tool in numerous documented cases (e.g., Ellis et al., 2004; Linkov et al., 2004; Mustajoki et al., 2004; Kiker, et al., 2005). Water management has benefited from these concepts, particularly when the decision making process involved numerous stakeholders. For example, the study completed by Merrick et al. (2005) applied an MODM approach to watershed improvement. The main objective of the study was to identify major problems in the watershed through the means of an integrated watershed assessment tool for decision makers (Merrick et al., 2005). The approach was applied to an improvement project for the Upham Brook Watershed in Richmond, Virginia (Merrick et al., 2005). The result of the study was the development of a model that was used to identify the largest "value gaps" (Merrick et al., 2005), as well as identify programs required to improve the quality of the watershed.

Febriamansyah (2009) examined the relationship between the social aspects of water users in the Tampo basin of West Sumatra, Indonesia, and the physical aspects of the water resources. The objective was to develop a water resource development and management strategy for the Tampo basin to solve the changes in water demand and supply that has been seen along the basin. The AHP method was used to obtain alternatives for irrigation water allocation for all the water users along the river. The method proved to be useful since the project required the participation of a variety of stakeholders. It allowed for the stakeholders to express their preference for the alternatives, which led to the final selection of the acceptable water allocation pattern. While this study demonstrated the usefulness of this method to allowing a variety of stakeholders to participate in the decision-making process, it was also highlighted that a disadvantage of this method is that it can be time-consuming process to some stakeholders due to its participatory nature.

The study carried out by Anagnostopoulos et al., (2005) evaluated four alternative irrigation projects for a district near the Nestos River that lies partially in Bulgaria and Greece. The irrigation alternatives focused on the operation of two constructed dams to achieve water resource management on the Greek portion of the river. The study applies two multi criteria methods, AHP and PROMETHEE, to carry out the analysis. The evaluation model for the project alternatives consisted of three scenarios and four criteria (economic, social, environment and cost criteria), which were further divided into sub-criteria. The three alternative scenarios were based on the future availability of water resources and were based on the rainfall data. The economic criterion took into account the positive side effect of aspects such as rural income, employment, and rural production. The social criterion considered the impacts of increases in economic aspects on the quality of life for residents of the region. The environmental criterion included the negative side effects of the construction of new reservoirs on the ecosystems. Finally, the cost criterion incorporated life-cycle costs into the evaluation model. This study provided an example on how these MCDM methods can be used to select the most appropriate alternative. It also showed how a more holistic approach can be taken to making environmental decisions by including technical, economic, social, and environmental criteria. This approach was highly applicable to the LID planning framework proposed in this thesis since the components considers similar aspects.

There have been limited documented studies that apply MCDM methods in the decision making process for BMP and LID planning. Some examples of such studies include Ellis et al. (2004), Perez-Pedini et al. (2005), Ellis et al. (2006), and Martin et al. (2007). In the study carried out by Martin et al. (2007), various MCDM tools were applied to urban stormwater management in France. The objective of the study was to develop an approach to assist BMP users in selecting stormwater source solutions in France with respect to various criteria. Various alternatives were developed based on results from a national survey to assess the performance of different BMPs, a literature review, and results from previous studies. The study applies an Outranking approach called ELECTRE III. The reasons for choosing this approach included its ability to enable continuous participation and "dialogue" between the various stakeholders involved in the decision-making process; the allowance for weighing the criteria which provided the means of including stakeholders' opinions; the characteristic that the ELECTRE III method is based on fuzzy logic which accounts for uncertainties in performance evaluation by means of "pseudo-criteria"; and, the weights are not used as tradeoffs, as in the target criteria are not taken into account in a compensatory manner (Martin et al., 2007). The evaluation model allowed for the ranking of various alternatives by either giving a score on an appreciation scale or by quantifying a specific value. The appreciation scale was based on criteria such as the need and frequency of operation and maintenance, the environmental impact of BMP on groundwater, or the contribution to sustainable development policies. This study showed how stakeholder preferences can vary according to different management strategies and levels of interests, methods should be applied to consider these aspects. The approach taken demonstrated some noteworthy points applicable to decision-making for LID planning. Due to the nature of BMPs and LID practices, having strong participation from stakeholders is expected to strengthen the probability of successful implementation. The method in this study selected an approach that encourages and supports the participation of stakeholders from the initial stages of the project. It also allowed for their opinions to be incorporated as weights into the decision. Finally, other criteria were taken into consideration in addition to the commonly applied cost-benefit analysis. The study considered technical, hydraulic, environmental, social, economic, and maintenance criteria.

6.2 A decision-making approach for LID planning

As shown above, there are many MCDM tools available to the decision-maker to assist in selecting the most appropriate solution. However, choosing a suitable method can be challenging. In addition, each method may produce a different ranking (Martin et al., 2007). While it could be suggested that one or more MCDM method be used in order to enhance the selection process, in the context of this proposed LID planning framework, a single approach is suggested.

Previously, it was described that the MODM method aims to identify the optimal solution given a number of different objective functions, each subject to a set of system constraints. The approach taken in this framework can be based on this concept since the main components are centred on distinct objectives. The first component, which evaluates the hydrological performance of the LID practices, ultimately intends to determine the effectiveness of implementing the technology. The second component, application of cost-estimate functions, provides a means of estimating the LID implementation in a targeted area, as well as optimizing the strategies indicated by the first technically-centred component. While another MCDM approach could be used in this typical cost-effectiveness analysis, the third component provides an element that changes the problem and produces an uncountable set of solutions. The third component, the inclusion of stakeholder opinions, complexes the decision-making process further in that the concept of acceptance becomes a factor in successful LID implementation. It is this last component that necessitates an approach to be based on the concepts of MODM methods. Furthermore, the decision-making method should also seek to determine the Pareto optimum, which will provide a non-dominated set of solutions.

Evaluation of the LID effectiveness and cost was based on the concept of HRUs. This idea can be extended in this decision-making point as well. The HRUs defined in Component 1 were evaluated to determine the hydrological performance of implementing a particular LID practice. Performance values for a number of HRUs were the output from this component. Component 2 attached cost estimates to these HRUs for each LID practice. Component 3 investigated the opinions of stakeholders; however it was not done in the context of HRUs. It is the results from this component that will be need to be put into a form useable to include in the decision-making process.

It has been well established throughout this thesis that the success of effective LID implementation hinges on the acceptance by stakeholder and their support of LID principles. It is this concept of acceptance that should be included in decision making process. The definition of acceptance and quantifying it from the results of the third component can be done in a number of ways. Evaluation of Component 3 can include the direct assessment of gather the acceptance level from stakeholders, such as specifically asking targeted questions related to the approval of LID practices. It can also be more complex in that it is defined as an amalgamation of the various opinion topics probed within this component. Regardless of the method chosen, the acceptance must be defined with the results obtained from Component 3. The definition should translate to a score on a defined scale determined by the user. For example, each LID practice could be given an acceptability score defined as the likelihood for stakeholders to implement the practice. Each score ranks the LID practices included in the question against each other. Determining the acceptability in this manner puts it in a form that can be used with the results from the previous two components. Since the HRUs defined in Component 1 are according to LID practices, each HRU can now be given an acceptability score. This enables the possibility of making a decision based on all three objectives.

The next step in this decision-making approach is to plot the results from each component. From the assessment of all three components, the HRUs for each LID practice now has value describing its hydrological performance, the total cost estimated for implementation, and an acceptability score for implementing the technology. These values for all HRUs can plot on a three axis graph representing the components of hydrological performance, cost, and acceptability. This is shown in Figure 6-3. As a result of the acceptability score attached to each HRU, the graph will show HRUs arranged in levels according to their score. The solutions within each score level will indicate the relationship between the cost and effectiveness of the HRUs. The final step will be to identify the Pareto front to identify the optimal solutions.

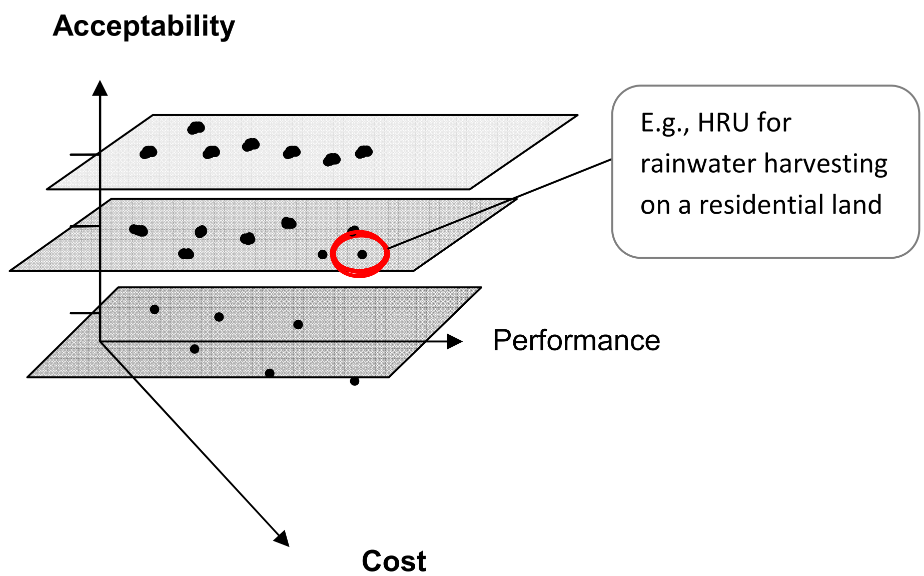

Figure 6-3: Plot of LID planning framework components

7.0 Case Study: Application of the LID Planning Framework to the Lake Simcoe Watershed

To illustrate the use and benefit of the LID Planning Framework proposed in this thesis, data pertaining to the Lake Simcoe watershed are examined in this chapter as a case study. As discussed in Chapter One, the LSRCA is currently engaged in a study to assess the benefit of LID technologies placed throughout the watershed. The data used within the LSRCA LID Planning Study are used in this chapter to evaluate each component of the LID Planning Framework in detail. The conclusion of this case study provides a set of recommended management strategies applicable to the Lake Simcoe watershed.

7.1 Case Study Background

7.1.1 Lake Simcoe Watershed

The Lake Simcoe Watershed, shown in Figure 7-1, is a large area that lies within the Southern Georgian Bay Drainage area (LSRCA, 2003) in Ontario, Canada. It includes parts of Simcoe County, Durham Region, and York Region (Li et al., 2009). The watershed contains five major physiographical areas: the Oak Ridges Moraine, the Peterborough Drumlin Fields, the upland till plains, the Simcoe Lowlands, and the Oro Moraine (LSRCA, 2003). The total land portion of the watershed is approximately 2,857 km^2 and is drained by 35 tributary rivers. Out of the 35 tributaries that drain the land surrounding the lake, five major tributary rivers comprise 60 percent of the total drainage area. The lake itself occupies about 20 percent of the whole watershed (722 km^2).

Over the recent decades, development in the watershed has increased rapidly, resulting in significant land use changes (Li et al., 2009). Although the Lake Simcoe Watershed is recognized as containing provincially significant wetland and woodlands, only approximately 35 percent of the land area is comprised of this cover, where much of it exists in a fragmented state with the quality unknown (Government of Ontario, 2009). Almost half of the watershed (approximately 47 percent) is currently used for agriculture purposes (Government of Ontario, 2009). Urban land use amounts to about 6.3 percent and is currently home to over 350,000 permanent residents. Residential populations are unevenly distributed where populations continues to grow in the southern urban centres of York Region and the western agricultural areas (Li et al., 2009).

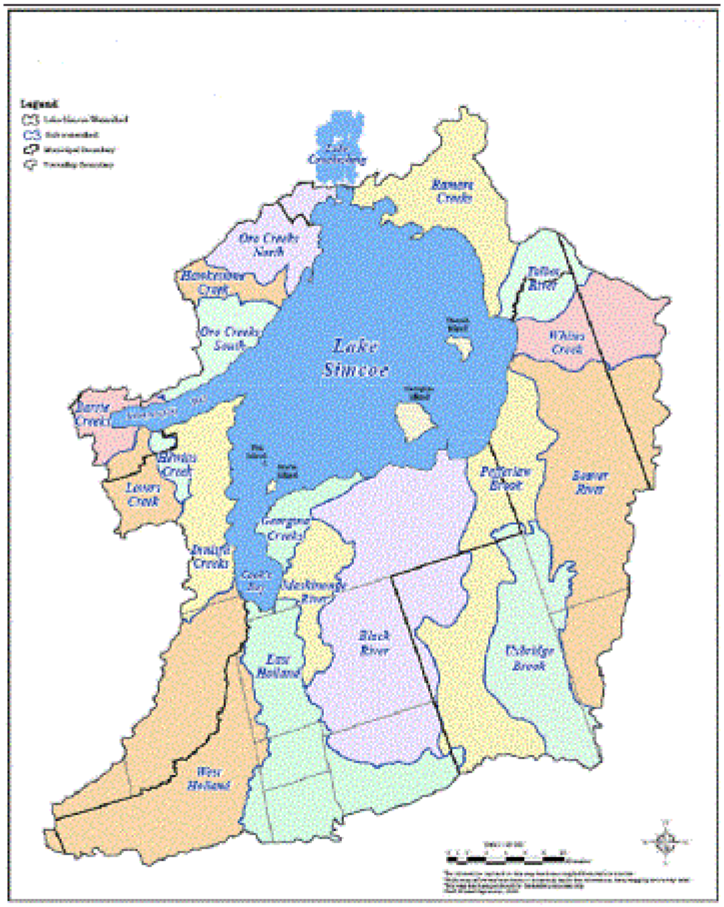

Figure 7-1: Relief map of Lake Simcoe Watershed (Source: LSRCA, n.d.)

7.1.2 Legislation impacting the watershed

There are a few pieces of legislation that govern the management of the Lake Simcoe Watershed. Management of Ontario watersheds is carried out by conservation authorities. The Conservation Authorities Act (R.S.O. 1990, c. C.27) gives power to these authorities to perform many critical functions related to planning and management. Specifically, conservation authorities are to:

- to study and investigate the watershed and to determine a program whereby the natural resources of the watershed may be conserved, restored, developed and managed; and, to cause research to be done" (Conservation Authorities Act,1990, S.21); and

- to make regulations applicable in the area under its jurisdiction" (Conservation Authorities Act,1990, S.21).

The Lake Simcoe Region Conservation Authority (LSRCA) is the designated authority under The Conservation Authorities Act for the Lake Simcoe Watershed. They provide leadership in the restoration of the environmental health and quality of the lake and the surrounding watershed. The LSRCA works the community, watershed municipalities, and government partners to develop improved stormwater management strategies and more.

The work and efforts of the LSRCA compliments the recently enacted Lake Simcoe Protection Act (S.O. 2008, C. 23). Ratified in 2008, the overall objective of the Act is to protect and restore the ecological health of the Watershed (Government of Ontario, 2009). A product of the Act was the development of the Lake Simcoe Protection Plan which specifies the action plan for achieving water quality and quantity targets. It is required that within five years of its enactment, the municipalities belonging to the watershed must develop comprehensive management master plans for each settlement area (Government of Ontario, 2009). These master plans must include a comparative review of current practices, new technologies, and retrofit opportunities in order to determine the best course of action to optimize stormwater management efficiencies (Government of Ontario, 2009). It is intended that the Lake Simcoe Protection Plan be read in conjunction with relevant provincial policies, plans and Acts. In addition to the Conservation Authorities Act, this includes the following (Government of Ontario, 2009):

- Provincial Policy Statement, 2005,
- the Greenbelt Plan,
- the Oak Ridges Moraine Conservation Plan,
- the Clean Water Act, 2006,
- the Ontario Water Resources Act,
- Environmental Protection Act,
- the Public Lands Act, and
- the Planning Act.

7.1.3 Significant Environmental Issues in Lake Simcoe Watershed

The LSRCA performs environmental monitoring and management of the watershed. As a result of water quality monitoring activities, LSRCA has found that the Lake Simcoe Watershed is impacted by many contaminants (LSRCA, 2007). Contaminants such as phosphorus and chloride have been detected in entering the watershed through multiple means at levels exceeding provincial guidelines. While point sources, such as pipes discharging industrial waste, are commonly known means of pollution input, more recently non-point sources have been found to be major contributors to poor water quality issues. Non-point sources are of significant concern since they cannot be traced to a distinct discharge point and require a different approach to pollution control. Some examples of non-point sources are faulty septic systems on private properties, agricultural land, and impermeable surfaces such as rooftops, roads or sidewalks.

Phosphorous loading is LSRCA's largest concern in terms of water quality. When phosphorous is washed from terrestrial sources, such as an agricultural field that uses fertilizer, into aquatic habitats, aquatic macrophytes and phytoplankton grow to excessive levels. The aquatic primary producers are essential to lake and river ecosystems (Li et al., 2009); however, extreme growth can lead to negative impacts. For example, spawning and feeding grounds for animals living in these aquatic ecosystems suffer as a result of murky water and choked plants caused by phosphorous loading (Li et al., 2009). To mitigate these harmful effects of phosphorous loading (i.e., depleted oxygen levels, decrease in fish and invertebrate populations, taste and odour problem in potable water, etc.), the LSRCA has adopted some vigorous goals and targets. In the early 1990s, the phosphorous loading was recorded as exceeding 100 tonnes/year (Government of Ontario, 2009). Although these levels were recorded as being between 70 and 77 tonnes/yr during the period of 2004 to 2007 (Government of Ontario, 2009), the Lake Simcoe Protection Plan has outlined ambitious targets for curtailed phosphorous loading (44 tonnes/yr) and improved dissolved oxygen levels (7 mg/L) (Government of Ontario, 2009).

The LSRCA have also identified water quantity as an issue that can cause significant environmental problems. Aquatic ecosystems require adequate flow rates and are sensitive to disturbances in flow rates. As urbanization continues to intensify, increased needs for use of drinking water, irrigation, and industrial processing also similarly grows which exerts pressure on the already stressed watershed. Water quantity also impacts water quality. As the amount of water present in the system fluctuates, so do the contamination levels which are dependent on the amount of dilution (Li et al., 2009).

Due to these numerous water quality and quantity issues in the Lake Simcoe Watershed, several initiatives, such as the Government of Canada's Lake Simcoe Clean-up Fund, are currently underway. The purpose of these programs is to encourage watershed stakeholders to not only apply conventional techniques of stormwater management, but to apply alternative practices as well. In addition, the Lake Simcoe Protection Plan has stated that municipalities should consider source and lot-level controls before proposing traditional stormwater treatment facilities (Government of Ontario, 2009). As a result, the LSRCA is currently engaged in a study to plan for LID technologies throughout selected areas in the watershed. It is a desired outcome by the organization that the study will provide guidance to watershed municipalities for incorporating LID technologies into their stormwater management master plans (Li et al., 2009).

7.2 Objectives and Scope of Case Study

The overall objective of the Lake Simcoe LID Planning project is to identify opportunities for the implementation of LID practices within the Lake Simcoe watershed, as well as quantify at a planning level the benefits that could be provided in terms of reduced pollutant loading to Lake Simcoe from locations within the watershed referred to as "uncontrolled areas." Uncontrolled areas are areas that were developed before the introduction of modern stormater management practices (Li et al., 2009). The goal of the study is to provide guidance to municipalities for incorporating LID technologies into their respective stormwater management master plans for these uncontrolled areas (Li et al., 2009)

For this thesis, the information presented for this case study will be a portion of the overall study and the work completed to date (May 2010). Specifically, this primarily includes the evaluation of point-based LID practices that treat primarily roof-top runoff (i.e., green roof, soakaway pit, rainwater harvesting, downspout disconnection, and dry well). The performance of three LID practices (i.e., rainwater harvesting, downspout disconnection, and dry well) were assessed over the watershed by the author of this thesis, and the remaining two were evaluated by another member of the LSRCA LID Project research team, Celia Fan.

The case study is arranged to coincide with the components of the proposed LID Planning Framework. The methodologies applied for all five LID technologies in evaluating each component and the results obtained bedare descr in separate sections. Relevant conclusions are provided to summarize the results of evaluating each component. The last part of the case study integrates the results of the Framework Components to recommend optimal management strategies that could be applied in Lake Simcoe Watershed.

7.3 Evaluation of LID hydrological performance for the Lake Simcoe Watershed

The objective of the first component is to determine the effectiveness of LID implementation on a watershed level. The approach described in Chapter 3 is applied here. The following sections describe the methodology and results obtained in the context of the Lake Simcoe LID Planning Project (Li et al., 2009).

7.3.1 Data Collection

Screening Criteria Properties

The first set of data that was collected was properties that could be used in identifying LID opportunities throughout the watershed. A literature review was conducted of existing stormwater management and LID manuals (Prince George’s County, 1999; CIRIA, 2007; SEMCOG, 2008; CVC & TRCA, 2010). Table 7-1 shows the information gathered for the five roof-based LID technologies of interest.

Table 7-1: Information collected for screening criteria

LID Practice	Soil Infiltration (mm/hr)	Separation from watertable/ bedrock (m)	Slope (%)	Setback from building (m)	Utilities, Overhead wires, Wells	Parking lots, Roads, sidewalks	Relation to Trees
Green Roof	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Soakaway Pit	Max. 25	1	0 – 5	4	1.5m from public utility line	Receives only roof and walkway runoff	Root intrusion should be considered
Downspout Disconnection	> 15	N/A	1 – 5,	3	N/A	N/A	N/A
Rainwater Harvesting	N/A	Must be considered for subsurface systems	N/A	3	Check there is no interference	N/A	Check there is no interference
Dry Well	Max.13	1	Max. 20	3	Check there is no interference	Receives only roof and walkway runoff	Root intrusion should be considered

Properties used to characterize HRUs (GIS data)

An initial list of data needs similar to that described in Table 3-2 was proposed to characterize the HRUs to a level sufficient for conducting a meaningful analysis. To acquire the information needed, ArcGIS was used was used to compile and process the spatial information received from the various data sources. Specifically, data were obtained from the LSRCA as well as municipal data from Barrie, Newmarket, Aurora, and East Gwillimbury municipalities. There were a number of issues regarding the quality and format of the data received, and as a result, data from the City of Barrie were used primarily in this case study. Where the required information was not available, other sources were used such as the LSRCA and commercial data suppliers. Further description of the data sources, the data gaps, and the challenges experienced are detailed in Li et al. (2010).

The first data requirement listed in Table 7-1 seeks to obtain information regarding the areas that are amenable to LID implementation in the watershed. Using the screening criteria properties described in Table 7-1:, a screening criterion was developed for each LID practice. The criterion applied for each LID technology as well as the information obtained is shown in Table 7-2.

Table 7-2: Applied screening criterion used in GIS and results (Li et al., 2010)

LID Practice	Screening Criterion	Information Obtained
Green Roof	▪ On buildings larger than 350 m^2 in area	▪ Simplified identification of lots with sufficient roof area[2]. ▪ Determined the roof area contributing water that could be diverted by green roofs (0.82 km^2 across the study area in Barrie).
Soakaway Pit	▪ Soils over 2 m deep to water or bedrock ▪ Minimum Slopes below 15% ▪ On soil Hydrologic Groups A or B ▪ Beyond buildings and their (4m) buffers ▪ Off trees and roads	▪ Identified lots with appropriate conditions and space available ▪ Determined the roof area contributing water that could be diverted to soakaway pits (1.83 km^2 across the study area in Barrie).
Downspout Disconnection	▪ Minimum slopes below 5% ▪ On soil Hydrologic Groups A or B ▪ Beyond buildings ▪ Off trees and roads	▪ Identified lots with appropriate conditions and space available ▪ Determined the roof area contributing water that could be diverted by downspout disconnection was also available (2.62 km^2 across the study area in Barrie.
Rainwater Harvesting	Commercial and industrial sites ▪ Soils over 2m deep to water or bedrock ▪ Off trees ▪ Beyond buildings and their (3m) buffers ▪ Off roads Residential sites ▪ Soils over 2m deep to water or bedrock ▪ Off trees ▪ Beyond buildings and their (3m) buffers ▪ Off roads	▪ Identified lots with appropriate conditions and space available ▪ Determined the roof area contributing water that could be diverted by rainwater harvesting (2.74 km^2 across the study area in Barrie).
Dry Well	▪ Soils over 2m deep to water or bedrock ▪ Minimum slopes below 20% ▪ Beyond buildings and their (3m) buffers ▪ Off trees and roads	▪ Identified lots with appropriate conditions and space ▪ Determined roof area contributing water that could be diverted to LID technology (2.55 km^2 across the study area in Barrie)

[2] Details of roof and buildings were not available: building height, building age, roof type (flat or sloping), roof age, roof material, and storm-sewer connectivity (Refer to Li et al., 2010).

In addition to the areas suitable for implementation, other information were collected to characterize the HRUs. For each LID practice, the following data was produced (Li et al., 2010):

- Assessment number (a unique identification number associated with privately owned plots of land)
- Address (the street and number, where known)
- Lot area (the original lot size, without any subdivision)
- Building area
- Building size-to-lot size ratio (the ratio of original building (over 20 m^2) areas to the enclosing original lot area)
- Land use
- Stormwatershed (LSRCA developed ID for stormwatersheds)
- Area of driveways
- Area of parking lots
- Impervious area (calculated from driveways, parking lots, and building size information)

In terms of the land use, there were a few specific types that were of interest for each LID practice. This is shown in Table 7-3: Land use data evaluated for each LID (Li et al., 2010) below.

Table 7-3: Land use data evaluated for each LID (Li et al., 2010)

LID Practice	Land Use
Green Roof	▪ N/A – Screening criteria resulted in buildings larger than 350 m^2 in area. No further refinement required
Soakaway Pit	▪ Commercial ▪ Residential
Downspout Disconnection	▪ Commercial ▪ Industrial ▪ Residential
Rainwater Harvesting	▪ Commercial ▪ Industrial ▪ Residential

Dry Well	▪ Commercial ▪ Industrial ▪ Residential

As shown, the main land use types in which the LID technology would typically be implemented, as well as those representing majority of the space within each stormwatershed were chosen. Data were only collected for these land use types. As a result of soakaway pits being a practice that promote infiltration significantly, it was decided to assume implementation is not ideal on commercial or industrial lots due to the potential of stormwater runoff containing a higher amount of elements not typically found in rainfall (i.e., chemicals, oil, etc).

Input data

- *Rainfall input data*

Precipitation data were an essential input for hydrological modelling. Since the case study primarily utilized data from the City of Barrie, rainfall input data were obtained for this location. The Ontario Climate Center of Environment Canada provided rainfall data from the Barrie Water Pollution Control Center (Barrie WPCC) rain gauge station (Li et al., 2010). The station possesses hourly rainfall records from year 1968 to the year 2003. The records were analyzed to determine the average rainfall year. Appendix D.1 shows the annual rainfall records that were obtained, as well as indicates the years that were not included in the analysis as result of significant amount of missing records. The annual rainfall records were analyzed further by the considering the average and median of the total annual precipitation (Li et al., 2010). Table 7-4 shows the total annual precipitation of the selected years that resulted from this analysis. The average total annual precipitation was determined to be 531.4mm (Li et al., 2010). The median year was found to be 1981 and the year that had the total annual precipitation closest to the average value was determined to be 1985. The year with total annual precipitation closest to the average (i.e., 1985) was selected to be used for the rainfall input data. This year was also a good selection because there is no missing records compare to the median (i.e., 1981) (Li et al., 2010).

- *Evapotranspiration Input Data*

Table 7-5 shows the calculated average total daily evapotranspiration data for the Barrie Creek Subwatershed. This input data were provided by the LSRCA (Li et al., 2010).

Table 7-4: Total Annual Precipitation of the Selected Years in Barrie WPCC Rain Gauge Station (adapted from Li et al. (2010))

Year	Total Annual Precipitation (mm)
1986	768.8
1996	726.0
1995	718.3
2000	669.2
1999	572.9
2001	545.7
1993	544.3
1985	544.1 (closest to the average total annual precipitation)
2002	507.1
1990	502.5
1981 (median year)	500.1
2003	489.3
1991	489.2
1979	487.4
1989	487.3
1998	485.8
1983	479.5
1984	472.3
1994	470.8
1980	418.2
1988	281.1

Table 7-5: Average Total Daily Evapotranspiration of Barrie Creeks Subwatersheds (adapted from Li et al. (2010))

Month	Average Daily Evapotranspiration, (mm/day)	Month	Average Daily Evapotranspiration (mm/day)
Jan	0	July	4.129
Feb	0	Aug	3.684
Mar	0.01864	Sept	2.580
Apr	0.9428	Oct	1.223
May	2.519	Nov	0.3149
June	3.766	Dec	0

7.3.2 Evaluation of LID performance on a HRU level

Identification of HRU types

The results of the GIS screening was used as primary input in the development of HRUs. It was intended originally that the HRUs would be developed based on the data listed above as well as the areas suitable for each LID practice. The unit for the HRU would be the stormwatershed. In order to identify hydrologically similar stormwatersheds, the areas amenable to each LID practice were determined as a percentage of each stormwatershed. The resulting spider graph of the distribution of area characteristics produced no distinguishable patterns, indicating that the unit for HRU was too broad and the methodology needed further defining. The conclusion after the first iteration of HRU methodology development resulted in the reduction of the unit to a smaller area than a stormwatershed. It was also decided to develop the HRUs separately for each LID method rather than grouping all the characteristics to identify similarities.

The second iteration of the methodology development resulted in the HRU unit being the parcel area (described in the GIS tool by the Assessment ID). It recognized that this would allow for distinct characterization of hydrologically similar areas within the watershed. Furthermore, the additional aspect of developing the HRUs according to each LID practice would allow for a more meaningful evaluation of each individual technology over the study area to be achieved.

HRU Modelling Methodology

Identification of number of models to run

Using the data collected using GIS for each LID technology, an analysis was conducted to determine the distribution of the building size-to-lot size ratios. An example of the method applied is shown for the assessment for downspout disconnection below in Table 7-6. The ratios were placed in various, evenly distributed bins ranging from 0 to 100. The frequency of the ratios was then calculated and the results were plotted in a histogram. This is shown again for downspout disconnection in Figure 7-2. The histogram was further analysed by dividing it into three regions that corresponded to the lower, middle and upper thirds of the range of values identified in screened lots. This is demonstrated in Figure 7-2 as well. It was determined that selecting one lot in the middle of each region would be sufficient in developing a relationship to evaluate the performance of the LID in the area. Using the GIS layer that identified the areas for potential implementation of LID technology in combination with orthographic photos of the area, several lots within the middle of each region were examined to confirm their suitability for modelling. Upon completion of this step, one representative lot was chosen for each region to be used in modelling. An example of the type of aerial photograph used to select the lots for modelling is shown for a commercial lot suitable for downspout disconnection in Figure 7-3. The histograms developed for each land-use type for each LID practice studied, as well as descriptions and illustrations of the lots selected are shown in Appendix D.1.

Table 7-6: Frequency of Building size-to-Lot Size Ratios for Downspout Disconnection (Commercial Application)

Building-Size/Lot-Size Percent Class Limits	Frequency	Cumulative %
0	0	0.00%
11	21	9.25%
22	71	40.53%
33	72	72.25%
44	30	85.46%
55	10	89.87%
66	9	93.83%
77	3	95.15%
88	4	96.92%
100	7	100.00%
Total Lots	**227**	

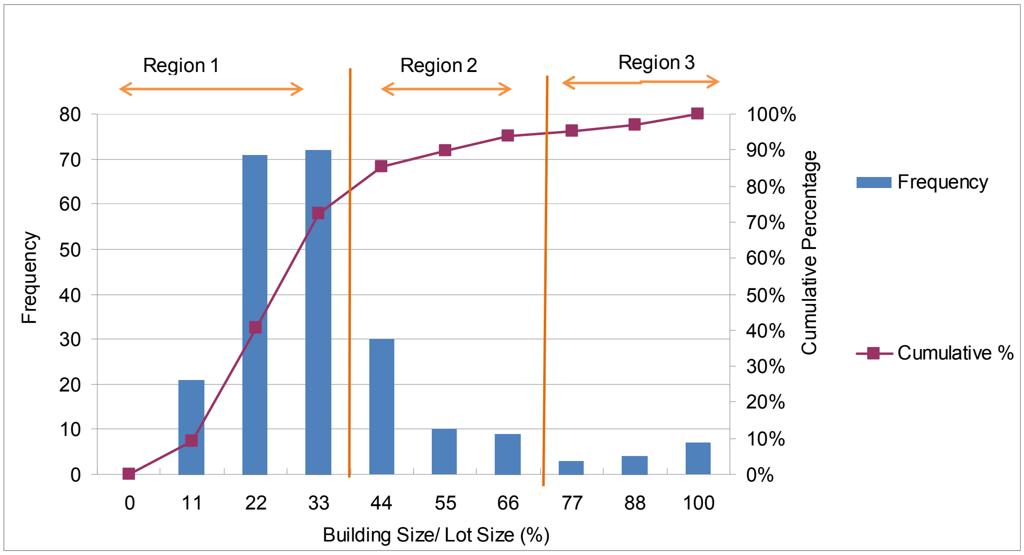

Figure 7-2: Histogram of Building Size-to-Lot Size Ratio for Downspout Disconnection (Commercial Land Use)

Figure 7-3: Aerial photograph of the selected lot in Region 1 for downspout disconnection application (Commercial Land Use) (adapted from Li et al., 2010)

Modelling Tool Selection

Chapter 3 reviewed a number of modelling tools currently available appropriate for application of LID evaluation. The modelling tool that was to be chosen had to possess certain characteristics. It was recognized that it would be advantageous to apply a tool that is versatile, has a well-developed interface, open source, guidance documentation and support is available, and there are existing cases studies for evaluating LID practices. In addition, due to the goal of the study to provide guidance to watershed municipalities for incorporating LID technologies into their stormwater management master plans, it was particularly ideal for the software to be publicly available with minimal requirement for additional operating system needs (i.e., ArcGIS). At the beginning of the study, among the current tools available at the time, the most appropriate tool to fit into this selection criterion was U.S. EPA SWMM5. However, before commencement of the modelling stage, the U.S. EPA released the beta version of the SWMM-LID which includes specific modules for representing the implementation of various LID technologies. As described in Chapter 3, this model is an extension of SWMM5, sharing all algorithms and interface. SWMM-LID was chosen as the modelling tool to assist with the evaluation of the hydrological benefit of LID implementation over the Lake Simcoe watershed based on its capability to explicitly represent LID technologies. As a result, the modelling effort was reduced substantially.

Sensitivity Analysis of SWMM-LID Program

A sensitivity analysis was performed for the SWMM5-BMP/LID Extension Beta Model to understand the factors that may affect the capabilities of the program, as well as identify the limits of the model. The sensitivity analysis was performed specifically for the LID modules included in the program (i.e., infiltration trench, porous pavements, vegetative swales, rain barrel and bio-retention). These LID techniques were tested one at a time using continuous rainfall records between April 1 of 1988 and October 31 of 1988 from the Toronto Bloor station as the input data. The sensitivity of each module was tested at various upper and lower bound limits. The number of limits that were used in testing depended on each module individually. Once a limit was selected where a noticeable change was seen, the testing stopped. The upper and lower bound limits were applied to only the parameters in the “BMP controls editor” box and the “BMP controls for subcatchment”.

For the testing of the Infiltration Trench SWMM-LID module, the upper bound and lower bound limits were set to be 10 percent. There are two layers that describe this module, the Surface Layer and Storage Layer. In the Surface Layer, Mannings n, affected the runoff volume result the most for both the upper and lower bound limit variations. The parameters “height or thickness” and “void ratio” in the storage layer was the most sensitive parameters on the runoff volume.

The sensitivity analysis of the Porous Pavement Module that was performed to assess the impact on the subcatchment runoff result showed no change in the limits that were tested. For this case, two upper bound and lower bound limits scenarios of 10 percent and 50 percent were chosen. The purpose of doing the second scenario of 50 percent limits was due to the small changes in the overall results of the 10 percent limits test. Despite the large difference in limits, the module parameters produced no change on the runoff volume generated.

The testing for the Vegetative Swales SWMM-LID module was done for a 10 percent upper bound and lower bound limit variation. All parameters produced some affect on the subcatchment runoff volume generated. The most sensitive parameters were “storage depth”, “swale side slope”, and “length to width ratio”.

The Rain Barrel SWMM-LID module consists of only one layer, the Storage Layer. Two testing scenarios were completed for this SWMM-LID module, the first having limits of ±10 percent and the second with ±30 percent. It was found that the “height or thickness” parameter had the most impact on the runoff volume result. The “drain exponent” and “drain coefficient” also showed to affect the subcatchment runoff results, although not as significantly as the “height or thickness” parameter.

The Bio Retention LID Module was tested using an upper and lower bound limit of10 percent and 50 percent. Varying the parameters by 10 percent resulted in no impact to the runoff volume. Increasing the upper and lower bound testing limits to 50 percent resulted in the “storage depth” from the Surface Layer having the most impact on the runoff volume result. The “thickness, field capacity, and ”wilting point” in the Soil Layer Properties showed to be the most sensitive in terms of the runoff volume generated. In terms of the parameters in the Storage Layer, they all affected the runoff results, however the “drain exponent parameter in this layer affected runoff volume reduction result the most.

Modelling Assumptions for LID practices

The HRU models were developed for each LID practice. The modelling assumptions used are described in Table 7-7.

Table 7-7: Modelling assumptions for LID practices evaluated

LID Practice	Modelling Assumptions
Green Roof	▪ Applied on rooftops greater than 350 m². ▪ The shape of the green roof depends on the roof area. ▪ Occupies 75 percent of the total roof area. ▪ Sizing of layers.
Soakaway Pit	▪ Stone depth = 1.5 m. ▪ Storage layer filled with uniformly-graded, washed 50 mm diameter stone with a 40 percent void capacity. ▪ Sizing criteria – see Appendix D.1 for description.
Downspout Disconnection	▪ Roof runoff directed to the pervious area of the subcatchment. ▪ Modelled as "rain barrel" LID module in SWMM-LID where the void ratio was set to be 0.99 (see Appendix D.1 for further details).
Rainwater Harvesting	▪ Roof runoff directed to the pervious area of the subcatchment. ▪ Sizing criteria – see Appendix D.1 for description. ▪ Captured rainwater directed 100 percent to a pervious surface. ▪ Modelled as "rain barrel" LID module.
Dry Well	▪ Storage (gravel) depth of 0.9m. ▪ Sizing criteria – see Appendix D.1 for description. ▪ Storage layer is filled with a uniformly-graded, washed 50 mm diameter stone with a 40 percent void capacity. ▪ No underdrain. ▪ Modelled as "infiltration trench" LID module.

Additional steps completed for HRU modelling

The models for the three representative regions for each LID technology were developed in SWMM-LID using the assumptions described in Table 7-7. The input values for each parameter in the modules are described for each LID practices simulated in Appendix D.1. For each region, models were developed to describe conditions with and without the application of the LID practice. The models were run over a typical year to determine stormwater runoff volumes in each scenario. This enabled the production of a curve to described runoff volumes for existing conditions as a function of lot size and percent impervious area of the lot. To create this curve, the results obtained from all the models produced to determine the runoff volume without LID implementation was used as the data. This was plotted as a function of the associated lot sizes used in each region model.

Following the creation of this curve, separate curves were developed for each LID technology for each land use type to represent the percent volumetric reduction in stormwater runoff and the pollutant loading with LID application, both as a function of building size-to-lot size ratio. The development of these functions was the main requirements to assessing the benefit of implementing these technologies over the uncontrolled areas of the watershed. This is used as the input into the next stage of the modelling methodology described in Chapter 3.

Characterization of Existing Condition for HRU Models

The results obtained for the modeled lots using the developed spreadsheet model for roof-based LID technologies are shown in Table 7-9. These values were used to produce a curve to describe the runoff volumes for existing conditions as a function of lot size and percent impervious area of the lot. To strengthen the validity of the function, additional lots (listed in Appendix D.1) were modelled to obtain the runoff volume for their existing conditions (Li et al., 2010). To develop the function to describe the runoff volume without LID application, an online curve fitting tool (zunzun.com) was used. The fitting of the modelled lots runoff volume for existing conditions resulted in the following equation (Li et al., 2010):

$$\boldsymbol{z} = \left(\frac{\boldsymbol{a}+\boldsymbol{bln}(\boldsymbol{x})+\boldsymbol{cln}(\boldsymbol{y})+\boldsymbol{dln}(\boldsymbol{x})\ln(\boldsymbol{y})}{\mathbf{1}+\boldsymbol{eln}(\boldsymbol{x})+\boldsymbol{fln}(\boldsymbol{y})+\boldsymbol{gln}(\boldsymbol{x})\ln(\boldsymbol{y})}\right)(\mathbf{hxy}) + \mathbf{offset} \qquad (7\text{-}1)$$

where z is the runoff volume (m^3), x is the lot area (m^2), and y is the parcel impervious area (%). The equation coefficients are the following:

$a = 9.864 \times 10^4$

$b = -1.402 \times 10^4$

$c = 7.404 \times 10^4$

$d = -8.904 \times 10^3$

$e = -1.046 \times 10^{-1}$

$f = -2.307$

$g = 2.845 \times 10^{-1}$

$h = -9.321 \times 10^{-8}$

$\text{offset} = 1.684 \times 10^1$

It is this function that was applied to all lots to determine the runoff volume before LID application.

HRU Modelling Results

Determination of Runoff Volume Reduction

To estimate the runoff reduction potential for each LID practice studied, performance curves were developed from the SWMM-LID modelled lots. A plot of the percent volume reduction as a function building-to-size ratio for each LID was produced. All plots are shown in Appendix D.1. The functions that represent this relationship for each LID technology according to land-use type are shown in Table 7-8.

Table 7-8: Function to determine percentage of runoff volume reduction for each LID practice

LID Practice	Land-Use Type	Function for Percent Volumetric Runoff Reduction
Green Roof	All types – buildings over 350 m^2	y = 24.41x + 1.5748
Soakaway Pit	Commercial	y = 28.11x - 0.78
	Residential	y = 17.72x + 6.69
Downspout Disconnection	Commercial	y = 0.8069x + 17.047
	Industrial	y = 30.489x + 5.7546
	Residential	y = -15.206x + 46.145
Dry Well	Commercial	y = 24.619x + 2.4297
	Industrial	y = 31.115x - 0.4965

	Residential	y = 15.011x + 12.727
Rainwater Harvesting	Commercial	y = 14.54x + 18.32
	Industrial	y = 53.54x + 5.62
	Residential	y = -16.633x + 58.448

Note: y = percent reduction, x = building-to-lot size ratio

The appropriate function was applied to all lots, which assessed the percentage of volumetric reduction on a HRU level. In order to evaluate the benefit achieved from each LID practice on a HRU level, a relationship was developed from the modelled lots results. This relationship is characterized by the following equation:

$$\left(1 - \frac{\%Runoff\_Reduction}{100}\right) * Runoff_{without}LID \qquad (7\text{-}2)$$

This equation was used in determining the total volume reduction for each HRU with LID application. Application of these three relationships allowed for the evaluation of performance for each LID practice within the uncontrolled areas of the watershed. A discussion of the benefit achieved for each practice is described in further detail below.

Table 7-9: Roof-based LID Technologies Spreadsheet model

LID Practice	Land-use Type	Assessment ID Number	Address	Stormwatershed ID	Lot Size (m^2)	Bldg Size (m^2)	Building Size-to-Lot Size Ratio (%)	Impervious Area (%)	Total Runoff without LID application (m^3)	Total Runoff with LID application (m^3)	Volume Reduction (%)
Green Roof	Residential	434202200809800	114 DUNLOP ST E	BAR-NE40	642.00	532.43	82.93	96.51	256.16	195.00	23.88
	Industrial	434204000603502	80 MORROW RD	BAR-SW13	1860.14	922.38	49.59	91.20	742.20	672.00	9.46
	Industrial	434203200306100	20 ELLIOTT AVE	BAR-C23	13323.80	2386.12	17.91	91.83	5316.20	4885.00	8.11
Soakaway Pit	Commercial	434202200305600	115 COLLIER ST	BAR-NE32	755.20	123.26	16.32	84.08	279.00	268.00	3.94
	Commercial	434202200306000	105 COLLIER ST	BAR-NE40	319.29	106.67	33.41	77.58	110.00	101.00	8.18
	Commercial	434202201003701	44 COLLIER ST	BAR-NE39	2957.15	1218.86	41.22	75.19	991.00	881.00	11.10
	Residential	434201100503600	148 PUGET ST	BAR-NE8	789.48	130.78	16.57	28.88	126.00	114.00	9.52
	Residential	434205000606798	29 STEPHANIE LANE	BAR-SE85	406.85	201.07	49.42	60.75	115.00	97.00	15.65
	Residential	434203200510000	14 HIGH ST	BAR-C5	906.74	706.65	77.93	77.93	314.00	250.00	20.38
Downspout Disconnection	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92	205.00	166.00	19.02
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86	247.00	213.00	13.77
	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69	658.00	530.00	19.45
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70	128.00	94.00	26.56
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65	1383.00	1102.00	20.32
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62	823.00	732.00	11.06
	Residential	434202200805800	50 DUNLOP ST E	BAR-NE39	497.97	433.71	87.10	87.10	190.00	136.00	28.42
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15	112.00	58.00	48.21
	Residential	434201201613800	12 MELROSE AVE	BAR-NE13	835.64	137.88	16.50	24.80	122.00	75.00	38.52
Dry Well	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69	658.00	611.00	7.14
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86	247.00	219.00	11.34
	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92	205.00	159.00	22.44
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70	128.00	102.00	20.31
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65	1383.00	1176.00	14.97
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62	823.00	784.00	4.74
	Residential	434202200810700	65-69 COLLIER ST	BAR-NE40	942.12	834.84	88.61	88.96	366.00	272.00	25.68
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15	110.00	87.00	20.91
	Residential	434202101404700	136 OWEN ST	BAR-NE39	1334.87	220.22	16.50	20.29	169.00	144.00	14.79
Rainwater Harvesting	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92	205.00	141.00	31.22
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86	247.00	196.00	20.65
	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69	658.00	507.00	22.95
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70	128.00	74.00	42.19
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65	1383.00	952.00	31.16
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62	823.00	700.00	14.95
	Residential	434202200810700	65-69 COLLIER ST	BAR-NE40	942.12	834.84	88.61	88.96	366.00	230.00	37.16
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15	110.00	39.00	64.55
	Residential	434202101404700	136 OWEN ST	BAR-NE39	1334.87	220.22	16.50	20.29	169.00	88.00	47.93

Green Roof

As shown in Table 7-8, the performance curve that described the percentage of volumetric reduction as a function of building-to-lot size ratio is a positive relationship. It is expected that for large size buildings in the uncontrolled areas within the Lake Simcoe watershed suitable for green roof application, a significant reduction in runoff volume should be achieved. There were 552 lots in the Barrie watershed that were identified from the GIS screening stage as being suitable for green roof application. Using the functions discussed above, the total runoff for existing conditions and with LID application was determined to be 1.24 x 10^6 m^3 and 1.15 x 10^6 m^3, respectively, and shown inTable 7-10. As a result, a percentage of runoff volume reduction was calculated to be 7.40 percent for the 552 lots found suitable in the study area for green roof application, and 0.86 percent volume reduction over the watershed. To assess the validity of this result, a comparison can be made to available literature values. The TRCA and CVC (2010) reviewed selected monitoring studies to predict the performance of green roofs in Ontario's climate. It was determined that for extensive green roofs, a runoff reduction rate of 45 to 55 percent is achievable per lot. In comparison, the average values of the lots modelled in SWMM-LID (shown in Table 7-11) is 13.81 percent, which underestimates the predicted performance of green roofs. However, it is discussed by TRCA and CVC (2010) that from the numerous available research and monitoring studies in recent years, runoff reduction potential from green roofs is a function of media depth, roof slope, annual rainfall, and cold climate effects. The SWMM-LID and LID Performance Spreadsheet models used here do not take into account these aspects, which can explain for the significantly conservative estimate for green roof performance.

Table 7-10: Summary of overall performance results achieved by each LID practice

LID Practice	Land Use Type	Number of Lots	Total Runoff Volume without LID implementation (m^3)	Total Runoff Volume with LID implementation (m^3)	Percent Volume Reduction (%)	Watershed Volume Reduction (%)
Green Roof	All types (buildings over 350m^2)	552	1.24E+06	1.15E+06	7.40	0.86
Soakaway Pit	Commercial	98	1.26E+05	7.36E+04	41.73	1.19
	Residential	7126	1.12E+06	1.00E+06	10.72	
Downspout Disconnection	Commercial	227	2.26E+05	1.87E+05	17.24	6.88
	Industrial	711	8.96E+05	7.84E+05	12.57	
	Residential	7628	1.27E+06	6.84E+05	46.10	
Dry Well	Commercial	194	2.38E+05	2.19E+05	7.98	3.60
	Industrial	705	9.09E+05	8.51E+05	6.32	
	Residential	10095	2.20E+06	1.88E+06	14.78	
Rainwater Harvesting	Commercial	194	2.38E+05	1.87E+05	21.60	8.40
	Industrial	705	9.09E+05	7.52E+05	17.27	
	Residential	8331	1.35E+06	6.12E+05	54.66	

Table 7-11: Average lot-level performance results achieved by each LID practice

LID Practice	Land-use Type	Avg Runoff without LID per land use (m^3)	Avg Runoff with LID per land use (m^3)	Avg Volume Reduction per land use (%)	Avg Total Runoff without LID application (m^3)	Avg Total Runoff with LID application (m^3)	Avg Volume Reduction (%)
Green Roof	All land-use types	2104.85	1917.33	13.81	2104.85	1917.33	13.81
Soakaway Pit	Commercial	460.00	416.67	7.74	322.50	285.17	11.46
	Residential	185.00	153.67	15.19			
Downspout Disconnection	Commercial	370.00	303.00	17.41	429.78	345.11	25.04
	Industrial	778.00	642.67	19.31			
	Residential	141.33	89.67	38.39			
Dry Well	Commercial	370.00	329.67	13.64	454.33	394.89	15.81
	Industrial	778.00	687.33	13.34			
	Residential	215.00	167.67	20.46			
Rainwater Harvesting	Commercial	370.00	281.33	24.94	454.33	325.22	34.75
	Industrial	778.00	575.33	29.43			
	Residential	215.00	119.00	49.88			

Soakaway Pit

GIS screening criteria focused the assessment on lots within commercial and residential land use types. There were 98 commercial lots and 7126 residential lots found suitable for soakaway pit application. The performance curves yielded for each of these land-use types produced two different relationships. As indicated in Table 7-8, the function to describe the performance for soakway pits on commercial and residential lots are both positive relationships. This suggests that as the building size on the lot increases, the soakaway pit, when sized appropriately, can increasingly reduce the volume of stormwater runoff. Table 7-10

Table 7-10 shows the performance results for soakaway pit according to land use area. It was found that the total runoff for existing conditions is 1.26 x 10^5 m^3 for commercial land-use types and 1.12 x 10^6 m^3 for residential lots. With soakaway pit application, a total runoff of 7.36 x 10^4 m^3 and 1.0 x 10^6 m^3 for commercial and residential land-use types respectively was determined. The percentage of total runoff reduction was determined to be 6.54 percent from commercial lots and 10.72 percent from residential lots. The overall runoff volume reduction on a watershed level with application of soakway pits on both types of lots is 1.19%. The review of monitoring studies carried out by the TRCA and CVC estimate a runoff reduction of 85 percent (TRCA & CVC, 2010). The average percentages of runoff reduction for the modelled lots shown in Table 7-11 are again below this reported estimated literature value. However, this could be due to a number of reasons. The report literature value is generalized for other similar technologies to soakaway pits, such as infiltration trenches and perforated pipes. In addition, there is no indication of the drainage area and type. In this particular case, the focus is solely on treated roof runoff. It is also specified that there is limited monitoring studies related to these technologies. Consequently, while the results obtained in this case study are more conservative than the estimates reported in TRCA and CVC (2010), there are insufficient literature values to assess the appropriateness of these simulated results.

Downspout Disconnection

The watershed was screened for areas to implement downspout disconnection on commercial, industrial, and residential land-use spaces. There were 227 lots found suitable for downspout disconnection on commercial land-use types; 711 lots that are of the industrial type; and 7628 of residential land use type. As shown in Table 7-8, the performance curves that were developed for each land-use type produced positive relationships for commercial and industrial lots, and a negative relationship for residential lots. Applying the functions developed from the numerical model results on all applicable lots for this LID practice, it was found that the total runoff and percentage of total runoff reduction with downspout disconnection application was 1.87 x 10^5 m^3 and 17.24 percent, 7.84 x 10^5 m^3 and 12.57 percent, and 6.84 x 10^5 m^3 and 46.10 percent for commercial, industrial, and residential land-use types respectively. These performance results are shown in Table 7-10. On a watershed level, application of downspout disconnection can achieve a volume reduction of 6.88 percent. Comparing the averaged performance results obtained for the modelled lots shown in Table 7-11 to the reported values of the monitoring studies (TRCA & CVC, 2010), it can be seen that while the results are conservative, they are comparable. Average volume reductions ranging from 17 to 40 percent were achieved for lots that have downspout disconnection implemented. An estimated 50 percent reduction on HSG A and B soils was reported by TRCA and CVC (2010). While the soils that were selected for the modelled lots are of this type, the estimate reported by the TRCA and CVC (2010) specify that runoff reduction for this LID practice is a function of slope, vegetative cover, and flow path length across the pervious surface in addition to soil type. In addition, the value report is based on monitoring studies for vegetative swales due to the very limited research that has been done for runoff reduction for downspout disconnection. Therefore, the results obtained for all the lots suitable for downspout disconnection within the watershed is reasonable.

Dry Well

Similar to downspout disconnection, the study area was screened for commercial, industrial, and residential land use lots suitable for LID implementation. As indicated in Table 7-10, 194 commercial lots were identified suitable for dry well application. From these commercial lots, a total runoff volume before and after dry well application was determined to be 2.38 x 10^5 m^3 and 2.19 x 10^5 m^3, respectively. For the industrial land-use type, 705 lots were found suitable where 9.09 x 10^5 m^3 was estimated for the total runoff volume before dry well application and 8.51 x 10^5 m^3 after implementation. For the residential land-use type, 10095 were found appropriate for dry well application. Applying the appropriate functions, 2.20 x 10^6 m^3 was determined for the total runoff volume before dry well application and 1.88 x 10^6 m^3 after implementation. Using the functions described in Table 7-8, the percentage of total runoff volume reduction was determined to be 7.51 percent from commercial land-use type lots, 5.11 percent from industrial land-use type lots, and 14.29 percent from residential lots. The overall benefit of application of dry well on all these lots was determined to be 3.60 percent. There are limited monitoring studies conducted for dry well implementation to compare these results. The literature review carried out by TRCA and CVC (2010) provide an estimate for dry well runoff reduction capabilities as part of the reported estimate for soakaway pits, infiltration trenches, and chambers. As stated previously, it is estimated from monitoring studies that this runoff reduction estimate is 85 percent. The results of the modelled lots with dry well application in Table 7-11 show a range of 13 to 20 percent volumetric runoff reduction. Similar to soakaway pits, this value is quite below the literature value. However, as specified before, this value generalizes for a number of technologies and there is no indication of the types of drainage areas. Therefore, the results received on a watershed level provide an estimate on a planning level for the implementation of dry wells.

Rainwater Harvesting

Commercial, industrial, and residential land-use type lots also were focused on for rainwater harvesting. There were 194 commercial type lots found appropriate for rainwater harvesting application; 705 lots that are of the industrial type; and 8331 of residential land use type. Applying the appropriate functions from Table 7-8, it was found that the total runoff volume generated and percentage of total runoff reduction with rainwater harvesting application was 1.87×10^5 m^3 and 21.60 percent, 7.52×10^5 m^3 and 17.27 percent, and 6.12 10^5 m^3 and 54.66 percent for applicable lots of commercial, industrial, and residential land-use types respectively. The combined benefit that is achieved from the implementation of this LID over the watershed is 8.40 percent, as shown in Table 7-10. Referring to the literature review of monitoring studies carried out by the TRCA and CVC (2010), a runoff reduction rate of 40 percent is estimate to be achieved on the lot-level. The lots modelled with SWMM-LID produced a range of 25 – 50 percent as indicated in Table 7-11, which is comparable to the literature value reported. Therefore, it can be concluded that the results obtained on the watershed scale, provides a good planning level estimate of the benefit that can be achieved by large-scale rainwater harvesting implementation in the Lake Simcoe region.

A summary of all performance results for each LID practice examined in this case study is shown in Table 7-10. As it can been seen, the greatest percentage of runoff volume reduction on a watershed level will come from implementing downspout disconnection and rainwater harvesting. Application on commercial and residential land use types will achieve the greatest benefit.

Determination of Pollutant Loading

In addition to determining the percentage of runoff volume reduction, the impact on pollutant loading was also assessed. These calculations were carried out using event mean concentration (EMC) data and LID removal efficiencies obtained from a literature review of appropriate studies (TRCA & CVC, 2010; Fairfax County, 2005; UFC, 2004; NAHB Research Center, Inc., 2003; Virginia Department of Conservation and Recreation, 2002; Hardin & Wanielista, n.d.; Peck et al., 2009; Winer, 2000). The literature values for the EMC data and LID pollutant removal efficiencies are shown in Table 7-12 and Table 7-13. The values determined for the pollutant loadings with and without LID application are shown as well in Appendix D.4 according to stormwatershed.

Table 7-12: EMC data used in pollutant loading assessment

Value/ Land use	TSS[3] (mg/l)	TP[4] (mg/l)	Zinc (mg/l)	Copper (mg/l)	E. Coli (counts /100ml)	TKN[5] (mg/l)	Nitrate (mg/l)	Nitrate (mg/l)
Average[6]	266	0.41	0.22	0.04	39,500	1.55	0.13	6.7
Industrial Average	108.3	0.88	0.16	0.25	9,882.90	3.35	0.06	12.20
Residential Average	183.9	0.68	0.18	0.04	217,119.60	3.03	0.15	5.2

3 Total suspended solids (TSS)

4 total phosphorus (TP)

5 total kjeldahl nitrogen (TKN)

6 Average EMC values between town of East York and St. Catherines, Ontario. These values were used in calculation

Table 7-13: LID removal efficiencies

LID Practice	TSS	TP	TN	Zinc	Lead	BOD	Bacteria
Green Roof	69	-80	-149	18	-	-	-
Soakaway Pit	90	70	90	70	90	70	70
Downspout Disconnection	80	60	80	60	-	-	-
Dry Well	90	50	50	90	90	70	70
Rainwater Harvesting	100	100	100	100	100	100	100
Infiltration Trench[7]	80	65	50	80	90	70	70

To estimate the pollutant loading without LID application, the following equation was used:

$$Pollutant\ loading\ of\ untreated\ runoff = Runoff\ Volume\ (m^3) * EMC \qquad (7\text{-}3)$$

The pollutant loading reduction potential for each LID practice was estimated in a similar manner as the percentage of volumetric runoff reduction. To determine the pollutant loading with LID application for each lot, the following equations were used:

$$Pollutant\ loading\ after\ LID\ application = Pollutant\ loading\ of\ untreated\ runoff + Pollutant\ loading\ of\ treated\ runoff \qquad (7\text{-}4)$$

where,

$$Pollutant\ loading\ of\ untreated\ runoff\ = untreated\ runoff\ volume\ * EMC \quad (7\text{-}5)$$

$$Pollutant\ loading\ of treated\ runoff\ = treated\ runoff\ volume\ * EMC * (1 - \%LID\_Effciency) \qquad (7\text{-}6)$$

[7] Due to the similarities in technology, the values for infiltration trench were used for the assessment for soakways pits since there were no data available specifically for this LID practice.

These equations were applied to the modelled lots to obtain the percent pollutant loading reduction achieved after LID application. The pollutants that were assessed were total suspended solids (TSS), total phosphorus (TP), and zinc. Performance curves were developed from the SWMM-LID modelled lots for each LID practice according to land-use type. The curves produced functions that determined the percent pollutant loading reduction obtained after LID application as a function of building size-to-lot size ratio. All plots are shown in Appendix D.1. The functions that represent this relationship for each LID technology according to land-use type are shown in Table 7-14.

Table 7-14: Function to determine percent pollutant loading reduction with application of LID practice

		Function for %pollutant loading reduction		
LID Practice	**Land-Use Type**	**TSS**	**TP**	**Zinc**
Green Roof	All types – buildings over 350 m^2	y_{TSS} = 56.452x + 1.5748	y_{TP} = -12.74x + 1.5748	y_{Zinc} = 32.769x + 1.5748
Soakaway Pit	Commercial	y_{TSS} = 123.95x - 2.9778	y_{TP} = 102.65x - 2.4892	y_{Zinc} = 123.95x - 2.9778
	Residential	y_{TSS} = -7.2062x + 35.858	y_{TP} = -7.2062x + 35.858	y_{Zinc} = -7.2062x + 35.858
Downspout Disconnection	Commercial	y_{TSS} = 68.824x + 25.79	y_{TP} = 49.645x + 24.164	y_{Zinc} = 68.824x + 25.79
	Industrial	y_{TSS} = 118.52x + 6.2807	y_{TP} = 95.828x + 6.3149	y_{Zinc} = 118.52x + 6.2807
	Residential	y_{TSS} = 4.0244x + 77.214	y_{TP} = -9.6053x + 67.69	y_{Zinc} = 4.0244x + 77.214
Dry Well	Commercial	y_{TSS} = 87.945x + 8.1251	y_{TP}= 59.8x + 5.5938	y_{Zinc} = 87.945x + 8.1251
	Industrial	y_{TSS}= 106.67x - 0.7952	y_{TP} = 73.088x - 0.6624	y_{Zinc}= 106.67x - 0.7952
	Residential	y_{TSS} = 56.405x + 29.889	y_{TP} = 38.008x + 22.261	y_{ZInc} = 56.405x + 29.889
Rainwater Harvesting	Commercial	y_{TSS} = 116.42x + 11.714	y_{TP} = 116.42x + 11.714	y_{Zinc} = 116.42x + 11.714
	Industrial	y_{TSS} = 136.77x + 17.162	y_{TP} = 136.77x + 17.162	y_{Zinc} = 136.77x + 17.162
	Residential	y_{TSS} = 100	y_{TP} =100	y_{Zinc} = 100

Note: y = %pollutant loading reduction, x = building-to-lot size ratio

The appropriate function was applied to all lots, which assessed the percent pollutant loading reduction with LID application on a HRU level. In a similar manner to the volumetric reduction assessment, the percent pollutant loading reduction was found for the applicable areas for each LID practice. For the pollutant loading before LID application, the runoff volume obtained for each LID practice applicable areas was used in Equation 7-3. This allowed for the assessment of pollutant loading with LID practice, which used an equation similar to that used for the assessment of volume with LID application, as shown described in Equation 7-7.

$$\left(1 - \frac{\%pollutant - loading\_Reduction}{100}\right) * Pollutant - Loading_{without} LID \qquad (7\text{-}7)$$

A summary of the overall performance for each LID practice examined in this case study is shown in Table 7-15[8]. As it can been seen, the greatest percentage of pollutant loading reduction on LID applicable areas for TSS, TP, and zinc will come from implementing downspout disconnection and rainwater harvesting on commercial and residential land use types, and dry well on residential lots. On a watershed level, rainwater harvesting would be the most advantageous LID option for TSS, TP, and zinc reduction. Downspout disconnection and dry well also show to have good pollutant reduction capabilities particularly for TSS reduction. The results show that application of green roofs throughout the study area will produce the least benefit by negative numbers, indicating the LID practice contributes to pollutant loading. This conclusion for green roofs have also been shown in other case studies assessing the pollutant loading reduction potential for green roofs (TRCA & CVC, 2010).

7.3.1 Aggregation of HRU modelling results over study area

The final step in this methodology is to combine the results from the HRUs to determine the hydrological performance of LID application over the study area. In the previous step, runoff volumes (with and without LID application) were determined and applied to all available lots suitable for each LID practice included in this case study. As discussed above, the hydrological performance for each LID practice was evaluated according to land use type. Using a

[8] As it can been seen, some of the LID practices, such as rainwater harvesting, produce substantially significantly positive results. While the benefits of rainwater harvesting have been documented (TRCA& CVC, 2010; Farahbakhsh et al., 2008), these results may overestimate the performance ability of these LID practices. These values are presented based on the beta version of the SWMM-LID modelling tool and the methodologies employed within the tool may be in need of further refining. However, the methodologies presented in this thesis are sound.

spreadsheet model developed through the study, these HRU results were integrated to determine the performance according to stormwatershed. A table summarizing the percentage of runoff volume reduction for all stormwatersheds according to each LID practice included in the study is shown in Appendix D.4. Figure 7-4 shows the maximum percent volume reduction that is possible to be achieved in each stormwatershed if one LID practice is selected for application. In this scenario, approximately 45 percent of the stormwatersheds in the study area could attain a runoff volume reduction over 10 percent.

In a similar manner to the volumetric reduction assessment, the potential pollutant loading reduction with LID application was found over the study area. To determine the percent pollutant loading reduction within the uncontrolled areas of the watershed, the runoff volume without LID application obtained previously on a stormwatershed basis for each LID practice was used. Equation 7-3 was applied to each applicable area and the percent pollutant loading reduction was evaluated for each LID practice within the uncontrolled areas of the watershed. These results are summarized as well in Appendix D.4. Figure 7-5 to Figure 7-7 shows the potential annual maximum percent loading reduction for each pollutant assessed in each stormwatershed if one LID practice is selected for application. It was found that sixty-eight stormwatersheds have the potential to reduce 15 percent or greater of TSS loading annually. For phosphorus, sixty-nine stormwatersheds can reduce 15 percent or greater of loading. Finally, eighty-one stormwatersheds can reduce their zinc loading by 15 percent or greater annually.

Table 7-15: Summary of overall pollutant loading reduction performance results achieved by each LID practice

LID Practice	Land Use Type	Number of Lots	Total Runoff Volume without LID implementation (m³)	Pollutant Loading without LID Application (kg/yr)			Pollutant Loading with LID Application (kg/yr)			Pollutant Loading Reduction with LID Application Over Applicable Area			Pollutant Loading Reduction (%) over Watershed		
				TSS	TP	Zinc	TSS	TP	Zinc	TSS	TP	Zinc	TSS	TP	Zinc
Green Roof	All types (buildings over 350m^2)	552	1.24E+06	3.30E+05	5.09E+02	2.73E+02	2.80E+05	5.16E+02	2.47E+02	15.05	-1.47	9.40	1.74	-0.17	1.09
Soakaway Pit	Commercial	98	1.26E+05	3.36E+04	5.18E+01	2.78E+01	2.52E+04	4.10E+01	2.08E+01	25.08	20.75	25.08	3.87	3.82	-2.92
	Residential	7126	1.12E+06	2.98E+05	4.60E+02	2.47E+02	1.96E+05	3.02E+02	1.62E+02	34.22	34.22	34.22			
Downspout Disconnection	Commercial	227	2.26E+05	6.01E+04	9.26E+01	4.97E+01	3.48E+04	5.94E+01	2.88E+01	42.04	35.89	42.04	12.79	10.13	12.12
	Industrial	711	8.96E+05	2.38E+05	3.68E+02	1.97E+02	1.60E+05	2.66E+02	1.33E+02	32.78	27.74	32.78			
	Residential	7628	1.27E+06	3.38E+05	5.21E+02	2.79E+02	7.34E+04	1.81E+02	6.07E+01	78.26	65.17	78.26			
Dry Well	Commercial	194	2.38E+05	6.34E+04	9.78E+01	5.25E+01	4.57E+04	7.91E+01	3.78E+01	27.96	19.08	27.96	14.19	6.99	9.71
	Industrial	705	9.09E+05	8.43E+05	3.73E+02	2.00E+02	6.61E+05	3.16E+02	1.55E+02	21.60	15.23	22.41			
	Residential	10095	2.20E+06	5.86E+05	9.04E+02	4.85E+02	3.66E+05	6.56E+02	3.03E+02	37.62	27.47	37.62			
Rainwater Harvesting	Commercial	194	2.38E+05	6.34E+04	9.78E+01	5.25E+01	3.93E+04	6.06E+01	3.25E+01	37.97	37.97	37.97	16.67	18.78	23.28
	Industrial	705	9.09E+05	2.42E+05	3.73E+02	2.00E+02	1.28E+05	1.98E+02	1.06E+02	46.91	46.91	46.91			
	Residential	8331	1.35E+06	3.59E+05	5.54E+02	2.97E+02	0.00E+00	0.00E+00	0.00E+00	100.00	100.00	100.00			

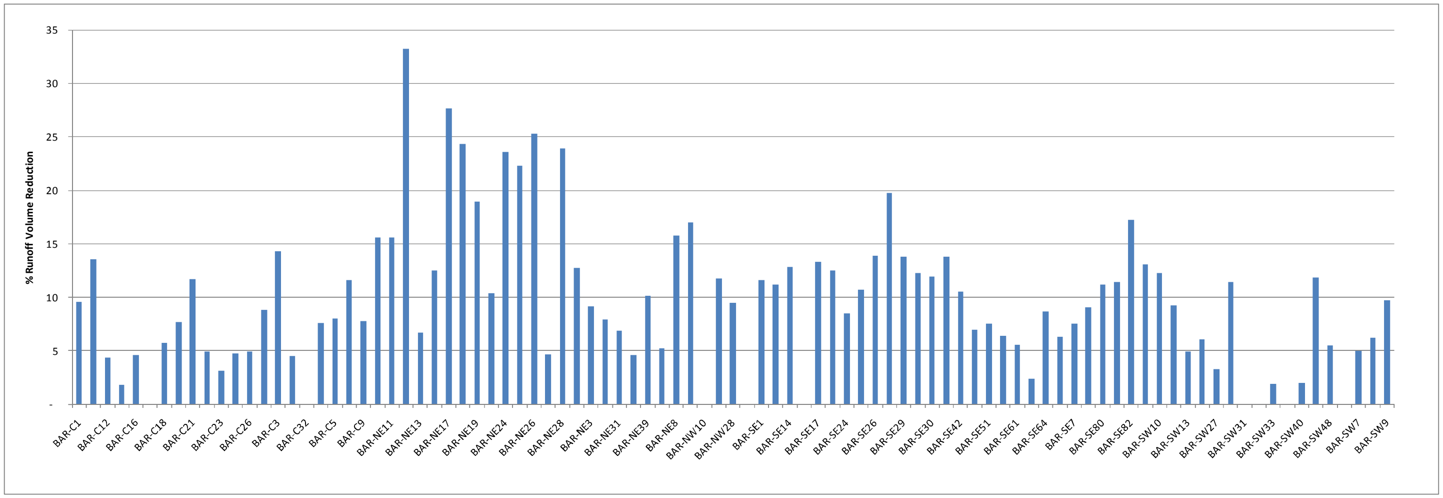

Figure 7-4: Maximum potential of runoff volume reduction (%) per stormwatershed with one LID practice selected for application

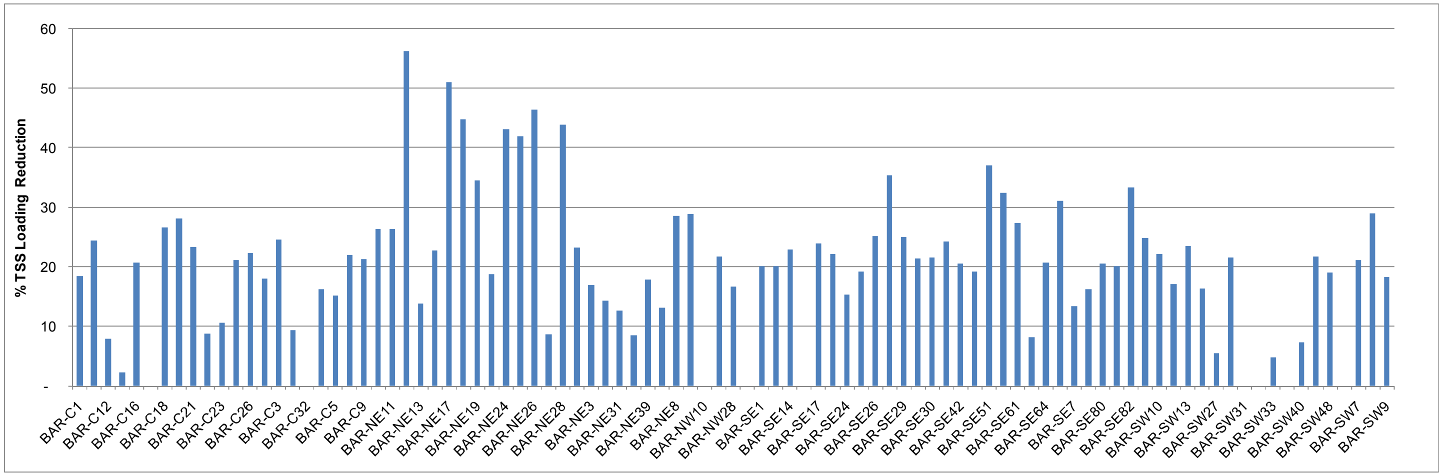

Figure 7-5: Maximum Potential of TSS Loading Reduction (%) per stormwatershed with one LID practice selected for application

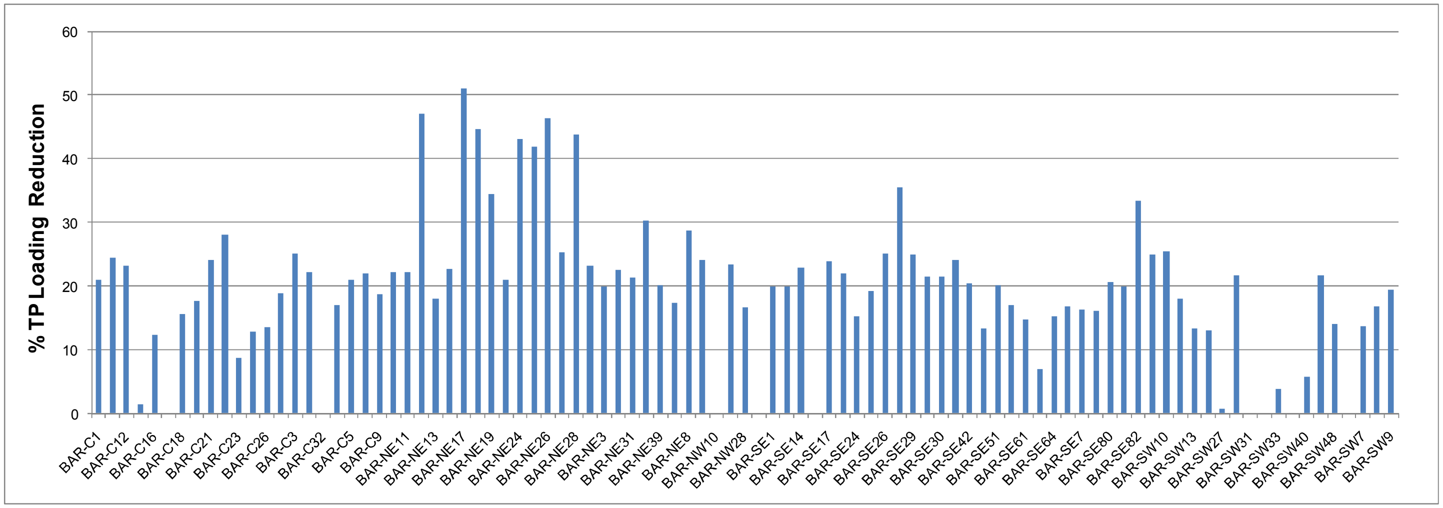

Figure 7- 6: Maximum potential of TP loading reduction (%) per stormwatershed with one LID practice selected for application

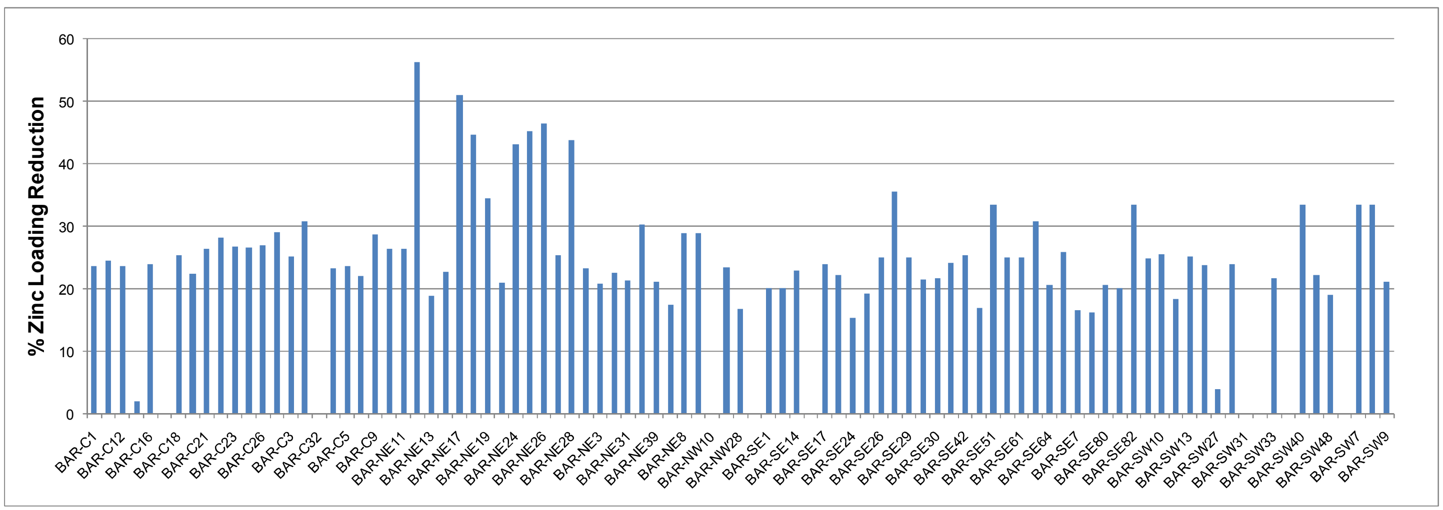

Figure 7-7: Maximum potential of zinc loading reduction (%) per stormwatershed with one LID practice selected for application

7.4 Evaluation of cost-effectiveness for LID practices suitable for application in the Lake Simcoe Watershed

This component determines the cost-effectiveness of implementing LID practices, which can be applied in optimizing planning strategies on a watershed scale. The cost functions from Table 4-1 are applied to the LID practices considered in this case study. Total costs in 2010 Canadian dollars were determined for all HRU parcels according to each LID practice using the cost functions developed in Chapter 4. For the calculation of the present value worth of O&M costs, it was assumed that the number of periods is 25 years in which there is no savage value at the end of life for these technologies. The Bank of Canada default value for interest rate (3.0 percent) on future value calculations is used as the rate for all calculations (Bank of Canada, 2010). Finally, it is assumed that the payment occurs at the end of each period.

Similar to the hydrological performance evaluation, a spreadsheet model was used to determine the total cost of implementing each LID practice within each stormwatershed. An example of the type of information that was determined by the LID cost spreadsheet model is shown in Appendix D.2 for green roof application. Cost tables such as this were produced for each LID practice according to land use type. The total cost for implementing each LID practice according to stormwatershed was determined from each of these spreadsheet models. A summary table of these estimate cost of each LID implementation per stormwatershed is shown in Appendix D.4. An estimate of the total cost of implementing each LID practice throughout the Lake Simcoe watershed is shown in Table 7-16 below. These are presented as life-cycle costs over an assumed life span of 25 years.

Table 7-16: Total-Cost Estimates of implementation of specific LID practice in Lake Simcoe Watershed

LID Practice	Applicable area (m^2)	Estimate Total-Cost (2010, $CDN)
Green Roof	1,009,500	$381,025,671
Soakaway Pit	1,400,137	$91,561,201
Downspout disconnection[9]	2,373,749	$169,611,565
Dry Well[10]	2,363,479	$26,271,165
Rainwater Harvesting	2,643,144	$263,066,467

[9] A base cost of $100 was assumed for each application

[10] Annual O&M costs were estimated at 7.5%

7.5 Incorporation of Stakeholders' opinions in Lake Simcoe LID Project

A number of activities to engage stakeholders in the LID planning process have been completed to date. The project leaders have identified various methods in which stakeholder engagement can occur. For example, while the study is being managed by the LSRCA and being carried out by a team of researchers from Ryerson University, a Steering Committee has been set up to guide the progress of the study and to ensure that a meaningful outcome is obtained for watershed stakeholders. The members of the Steering Committee consist of representatives of municipalities within the watershed, officials from various levels of governments, the research team, and employees of the LSRCA.

In addition to the participation of stakeholders with direct and immediate interests in the Lake Simcoe Region LID Planning Study, the "Phase 1 Workshop for Stormwater Management Strategies for Uncontrolled Urban Areas in the Lake Simcoe Watershed" (hereafter, "LSRCA LID Workshop") was held on September 28, 2009 by the Lake Simcoe Conservation Authority (Ogilvie, Ogilvie & Company, 2009). The purpose of the workshop was to engage additional stakeholder groups, such as private consulting firms, conservation authorities, and urban planners. It was also used as an education medium for the stormwater and urban development community and a forum to provide feedback on concerns regarding LID implementation. During the workshop, an independent facilitator moderated several discussions, including a question and answer period and a force-field-analysis session to investigate the opinions and concerns of traditional stakeholders of LID implementation as a new practice of stormwater management.

Building upon the stakeholder participation activities initiated by the LSRCA for the Lake Simcoe Region LID Project, further research activities have been carried out to gain a deeper insight into the current challenges and concerns that exist by the stakeholders of LID implementation. To gauge these perceptions, a brief questionnaire was distributed to traditional stakeholders of stormwater management. Questions were posed to identify the opinions of specific stakeholder groups regarding LID planning for retrofit and new development cases in the Lake Simcoe watershed. This component presents the results of the surveys and the author's conclusions on the responses.

7.5.1 Methodology

The purpose of including stakeholders' opinions in this study aimed to satisfy a number of objectives in the context of LID planning on a watershed level, as detailed in Chapter Five. There are numerous types of stakeholders that the LSRCA collaborates regularly with in watershed management activities. Due to the nature of the project and time constraints, the focus of the engagement activities was on assessing the perceptions of traditional stakeholders of stormwater management in the Lake Simcoe watershed. The assessment employed a questionnaire consisting of multiple-choice and open-ended type questions developed based on the outcomes from the break-out sessions held at the LSRCA LID Workshop (Ogilvie, Ogilvie & Company, 2009). The purpose of selecting questionnaires as the consultation method was due to it possessing the ability to gather opinions from a large group of people quickly and at a low cost. This method was particularly useful since there were a few opportunities during the project period where a large number of traditional stakeholders within the Lake Simcoe watershed were gathered. This technique is also advantageous in this case since the audience is targeted and identifiable who attitudes can be measured. Distributing questionnaires was also the best tool to use since the purpose of engaging stakeholders in this initial planning phase is to assess the general current awareness, feelings and opinions that exist among the stakeholders in the community.

Data for this case study was collected in a 3-month sample period that ranged from September 28, 2009 to December 28, 2009. There were three opportunities within this sample period to assess the opinions of traditional groups of stormwater management. The first set of surveys was distributed at LSRCA LID Workshop on September 28, 2009. The design of this survey focused on providing a preliminary understanding of the general knowledge and concerns for LID implementation in the watershed. This initial investigation was to serve the purpose of testing the format of the questionnaire and to confirm the correct line of questioning was being applied. The survey consisted of six multiple-choice questions and two open-ended questions, designed to inquire about the previously stated research objectives (with the exception of the cost perception question). Each question was based on sixteen LID technologies that could be implemented in a watershed, specifically soakaway pit, bioretention, dry well, rainwater harvesting, green roof, downspout disconnection, filter strip, permeable pavement, grass channel, dry swale, infiltration trench, level spreader, roadway reduction, soil amendments, tree clusters, and home clustering. A total of 71 questionnaires were distributed to the attendees of the LSRCA LID Workshop, in which 46 (65 percent) responses were received.

Sample 2 was distributed at the “New Directions ’09 in Stormwater Management” Conference (hereafter, “SWM Conference”) held from November 30 to December 2, 2009. Based on the lessons learned from Sample 1, a few improvements were made to format and questioning for the survey distributed to Sample 2 participants. This survey consisted of eleven multiple-choice questions which provided respondents the opportunity to rank their opinions. One additional open-ended question was provided at the end to collect general comments from the stakeholders. The survey was designed to investigate the same subject areas previously mentioned and was based on the same sixteen LID technologies used in Sample 1. A total of 107 questionnaires were distributed to the conference attendees, in which 38 (36 percent) were returned.

Sample 3 was similar in format and type of questions as the questionnaire used in Sample 2. The main difference in this third survey was that a description of the study background and research motivation was provided at the beginning of the survey for the participants’ knowledge. Sample 3 questionnaire was distributed at a two-day LID training course hosted in conjunction by the Toronto Region Conservation Authority (TRCA) and the Canadian Standards Association (CSA) on December 8 and 9, 2009 (hereafter, “TRCA/CSA LID Training Course”). This course educated stormwater practitioners on LID techniques and design. There were 66 attendees at the training course, in which 22 (33 percent) completed surveys were received.

A summary of the three samples, the dates the data were collected, and the methodology used are shown in Table 7-17. A copy of each questionnaire distributed, as well as the results for each phase can be found in Appendix D3.

Table 7-17: Key summary stats of sample phases

Sample	Location	Date	Total stakeholders in attendance	Total surveys received	Response rate
1: LSRCA LID Workshop	King City, Ontario, Canada	Sept. 28, 2009	71	46	65%
2: SWM Conference	Vaughn, Ontario, Canada	Nov. 30 to Dec. 2, 2009	107	38	36%
3: TRCA/CSA LID Training Course	Mississauga, Ontario, Canada	Dec. 8 to 9, 2009	66	22	33%

7.5.2 Results and Discussion

The responses obtained from each sample were manually entered into the web-based QuestionPro Survey Software (2009). The online tool provided the means to perform the required analysis to obtain meaningful conclusions. Where needed, a spreadsheet was used to conduct any additional analysis. The results for all samples will be presented and discussed according to topic addressed in the surveys, and will more or less coincide with the order in which the research objectives are stated above. Since the questionnaires distributed in Sample 2 and 3 is longer and more detailed in format compared to Sample 2, a stronger emphasis may be placed on the discussion for these latter two samples. In some cases, the total number of responses reported below may not equal the sample size stated above. This is due to the respondents leaving the questions blank or filling in more than one choice. In these cases, the responses for the question were not included in the analysis.

Main Stakeholder Groups Represented

The survey participants were asked to identify the stakeholder groups that represents them the best. In the first sample, this question was an open-ended question, which resulted in a lower level of response. Thirty-six of the forty-six respondents (78 percent) provided an answer to the question. The format of this question was modified for Sample 2 and 3. Each participant was asked to select from a list of stakeholder groups to describe themselves. This resulted in a 100 percent response rate for both Sample 2 and 3.

The number of participants according to each stakeholder group is shown in Appendix D.3 for each sample phase. A summary of the main stakeholder groups that participated in each phase is shown in Table 7-18. Any analysis completed in assessing the opinions or concerns according to stakeholder group will be focused on these four main parties since they are identified as having the largest presence within each sample.

Table 7-18: Summary of main stakeholder groups represented in each sample

Main Groups in Attendance	Sample #1: LSRCA LID Workshop	Sample #2: SWM Conference	Sample #3: TRCA/CSA LID Training Course
Municipal government	50%	34%	27%
Conservation authority	14%	3%	9%
Private consulting firms	14%	16%	14%
Stormwater professionals	3%	34%	32%
Other	19%	13%	18%

Current knowledge of LID practices

The survey participants in all three samples were asked to rank their knowledge of specific LID practices. The respondent could choose between three options to describe their familiarity with the practice. These options were:

- Never heard of it
- Have some knowledge
- Very familiar - Currently implementing LIDs

The results obtained for this question according to each sample group is shown in Appendix D.3. Figure 7-8 displays the average results of the three sample groups. On average, over 90 percent of survey participants have some knowledge or more of over 50 percent of the LID practices specified in the questionnaires. As shown in Figure 7-8, the current knowledge capacity among stakeholder groups is limited to lot-based and linear-based LID practices.

LID practices most likely to be supported by stakeholders

The purpose of investigating this topic was to determine, based on the current knowledge capacity, which LID practices would possibly have immediate support for implementation. The results of this question could also assist planners in determining which LID practices would need to be focused on to overcome barriers for support.

In the survey distributed to the participants in Sample 1, the question posed was slightly different from Sample 2 and 3. Specifically, it was asked “given the information presented in this workshop, which LID practices would you invest in?”. In the other samples it was asked, “Based on your current knowledge, check off the LID practices you would most likely implement”. It is recognized that this slight difference in questioning could have skewed the outcome obtained among the samples. For this reason, the outcomes for Sample 1 will be presented separately to Sample 2 and 3.

In the results obtained in Sample 1, it was found that over 95 percent of the respondents said they would consider investing or “definitely invest” in 75 percent of LID practices. The practices indicated to be of most interest again mainly limited to the lot and linear-based LID technologies. However, tree clusters were included as a possible LID that would be implemented, and green roofs were excluded among the selected practices. Over 50 percent of the survey participants indicated they would “definitely invest” in rainwater harvesting, downspout disconnection, and grass channel, which are practices that are commonly implemented in general.

Figure 7-9 shows the average results obtained in Sample 2 and 3. Results for each sample can be found in Appendix D.3. On average it was found that over 90 percent of survey participants in Sample 2 and 3 would consider or definitely implement over 50 percent of LID practices. The LID practices that had the most support for implementation was downspout disconnection, grass channel and dry swale.

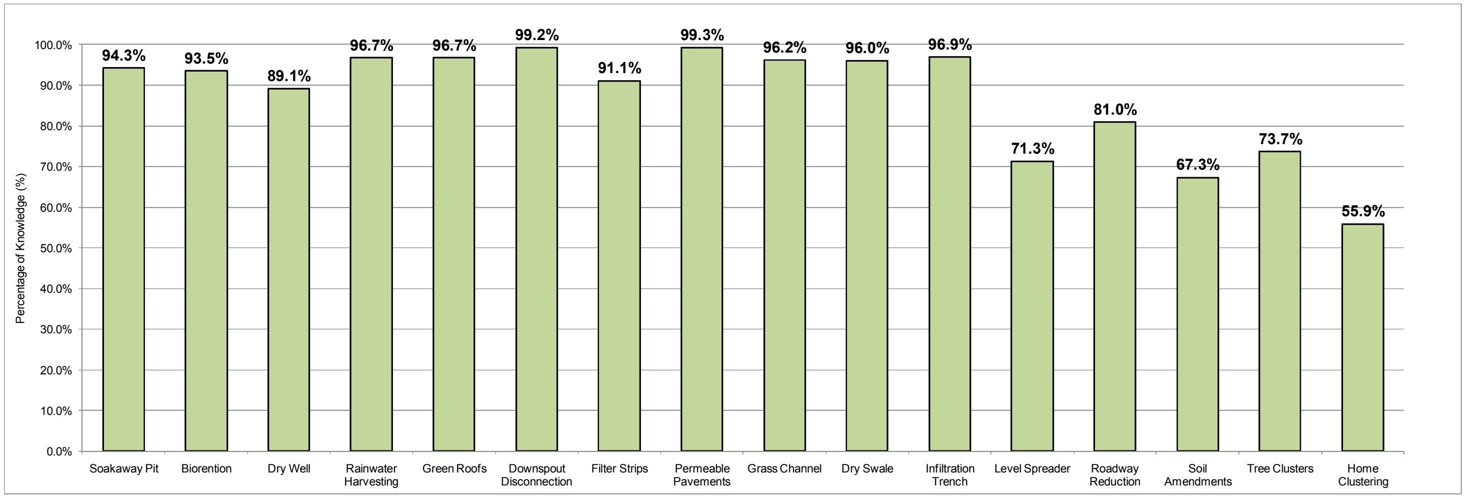

Figure 7-8: Average percentage of respondents among all samples who “have some knowledge” or is “very familiar” with LID practices

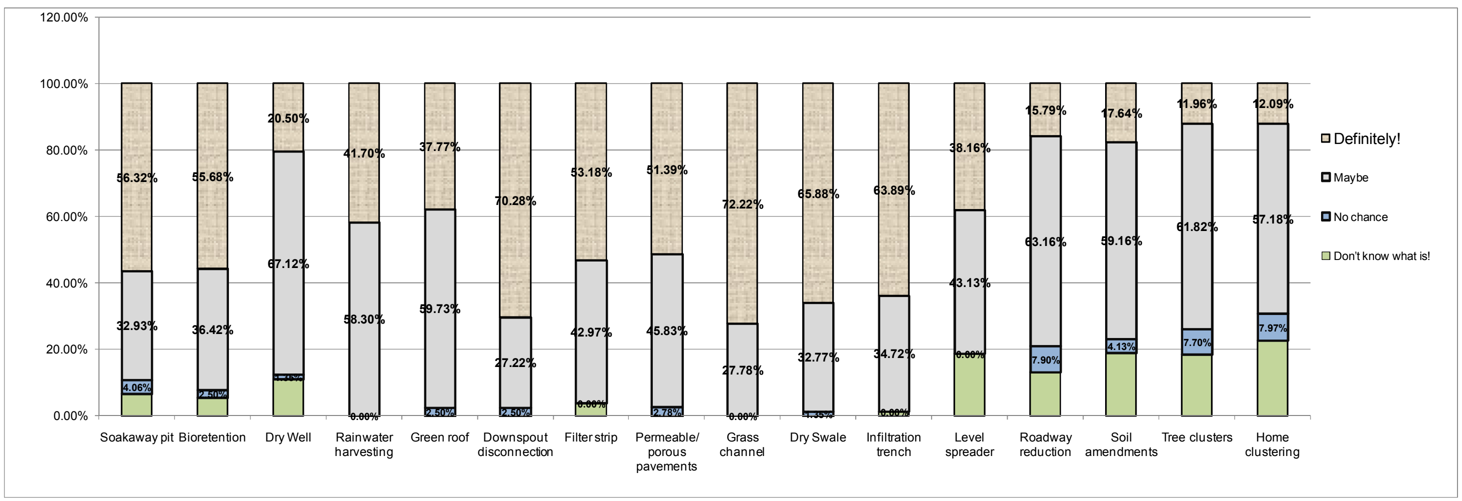

Figure 7-9: Likeliness to implement LID practices (Sample 2 & 3)

Expanding further on this question, the survey participants were asked to indicate their reasons for selecting those particular LID practices they would either “maybe” or “definitely” implement. The reasons that were made available as options to select were:

- Low capital and implementation costs
- Low Operating and Maintenance costs
- Clear existing guidelines & standards
- Proven case studies of effectiveness & performance
- Aesthetics
- Existing rebates and financial support programs
- Significant environmental benefits
- Reduces infrastructure required to achieve stormwater benefits
- Other reasons (please specify):

As shown in Table 7-19, the top three reasons that were selected on average by the survey participants of Sample 2 and Sample 3 for each LID are indicated with an “X”. It was found that the reasons that had the least amount of impact on the likeliness to implement the practices are “the existence of clear guidelines and standards”, as well as “rebates and financial support programs”. The greatest reasons for LID implementation were specified to be “significant environmental benefits” and “proven case studies of effectiveness and performance”. This suggests that more pilot studies are needed, particularly ones that focus on technologies that have been least investigated in the past. Appendix D.3 provides the results for each sample group

Table 7-19: Reasons for implementing LID practices (average results of Sample 2 and Sample 3)

LID Practice	Reasons for Implementation								
	Will not implement	Low capital & implementation costs	Low O&M costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits
Soakaway pit									
Bioretention					X			X	X
Dry Well					X			X	X
Rainwater harvesting					X			X	X
Green roof					X	X		X	
Downspout disconnection		X			X			X	
Filter strip			X		X			X	
Permeable/porous pavements					X			X	X
Grass channel		X	X		X				
Dry Swale		X	X						X
Infiltration trench					X			X	X
Level spreader		X						X	X
Roadway reduction					X			X	X
Soil amendments					X			X	X
Tree clusters			X			X		X	
Home clustering			X					X	X
Total number of reason selected		4	5	0	11	2	0	13	10
Total number of reason selected (%)		25%	31%	0%	69%	13%	0%	81%	63%

X –reason selected on average by the survey participants

Concerns and barriers to LID implementation

The question was posed to each sample group to indicate from a given list of barriers the degree in which it was a concern or preventing them from implementing LID practices in general. The survey participants were provided with the opportunity to rank each of the barriers listed from low to high concern. The results for each sample group are provided in Appendix D.3. Table 7-20 summarizes the results of each sample group where the survey respondents selected the barrier to be of medium and high concern. As shown, over 95 percent of the participants in Sample 1 chose costs, long pay-back period, lack of design guidelines, and liability to be of medium and high concern. In Sample 2, only 75 percent respondents indicated these same barriers, except for “liability”, to be of the same concern. In Sample 3, “liability” nor “buy-in” were indentified to be the barriers of medium concern. In addition to costs, long pay-back period, and lack of design guidelines as barriers, space was indicated to be an additional concern in general among Sample 3 participants.

Table 7-20: Barriers identified in each sample that are of medium and high concern

Barriers	Sample 1: LSRCA LID Workshop	Sample 2: SWM Conference	Sample 3: TRCA/CSA LID Training Course
Costs – capital	93%	83%	89%
Cost – O&M	98%	83%	88%
Time and effort to implement as well as to maintain over time	Option not included in survey	86%	94%
Lack of design guidelines/standards/policies	100%	78%	82%
Possible long payback period	77%	63%	53%
Lack of Life-cycle-analysis and economic studies	Option not included in survey	62%	76%
Space	77%	71%	83%
Municipal approval	81%	56%	67%
Liability	85%	64%	68%
Buy-in (i.e., acceptance from influencing stakeholders e.g., support from public, gov't, etc.,)	100%	80%	79%
Aesthetics	71%	19%	32%
Winter maintenance:	Option not included in survey	64%	72%
Lack of existing examples and case studies	Option not included in survey	61%	63%
Minimal simulation models and tools to predict performance and effectiveness	Option not included in survey	68%	75%

As stated previously, the purpose of this question was to investigate the concerns held by each stakeholder group for implementing LID practices. Focusing the analysis on the main stakeholder groups identified in Table 7-18, the concerns were determined for each party. Sample 1 could not be included due to the open-ended format of the first question which identified the main stakeholder groups. As a result, application of the analytic tools to cross-link information provided from each question could not be applied to Sample 1. The results for each main stakeholder group averaged over Sample 2 and 3 are shown below in Figure 7-10.

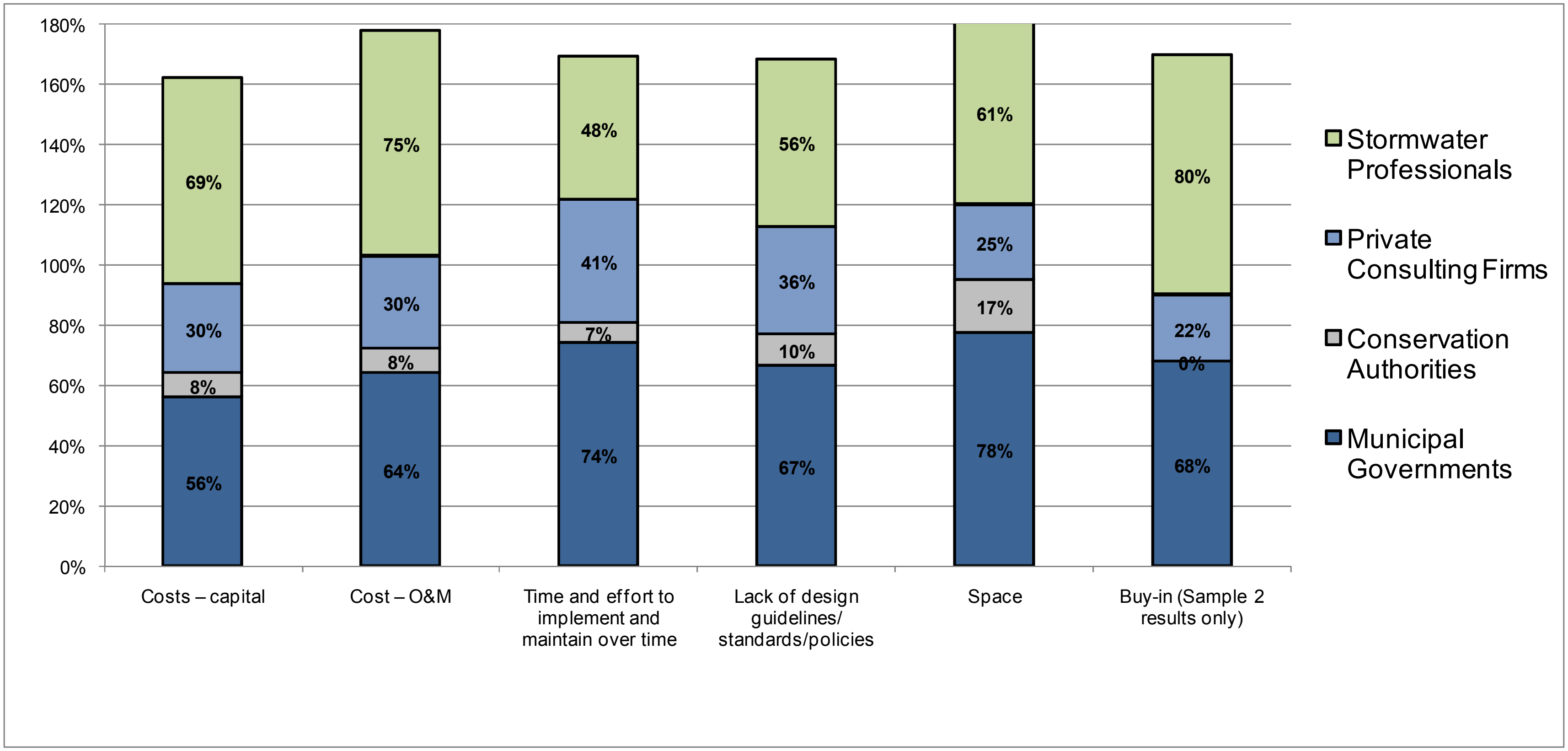

Figure 7-10: Main concerns identified by main stakeholder groups (percent average of Sample 2, and 3)

Sample 2 and 3 identified the same barriers to be of top concern with the exception of “buy-in”, which was identified only by the participants in Sample 2. On average, the top concern for each group was “space” for municipal government and conservation authority representatives; “time and effort” for private consulting firms; and “O&M costs” for stormwater professionals. This is indicated in Figure 7-10.

Perception of benefits of LID implementation

The survey participants were asked to identify the benefits they perceived to be associated to LID implementation. The available options that were included in the question are listed below:

- Possible rebates
- Public image
- Aesthetics
- Environmental benefits
- Reduces infrastructure and utility maintenance costs (i.e., streets, curbs, storm sewers)
- Can be integrated into existing infrastructure
- Assists in meeting regulatory obligations.
- Assists in meeting LEED certification requirements.
- Reduces stormwater management construction costs.
- Increased property value
- Potentially increases lot yields/amount of developable land
- Provides environmental education opportunities
- No benefits (only Sample 1)

The list of options given in Sample 1 was limited to the first five benefits, as well as the “no benefit” option. The “no benefit “ option was not given as a choice in Sample 2 and 3. The results for each sample are shown in Appendix D.3. Figure 7-11 shows the percentages of each benefit that the survey participants in each sample identified to be of medium and high rating. The top three benefits selected in each sample is circled. As it is shown, the respondents in all sample groups chose “aesthetics” and “environmental benefits” to be the most advantageous aspects of implementing LID technologies. Only Samples 1 and 2 identified “public image” to be positive. Analysing the results further by stakeholder group, shows that representatives from municipal governments and conservation authorities are the groups that view “public image” as a high benefit to LID implementation. Table 7-21 shows the results of these perceptions held by each group that selected the benefits to be 100 percent of medium and high concern, which is indicated by an "x" in the figure. Additional benefits selected in Sample 2 that held equal ranking by respondents were "assists in meeting regulatory obligations" and "increased property value".

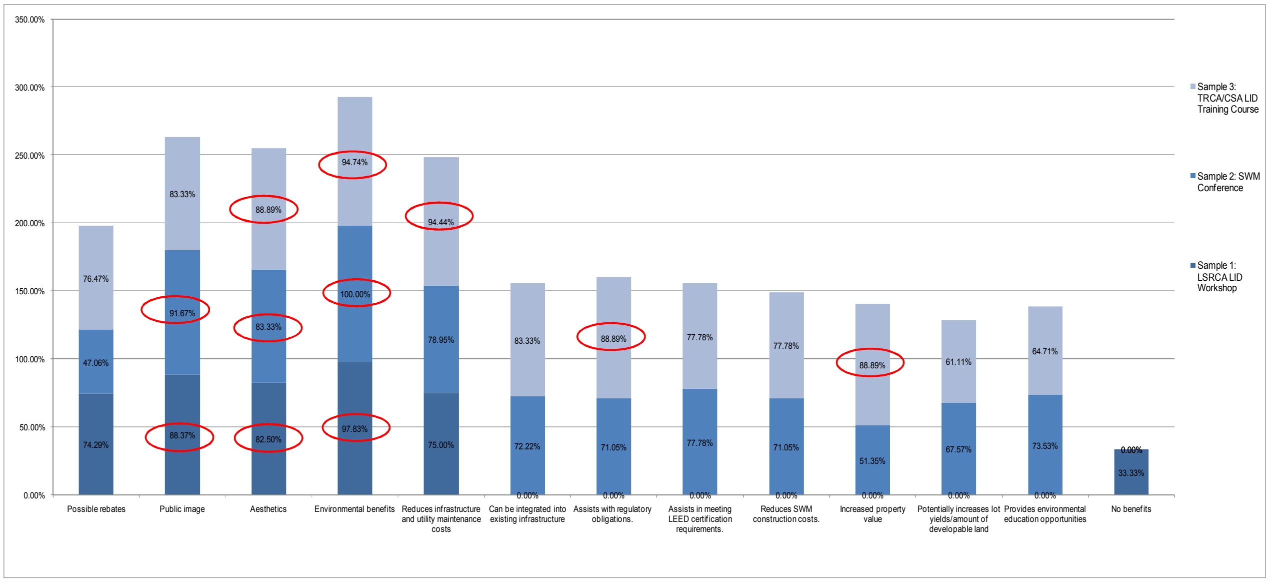

Figure 7-11: Perceptions of benefits identified by stakeholders to be of medium and high ranking

Table 7-21: Perception of top benefits held by main stakeholder groups in Sample 2 and 3

Top Benefits	Main Stakeholder Groups							
	Municipal Governments		Conservation Authorities		Private Consulting Firms		Stormwater Professionals	
	Sample 2	Sample 3	Sample 2	Sample 3	Sample 2	Sample 3	Sample 2	Sample 3
Public image	x	Not selected as a top benefit	x	Not selected as a top benefit		Not selected as a top benefit		Not selected as a top benefit
Aesthetics		x	x	x		x		
Environmental benefits	x	x	x	x	x	x	x	x
Reduces infrastructure and utility maintenance costs	Not selected as a top benefit	x	Not selected as a top benefit	x	Not selected as a top benefit	x	Not selected as a top benefit	
Assists in meeting regulatory obligations.	Not selected as a top benefit		Not selected as a top benefit	x	Not selected as a top benefit	x	Not selected as a top benefit	x
Increased property value	Not selected as a top benefit		Not selected as a top benefit	x	Not selected as a top benefit		Not selected as a top benefit	x

Perceived drivers for LID support in the watershed

The perception of drivers required to support widespread LID implementation was also investigated. Survey participants were asked to select from a list all options they believed would be effective. Figure 7-12 shows the results for each sample. As shown, municipal programs and policies (i.e., rebates, by-laws, education, stormwater charges, etc) and provincial regulations and guidelines were perceived to be the main drivers required by the survey participants in each sample group. Further analysis was done of the perceptions for required drivers by main stakeholder groups. In Sample 2, municipal governments and stormwater professionals both identified developers as an additional driver whereas conservation authorities and private consulting firms saw the market driving the uptake of LID principles. For Sample 3, municipal governments and stormwater professionals were the only stakeholder groups to identify additional drivers. Municipal governments selected local NGOs as the next top driver, whereas stormwater professionals equally weighted developers, grass root initiatives, local NGOs, and community groups, and the market as additional drivers. Conservation authorities and private consulting firms perceived only the two main drivers as those required to ensure widespread LID support.

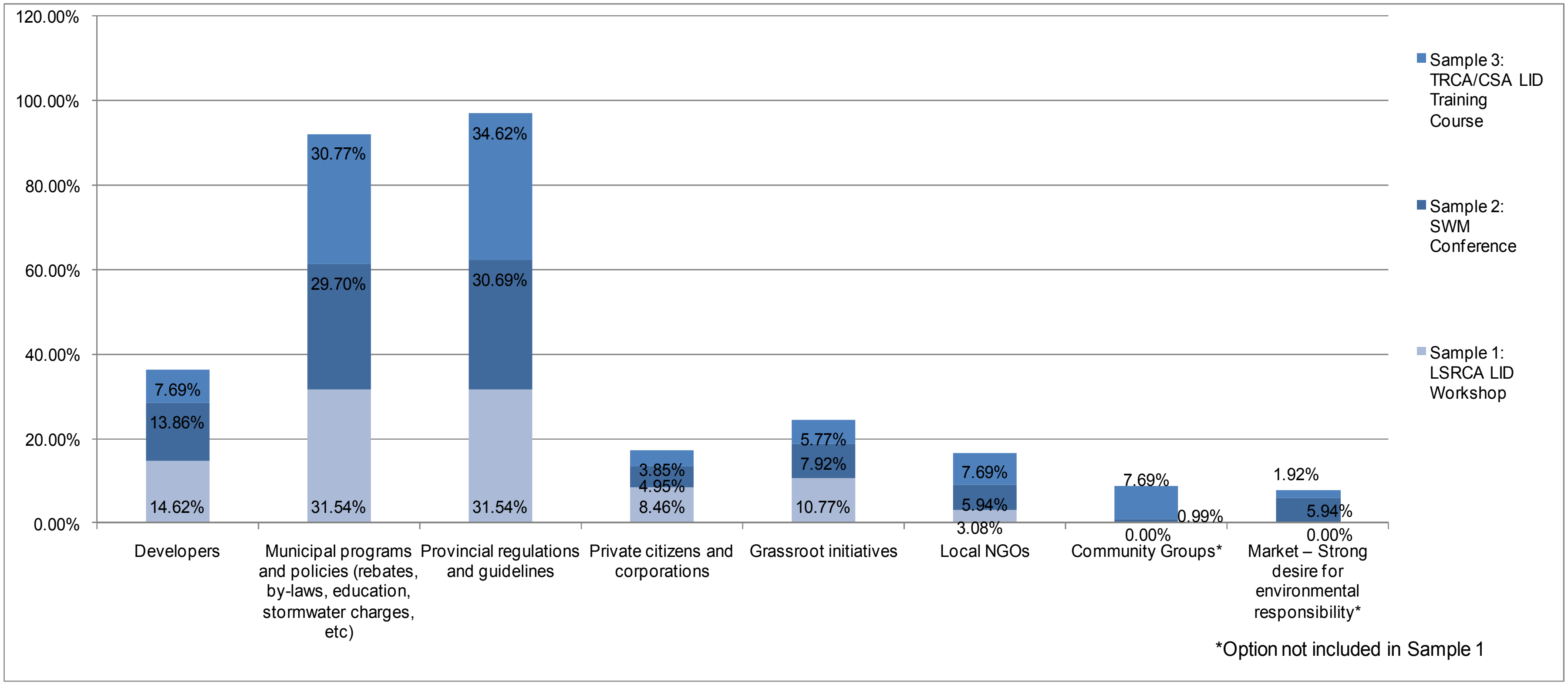

Figure 7-12: Perceived drivers for LID support in Sample 2 and 3

Type of incentive programs required for effective implementation

Figure 7-13 shows the responses by survey participants in each sample group on their opinion of incentive programs that should be in place to support LID implementation. On average, “reduced requirements for stormwater management”, “streamlined approvals” (e.g., accelerated reviews for site plans), and “bonuses if LID practices are used that accomplish stormwater management goals” (i.e., municipal rebate, increased floor area (ratio), etc), were selected among all participants in each group as the top incentive programs required to gain widespread support for LID principles. Further analysis of the required incentive programs perceived by the main stakeholder groups in the samples was done. It was found that in Sample 2, while the top incentive programs selected by all stakeholder groups surveyed were incentive programs listed above, not all main stakeholder groups identified selected these programs. For example, municipal governments in addition to the top incentive programs, they also selected “recognition programs” and “grants” for funding LID projects. Conservation authorities did not see bonuses as the top incentive, but place equal weighting on “reduced requirements for stormwater management”, and “tax credits”. Private consulting firms did not select “bonuses” or “credits for stormwater utilities” as an incentive program. Rather they selected “reduced requirements for stormwater management” and “tax credit” for qualifying LID projects to be better suited incentive programs. Stormwater professionals, unlike the other main groups, did not choose “streamlined approvals”, but chose “reduced requirements for stormwater management” in addition to the “bonuses” and “credits for stormwater utiltiy fees”. Similarly for Sample 3, municipal governments selected “recognition programs”, “streamlined approvals”, and “grants for funding” as the top incentive programs to be in place. Conservation authorities saw “bonuses” as the top incentive, and equally weighted “reduced requirements for stormwater management”, “streamlined approvals”, and “reduced fees”. Stormwater professionals and private consulting firms identified with two out of the three identified top incentives. Private consulting firms saw “reduced requirements” for stormwater management as being an additional means of motivation. Stormwater professionals equally weighting on six out of the eight programs, where the incentives of creating a “recognition program” and the availability of “tax credits” were placed at slightly higher value compared to the other selected incentives.

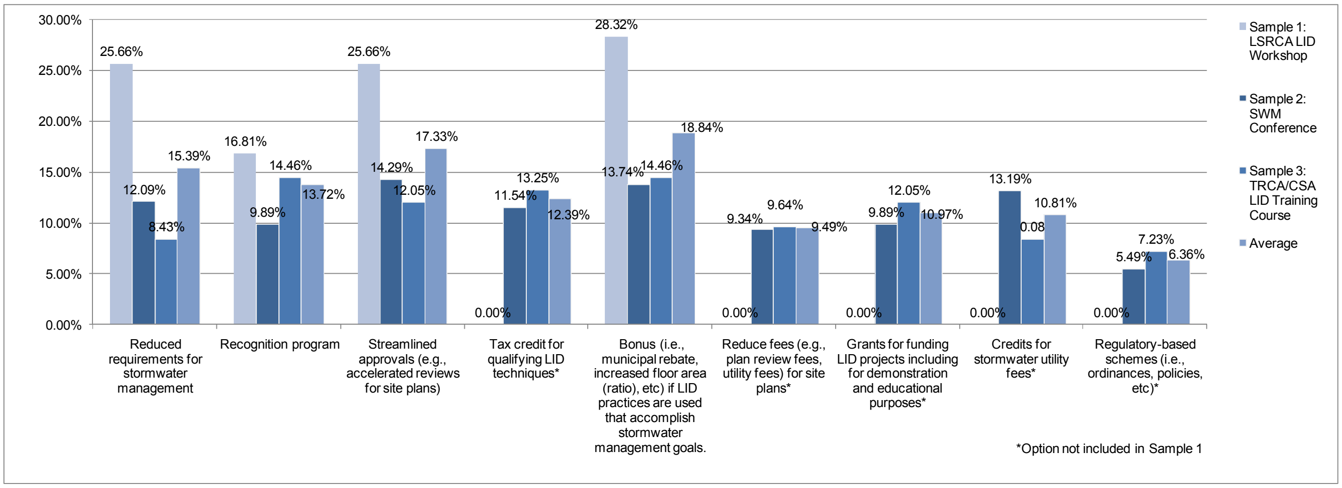

Figure 7-13: Incentive programs identified by survey participants in Sample 2 and 3

Perception of costs for implementing and maintaining LID

The final research objective was to investigate the perceptions of associated costs to LID implementation. The question was posed to survey participants in Sample 2 and 3 to rank their opinion of costs connected to each LID practice. The results for each sample are shown in Appendix D.3. Figure 7-14 displays the distribution of perceptions for each LID technology believed to be of high costs according to the survey participants of Sample 2 and 3. As shown, the implementation and maintenance costs associated to green roofs, permeable pavements, and soil amendments were perceived to be on average to incur the highest expenses. Despite these perceived costs, green roofs and permeable pavements, were also identified by survey participants in these sample groups as LID practices they are very familiar with and would likely invest in. While soil amendments were identified in this question to be a practice of high cost in the opinion of the respondents, it was also selected as a practice with that many of the participants have very little knowledge and one that would likely not be considered for investment.

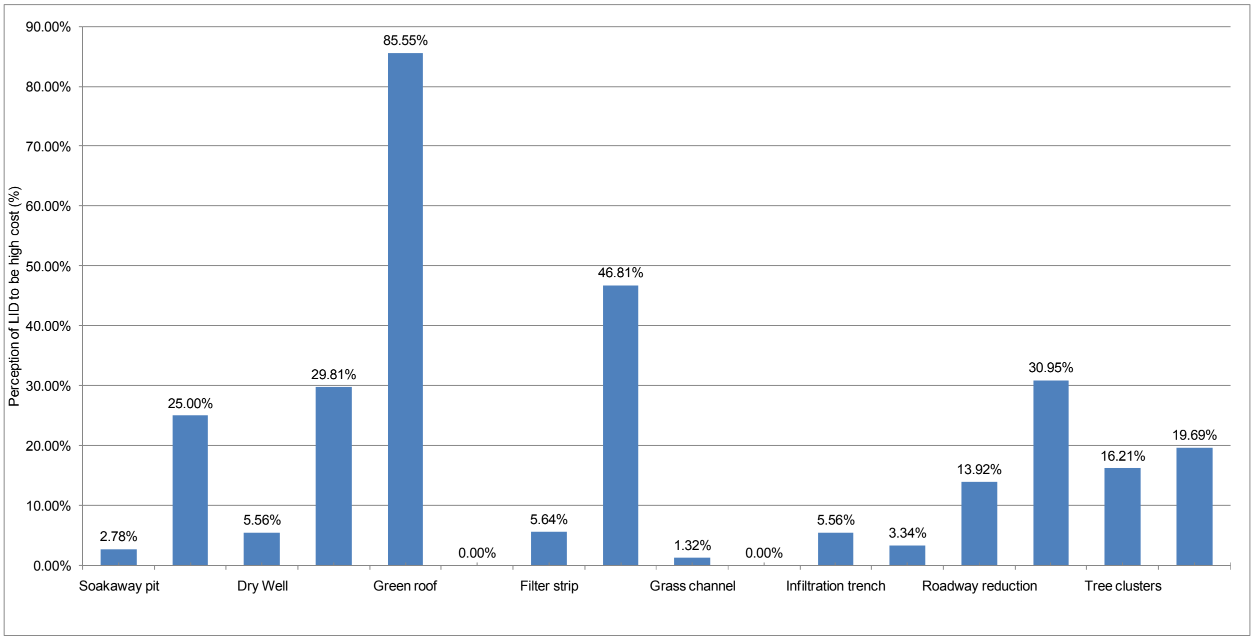

Figure 7-14: Perception of LID practices to be a high cost for implementation and maintenance (percent average of Sample 2 and 3)

The results of this portion of the LID Planning Framework provided a greater insight into the opinions and concerns of traditional stakeholders of stormwater management within the Lake Simcoe watershed. From the outcomes of the questionnaires distributed on three occasions in the sample period of September 28, 2009 to December 28, 2009, it was found that the main stakeholder groups among the participants were representatives from municipal governments, conservation authorities, private consulting firms, and stormwater professionals. Over 90 percent of the survey participants indicated to have some knowledge or more of over 50 percent of the LID practices specified in the questionnaires. Based on this current knowledge capacity, over 90 percent of the respondents in all samples indicated they would at least consider investing in over half of the LID technologies listed. However, the stakeholder groups that responded voiced a number of concerns regarding implementation. Some of the major barriers that were identified as preventing these groups from full-scale support are space, time and effort required, as well as capital and O&M costs. The issue of associated costs were investigated further by probing the participants regarding their perception of costs. LID practices such as green roofs, permeable pavements, and soil amendments were perceived to be on average to have highest implementation and maintenance costs. Despite these barriers, the survey participants do recognize the benefits that are associated with LID application. Aesthetics and environmental benefits were indicated among the participants to be the most advantageous aspects of implementing these sustainable technologies. Opinions gathered from the respondents showed that with the assistance of drivers such as municipal programs and policies, as well as incentive programs such as reducing the requirements for stormwater management and streamlined approvals will encourage widespread support for LID principles.

7.6 Decision-Making Solutions

As described in Chapter 6, selecting the most favourable course of action is an important step in any project. Due to the objectives outlined in this case study there are a number of solutions that can be identified as being appropriate in different parts of the watershed. An approach to determining these options was outlined as well in Chapter 6. The objectives of the solutions are based on the three components of the LID Planning Framework – LID Performance; Cost-Effectiveness; Stakeholder Involvement. A developed spreadsheet model was used to evaluate the performance of the five roof-based LID practices included in this study in terms of runoff volume reduction and pollutant loading reduction. Cost-effectiveness functions estimated the total cost for implementing these LID technologies within each stormwatershed. The outcomes of evaluating Component 1 and 2 of the LID Planning Framework are shown in one comparative table in Appendix D.4. The last column of this table shows the acceptance level of stakeholders. These values were determined based on the results from the stakeholder involvement methods addressed in Component 3 of the Framework. Specifically, the question was posed to survey participants in Sample 2 and 3 of the likeliness to invest in LID practices. The responses of these samples, shown in Figure 7-9, were converted into an acceptance level score for each LID practice included in this case study. Weights were assigned to each opinion level surveyed (i.e. “Definitely”, “Maybe”, “No Chance!”, “Don’t know what it is”) and a score was calculated using the following equation:

LID acceptance level score = (“Definitely” x 1) + (“Maybe” x 0.75) + (“No Chance” x 0.5) + (“Don’t know what it is” x 0.75) *(7-8)*

The opinion level “Don’t know what it is” was given the same score as “Maybe” because if the respondent is informed of the practice, then there is an equal chance that they would accept or reject implementing the practice. The scores that were calculated enabled the ranking of each LID practice. Table 7-22 shows the final acceptance level ranking of the LID practices included in this case study. These ranks are also shown in the last column in Table D.4.3 found in Appendix D.4.

Table 7-22: Stakeholder Acceptance Levels for Selected LID Practices

LID Practices	Survey Results from Figure 7.9				Score	Rank
	Definitely	Maybe	No chance	Don't know		
Green Roof	37.8%	59.7%	2.5%	0.0%	83.8%	4
Soakaway Pit	56.3%	32.9%	4.1%	6.7%	88.1%	2
Downspout Disconnection	70.3%	27.2%	2.5%	0.0%	91.9%	1
Dry Well	20.5%	67.1%	1.4%	11.0%	79.8%	5
Rainwater Harvesting	41.7%	58.3%	0.0%	0.0%	85.4%	3

To identify the appropriate management strategies based on these three objectives, the results shown in Appendix D.4 are plotted on a three-axis graph as outlined in Chapter 6 to determine the Pareto-front. Specifically, Figure 7-15 to Figure 7-18 show each of the performance parameters assessed (i.e., runoff volume removed (mm), pollutant loading reduction (kg/yr/m^2)) in relation to the cost and stakeholder acceptance objective functions.

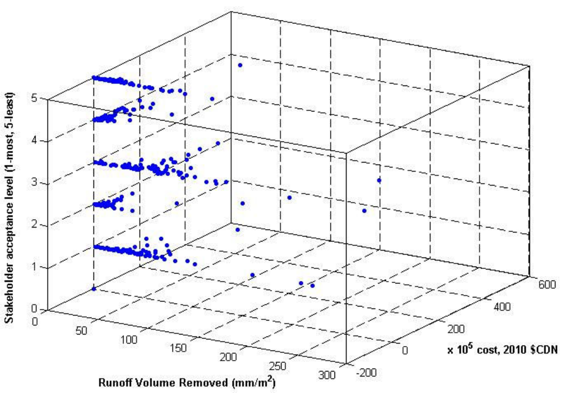

Figure 7-15: Plot of runoff volume removed (mm/m^2) in relation to total cost of the LID practices (2010 $CDN) and stakeholder acceptance rank of the LID practices

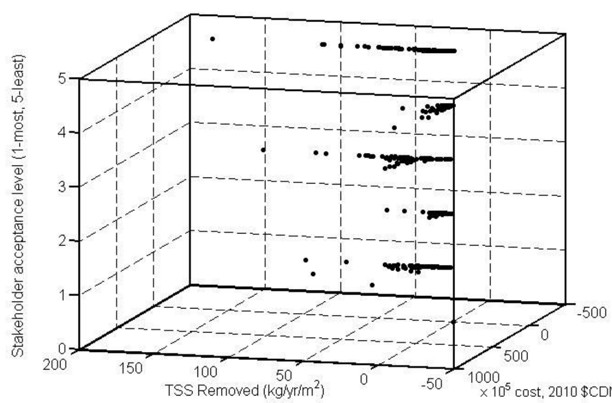

Figure 7-16: Plot of TSS removed (kg/yr/m^2) in relation to total cost of the LID practices (2010 $CDN) and stakeholder acceptance rank of the LID practices

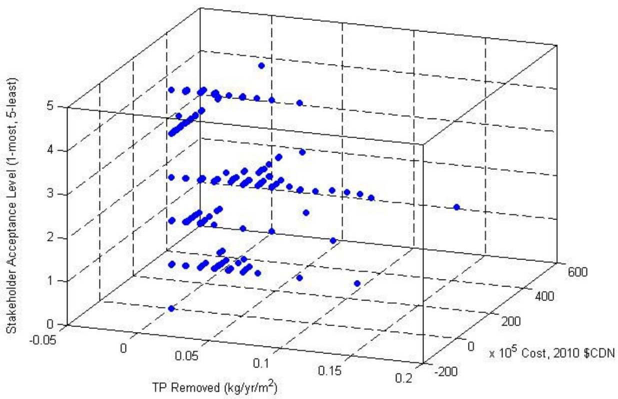

Figure 7-17: Plot of TP removed (kg/yr/m^2) in relation to total cost of the LID practices (2010 $CDN) and stakeholder acceptance rank of the LID practices

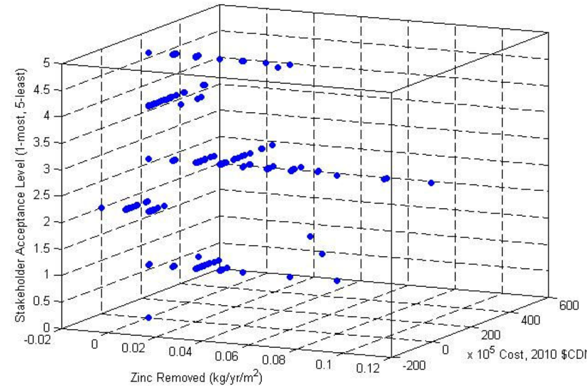

Figure 7-18: Plot of Zinc removed (kg/yr/m^2) in relation to total cost of the LID practices (2010 $CDN) and stakeholder acceptance rank of the LID practices

To identify the most optimal management strategies for LID implementation on the watershed level, the Pareto optimal solutions were determined. A function developed by an external Matlab user was applied to calculate the non-dominated, efficient, pareto points (Polityko, 2008). Application of the function identified a number of options. As shown in Table 7-23, many of the options are consistent among the performance parameters assessed, such as the implementation of downspout disconnection in stormwatershed BAR-SE21 and rainwater harvesting in stormwatershed BAR-SE38. However, for each parameter, a specific LID practice can be chosen. To maximize the runoff volume reduction, rainwater harvesting is the best option to be chosen for implementation. If cost is a factor, then downspout disconnection should be chosen to achieve this intended performance. Both these LID practices have a medium to high stakeholder acceptance level rank, which allows the focus of the decision to be on the performance and cost components. In terms of increasing TSS loading reduction, the results indicate that dry well would is a good option in terms of hydrological performance and cost aspects. However, this practice was ranked the least accepted among the LID practices included in this study. In cases such as this, LID planners can use this information on where to direct their efforts. Since it is known that this practice will provide optimal performance and it is cost effective, the focus of the implementation strategy can be on gaining stakeholders acceptance. Generally, the most appropriate management strategy that should be employed will depend on the objectives of Lake Simcoe watershed planners and project constraints. This decision-making methodology presented in this case study demonstrates how the Framework can be a useful tool to identify all optimal options for LID implementation strategies that can be employed in a watershed.

Table 7-23: Optimal management strategies identified for case study

Performance Parameter Assessed	Stormsewershed ID	Stormsewershed Area (m²)	LID Type	LID Applicable Area in Stormwatershed (m^2)	Runoff Volume Removed by LID (mm/m^2) in Stormwatershed	Pollutant Removed by LID ($kg/yr/m^2$) in Stormwatershed			Total-Cost (2010, $CDN)	Stakeholder Acceptance Level Rank
						TSS	TP	Zinc		
Runoff Volume Removed (mm/m^2)	BAR-NW28	11383	Dry Well	1829	92.06	59.12	0.07	0.05	$21,790.15	5
	BAR-SE1	29787	Downspout Disconnection	451	71.45	12.18	0.02	0.01	$2,905.51	1
	BAR-SE1	29787	Rainwater Harvesting	451	89.51	15.74	0.02	0.01	$31,553.03	3
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.12	0.01	0.00	$669.90	1
	BAR-SE21	34663	Downspout Disconnection	272	3.64	1.63	0.00	0.00	$210.47	1
	BAR-SE38	29550	Downspout Disconnection	2703	219.91	98.35	0.13	0.08	$58,113.54	1
	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
TSS Removed ($kg/yr/m^2$)	BAR-C11	26627	Downspout Disconnection	3693	52.14	23.49	0.03	0.02	$6,434.94	1
	BAR-NW28	11383	Soakaway Pit	1829	28.14	32.34	0.05	-0.02	$27,881.40	2
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.12	0.01	0.00	$669.90	1
	BAR-SE21	34663	Downspout Disconnection	272	3.64	1.63	0.00	0.00	$210.47	1
	BAR-SE29	73451	Downspout Disconnection	11676	63.77	28.70	0.04	0.02	$24,741.19	1
	BAR-SE38	29550	Downspout Disconnection	2703	219.91	98.35	0.13	0.08	$58,113.54	1
	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
	BAR-SE51	14846	Downspout Disconnection	3005	20.32	20.32	0.02	0.01	$3,680.64	1
	BAR-SW8	17096	Downspout Disconnection	2826	19.60	19.60	0.02	0.01	$3,034.68	1
TP Removed ($kg/yr/m^2$)	BAR-NW28	11383	Soakaway Pit	1829	28.14	90.78	0.14	0.08	$27,881.40	2
	BAR-NW28	11383	Dry Well	1829	92.06	178.91	0.28	0.15	$21,790.15	5
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.80	0.01	0.00	$669.90	1
	BAR-SE21	34663	Downspout Disconnection	272	3.64	1.74	0.00	0.00	$210.47	1
	BAR-SE38	29550	Downspout Disconnection	2703	219.91	125.50	0.19	0.10	$58,113.54	1
	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
	BAR-SE63	66392	Downspout Disconnection	8184	37.71	137.22	0.21	0.11	$843,971.04	1
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	138.45	0.21	0.11	$222,589.63	3
	BAR-SE64	111448	Dry Well	6103	118.70	240.84	0.37	0.20	$68,019.28	5
	BAR-SW33	243566	Downspout Disconnection	437	10.64	47.50	0.07	0.04	$2,679.80	1
Zinc Removed ($kg/yr/m^2$)	BAR-NW28	11383	Soakaway Pit	1829	28.14	90.78	0.14	0.08	$27,881.40	2
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.80	0.01	0.00	$669.90	1
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	138.45	0.21	0.11	$222,589.63	3
	BAR-SE64	111448	Dry Well	6103	118.70	240.84	0.37	0.20	$68,019.28	5
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	32.61	0.05	0.12	$222,589.63	3
	BAR-SW33	243566	Rainwater Harvesting	437	10.52	8.51	0.01	0.04	$30,798.97	3

8.0 Conclusions and Recommendations

The issues surrounding stormwater impact on the receiving waters were outlined extensively in Chapter One. The increasing concentration of populations in urban centres and the rapid rate of development have intensified stormwater effects as shown by elevated levels of contaminants polluting our receiving waters, flooding, erosion, and the reduction in groundwater recharge. The degradation of water resources has led to the promotion of LID principles for stormwater management. Despite the beneficial effects of LID application, deficiencies in LID selection and performance assessment have been identified.

The aim of this study was to assist with closing the gaps in LID planning methodology. The scope of the study outlined two key tasks to meet the study's main objectives of developing a LID Planning Framework to be applied on a watershed level in Ontario. The first task outlined the functions of each component of the LID Planning Framework. Through the development of the Framework components, methodologies were established to: 1) evaluate LID implementation on a watershed basis through a proposed modelling approach; 2) determine cost-functions to conduct a cost-effectiveness analysis to identify successful management strategies; 3) collect stakeholders' opinions and use in an analysis approach that can be applied for LID planning; 4) integrate all outcomes of The Framework components to optimize management strategies for LID planning. The second major task was to apply the components of The Framework in detail to a case study for the Lake Simcoe Watershed. This purpose of this exercise was to demonstrate the effectiveness of the methodologies suggested to plan for the implementation of LID technologies on a watershed level. These tasks were successfully performed, and the following two sets of conclusions are made, one based on the LID Planning Framework, and the other based on the case study findings.

8.1 LID Planning Framework Conclusions

1. Despite the fact that current stormwater management guidance issued by the OMOE reflects some current technology, such as the use and design of BMPs, the information is becoming rapidly outdated. Most of the material reviewed is dated previous to1999; climate change factors and methods of adaption are not discussed; and newer philosophies and practices are not included (CVC & TRCA, 2010; Environmental Commissioner of Ontario., n.d.).

2. One major challenge facing users of LID practices is the selection of technologies for specific locations to support large-scale watershed planning. Existing manuals issued by governments and other institutions provide guidelines for implementation of LID technologies on primarily a lot-level. The focus is primarily on design and implementation of LID methods, where relevant site, development, and hydrological characteristics are detailed. While these guidelines are useful, the task of selection and placement is still a challenging task for many planners working beyond the development-level. A more appropriate, all encompassing framework for LID planning and implementation is needed.

3. The framework currently used in stormwater management in Ontario is not as developed and current as those being developed in other parts such as SUSTAIN in the U.S., Hydrolpolis in Europe, MUSIC in Australia, and even WBM in British Columbia.

4. The proposed LID Planning Framework is a new contribution to sustainable stormwater management as it has not been formally developed in Ontario. The individual components of The Framework are typically addressed individually, but not collectively. They include evaluation of hydrological performance, cost-effective analysis, and stakeholder involvement.

5. The Framework is a systematic approach to large-scale LID planning. Each component involves detailed steps that, when evaluated in the prescribed methodology, contribute to the overall capability of identifying holistic and practical solutions to effectively implement LID practices over a watershed.

6. The Framework is not intended as a detailed design approach and should be viewed as a tool for initial planning activities. The aim of this planning methodology is to provide planners with the capability to identify appropriate and cost-effective LID practices that could be used in a given area within a watershed that will achieve a desired performance and level of acceptance by watershed stakeholders.

7. The evaluation of LID performance utility proposes a new approach to determining the hydrological benefit of LID implementation on a watershed level. The widely used concept of HRUs and the GIS tool are combined to create an effective method to determine LID application potential. The Framework includes this component as a key feature for LID

planning and implementation, as it strategically points to watershed locations that can offer the greatest benefit to achieve environmental objectives.

8. The components that address cost and stakeholder issues are vital elements of optimizing management strategies and ensuring effective wide-spread implementation. While typical planning methods only include cost as the optimization element, the essential inclusion of stakeholders' opinions from the initial LID planning stages is a new dimension. It allows for the participation of all affected stakeholders, traditional and non-traditional, to direct the effective application of LID technologies.

9. While based on known decision analysis methods, the decision-making component of the Framework is developed to address the objectives of LID planning specifically. The approach relies on information attained from the evaluation of the three main components of the Framework to identify the appropriate strategies for LID implementation.

8.2 Case Study Conclusions

1. The case study focused on data pertaining to the Lake Simcoe watershed, a region currently affected by numerous environmental issues. Five point-based LID practices that treat primarily roof-top runoff (green roof, soakaway pit, rainwater harvesting, downspout disconnection, and dry well) were evaluated to determine the benefit of their application over the watershed. Applying the methodology of Component One in the Framework, it was found that the greatest percentage of volume reduction will come from implementing downspout disconnection and rainwater harvesting. Application on commercial and residential land use types will achieve the greatest benefit. The results also show that a significant reduction will be achieved by soakway pit application on a residential land-use type. It was also determined through this study that the greatest percentage of pollutant loading reduction on LID applicable areas for TSS, TP, and zinc will come from implementing downspout disconnection and rainwater harvesting, particularly on residential lots. Dry well as well showed to have adequate pollutant reduction capabilities on residential lots. On a watershed level, rainwater harvesting would be the most advantageous LID option for TSS, TP, and zinc reduction. Downspout disconnection and dry well also show to have good pollutant reduction capabilities particularly for TSS reduction. The results show that application of green roofs throughout the study area will produce the least benefit in the LID

practice demonstrated to contribute to phosphorus loading, and possess low removal capabilities for TSS and zinc.

2. The concept of HRUs employed proved to be an effective means of evaluating the implementation of small-scale LID practice over a watershed. Developing the HRUs based on stormwatershed and geographical characteristics allowed for the flexibility to understand the benefit achieved by each LID practice, as well as allow for prioritization and ranking of areas within the watershed that could attain the greatest benefit.

3. The cost-functions developed from the Component Two of the Framework were applied to the LID practices considered in this case study. An estimate of the total cost of implementing each LID practice throughout the Lake Simcoe watershed is shown in Table 8-1.

Table 8-1: Total-Cost Estimates of implementation of specific LID practice in Lake Simcoe Watershed

LID Practice	Applicable area (m^2)	Estimate Total-Cost (2010, $CDN)
Green Roof	1,009,500	$381,025,671
Soakaway Pit	1,400,137	$91,561,201
Downspout disconnection[11]	2,373,749	$169,611,565
Dry Well[12]	2,363,479	$26,271,165
Rainwater Harvesting	2,643,144	$263,066,467

4. Application of the concepts described in Stakeholder Involvement Component of the LID Planning Framework provided initial insight into the importance of including stakeholders' opinions as a means to support effective widespread LID implementation. For example, based on the outcomes of the surveys, strategies for buy-in can be developed, possibly directed towards the main stakeholder groups that were present in all three samples. Guidelines and manuals can be created, particularly for specific LID practices. The LID practices that were identified by respondents to be the most familiar with are practices that have existing manuals present. The results can also assist in the development of policies and programs, provide direction for subwatershed planning, as well as identify further studies required by stakeholders for implementation (i.e., performance case studies, feasibility studies, provides research direction, etc).

[11] A base cost of $100 was assumed for each application

[12] Annual O&M costs were estimated at 7.5%

5. Application of the decision-making approach outlined in Chapter 6 and the use of a Matlab script was used to determine the Pareto points of a data set. A number of optimal management strategies were identified, as shown in Table 8-2. These options for management strategies are shown below

Table 8-2: Best set of options for management strategies identified for case study

Performance Parameter Assessed	Stormsewershed ID	Stormsewershed Area (m^2)	LID Type	LID Applicable Area in Stormwatershed (m^2)	Runoff Volume Removed by LID (mm/m^2) in Stormwatershed	Pollutant Removed by LID ($kg/yr/m^2$) in Stormwatershed			Total-Cost (2010, $CDN)	Stakeholder Acceptance Level Rank
						TSS	TP	Zinc		
Runoff Volume Removed (mm/m^2)	BAR-NW28	11383	Dry Well	1829	92.06	59.12	0.07	0.05	$21,790.15	5
	BAR-SE1	29787	Downspout Disconnection	451	71.45	12.18	0.02	0.01	$2,905.51	1
	BAR-SE1	29787	Rainwater Harvesting	451	89.51	15.74	0.02	0.01	$31,553.03	3
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.12	0.01	0.00	$669.90	1
	BAR-SE21	34663	Downspout Disconnection	272	3.64	1.63	0.00	0.00	$210.47	1
	BAR-SE38	29550	Downspout Disconnection	2703	219.91	98.35	0.13	0.08	$58,113.54	1
	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
TSS Removed ($kg/yr/m^2$)	BAR-C11	26627	Downspout Disconnection	3693	52.14	23.49	0.03	0.02	$6,434.94	1
	BAR-NW28	11383	Soakaway Pit	1829	28.14	32.34	0.05	-0.02	$27,881.40	2
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	BAR-SE21	34663	Downspout Disconnection	272	3.64	1.63	0.00	0.00	$210.47	1
	BAR-SE29	73451	Downspout Disconnection	11676	63.77	28.70	0.04	0.02	$24,741.19	1
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	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
	BAR-SE51	14846	Downspout Disconnection	3005	20.32	20.32	0.02	0.01	$3,680.64	1
	BAR-SW8	17096	Downspout Disconnection	2826	19.60	19.60	0.02	0.01	$3,034.68	1
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	BAR-SE38	29550	Rainwater Harvesting	2703	271.78	126.80	0.20	0.10	$190,623.11	3
	BAR-SE63	66392	Downspout Disconnection	8184	37.71	137.22	0.21	0.11	$843,971.04	1
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	138.45	0.21	0.11	$222,589.63	3
	BAR-SE64	111448	Dry Well	6103	118.70	240.84	0.37	0.20	$68,019.28	5
	BAR-SW33	243566	Downspout Disconnection	437	10.64	47.50	0.07	0.04	$2,679.80	1
Zinc Removed ($kg/yr/m^2$)	BAR-NW28	11383	Soakaway Pit	1829	28.14	90.78	0.14	0.08	$27,881.40	2
	BAR-SE10	12707	Downspout Disconnection	260	9.18	4.80	0.01	0.00	$669.90	1
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	138.45	0.21	0.11	$222,589.63	3
	BAR-SE64	111448	Dry Well	6103	118.70	240.84	0.37	0.20	$68,019.28	5
	BAR-SE63	66392	Rainwater Harvesting	8184	42.08	32.61	0.05	0.12	$222,589.63	3
	BAR-SW33	243566	Rainwater Harvesting	437	10.52	8.51	0.01	0.04	$30,798.97	3

Depending on the objectives and constraints of a LID project, Lake Simcoe watershed planners can select from these options to direct further implementation plans.

6. Based on the outcomes of this research, existing case studies, and the nature of LID technologies to control stormwater at-source and/or through conveyance systems, the requirement to involve a range of groups representing various interests, socially, technically, and politically, is essential for effective LID application. It is believed that as result of taking a more holistic approach early in the LID planning process, a stronger support from all appropriate actors of stormwater management will be achieved throughout the project. Not only will a greater understanding into these identified groups' capacity in applying LID technologies within the watershed be achieved, but also insight into the challenges that maybe encountered in future implementation. Engaging stakeholders throughout the planning, decision-making, and project phases could lead to minimizing a significant number of barriers, facilitating uptake of LID principles, encouraging widespread implementation, and ensuring support in the long-term. Without the support of all affected groups effective LID implementation will not occur.

8.3 Recommendations

Upon completion of this study, a number of recommendations can be made to support and improve LID application for stormwater management, as well as suggest additional areas of research.

1. The LID Planning Framework should be adopted by planners involved in watershed planning such as conservation authorities and municipal governments, as it organizes and contains information and methodologies to support effective large-scale LID planning and implementation. The methodologies established within the Framework can be used appropriately to customize to any range of objectives specified by LID planners. As a result of an application of this Framework, this could enable the reduction of stormwater impacts experienced currently by watersheds.

2. While the methodologies applied in developing the data using GIS were not discussed, it was made apparent through the course of the case study that it is imperative that having access the appropriate GIS data sets for watersheds plays a significant role in terms of identifying potential locations suitable for LID practices and facilitate more efficient modeling. It is recommended that watershed stakeholders, such as municipalities, direct

their resources in establishing a comprehensive database of geographical information to enable efficient and accurate LID planning. In addition, in order for effective watershed planning to occur, the data sets must be consistent across jurisdictions.

3. The investigation into the identifying opinions of traditional stakeholders of stormwater management highlighted strong concerns currently being experienced. In order for effective LID implementation to occur on a watershed, these concerns must be further investigated in order to remove the barriers that are preventing successful long-term application. In addition, the opinions and concerns of non-traditional stakeholders should not be ignored. As shown through the case study, residential land-use type lots represent a significant portion of LID application opportunities and achieving stormwater goals. It is therefore imperative to gain the support from stakeholders of these lot types in order to have an effective LID implementation plan.

4. The cost-functions developed were a based on current available studies. While they can be applied and be used for planning purposes, the amount of existing studies is limited. The accuracy in these functions to estimate total cost of LID technologies can be strengthened as more studies are published. These cost-functions should be updated upon each application of the LID Planning Framework.

5. The case study focused solely on five point-based LID practices that accept specifically roof-based runoff. Additional investigations should be done to (1.) expand the list of technologies assessed to linear and area based LID practices; and (2.) to determine the benefits that could be reached from not only evaluating roof-based runoff, but runoff from all impervious surfaces on a lot.

6. In addition to the above recommended investigation, it is also advised that further assessments should be done on examining the benefits of implementing combinations of LID practices on lots. Lines of study could include application of the treatment train approach, as well as various mixes of traditional and non-traditional combinations of LID practices.

7. The Evaluation of Hydrological Performance section of the Framework (Component 1) developed an approach to assessing the effectiveness of an LID technology implemented throughout a watershed. To determine the performance of each LID (i.e., in terms of percent volume reduction and percent pollutant loading reduction), the runoff volume

generated without LID implementation was required. A function was developed based on information pertaining to selected lots throughout the study area. Specifically, the runoff volume modelled in SWMM-LID, the lot size, and the amount of impervious area on the lot was used to develop the function. However, additional parameters could be used to strengthen the capability of this function to predict the runoff volume of existing conditions.

8. In addition to the above recommendation, the functions to determine the performance of the LID practices could be strengthened by modelling additional lots. In this case study, only three lots were selected to be modelled within each land-use for each LID practice. It is recommended that further sensitivity analysis be carried out to determine the appropriate number of lots that should be modelled to develop the performance functions.

9. The Decision-Making methodology employed was based on determining the Pareto-front. The best set of Pareto solutions were identified using an externally developed Matlab function. It is possible to apply this approach beyond the initial planning stages of a LID project for a watershed. Additional iterations could be carried out to represent sets of optimal stormwater solutions which could be implemented in a staged approach if a time dimension is included.

10. The impacts of climate change were also not included in this LID Planning Framework. Aspects related to this change in global weather patterns will affect all components of the Framework. For example, in evaluating the performance of an LID practice, their capability will be dependent on the season. It will also impact the cost associated to various technologies, as well as determine the support for one practice over another by stakeholders. Therefore, the LID Planning Framework will need to be refined further to include the aspects of climate change.

9.0 List of References

1. Adams, L.W., Dove, L.E., & Leedy, D.L. (1984). Public Attitudes toward Urban Wetlands for Stormwater Control and Wildlife Enhancement. *Wildlife Society Bulletin, 12* (3), pp. 299-303. Retrieved from http://www.jstor.org/stable/3781998.

2. Apostolaki, S., Jefferies, C., & Wild, T. (2006). The social impacts of stormwater management techniques. *Water Practice & Technology,* 1(1). doi:10.2166/WPT.2006009

3. Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J. and Sorenson, K. (2002) *Guidebook to Decision-Making Methods*, WSRC-IM-2002-00002, Department of Energy, USA. Retrieved from http://www.dss.dpem.tuc.gr/pdf/Decision%20Making%20Guidebook_2002.pdf

4. Banting, D., Doshi, H., Li, J., Missios, P., Au, A., Currie, B.A., & Verrati, M. (2005). *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto.* Prepared for City of Toronto and Ontario Centres of Excellence – Earth and Environmental Technologies (OCE-ETech) by Ryerson University. Retrieved from http://www.toronto.ca/greenroofs/findings.htm#findings.Brown, R. R. (2005). Impediments to integrated urban stormwater management: The need for institutional reform. Environmental Management, 36 (3), 455-468. doi: 10.1007/s00267-004-0217-4.

5. Bank of Canada. (2010). Investment Calculator. Retrieved from http://www.bankofcanada.ca/en/rates/investment.html#foot.

6. Beierle, T.C. (1999). Using social goals to evaluate public participation in environmental decisions. *Review of Policy Research, 16(3-4)*, 75-103. doi: 10.1111/j.1541-1338.1999.tb00879.x

7. Beierle , T.C., & Konisky, D.M. (2000). Values, Conflict, and Trust in Participatory Environmental Planning. *Journal of Policy Analysis and Management*, *19*(4), pp. 587-602. Retrieved from http://www.jstor.org/stable/3325576.

8. Bradford, A., & Gharabaghi, B. (2004). Evolution of Ontario's stormwater management planning and design guidance. *Water Quality Research Journal of Canada,* 39 (4), 343–355. Retrieved from http://www.cawq.ca/cgi-bin/journal/display.cgi?language=english&pk_journal=68.

9. Brilly, M., Smith, M., & Vidmar, A. (1993). Spatially Oriented Surface Water Hydrological Modelling and GIS. In HydroGIS 93: Application of Geographic Information Systems in Hydrology and Water Resources (Proceedings of the Vienna Conference, Publ. no 211) (pp. 547-557). Vienna, Austria: IAHS.

10. Brimicombe, A. (2010). *GIS, environmental modeling and engineering* (2nd Edition). Boca Raton: CRC Press.

11. British Columbia Inter-Governmental Partnership. (n.d.). Water Balance Model – Powered by QUALHYMO: An Overview of the QUALHYMO Engine. Retrieved from http://beta.waterbalance.ca/index.asp?type=single&section=About%20the%20Model&sid=6&id=78.

12. Brown, R. R. (2005). Impediments to integrated urban stormwater management: The need for institutional reform. *Environmental Management, 36* (3), 455-468. doi: 10.1007/s00267-004-0217-4.

13. Brown, R.R, Clarke, J. (2007) The transition towards water sensitive urban design: the story of Melbourne, Australia, Report No. 07/ 01, Facility for Advancing Water Biofiltration, Monash University, June 2007, ISBN 978-0-9803428-0-2

14. Brown, R., & Farrelly, M. (2008). Sustainable Urban Stormwater Management in Australia: Professional Perceptions on Institutional Drivers and Barriers. *In Ashley, R.M. (Ed) Proceedings of the 11th International Conference on Urban Drainage, Edinburgh, Scotland, 31st August - 5th September 2008*. Retrieved from http://www.urbanwatergovernance.com/publications.html.

15. CalculatorSoup. (n.d.). Present Value Calculator. Retrieved from http://www.calculatorsoup.com/calculators/financial/present-value.php.

16. California Department of Transportation [CALTRANS]. (2004). *BMP Retrofit Pilot Program Final Report (Report No. CTSW -RT-01-050).* Retrieved from http://www.dot.ca.gov/hq/env/stormwater/

17. Canadian Mortgage and Housing Corporation [CMHC]. (2009, 15 September). *Downspout Disconnection.* Retrieved from http://www.cmhc.ca/en/inpr/su/waho/waho_014.cfm.

18. Center for Watershed Protection [CWP]. (2003). *New York State Stormwater Management Design Manual.* Prepared for the New York State Department of Environmental Conservation. Retrieved from http://www.dec.ny.gov/chemical/29072.html.

19. Centre for Watershed Protection [CWP]. (2007). *Urban subwatershed restoration manual No. 3: Urban stormwater retrofit practices V1.0*. Prepared for the Office of Wastewater Management of the U.S. Environmental Protection Agency [U.S. EPA]. Retrieved from http://www.cwp.org/Store/usrm.htm#3.

20. Cheng, M., Coffman, L.S., Zhang, Y, Riverson, J & Zhen, J. (2004). BMP model for low-impact development. In G. Sehlke, D. F. Hayes, & D. K. Stevens (Eds.), *The 2004 World Water and Environmental Resources Congress: Critical Transitions in Water and Environmental Resources Management*. Reston, VA: The American Society of Civil Engineers. doi: 10.1061/40737(2004)78.

21. Cheng, M.S., Dai, T., Zhen, J., Alvi, K., & Shoemaker, L. (2007). *BMP/LID Decision Support System for Watershed-Based Stormwater Management User's Guide*. Prepared for Prince George's County Department of Environmental Resourcesby Tetra Tech, Inc. CIRIA. (2007). *The SUDS manual*. Retrieved from http://www.ciria.org//service/knowledgebase/AM/ContentManagerNet/Default.aspx?Section=knowledgebase&Template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=8&ContentID=4474

22. City of Chicago. (2003). *A guide to stormwater best management practices*. Retrieved from http://www.nipc.org/environment/sustainable/water/ChicagoGuideToStormwaterBMPs.pdf

23. City of Hamilton. (2007). *City of Hamilton stormwater master plan – class environmental assessment report (city-wide).* Prepared for the City of Hamilton by Aquafor Beech Limited. Retrieved from http://www.hamilton.ca/CityDepartments/PublicWorks/CapitalPlanning/StrategicPlanning/StrategicEnvironmentalPlanningProjects/GRIDS/Stormwater+Management+Master+Plan.htm.

24. City of Toronto. (2003). Wet-Weather Flow Management Plan. Toronto, Ontario: Author. Retrieved from http://www.toronto.ca/water/protecting_quality/wwfmmp/reports.htm.

25. Clean Water Act, 2006, S.O. 2006, c. 22. Retrieved from http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_06c22_e.htm

26. Coello, C.A.C. (1999). A comprehensive survey of evolutionary-based multiobjective optimization techniques. Available on CiteSeerX. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.48.3504.

27. *Conservation Authorities Act*, R.S.O. 1990, c. C.27. Retrieved from http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90c27_e.htm#BK1

28. Conservation Ontario. (2009).*Mandate*. Retrieved from http://www.conservation-ontario.on.ca/about/mandate.html.

29. Cooper, D.M, & Naden, P.S. (1998). Approaches to delivery modelling in LOIS. *Science of The Total Environment, 210-211*, 483-498. doi: 10.1016/S0048-9697(98)00033-3.

30. Credit Valley Conservation [CVC], & Toronto and Region Conservation Authority [TRCA]. (2010). *Low impact development stormwater management manual (Draft ed.)*. Retrieved from http://www.sustainabletechnologies.ca/.

31. Devito, K., Creed, I., Gan, T., Mendoza, C., Petrone R., Silins, U., Smerdon, B. (2005). A framework for broad-scale classification of hydrologic response units on the Boreal Plain: is topography the last thing to consider? *Hydrological Processes, 19(*8),1705 – 1714. doi: 10.1002/hyp.5881.

32. Dietz, M.E. (2007). Low impact development practices: A review of current research and recommendations for future directions. *Water, Air, Soil Pollution, 186*, 351 - 363. doi: 10.1007/s11270-007-9484-z.

33. Dolnicar, S. & Schäfer, A.I., (2009). Desalinated versus recycled water: Public perceptions and profiles of the accepters*. Journal of Environmental Management*, *90*, 888–900. doi:10.1016/j.jenvman.2008.02.003

34. Duram, L.A., & Brown, K.G. (1999). Insights and Applications Assessing Public Participation in U.S. Watershed Planning Initiatives. *Society & Natural Resources, 12 (5)*, 455 – 467. doi: 10.1080/089419299279533.Elliott, A.H., & Trowsdale, S.A. (2006). A review of models for low impact urban stormwater drainage. *Environmental Modelling & Software, 22,* 394-405, doi:10.1016/j.envsoft.2005.12.005.

35. Easton, Z. M., P. Gérard-Marchant, M. T. Walter, A. M. Petrovic, & T. S. Steenhuis. (2007). Hydrologic assessment of an urban variable source watershed in the northeast United States. *Water Resources Research, 43*(3), W03413, doi:10.1029/2006WR005076, 2007

36. Elliott, A.H., & Trowsdale, S.A. (2006). A review of models for low impact urban stormwater drainage. *Environmental Modelling & Software, 22,* 394-405, doi:10.1016/j.envsoft.2005.12.005.

37. Elliott, A.H., Trowsdale S.A., & Wadhwa, S. (2009). Effect of aggregation of on-site stormwater control devices in an urban catchment model. *Journal of Hydrologic Engineering*, *14 (*9), 975-983, doi: 10.1061/(ASCE)HE.1943-5584.0000064.

38. Ellis, J.B., Deutsch, J.C., Mouchel, J.M., Scholes, L., & Revitt, M.D. (2004). Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff. *Science of the Total Environmen*t, *334 - 335*, 251 – 260, doi:10.1016/j.scitotenv.2004.04.066.

39. Ellis, J.B., Deutsch, J.C., Legret, M., Martin, C., Revitt, D. M., Scholes, L., ... Zimmerman, U. (2006). The DayWater decision support approach to the selection of sustainable drainage systems: A multi-criteria methodology for BMP decision makers. *Water Practice & Technology*, *1* (1). doi: 10.2166/WPT.2006002.

40. Environment Canada. (2007). *Water*. Retrieved from http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=CD467AE6-1.

41. Environment Canada. (2009). Cleaning up Lake Simcoe. Retrieved from http://www.ec.gc.ca/doc/eau-water/simcoe_e.html.

42. Environmental Commissioner of Ontario. (n.d.). Review of Applications R2007007, R2007008, R2007009: The Need for Municipal Climate Change Adaptation Strategies (Review undertaken by MOE, denied by MNR and MMAH) - Background/Summary of Issues. Retrieved from http://www.eco.on.ca/eng/index.php?page=295.

43. *Environmental Protection Act*, R.S.O. 1990, c. E.19. Retrieved from http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90e19_e.htm

44. ESRI. (n.d.) *What is G.I.S*. Retrieved from http://www.esri.com/what-is-gis/index.html.

45. European Commission. (2009, December 4). *Stakeholder Consultation*. Retrieved from http://ec.europa.eu/regional_policy/sources/docgener/evaluation/evalsed/sourcebooks/method_techniques/structuring_evaluations/stakeholders/description_en.htm.

46. European Parliament, Council. (Consolidated 2009). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Retrieved at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:NOT.

47. Fairfax County. (2005). LID BMP Fact Sheet – Bioswales. Retrieved from: http://www.lowimpactdevelopment.org/ffxcty/1-4_bioswale_draft.pdf \.

48. Fairfax County. (2005). *Fact Sheets for LID BMPs for the Fairfax County, Virginia Public Facilities Manual*. Prepared for Fairfax County Department of Public Works and Environmental Services by Fairfax County Low Impact Development Center, Fairfax, VA. Retrieved from http://www.lowimpactdevelopment.org/fairfax.htm.

49. Farahbakhsh, K., Despins, C., & Leidl, C. (2008). *Evaluating the feasibility and developing design requirements and tools for large-scale rainwater harvesting in Ontario*.

Prepared for the Canadian Mortgage and Housing Corporation [CMHC] by the University of Guelph.

50. Farrell, A.C., Scheckenberger, R.B. (2010, February). *Subwatershed-scale assessment technique of Low Impact Development Best Management Practices for infiltrating urban runoff (A LID BMP analytical technique for subwatersheds).* Paper presented at the New Directions '09 in Stormwater Management Conference, Toronto.

51. Flugel, W.A. (1995). Hydrological response units (HRUs) to preserve basin heterogeneity in hydrological modelling using PRMS/MMS – case study in the Brol basin, Germany. In S. P. Simonovic, Z. Kundzewicz, D.Rosbjerg, & K. Takeuchi (Eds.), Modelling and Management of Sustainable Basin-Scale Water Resource Systems (pp. 79 – 87). Wallingford, Oxfordshire: IAHS Press.

52. Flugel, W.A. (1997). Combining GIS with regional hydrological modelling using hydrological response units (HRUs): An application from Germany. *Mathematics and Computers in Simulation, 43,* 297-304.doi: 10.1016/S0378-4754(97)00013-X.Gilroy, K.L, & McCuen R.H. (2009). Spatio-temporal effects of low impact development practices. *Journal of Hydrology*, *367*, 228 - 236. doi:10.1016/j.jhydrol.2009.01.008.

53. Fohrer, N., Haverkamp, S., Eckhardt, K., & Frede, H.G. (2001). Hydrologic Response to land use changes on the catchment scale. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 26*(7-8), 577-582. doi:10.1016/S1464-1909(01)00052-1.

54. Fowler, F.G., (2009). *Survey Research Methodology*. Sage Publications, Inc., Thousand Oaks, California.

55. Fulop, J. (2005). *Introduction to decision-making methods*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.86.6292&rep=rep1&type=pdf.

56. Gilroy, K.L, & McCuen R.H. (2009). Spatio-temporal effects of low impact development practices. *Journal of Hydrology*, *367*, 228 - 236. doi:10.1016/j.jhydrol.2009.01.008.

57. Government of Canada. (n.d.). Quality Services - Guide I - Client Consultation. Retrieved from http://www.tbs-sct.gc.ca/pubs_pol/opepubs/tb_o/1QG-PR-eng.asp?printable=True.

58. Government of Canada. (2009, January 21). Public Participation Guide: Annex A. Public Participation Activities and Techniques. Retrieved from http://www.ceaa.gc.ca/default.asp?lang=En&n=46425CAF-1&offset=37&toc=show#matrix.

59. Government of British Columbia. (2002). *Stormwater planning: A guidebook for British Columbia*. Retrieved from http://www.env.gov.bc.ca/epd/epdpa/mpp/stormwater/guidebook/pdfs/stormwater.pdf.

60. Government of Ontario. (2009). Lake Simcoe Protection Plan (PIBS 6932e01). Queen's Printer for Ontario.

61. Graham, P., Maclean, L., Medina, D., Patwardhan, A., & Vasarhelyi, G. (2004). The role of water balance modelling in the transition to low impact development. *Water Quality Research Journal of Canada*, *39* (4), 331–342. Retrieved from http://www.cawq.ca/cgi-bin/journal/display.cgi?language=english&pk_journal=68.

62. Groves, R.M., Fowler, F.J., Couper, M.P., Lepkowski, J.M., Singer, E. Tourangeau, R. (2009). *Survey Methodology.* New Jersey: John Wiley & Sons, Inc.

63. Guitouni, A., & Martel. J-M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research, 109(2),* 501 – 521. doi:10.1016/S0377-2217(98)00073-3.

64. Hardin, M. D. and Wanielista, M. P. A Water Quality Assessment of Green Roof Stormwater Treatment Systems. Retrieved March 2010 from: http://www.stormwaterenvironments.com/Documents/GreenRoofWaterResourcesJournal WaterQuality.pdf.

65. Hathaway, J., & Hunt, W.F. (2007). *Stormwater BMP Costs*. Prepared for the North Carolina Department of Environment and Natural Resources by North Carolina State University. Retrieved from http://www.bae.ncsu.edu/stormwater/pubs.htm.

66. Heaney, J.P., & Sansalone, J.J. (2009). Urban stormwater management in 2050. *In World Environmental and Water Resources Congress 2009*: *Great Rivers Conference Proceedings* (pp. 1-9). doi 10.1061/41036(342)234.

67. Hellstrom, D., Jeppsson, U., Karrman, E. (2000). A framework for systems analysis of sustainable urban water management. *Environmental Impact Assessment Review*, 20 (3), 311–321. doi:10.1016/S0195-9255(00)00043-3.

68. Heuvelmans, G., Muys, B., & Feyen, J. (2004). Evaluation of hydrological model parameter transferability for simulating the impact of land use on catchment hydrology. *Physics and Chemistry of the Earth Parts A/B/C, 29*(11-12), 739-747. doi:10.1016/j.pce.2004.05.002.

69. Hwang, A. H.-S., Valeo, C., & Draper, D. (2006). Public perceptions and attitudes toward stormwater recycling for irrigation. *Canadian Water Resources Journal,* 31(3), 185-196. doi:10.4296/cwrj3103185

70. Irvin, R.A., & Stansbury, J. (2004). Citizen Participation in Decision Making: Is It Worth the Effort?. *Public Administration Review, 64*(1), 55-65. Retrieved from http://www.jstor.org/stable/3542626.

71. Johnson, L.E. (2009). Geographic information systems in water resources engineering. Raton: CRC Press.

72. Kiker, G.A., Bridges, T.S., Varghese, A., Seager, T.P., & Linkov, I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. *Integrated Environmental Assessment and Management*, *1(2),* 95 -108, doi: 10.1897/IEAM_2004a-015.1.

73. Lai, F., Dai, T., Zhen, J., Riverson, J., Alvi, K., & Shoemaker, L. (2007). Sustain – An EPA *BMP process and placement tool for urban watershed*. Fairfax, VA : Water Environment Federation.

74. Lai, D., Shoemaker, L., Riverson, J., Alvi, K., Zhen, J.X., Paul, S., Rafi, T. (2009). SUSTAIN - A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality (EPA Contract No. GS-10F-0268K). United States: U.S. EPA.

75. Lake Simcoe Conservation Authority [LSRCA]. (n.d.). *Our Watershed*. Retrieved from http://www.lsrca.on.ca/about/watershed.php

76. Lake Simcoe Environmental Management Strategy [LSEMS]. (2003). *State of the Lake Simcoe Watershed.* http://www.lsrca.on.ca/pdf/reports/lsems/state_lake.pdf.

77. Lake Simcoe Region Conservation Authority [LSRCA]. (2007). *Lake Simcoe Basin stormwater management and retrofit opportunities*. Retrieved from http://www.lsrca.on.ca/pdf/reports/stormwater_retrofit.pdf.

78. Lake Simcoe Region Conservation Authority [LSRCA]. (2008). *Lake Simcoe Region Conservation Authority Watershed Development Policies.* Approved by LSRCA Board of Directors November 28, 2008. Resolution No. BOD-08-140.

79. *Lake Simcoe Protection Act*, S.O. 2008, C. 23. Retrieved from http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_08l23_e.htm.

80. Larson, K.L., Lach, D. (2007). Participants and non-participants of place-based groups: An assessment of attitudes and implications for public participation in water resource management. *Journal of Environmental Management,* 88, 817–830. doi:10.1016/j.jenvman.2007.04.008.

81. Li, J., Banting, D., Joksimovics, D., Lawson, S., Hahn, K., & Ahmed, N. (2009). *Evaluation of Low Impact Development Stormwater Technologies and Water Reuse Options for the Lake Simcoe Regions Phase 1 Draft Report.* Toronto: Ryerson University.

82. Linkov, I., Varghese., A., Jamil, S., Seager., T.P., Kiker., G., Bridges., T. (2004). Multi-criteria decision analysis: A framework for structuring remedial decisions at contaminated sites. In Linkov, I. and Ramadan, A. (Eds.), *Comparative Risk Assessment and Environmental Decision Making* (pp. 15-54). Dordrecht, Netherlands: Kluwer Academic Publishing.

83. Linkov, I., Satterstrom,F.K., Kiker, G., Seager, T.P., Bridges, T., Gardner, K.H. (2006). Multicriteria Decision Analysis: A Comprehensive Decision Approach for Management of Contaminated Sediments. *Risk Analysis*, *26 (*1), 61-78. doi: 10.1111/j.1539-6924.2006.00713.x.

84. Lloyd, S., Wong, T. H.F., Chesterfield, C.J. (2002). Water sensitive urban design – A stormwater management perspective. Melbourne: Melbourne Water Corporation - Cooperative Research Centre for Catchment.

85. Luxburg, U & Ben-David, S. (2005). Towards a Statistical Theory of Clustering. In PASCAL workshop on Statistics and Optimization of Clustering. Retrieved from http://www.cs.uwaterloo.ca/~shai/LuxburgBendavid05.

86. Maguire, L.A. & Lind, E.A. (2003). Public participation in environmental decisions: stakeholders, authorities and procedural justice. *International Journal of Global Environmental Issues*, *3*(2), 133–148. doi: 10.1504/IJGENVI.2003.003861.

87. Makowski, M. (2001). *Multi-objective Decision Support Including Sensitivity Analysis.* Retrieved from http://www.iiasa.ac.at/~marek/ftppub/MM/eolss_mcma.pdf.

88. Makropoulos, C.K., Natsis, K., Liu, S., Mittas, K., & Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling & Software, 23,* 1448–1460. doi:10.1016/j.envsoft.2008.04.010.

89. Marks J.S., Martin, B., & Zadoroznyj, M. (2006). Acceptance of water recycling in Australia: national baseline data. *Water, March*, 151-157.

90. Marsalek, J., Jiménez-Cisneros, B.E., Malmquist, P.A., Karamouz, M., Goldenfum, J., & Chocat, B. (2006). *Urban water cycle processes and interactions*. Paris: UNESCO.

91. Martin, C., Ruperd, Y., & Legret, M. (2007). Urban stormwater drainage management: The development of a multicriteria decision aid approach for best management practices. *European Journal of Operational Research, 181(*2007), 338–349. doi: doi:10.1016/j.ejor.2006.06.019.

92. Mathworks Inc. (2009). Matlab (Version R2009a) [Software]. Available from http://www.mathworks.com/.

93. Merritt, W.S., Croke, B.F.W., Jakeman, A.J., Letcher, R.A., & Perez, P. (2004). A Biophysical Toolbox for assessment and management of land and water resources in rural catchments in Northern Thailand. *Ecological Modelling, 171*, 279–300. doi: doi:10.1016/j.ecolmodel.2003.08.010.

94. McKissock, G., D'Arcy, B.J., Wild, T.C., Usman, F., and Wright, P.W. (2003). An evaluation of SUDS guidance in Scotland. Diffuse Pollution Conference Dublin 2003

95. Mustajoki, J., Hamalainen, R.P., & Marttunen, M. (2004) Participatory multicriteria decision analysis with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling & Software, 19*, 537–547. doi:10.1016/j.envsoft.2003.07.002.

96. NAHB Research Centre. (n.d.). Low impact development (LID) practices for storm water management: A cost effective way to address storm water management through site design modifications and "Best Management Practices". Retrieved May 5, 2009, from http://www.toolbase.org/Techinventory/TechDetails.aspx?ContentDetailID=909&BucketID=6&CategoryID=11#top.

97. NAHB Research Center, Inc. (2003). *The Practice of Low Impact Development*. Prepared for U.S. Department of Housing and Urban Development .Office of Policy Development and Research. Retrieved from: http://www.huduser.org/publications/pdf/practLowImpctDevel.pdf

98. North Carolina State University. (2006). *Level spreaders: Overview, design, and maintenance.* State of North Carolina: Hathaway, J.M., & Hunt W.F.

99. Novotny, V. (2007). From Wingspread to Sustainable Urban Waters and Watersheds. In International Symposium on New Directions in Urban Water Management, Paris, France.

100. Ogilvie, Ogilvie & Company. (2009). Phase 1 Workshop Stormwater Management Strategies for Uncontrolled Urban Areas in the Lake Simcoe Watershed – Facilitator Summary. King City: Ogilvie, Ogilvie & Company.

101. Ontario Ministry of Environment [OMOE]. (2003). *Stormwater management planning and design manual*. (ISBN 0-7794-2969-9). Ontario: Queen's Printer for Ontario.

102. Ontario Ministry of Environment [OMOE]. (2007). *Code of practice: Consultation in Ontario's Environmental Assessment Process*. Toronto: Queen's Printer for Ontario. http://www.ene.gov.on.ca/publications/6259e.pdf.

103. Ontario Ministry of Environment. (2009). *Lake Simcoe Protection Plan*. Retrieved from http://www.ene.gov.on.ca/publications/6932e01.pdf.

104. Ontario Water Resource Act, R.S.O. 1990, c. O.40. Retrieved from http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90o40_e.htm.

105. Pearson, Coggan, Proctor, & Smith (2009). A Sustainable Decision Support Framework for Urban Water Management. *Water Resource Management*, 24, 363–376. doi 10.1007/s11269-009-9450-1

106. Peck, S. W., Cameron, R. D. Liptan, T. (2009). Green Roofs: Beautiful and Innovative Solutions to Stormwater Pollution .Webcast Sponsored by EPA's Watershed Academy. Retrieved March 2010 from: http://www.epa.gov/watershedwebcasts/pdf/greenroofs_feb18_slides.pdf.

107. Pennsylvania Department of Environmental Protection. (2006). *Pennsylvania Stormwater Best Management Practices Manual*. Retrieved from http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305.

108. Perez-Pedini, C., Limbrunner, J.F., & Vogel, R. M. (2005). Optimal Location of Infiltration-Based Best Management Practices for Storm Water Management. *Journal of water resources planning and management, 131(*6), 441-448. doi: 10.1061/ASCE0733-94962005131:6441.

109. Phillips Engineering Ltd. (2007). *Credit River Flow Management Study*. Burlington, Ontario: Credit Valley Conservation. Retrieved from http://www.creditvalleycons.com/bulletin/downloads/2007flowmgmt-study.pdf.

110. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. (2009). World Population Prospects: The 2008 Revision. Retrieved from http://esa.un.org/unpd/wpp2008/index.htm.

111. Prince George's County Government. (1999). *Low-impact development design strategies: An integrated design approach.* Retrieved from http://www.lowimpactdevelopment.org/pubs/LID_National_Manual.pdf.

112. The Rain Well. (n.d). *The Rain Well Galvanized Metal Cisterns*. Retrieved March 27, 2010, from http://www.therainwell.com/Docs/MetalCisternPriceList.pdf.

113. QuestionPro Survey Software. (2009). Seattle, WA: Survey Analytics LLC.

114. QUALHYMO User Manual and Documentation (2009, January). Retrieved from http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/QualhymoUserManual%20new%20Jan09.pdf

115. Rinaldo, A., & Rodriguez-Iturbe, I. (1996). Geomorphological theory of the hydrological response. *Hydrological Processes, 10(*6), 803-829. doi: 10.1002/(SICI)1099-1085(199606)10:6<803::AID-HYP373>3.0.CO;2-N.

116. RiverSides. (n.d.). *Downspout Disconnection*. Retrieved from http://www.riversides.org/rainguide/riversides_hgr.php?cat=2&page=39&subpage=41.

117. Rodriguez, F., Andrieu, H., & Creutin, J.D. (2003). Surface runoff in urban catchments: morphological identification of unit hydrographs from urban databanks *Journal of Hydrology, 283*(1-4), 146-168. doi:10.1016/S0022-1694(03)00246-4.

118. Rossman, L.A. (2009*). SWMM 5.0 Users Manual*. Retrieved from http://www.epa.gov/ednnrmrl/models/swmm/index.htm.

119. Rossman, L.A. (2010*).* Modelling Low Impact Development Alternatives with SWMM. In W. James, K.N. Irvine, J.Y. Li, E.A. McBean, R.E. Pitt, & S.J. Wright (Eds.), *Dynamic modelingg of Urban Water Systems: Monograph 18.* (pp. 167 – 180). Guelph, Ontario: Computational Hydraulics International (CHI).

120. Roy, A.H., Wenger, S.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Shuster, W.D., Thurston, H.W., Brown, R.R. (2008). Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States. *Environmental Management, 42*,344–359. doi: 10.1007/s00267-008-9119-1

121. Sadjadi, S. J., Habibian, M., & Khaledi, V. (2008). A Multi-Objective Decision Making Approach for Solving Quadratic Multiple Response Surface Problems. *International Journal Contemporary Math Sciences, 3*(32), 1595 – 1606.

122. Salama, R., Bekele, E., Pollock, D., Bates, L., Byrne, J., Hick, W., Watson, G., & Bartle, G. (2002). Hydrological Response Units of the Ord Stage I Irrigation Area and the Dynamic Filling of the Aquifers of the Ivanhoe and Packsaddle Plains. Technical Report 7/02. Perth: CSIRO Land and Water.Snyders Industries, Inc. (n.d.). *Introduction to rainwater harvesting*. Retrieved from http://www.snydernet.com/_pdf/_septic/Snyder%20Industries%20Introduction%20to%20Rain%20Harvesting.pdf.

123. SawTooth Software, Inc. (2010). Retrieved from http://www.sawtoothsoftware.com/index.shtml.

124. Shoemaker, L., Riverson, J., Alvi, K., Zhen, J.X., Paul, S., & Rafi, T. (2009). *SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality* (Report No. EPA/600/R-09/095). Retrieved from United States Environmental Protection Agency [US EPA] website: http://www.epa.gov/ednnrmrl/models/sustain/.

125. South Australian Government. (2009). *Water Sensitive Urban Design (WSUD) Technical Manual for Greater Adelaide*. Retrieved from http://www.planning.sa.gov.au/go/wsud.

126. Southeast Michigan Council of Governments [SEMCOG]. (2008). *Low impact development manual for Michigan: A design guide for implementers and reviewers.* Retrieved from http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf

127. Statistics Canada. (2008). *Population Growth in Canada*. Retrieved from http://www.statcan.gc.ca/pub/91-003-x/2007001/4129907-eng.htm#tphp.

128. Stormwater Management Requirements Guidance on the Chesapeake Bay Preservation Area Designation and Management Regulations, September 16, 2002. Retrieved March 2010 from: http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/documents/SWM.pdf

129. SurveyMonkey (1999- 2010). Retrieved from http://www.surveymonkey.com/.

130. Sustainability Reporting Program. (2007, April 24). *The Sustainability Report – Canada's Population* Retrieved from http://www.sustreport.org/signals/canpop_ttl.html.

131. SWITCH Central Management Unit. (n.d.). SWITCH – Managing Water for the City of the Future. Retrieved from http://www.switchurbanwater.eu/index.php.

132. Toronto and Region Conservation Authority [TRCA]. (2007). *An Economic Analysis of Green Roofs: Evaluating the costs and savings to building owners in Toronto and surrounding regions.* Retrieved from http://www.sustainabletechnologies.ca/.

133. Toronto and Region Conservation Authority [TRCA]. (2008). *Performance Evaluation of a Rainwater Harvesting System Toronto, Ontario*. Retrieved from http://www.sustainabletechnologies.ca/.

134. Tran, K.C., Euan, J., Isla, M.L. (2002). Public perception of development issues: impact of water pollution on a small coastal community. *Ocean & Coastal Management*, *45,* 405–420. doi:10.1016/j.ocecoaman.2006.02.005.

135. Ubuntu Linux. (n.d.). ZunZun.com - Online Curve Fitting and Surface Fitting Web Site. Retrieved from http://zunzun.com//

136. United States Environmental Protection Agency [U.S. EPA]. (1999). Storm Water Technology Fact Sheet Bioretention (EPA 832-F-99-012). Washington, DC: Author. Retrieved from http://www.epa.gov/owmitnet/mtb/mtbfact.htm.

137. United States Environmental Protection Agency [U.S. EPA]. (1999). Storm Water Technology Fact Sheet Porous Pavements (EPA 832-F-99-023). Washington, DC: Author. Retrieved from http://www.epa.gov/owmitnet/mtb/mtbfact.htm.

138. United States Environmental Protection Agency [U.S. EPA]. (2006). *Vegetated Filter Strip Factsheet.* Retrieved from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=76.

139. United States Environmental Protection Agency [U.S. EPA]. (2007). *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices (Report No. EPA 841-F-07-006).* Washington, D.C.: Author. Retrieved from http://www.epa.gov/owow/nps/lid/costs07/

140. United States Environmental Protection Agency [U.S. EPA]. (2008). Stormwater Basic Information. Retrieved from http://cfpub.epa.gov/npdes/stormwater/swbasicinfo.cfm.

141. Unified Facilities Criteria (UFC), Low Impact Development. UFC 3-210-10 25 October 2004. US Department of Defence, Retrieved March 2010 from: www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf.

142. Vanaskie, M.J. Myers, R.D., & Smullen, J.T. (2010, April). *Planning-level cost estimates for green stormwater infrastructure.* Paper presented at the Low Impact Development 2010: Redefining water in the city in urban watersheds, San Francisco, California.

143. Van Veldhuizen, D.A., Lamont, G.B. (1998). Evolutionary Computation and Convergence to a Pareto Front. *CiteSeerX*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.42.7224. doi: 10.1.1.42.7224.

144. Wanielista, M. P., & Yousef, Y.A. (1993). *Stormwater Management.* New York: John Wiley & Sons, Inc.

145. Water and Earth Associates, Ltd. [WESA]. (2007). A preliminary groundwater recharge impact assessment from rainwater harvesting in the regional municipality of Waterloo, Ontario.

146. Water Environment Research Foundation [WERF]. (2009a). User's guide to the BMP and LID whole life cost models V2.0 (Report No. SW2R08). Alexandria, VA: Author.

147. Water Environment Research Foundation [WERF]. (2009b). BMP and LID whole life cost models V2.0 [software tool]. Alexandria, VA: Author.

148. White, I., & Howe, J. (2005). Unpacking the Barriers to Sustainable Urban Drainage Use. *Journal of Environmental Policy & Planning, 7* (1), 25 – 41. doi: 10.1080/15239080500251866.

149. Winer, R. (2000). National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Retrieved March 2010 from: http://www.stormwatercenter.net/Library/STP-Pollutant-Removal-Database.pdf

150. Wong, T., Coleman, J., Duncan, H., Fletcher, T., Jenkins, G., Siriwardena, L., Taylor, A., & Wootton, R. (2005). Manual for Music Version 3. Cooperative Research Center for Catchment Hydrology. April 2005.

151. Wossink, A., & Hunt, B. (2003). An evaluation of cost and benefit of structural stormwater best management practices in North Carolina. Retrieved from http://www.bae.ncsu.edu/stormwater/pubs.htm.

152. Wright, L., Heaney, J.P., and Weinstein, N. (2000). Micro-scale Modeling of Low Impact Development. In M. Glade (Ed.), 2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management: Section 27, Chapter 1. Building Partnerships. Reston, VA: The American Society of Civil Engineers. doi 10.1061/40517(2000)106.

153. Young, K. D., Younos, T., Dymond, R.L., and Kibler, D.F. (2009). Virginia's Stormwater Impact Evaluation: Developing an Optimization Tool for Improved Site Development, Selection and Placement of Stormwater Runoff BMPs. Virginia: Virginia Water Resources Research Center.

154. Zhen, W., Juan, Y.Y., Cheng, G.H., Ye, Z.X., (2007). Application of Multi-attribute Decision Making Methods on Slope Treatment of Small Watershed. *Environmental Informatics Archives, 5,* 728-736. ISSN 1811-0231 / ISEIS Publication Series Number P002 Paper EIA07-077.

APPENDIX A: Definitions

Table A-1: Common point-based LID practices

LID Practice	Description
Soakaway Pit[13]	Soakaway pits are excavated trenches filled with stones that receive runoff from rooftop leaders through a downspout or swale. These trenches temporarily store water to be infiltrated.
Bioretention Cell	Bioretention areas in general are planted sites similar to a garden that collect and filter rainwater to enhance water quality. There are a number of functions that bioretention areas perform. They can be used to pre-treat runoff prior to discharge into infiltration systems. Bioretention cells are adapted to fit into containers of urban landscapes. The cells act as a storage area for excess stormwater when the downstream infiltration system has been surcharged. This allows infiltration to occur over an extended duration of time allowing more runoff to be infiltrated by the system. In addition to this function, bioretention areas also treat stormwater runoff by passing it through an engineered filter medium, collecting it in an underdrain and then returning it back to the storm drain system.
Dry Well[14]	Dry wells are similar to soakaway pits but with slightly different geometries. A dry well is a small pit filled with aggregate, such as gravel or stone, used to control runoff from building rooftops or paved areas. Dry wells are best suited to treat small impervious areas and can be implemented on steeper slopes. For runoff from large impervious areas such as parking lots, dry wells are not appropriate. Installation of dry wells should also be avoided in large areas with high sediment loads and low soil permeability. As a result, dry wells are suited to treat runoff from residential drive ways or rooftop downspouts.
Rainwater Harvesting	Rainwater harvesting is an LID practice that captures and stores rainfall for future use. A catchment surface, such as a rooftop, collects the rain that falls and conveys it into an above or below ground storage tank. Once captured, the rainwater is pumped into the building where it can be used for non-potable water uses such as toilet flushing, use in washing machines or for irrigation purposes. It is estimated that this application alone can reduce the household municipal water consumption by up to 55%. The capture and re-use of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also help reduce the demand on municipal treated water supplies.
Green Roof	Green rooftops are rooftops that consist of a layer of vegetation and soil installed on top. The rooftop can be a conventional flat or sloped roof. This LID practice behaves similar to a lawn or meadow in that it stores rainwater in the soil and pond areas. The excess water from rainfall passes to underdrains and overflow points, which is conveyed in a typical building drainage system. After a storm, stored water either evaporates or is evapotranspired by the plants. There are two types of green roofs, intensive and extensive. Intensive green roofs can be planted with deeply rooted plants and generally have a deeper soil layer. Extensive green roofs are systems consisting of a thin layer of soil with an

[13] LID practices described by CVC & TRCA (2010) except for dry well.

[14] Government of Prince George's County, 1999

	herbaceous vegetative cover.
Downspout Disconnection	Downspout disconnection is the practice of diverting flow from downspouts to a pervious area. As a result, stormwater is prevented from directly entering the storm drain system or flowing across a “connected” impervious surface such as a driveway that drains to a storm sewer system. As an LID practice, this system is combined with other LID practices. For example, in residential and non-residential rooftop applications, downspout disconnections can be combined with compost amendments, grass channels, filter strips, bioretention areas, rainwater harvesting systems, and soakway pits.

Table A-2: Common linear-based LID practices

LID Practice	Description
Bioretention[15]	Bioretention systems applied as a linear practice are similar to bioretention cells in function. These practices are typically carried out in commercial, institutional, and residential sites in spaces that are traditionally pervious and landscaped. These sites are generally also close to the impervious area that generates the runoff. Bioretention LID systems are commonly found along roadway right-of-ways, landscaping beds, and around parking areas.
Filter Strip	Filter strips are vegetated areas that are intended to treat sheet flow from adjacent impervious areas. Originally used as an agricultural treatment practice, this LID practice functions by slowing runoff velocities and filtering out sediments and other pollutants. Filter strips also provide some infiltration into underlying soils. In addition, the combination of proper design and maintenance allows for relatively high pollutant removal. Filter strips, however are limited in attenuating flows and are often “short circuited” by concentrated flows. This results in little or no treatment of stormwater runoff and it is often beneficial to combine filter strips with other LID practices to maximize water quality/flow attenuation benefits. Filter strips are also ideal for snow storage and treatment due to their capacity for meltwater infiltration.
Permeable Pavements	Permeable pavements are used as alternatives to traditional impervious paving surfaces such as concrete and asphalt to promote reduction of stormwater flows. Permeable pavements such as open joint permeable pavers, pervious concrete and porous asphalt, allow for filtration, storage, or infiltration of runoff. Common permeable pavers include plastic lattice, interlocking concrete modules, and brick pavers.
Enhanced Grass Swale/channel	Enhanced grass channels are generally used for conveyance, particularly to treat roadway drainage. The benefits of grass channels also include allowance of infiltration discharge at a lower rate and reduce pollutant loads. In addition, grass channels are closer in hydrologic properties to natural zero order headwater streams than drainage systems composed of curb and gutter, inlets, and pipes. A disadvantage in implementing this LID practice is that they are not capable of providing the same level of water balance and water quality benefits as dry swales due to their lack of engineered soil media and storage volumes.

[15] LID practices described by CVC & TRCA (2010) except for level spreaders and roadway reduction.

Dry swales	Dry swales are soil filter systems that temporarily store and then filter the water quality volume. Stormwater is treated by filtering first through the soil bed then flowing into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale. Dry swales are similar to bioretention cells in that they rely on the same soil mix at the bottom of the channel. One major difference is that they are configured as linear channels. The appearance of dry swales can be quite similar to simple grass channels with the same shape and turf cover, however elaborate landscaping has been seen in some cases.
Infiltration Trench	Similar to soakaway pits, an infiltration trench is a stone-filled subsurface basin that receives stormwater runoff. The stormwater that enters the trench is stored until it can be infiltrated into the soil, usually over a period of days. This LID practice often includes some form of pretreatment in the design. Common pretreatment techniques include filter strips or swales. Infiltration trenches are considered to be very adaptable since there are many practical configurations. This makes it a practice ideal for small urban drainage areas.
Level Spreader[16]	A level spreader is used to diffuse concentrated runoff and disperse it uniformly across a slope to prevent erosion. This dispersed flow, commonly referred to as sheet flow or overland flow, is a thin layer of runoff typically less than 25.4mm in depth moving over a wide surface. Level spreaders typically consist of three parts: the forebay, the channel, and the riparian buffer. The forebay is used for pre-treatment of stormwater. It is an excavated, semi-circle feature that reduced the incoming flow of stormwater. It also allows for heavy sediment and debris to settle. The stormwater then enters into the channel, which can be concrete, rock or grass. This is considered the main body of the level spreader. The final part in the system is the riparian buffer. The riparian buffer is a vegetated area along streams, rivers, and other water bodies that assists in the filtration of runoff, as well as prevents erosion. The main objective for this part of the system is to remove sediment and nutrients from runoff before it reaches the stream.
Roadway Reduction[17]	One of the main objectives of LID practices is to decrease the amount of impervious surface area. Reducing roadway surfaces is an effective and simple way of achieving this objective. It allows for the retention of more permeable land area, as well as avoids problems from storm water runoff and water table depletion. Roadway reduction methods include using longer, undulating roads rather than wider shorter streets. This decreases the amount of intersections as well as creates more available lot frontage. Other methods involve sharing of driveways, landscaped detention islands within cul-de-sacs, and flag lots with reduced street frontage.

[16] North Carolina State University, 2006

[17] NAHB Research Centre, n.d.

Table A-3: Common area-based LID practices

LID Practice	Description
Bioretention Area[18]	The implementation of bioretention practices over an area is also considered an area-based approach. The design principles and site considerations required for this LID practice for an area-based application is consistent with the description provided above.
Soil Amendments	The purpose of soil amendments is to restore soil properties to pre-development conditions. This is done by reversing the loss of organic matter and compaction. The practice of soil amendments is particularly useful on hydrologic group 'C' and 'D' soils (Government of Ontario: Ministry of Environment, 2003). Applying this practice on these types of soils allows for the implementation of LID technologies such as downspout disconnection, filter strips, and grass channels.
Tree Clusters	Tree clusters as a LID practice can reduce stormwater runoff volume and peak flow. Generally, trees at existing development sites should be conserved where possible to maintain a natural hydrologic regime. If tree conservation is not an option, new trees should be planted in pervious areas of sites. Trees planted in clusters function similarly to a forested area in that they intercept rainfall and provide the means of evapotrapiraiton and infiltration to take place which reduces stormwater runoff. Some clusters are designed to receive sheet flow, particularly from pervious areas.
Permeable Pavements	The application of permeable pavements over an area is also considered an area-based approach. The description as an area-based application is consistent with the description provided above.
Home Clustering	Preserving natural land areas can be achieved by minimizing the amount of development that occurs on the site. Clustering homes on smaller lots can assist with protection of natural features by allowing more open space to be available for aspects such as wildlife habitats and recreation. Home clustering can also reduce development and maintenance costs, which is ideal for both builders and homeowners. Through implementation of this LID practice, open, undeveloped space is maximized and the required length of roadway and lot size is minimized.

[18] LID practices described by CVC & TRCA (2010).

APPENDIX B: Comparison of Existing Modelling Tools Suitable for LID Modelling

Table B-1: SWMM 5.0 LID simulation capabilities

LID Practice	Simulation Type	Modelling Methods / Input Parameters
Rainwater Harvesting	**Implicit** (Lewis 2009) (Elliot and Trowsdale 2006)	• can be modeled using rainwater harvesting configuration consisting of a storage unit, a basin, an overflow element, and an outlet • principle input properties: Estimated Water quality volume (WQV), area of storage element, maximum depth of storage element, geometry of overflow weir, and storage elevation curve • optional specification of properties include ponded surface area when flooded and external inflow data
Green Roofs	**Implicit** (Lewis 2009) (Young et al. 2009) (Elliot and Trowsdale 2006)	• can be modeled using rainwater harvesting configuration consisting of a storage unit, a basin, an overflow element, and an outlet • principle input properties: estimated WQV, area of storage element, maximum depth of storage element, geometry of overflow weir, and storage elevation curve • optional specification of properties include ponded surface area when flooded and external inflow data • WQV is estimated differently for green roofs and rainwater harvesting
Downspout Disconnection	**Implicit** (Lewis 2009)	• can be represented as a pervious subarea of a subcatchment • runoff flow from a impervious subarea can be routed to a pervious subarea
Soakaway Pits / Dry Wells / Infiltration Trenches	**Implicit** (Young et al. 2009) (Lewis 2009)	• can be modeled using an infiltration configuration consisting of a basin, a storage unit, an overflow (weir/orifice), and an outlet • principle input properties: estimated WQV, design infiltration rate (half of field infiltration rate), surface area, basin depth, geometry of overflow weir, depth-area relationship, and pump rate that infiltrates the WQV
Bioretention **(all types)**	**Implicit** (Lewis 2009) (Young et al. 2009) (Elliot and Trowsdale 2006)	• can be modeled using an infiltration configuration consisting of a basin, a storage unit, an overflow (weir/orifice), and an outlet • principle input properties: estimated WQV, design infiltration rate (half of field infiltration rate), surface area, basin depth, geometry of overflow weir, depth-area relationship, pump rate that infiltrates the WQV, and desired pollutant removal efficiency

Soil Amendments	**Implicit** (Elliot and Trowsdale 2006)	• can be represented as a pervious subarea of a subcatchment with altered parameters • infiltration can be modeled using Horton, Green-Ampt, or SCS Curve Number methods • requires user specification of principle input properties: assigned rain gage, assigned land uses, tributary surface area, slope, depression storage, and characteristic width & Manning's n for overland flow
Tree Clusters	**Implicit** (Lewis 2009) (Elliot and Trowsdale 2006)	• can be represented as a pervious subarea of a subcatchment with altered parameters • infiltration can be modeled using Horton, Green-Ampt, or SCS Curve Number methods • requires user specification of principle input properties: assigned rain gage, assigned land uses, tributary surface area, slope, depression storage, and characteristic width & Manning's n for overland flow
Filter Strips	**Implicit** (Young et al. 2009) (Lewis 2009)	• can be modeled using a treatment configuration consisting of a basin, a storage unit, an overflow (weir/orifice), a pump, and an outlet for the BMP • principle input properties: estimated WQV, surface area, basin depth, geometry of overflow weir, depth-area relationship, pump rate representing the desired drawdown time for the WQV, and desired pollutant removal efficiency
Permeable Pavement	**Implicit** (Lewis 2009) (Elliot and Trowsdale 2006)	• can be modeled using an infiltration configuration consisting of a basin, a storage unit, an overflow (weir/orifice), and an outlet for the BMP • principle input properties: WQV, design infiltration rate (half of field infiltration rate), surface area, basin depth, geometry of overflow weir, depth-area relationship, and pump rate that infiltrates the WQV
Grass Channels	**Implicit** (Elliot and Trowsdale 2006)	• can be modeled using a treatment configuration consisting of a basin, a storage unit, an overflow (weir/orifice), a pump, and an outlet for the BMP • principle input properties: estimated WQV, surface area, basin depth, geometry of overflow weir, depth-area relationship, pump rate representing the desired drawdown time for the WQV, and desired pollutant removal efficiency
Dry Swales	**Implicit** (Elliot and Trowsdale 2006)	• can be modeled using a treatment configuration consisting of a basin, a storage unit, an overflow (weir/orifice), a pump, and an outlet for the BMP • principle input properties: estimated WQV, surface area, basin depth, geometry of overflow weir, depth-area relationship, pump rate representing the desired drawdown time for the WQV, and desired pollutant removal efficiency
Level Spreader	**Implicit**	• can be modeled by routing stormwater through a filter strip, into an infiltration trench, then onto an

		overflow area
Roadway Reduction	**Implicit**	• can be modelled by modifying the parameters of the original road area to reflect roadway reductions, such as the replacement of roadway with grass swales or bioretention
Home Clustering	**Implicit**	• can be modelled by modifying the parameters of the original subcatchments to reflect various home layouts

Table B-2: SWMM 5.0-LID/BMP extension model simulation capabilities

LID Practice	Surface	Pavement	Soil	Storage
Soakaway	X			X
Bioretention	X		X	X
Dry Well				X
Rainwater Harvesting				X
Downspout Disconnection				X
Green Roof	X		X	X
Filter Strips	X			
Permeable/Porous Pavements	X	X		X
Grass Channel	X			
Dry Swale	X			

Infiltration Trench	X			X
Level Spreader	X			
Soil Amendments			X	

Table B-3: MUSIC LID simulation capabilities

LID Practice	Simulation Type	Modelling Methods and Input Parameters
Rainwater Harvesting	Explicit (Wong, et al. 2005)	• modeled as a rainwater tank under the USTM • requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: surface area, extended detention depth, permanent pool volume, seepage, and evaporative loss • requires specification of outlet properties: equivalent pipe diameter, overflow weir width • advanced options require specification of orifice discharge coefficient, weir coefficient, number of CSTR cells, and k and C* values
Green Roofs	Implicit (Wong, et al. 2005) (Elliot and Trowsdale 2006)	• can be modeled using an infiltration system under the USTM by changing soil and subsoil properties • requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: surface area, depth to overflow weir, infiltration rate, and evaporative loss • requires specification of outlet properties: overflow weir width • advanced options require specification of the weir coefficient, number of CSTR cells, and k and C* values
Downspout Disconnection	Implicit (Wong, et al. 2005)	• isolation or separation of runoff from different sources • may be treated as the outlet of an infiltration system modeled as a green roof
Soakaway Pits / Dry Wells / Infiltration Trenches	Implicit (Wong, et al. 2005)	• can be modeled using a pond/sedimentation basin under the USTM • requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: surface area, extended detention depth, permanent pool volume, seepage, and evaporative loss

		• requires specification of outlet properties: overflow weir width and equivalent pipe diameter • advanced options require specification of the weir coefficient, number of CSTR cells, and k and C* values
Bioretention (all types)	Explicit (Wong, et al. 2005)	• modeled as a bioretention system under the USTM • requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: surface area, extended detention depth, and seepage • requires specification of infiltration properties: filter area, filter depth, filter median particle diameter, saturated hydraulic conductivity, and depth below underdrain pipe • requires specification of outlet properties: overflow weir width • advanced options require specification of the weir coefficient, void ratio, number of CSTR cells, and k and C* values
Soil Amendments	Implicit (Wong, et al. 2005) (Elliot and Trowsdale 2006)	• amended area can be represented by a pervious area with altered parameters • requires specification of infiltration properties: soil storage capacity, initial storage, field capacity, and infiltration capacity coefficient & exponent
Tree Clusters	Implicit (Wong, et al. 2005) (Elliot and Trowsdale 2006)	• tree cluster can be represented by a pervious area with altered parameters • requires specification of infiltration properties: soil storage capacity, initial storage, field capacity, and infiltration capacity coefficient & exponent
Filter Strips	Explicit(Wong, et al. 2005)	• modeled as buffer strips • requires user specification of transfer functions • requires user specification of treatment properties: percentage of upstream area buffered, buffer area, and seepage
Permeable Pavement	Implicit (Wong, et al. 2005)	• permeable pavement can be represented by a pervious area with altered parameters • requires specification of infiltration properties: soil storage capacity, initial storage, field capacity, and infiltration capacity coefficient & exponent
Grass Channels	Explicit (Wong, et al. 2005)	• modeled as a vegetated swale under the USTM • requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: length, bed slope, base width, top width, depth, vegetation height, and seepage • advanced options require specification of the number of CSTR cells, and k and C* values
Dry Swales	Explicit (Wong, et al. 2005)	• modeled as a vegetated swale under the USTM with no vegetation

		• requires specification of inlet properties: low flow bypass and high flow bypass values • requires specification of storage properties: length, bed slope, base width, top width, depth, vegetation height (none), and seepage • advanced options require specification of the number of CSTR cells, and k and C* values
Level Spreader	Implicit	• can be modeled by routing stormwater through a filter strip, into an infiltration trench, then onto an overflow area
Roadway Reduction	Implicit	• can be modelled by modifying the parameters of the original road area to reflect roadway reductions, such as the replacement of roadway with grass swales or bioretention
Home Clustering	Implicit	• can be modelled by modifying the parameters of the original subcatchments to reflect various home layouts

Table B-4: BMPDSS LID simulation capabilities

LID Practice	Simulation Type	Modelling Methods and Input Parameters
Rainwater Harvesting	Explicit (Tetra Tech Inc 2007)	• modeled as a rain barrel • requires user specification of basin dimensions: length and width • requires user specification of orifice parameters: orifice diameter, orifice height, and exit type • requires user specification of weir parameters: weir height and geometry • can specify number of dry days
Green Roofs	Explicit (Tetra Tech Inc 2007)	• modeled as a green roof • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and background infiltration
Downspout Disconnection	Implicit (Tetra Tech Inc 2007)	• reduced or disconnected imperviousness can be simulated by identifying the site layout and routing
Soakaway Pits / Dry Wells / Infiltration Trenches	Explicit (Tetra Tech Inc 2007)	• modeled as a detention basin • requires user specification of orifice parameters: orifice diameter, orifice height, and exit type • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and

		background infiltration
Bioretention (all types)	Explicit (Tetra Tech Inc 2007)	• modeled as a bio-retention site • requires user specification of orifice parameters: orifice diameter, orifice height, and exit type • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and background infiltration
Soil Amendments	Implicit (Tetra Tech Inc 2007)	• designated pervious areas can be simulated by identifying the site layout and routing • pervious area can be described as a percentage
Tree Clusters	Implicit (Tetra Tech Inc 2007)	• designated pervious areas can be simulated by identifying the site layout and routing • pervious area can be described as a percentage
Filter Strips	-	• may or may not be modeled • details and information on specific processes and input parameters required are not covered in present literature or documentation
Permeable Pavement	Explicit (Tetra Tech Inc 2007)	• modeled as a porous pavement • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and background infiltration
Grass Channels	Explicit (Tetra Tech Inc 2007)	• modeled as a swale • requires user specification of BMP dimensions: Manning's N, width, length, max depth, and various slopes • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and background infiltration
Dry Swales	Implicit (Tetra Tech Inc 2007)	• can be modeled as a swale with no vegetation • requires user specification of BMP dimensions: Manning's N, width, length, max depth, and various slopes • requires user specification of substrate properties: depth of soil, soil porosity, vegetative parameters, and soil layer infiltration • underdrain structure can be considered and requires specification of storage depth, media void fraction and background infiltration

Level Spreader	Implicit	• can be modeled by routing stormwater through a filter strip, into an infiltration trench, then onto an overflow area
Roadway Reduction	Implicit	• can be modelled by modifying the parameters of the original road area to reflect roadway reductions, such as the replacement of roadway with grass swales or bioretention
Home Clustering	Implicit	• can be modelled by modifying the parameters of the original subcatchments to reflect various home layouts

Table B-5: LID simulation capabilities in SUSTAIN

LID Method	Simulation Type	Modelling Methods / Input Parameters
Rainwater Harvesting	Implicit (Lai, et al. 2009)	• can be modeled as a hydrodynamic storage device • uses stage-outflow storage routing with weir/orifice equations • completely mixed pollutant routing and first order decay for treatment • advanced options include CSTRs in series and plug flow for pollutant routing, k-C* model, and sedimentation
Green Roofs	Explicit (Lai, et al. 2009)	• modeled explicitly as a roof garden • details and information on specific processes and input parameters required are not covered in present literature or documentation
Downspout Disconnection	Implicit (Lai, et al. 2009)	• reduced or disconnected imperviousness can be simulated by identifying the site layout and routing
Soakaway Pits / Dry Wells / Infiltration Trenches	Explicit (Lai, et al. 2009)	• modeled as an infiltration trench • uses Holtan-Lopez equation to model infiltration • uses constant ET rate to model evapotranspiration • uses stage-outflow storage routing with weir/orifice equations • completely mixed pollutant routing and first order decay for treatment • advanced options include the Green Ampt method for infiltration
Bioretention (all types)	Explicit (Lai, et al. 2009)	• modeled as a bio-retention system • uses Holtan-Lopez equation to model infiltration • uses constant ET rate to model evapotranspiration • uses stage-outflow storage routing with weir/orifice equations • completely mixed pollutant routing and first order decay for treatment • requires user specification of underdrain percent reduction • advanced options include the Green Ampt method for infiltration and calculation of potential ET and actual ET

Soil Amendments	Implicit (Lai, et al. 2009)	• designated pervious areas can be simulated by identifying the site layout and routing
Tree Clusters	Implicit (Lai, et al. 2009)	• designated pervious areas can be simulated by identifying the site layout and routing
Filter Strips	Implicit (Lai, et al. 2009)	• modeled as buffer strips or riparian buffer • pollutant trap efficiency is a function of strip width or flow length • advanced options include kinematic wave overland flow routing, process-based sediment interception method (VFSMOD), and first order decay nutrient/pollutant removal simulation method
Permeable Pavement	Explicit (Lai, et al. 2009)	• can be modeled explicitly as a porous pavement • details and information on specific processes and input parameters required are not covered in present literature or documentation
Grass Channels	Explicit (Lai, et al. 2009)	• modeled as a swale • uses kinematic flow routing by solving coupled continuity equation and Manning's Equation • completely mixed pollutant routing and first order decay for treatment • advanced options include plug flow pollutant routing, CSTRs in series and sedimentation.
Dry Swales	Implicit (Lai, et al. 2009)	• can be modeled as a swale with no vegetation • uses kinematic flow routing by solving coupled continuity equation and Manning's Equation • completely mixed pollutant routing and first order decay for treatment • advanced options include plug flow pollutant routing, CSTRs in series and sedimentation.
Level Spreader	Implicit	• can be modeled by routing stormwater through a filter strip, into an infiltration trench, then onto an overflow area
Roadway Reduction	Implicit	• can be modelled by modifying the parameters of the original road area to reflect roadway reductions, such as the replacement of roadway with grass swales or bioretention
Home Clustering	Implicit	• can be modelled by modifying the parameters of the original subcatchments to reflect various home layouts

Table B-6: LID simulation capabilities in WBM

LID Method	Simulation Type	Modelling Methods / Input Parameters
Rainwater Harvesting	Explicit (QUALHYMO User Manual and Documentation 2009)	• modeled as a simple rainwater cistern • requires user specification of cistern properties: initial cistern capacity, max storage capacity, and daily withdrawal rate • lateral inflow time series used for inflow
Green Roofs	Implicit (QUALHYMO User Manual and	• can be modeled as a soakaway area • requires user specification of storage properties: storage depth-area-outflow table based on actual surface grading and estimate

	Documentation 2009)	of ponding depth before spill outflow occurs • require user specification of infiltration properties: surface infiltration capacity and percolation capacity based on estimated saturated hydraulic conductivity of soil layers • lateral inflow time series used for inflow
Downspout Disconnection	Explicit (QUALHYMO User Manual and Documentation 2009)	• surface runoff and pollutant loadings can be split into as many as three fractions that can be redirected to another area
Soakaway Pits / Dry Wells / Infiltration Trenches	Explicit (QUALHYMO User Manual and Documentation 2009)	• modeled as an infiltration trench or gallery • requires user specification of infiltration properties: surface area, surface infiltration rates, soil moisture holding capacity, and percolation rate set to value representative of saturated hydraulic conductivity of surrounding native soil • ET factor is set to zero • lateral inflow time series used for inflow
Bioretention (all types)	Explicit (QUALHYMO User Manual and Documentation 2009)	• modeled as a bioretention facility • requires user specification of storage properties: storage depth-area-outflow table based on actual surface grading and estimate of ponding depth before spill outflow occurs • requires user specification of infiltration properties: surface infiltration capacity based on estimate d conductivity of surface soil/granular material and percolation rate based on estimated conductivity of underlying soil layers
Soil Amendments	Implicit (QUALHYMO User Manual and Documentation 2009)	• can be modeled by changing parameters of a pervious area
Tree Clusters	Implicit (QUALHYMO User Manual and Documentation 2009)	• can be modeled by changing parameters of a pervious area
Filter Strips	—	• may or may not be modeled • details and information on specific processes and input parameters required are not covered in present literature or documentation
Permeable Pavement	Explicit (QUALHYMO User Manual and Documentation 2009)	• can be modeled by changing parameters of a pervious area
Grass Channels	Explicit (QUALHYMO User Manual and Documentation 2009)	• modeled as a grassed swale • requires user specification of storage properties: storage depth-to-area-outflow table based on average or typical swale cross-section, hydraulic roughness, length, bed slope • requires user specification of infiltration properties: surface infiltration capacity and percolation capacity based on estimated saturated hydraulic conductivity of soil layers • lateral inflow time series used for inflow

Dry Swales	Implicit (QUALHYMO User Manual and Documentation 2009)	• can be modeled as a grassed swale with no vegetation • requires user specification of storage properties: storage depth-to-area-outflow table based on average or typical swale cross-section, hydraulic roughness, length, bed slope • requires user specification of infiltration properties: surface infiltration capacity and percolation capacity based on estimated saturated hydraulic conductivity of soil layers • lateral inflow time series used for inflow
Level Spreader	—	• cannot be modelled due to lack of routing capability
Roadway Reduction	Implicit	• can be modelled by modifying the parameters of the original road area to reflect roadway reductions, such as the replacement of roadway with grass swales or bioretention
Home Clustering	Implicit	• can be modelled by modifying the parameters of the original subcatchments to reflect various home layouts

APPENDIX C: Cost Data and Functions for LID Practices

Table C-1: Summary of cost data findings for LID practices

Study Location	Relevant LID Practices Studied	Study Details	Reference
Toronto, Ontario	Green Roof	Investigates the municipal level benefits of implementing green roof technology in the City of Toronto.	Banting et al., 2004
Various sites in California, United States	Infiltration Trench, Biofiltration Swale, Biofiltration Strip	Installation and operation of structural BMPs for existing CALTRANS facilities and to evaluate the performance and costs	CALTRANS, 2004
New York, United States	Rain gardens, cisterns, green roofs, stormwater planters, permeable pavement	New York State Stormwater Management Design Manual	CWP, 2003
Drawn from North Carolina and Maryland, United States, studies	Rain gardens, bioretention, cisterns, dry well, rain barrels, swales, permeable pavers, green roof.	Manual on urban stormwater retrofit practices	CWP, 2007
City of Chicago	Green roofs, downspouts, rain barrels and cisterns, permeable paving, filter Strips, rain gardens, drainage swales .	Stormwater best management practices guide	City of Chicago, 2003
Drawn from various North American studies	Roof disconnection, rain barrels, soakaway pit, pervious pavement, rooftop gardens, bioretention,	Stormwater Master Plan	City of Hamilton, 2007
Drawn from various North American studies	Rainwater harvesting, green roofs, downspout disconnection, soakaway pits/infiltration trenches, bioretention, vegetated filter stripspermeable pavement, grass swales, dry swales	Low impact development stormwater management manual	CVC & TRCA, 2010
Virginia, United States	Bioretention cells, bioretention slopes, bioretention swales, green roofs, water quality swales, dry well, downspout disconnection, infiltration trenches, permeable/porous pavements, cisterns and rain barrels	Fact Sheets for LID BMPs for the Fairfax County	Fairfax, 2005
Ontario, Canada	Rainwater harvesting	Developing design requirements	Farahbakhsh,

		and tools for large-scale rainwater harvesting	Despins, & Leidl, 2008
North Carolina	Bioretention areas (rain gardens), cisterns, greenroofs, permeable pavements, and swales	Study to estimate the cost of installing urban stormwater BMPs for small, residential and commercial areas (watersheds less than 2 acres).	Hathaway & Hunt, 2007
Drawn from various case studies in the United States	Bioretention, cistern, grassed swale, green roof, infiltration trench, porous pavement, rain barrel, vegetated filterstrip	An examination of cost-effectiveness of BMPs as part of a larger project to develop a framework for BMP placement in urban watersheds	Shoemaker et al., 2009
Toronto and surrounding regions	Green roofs	An Economic analysis of green roofs	TRCA, 2007
Toronto, Ontario	Rainwater harvesting	Performance Evaluation of a Rainwater Harvesting System Toronto, Ontario	TRCA, 2008
Drawn from various case studies in the United States	Bioretention, permeable/porous pavements, infiltration trench, vegetative swales, filter strips	Storm water technology fact sheets	U.S. EPA, 1999; U.S. EPA, 2006
Drawn from various case studies in the United States	N/A - examined whole project costs	Examination of stormwater Costs using LID strategies and practices	U.S. EPA, 2007
Drawn from various case studies in North America	Swale, permeable pavement, green roof, cistern, residential rain garden, curb-contained bioretention, in-curb planter vault	BMP and LID whole life cost-models	WERF, 2009a,b
North Carolina	Bioretention-raingarden	Evaluation of cost and benefit of structural stormwater BMPs in North Carolina.	Wossink & Hunt, 2003
Philadelphia, Pennsylvania	Green roofs, bioretention/bioinfiltration, porous pavement	Planning-level cost estimates for LID practices in urban watersheds	Vanaskie et al., 2010
Pennsylvania	Downspout disconnection, filter strips, grass channels	Pennsylvania Stormwater Best Management Practices Manual	Pennsylvania Department of Environmental Protection, 2006

Lot-based LID Practices

Table C-2: Summary of cost data for rainwater harvesting systems

LID Design Type	Size of component (Volume, m^3)	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/$m^2$ treated)	Annual Unit O&M Cost ($CDN/$m^2$ treated)	References
Prefabricated Cistern - Fiberglass	37.85	2005 USD	$13,000.00	$1,400.00	$18,813.08	$2,026.02	2023.45	$9.30	$1.00	Fairfax County, 2005
Rain barrel	0.21	2005 USD	$12,500.00	$900.00	$18,089.50	$1,302.44	2023.45	$8.94	$0.64	Fairfax County, 2005
Commercial rainwater harvesting system - cistern	18.00	2007 CAD	$18,000.00	No Info Given	$18,729.07	N/A	950.00	$19.71	N/A	TRCA, 2007
Commercial rainwater harvesting system - cistern	45.00	2007 CAD	$35,000.00	No Info Given	$36,417.64	N/A	2879.00	$12.65	N/A	TRCA, 2007
Rain barrel	No Info Given	2006 USD	$90,750.00	No Info Given	$99,279.09	N/A	4046.90	$24.53	N/A	CWP, 2007
Cistern	No Info Given	2006 USD	$54,450.00	No Info Given	$59,567.45	N/A	4046.90	$14.72	N/A	CWP, 2007
Cistern	2.08	2007 USD	$1,446.12	No Info Given	$1,538.22	N/A	51.10	$30.11	N/A	Hathaway & Hunt, 2007
Cistern	3.79	2007 USD	$1,756.12	No Info Given	$1,867.96	N/A	92.90	$20.11	N/A	Hathaway & Hunt, 2007
Cistern	9.46	2007 USD	$2,411.28	No Info Given	$2,564.85	N/A	232.25	$11.04	N/A	Hathaway & Hunt, 2007
Below-ground concrete tank	0.90	2007 CAD	$5,798.00	No Info Given	$6,032.84	N/A	160.00	$37.71	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	1.80	2007 CAD	$5,875.00	No Info Given	$6,112.96	N/A	160.00	$38.21	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	3.15	2007 CAD	$6,263.00	No Info Given	$6,516.68	N/A	160.00	$40.73	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	4.95	2007 CAD	$6,789.00	No Info Given	$7,063.98	N/A	160.00	$44.15	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	6.30	2007 CAD	$7,398.00	No Info Given	$7,697.65	N/A	160.00	$48.11	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	8.15	2007 CAD	$8,217.00	No Info Given	$8,549.82	N/A	160.00	$53.44	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	10.00	2007 CAD	$9,048.00	No Info Given	$9,414.48	N/A	160.00	$58.84	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	4.50	2007 CAD	$6,586.00	No Info Given	$6,852.76	N/A	160.00	$42.83	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	6.30	2007 CAD	$16,308.00	No Info Given	$16,968.54	N/A	480.00	$35.35	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	12.60	2007 CAD	$19,146.00	No Info Given	$19,921.49	N/A	480.00	$41.50	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	18.18	2007 CAD	$21,612.00	No Info Given	$22,487.37	N/A	480.00	$46.85	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	27.18	2007 CAD	$25,674.00	No Info Given	$26,713.90	N/A	480.00	$55.65	N/A	Farahbakhsh, Despins, & Leidl, 2008
Below-ground concrete tank	36.30	2007 CAD	$29,754.00	No Info Given	$30,959.16	N/A	480.00	$64.50	N/A	Farahbakhsh, Despins, & Leidl, 2008
Fiberglass cisterin	0.38	2008 USD	$878.00	$1,308.00	$906.66	$1,350.70	9.29	$97.60	$145.39	WERF, 2009b
Fiberglass cisterin	0.38	2008 USD	$878.00	$1,308.00	$906.66	$1,350.70	27.87	$32.53	$48.46	WERF, 2009b
Fiberglass cisterin	0.76	2008 USD	$1,107.00	$1,308.00	$1,143.14	$1,350.70	37.16	$30.76	$36.35	WERF, 2009b
Fiberglass cisterin	0.76	2008 USD	$1,107.00	$1,308.00	$1,143.14	$1,350.70	46.45	$24.61	$29.08	WERF, 2009b
Fiberglass cisterin	1.14	2008 USD	$1,337.00	$1,308.00	$1,380.65	$1,350.70	65.03	$21.23	$20.77	WERF, 2009b
Fiberglass cisterin	1.14	2008 USD	$1,567.00	$1,308.00	$1,618.15	$1,350.70	92.90	$17.42	$14.54	WERF, 2009b
Rain barrel	No Info Given	2007 CAD	$195.00	No Info Given	$202.90	N/A	239.13	$0.85	N/A	City of Hamilton, 2007

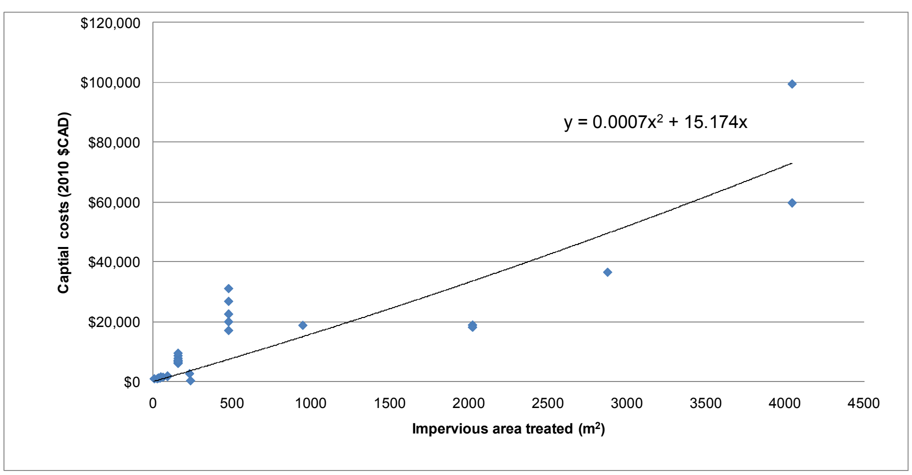

Figure C-1: Estimated capital cost per rainwater harvesting tank (in 2010 $CDN) vs. impervious area treated (in m²)

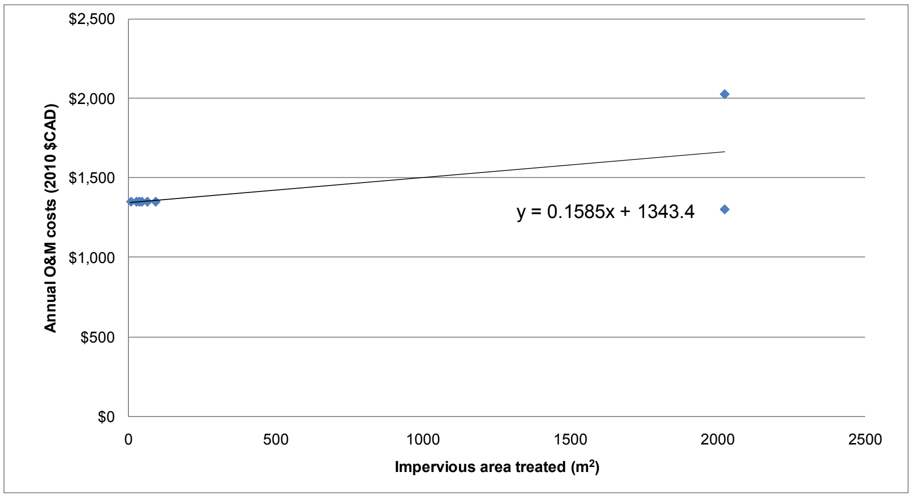

Figure C-2: Estimated O&M cost per rainwater harvesting tank (in 2010 $CDN) vs. Impervious area treated (in m²)

Table C-3: Summary of cost data for downspout disconnection

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m²)	Unit Capital Cost ($CDN/m² treated)	Annual Unit O&M Cost ($CDN/m² treated)	References
Downspout system	2010 CAD	$100.00	No Info Given	$100.00	No Info Given	160	$0.63	N/A	CVC & TRCA, 2010
Downspout system	2005 USD	$100.00	No Info Given	$110.21	No Info Given	160	$0.69	N/A	Fairfax County, 2005
Downspout system	2006 USD	$100.00	No Info Given	$107.88	No Info Given	160	$0.67	N/A	CWP, 2007
Downspout system	2009 CAD	$55.00	No Info Given	$55.00	No Info Given	160	$0.34	N/A	Farahbakhsh, Despins, & Leidl, 2008
Downspout system	2010 CAD	$25.00	No Info Given	$25.00	No Info Given	140	$0.18	N/A	RiverSides, n.d.
Roof disconnection	2007 CAD	500	No Info Given	520.25	No Info Given	239	$2.18	N/A	City of Hamilton, 2007

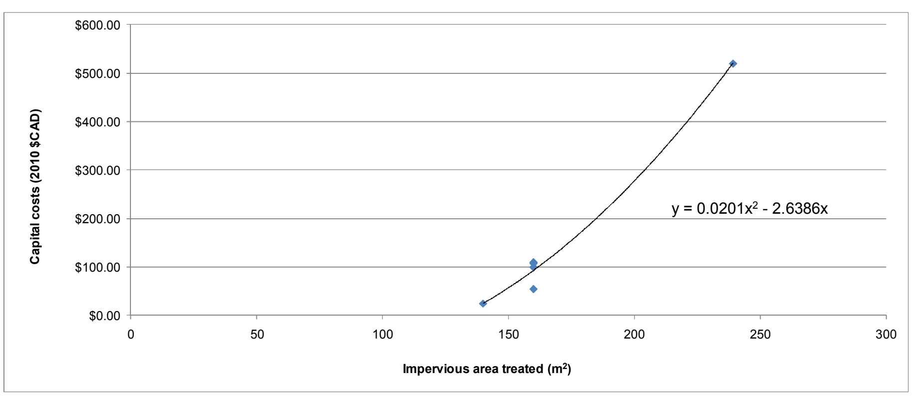

Figure C-3: Estimated capital cost for downspout disconnection installation (in 2010 $CDN) vs. Impervious area treated (in m²)

Table C-4: Summary of cost data for dry well

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/$m^2$ treated)	Annual Unit O&M Cost ($CDN/$m^2$ treated)	References
Dry well unit	2006 USD	$62,765.00	No Info Given	$68,663.93	N/A	10000	$6.87	N/A	CVC & TRCA, 2010
Dry well unit	2005 USD	$10,000.00	$800.00	$11,292.74	$903.42	2023	$5.58	$0.45	Fairfax County, 2005
Dry well unit	2006 USD	$41,745.00	No Info Given	$45,668.37	N/A	4047	$11.28	N/A	CWP, 2007

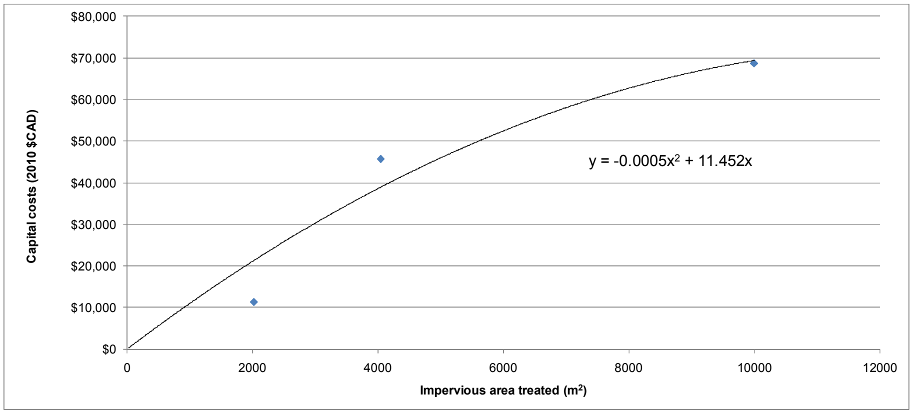

Figure C-4: Estimated capital cost for dry well installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-5: Summary of cost data for green roof

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/$m^2$ treated)	Annual Unit O&M Cost ($CDN/$m^2$ treated)	References
Extensive Green roof	2007 CAD	$147.50	$23.35	$152.95	$24.30	1	$170.16	$24.30	CVC & TRCA, 2010
Extensive Green roof	2005 USD	$17.50	No info given	$19.92	N/A	0.1	$214.42	N/A	Fairfax County, 2005
Extensive Green roof	2005 USD	$250,000.00	$1,600.00	$284,602.96	$1,821.46	2023	$140.66	$0.90	Fairfax County, 2005
Green roof assembly	2004 CAD	$82.50	No info given	$91.79	N/A	1	$91.79	N/A	Banting, Doshi, Li, Missios, Au, Currie, & Verrati, 2004
Green roof assembly	2007 USD	$13.35	No info given	$14.31	N/A	0.1	$154.04	N/A	Hathaway & Hunt, 2007
Extensive Green roof	2006 USD	$617,100.00	No info given	$900,741.68	N/A	4047	$222.58	N/A	CWP, 2007
Intensive Green Rooftops	2006 USD	$1,125,300.00	No info given	$1,241,021.86	N/A	4047	$306.66	N/A	CWP, 2007
Extensive Green roof	2003 USD	$11.75	No info given	$14.20	N/A	0.1	$152.85	N/A	City of Chicago, 2003
Intensive Green Rooftops	2003 USD	$21.50	No info given	$25.98	N/A	0.1	$279.66	N/A	City of Chicago, 2003
Extensive Green Roofs	2006 USD	$12.50	No info given	$13.78	N/A	0.1	$148.33	N/A	Portland BES, 2006 as cited in CWP, 2007
retrofit green roof	2003 USD	$13.50	No info given	$16.31	N/A	0.1	$175.57	N/A	CWP, 2003
new green roof	2003 USD	$8.50	No info given	$10.27	N/A	0.1	$110.55	N/A	CWP, 2003
Modular green roof assembly	2008 USD	$119,995.00	$3,469.00	$123,912.39	$3,582.25	300	$413.04	$11.94	WERF, 2007b
Modular green roof assembly	2008 USD	$151,604.00	$3,950.00	$156,553.29	$4,078.95	400	$391.38	$10.20	WERF, 2007b
Modular green roof assembly	2008 USD	$189,497.00	$4,477.00	$195,683.36	$4,623.16	500	$391.37	$9.25	WERF, 2007b
Modular green roof assembly	2008 USD	$227,406.00	$5,004.00	$234,829.95	$5,167.37	600	$391.38	$8.61	WERF, 2007b
Modular green roof assembly	2008 USD	$265,300.00	$5,532.00	$273,961.04	$5,712.60	700	$391.37	$8.16	WERF, 2007b
Modular green roof assembly	2008 USD	$303,193.00	$6,059.00	$313,091.11	$6,256.80	800	$391.36	$7.82	WERF, 2007b
Rooftop Gardens (commercial)	2007 CAD	$130.00	No info given	$135.27	N/A	1	135.27	N/A	City of Hamilton, 2007

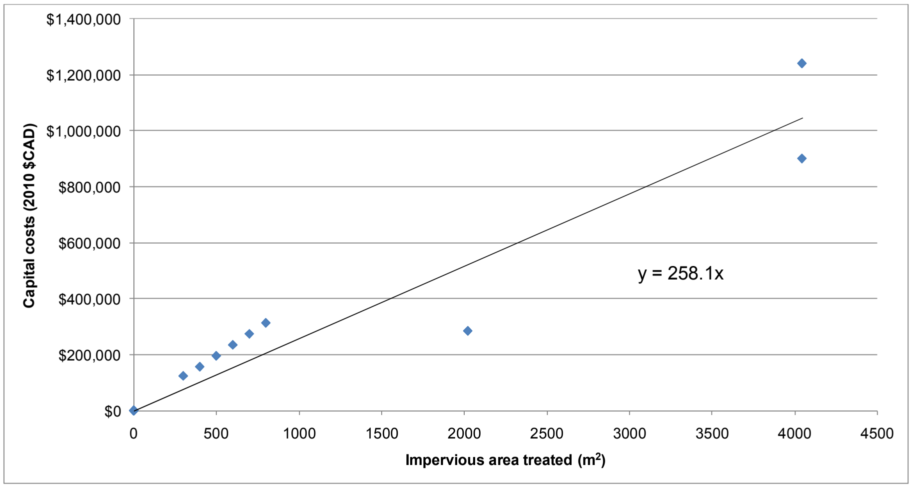

Figure C-5: Estimated capital cost for green roof installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

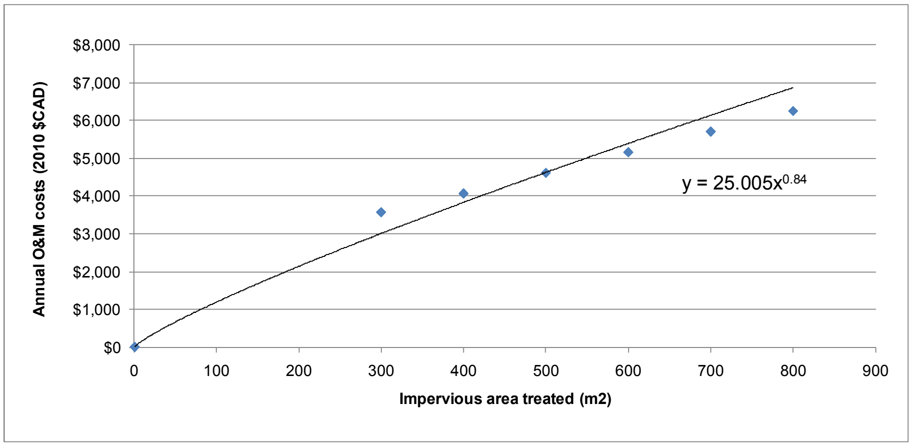

Figure C-6: Estimated O&M cost for green roof installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-6: Summary of cost data for permeable pavements

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/m^2 treated)	Annual Unit O&M Cost ($CDN/m^2 treated)	References
Paver	2005 USD	$12,000.00	No info given	$13,660.94	N/A	202	$67.51	N/A	Fairfax County, 2005
Paver	2007 USD	$9.61	No info given	$10.31	N/A	0.1	$110.98	N/A	Hathaway & Hunt, 2007
Paver	2006 USD	$435,600.00	No info given	$480,395.56	N/A	4047	$118.71	N/A	CWP, 2007
Paver - Asphalt	2003 USD	$0.75	$200.00*	$0.91	$0.01	0.1	$9.80	$0.06	CWP, 2003
Paver - Porous Concrete	2003 USD	$4.25	$200.00*	$5.14	$0.01	0.1	$55.33	$0.06	CWP, 2003
Paver - Grass/gravel pavers	2003 USD	$3.63	$200.00*	$4.38	$0.01	0.1	$47.15	$0.06	CWP, 2003
Interlocking Concrete Paving Blocks	2003 USD	$7.50	$200.00*	$9.06	$0.01	0.1	$97.52	$0.06	CWP, 2003
Paver - Asphalt	2005 USD	$28,780.00	$870.00	$33,873.53	$990.42	2023	$16.74	$0.49	WERF, 2007b
Paver - Porous Concrete	2005 USD	$186,960.00	$4,293.00	$220,048.48	$4,887.20	2023	$108.75	$2.42	WERF, 2007b
Paver - Grass/gravel pavers	2005 USD	$165,430.00	$3,827.00	$194,708.07	$4,356.71	2023	$96.23	$2.15	WERF, 2007b
Interlocking Concrete Paving Blocks	2005 USD	$287,580.00	$6,470.00	$338,476.38	$7,365.52	2023	$167.28	$3.64	WERF, 2007b
Single-lot Residential pervious driveway	2007 CAD	$3,360.00	No info given	$3,360.00	N/A	28	$120.00	N/A	City of Hamilton, 2007
Pervious pavements for driveway/parking areas (residential high-rise)	2007 CAD	$120.00	No info given	$124.86	N/A	1	$124.86	N/A	City of Hamilton, 2007
Pervious pavement in parking lots (commercial)	2007 CAD	$70,616.00	No info given	$73,476.23	N/A	10000	$7.35	N/A	City of Hamilton, 2007

* Annual maintenance in $/acre/year

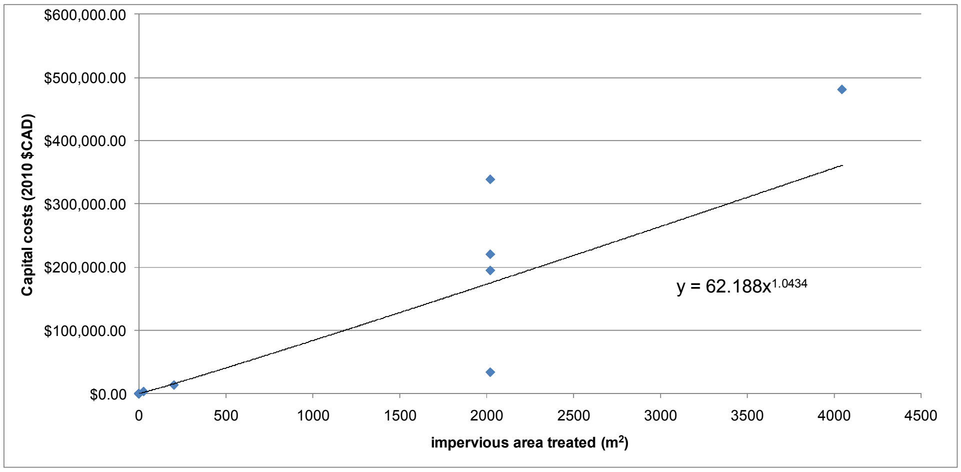

Figure C-7: Estimated capital cost for permeable pavement installation (in 2010 $CDN) vs. impervious area treated (in m2)

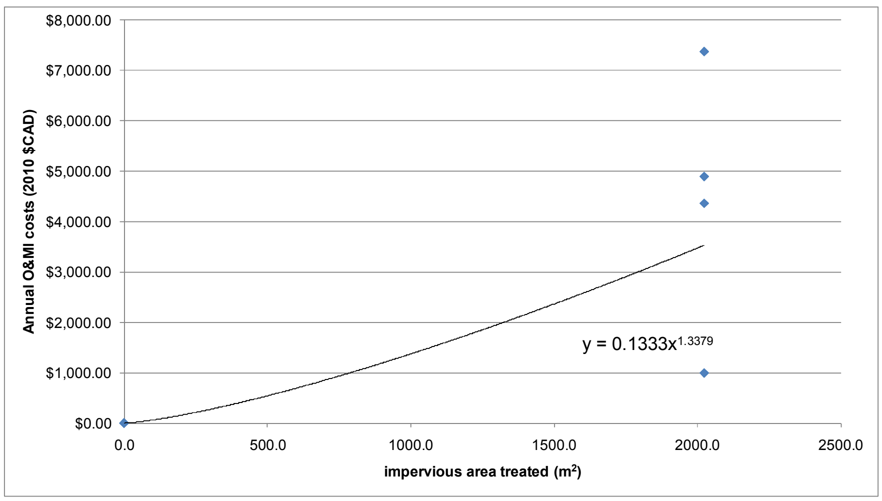

Figure C-8: Estimated O&M cost for permeable pavement installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-7: Summary of cost data for bioretention

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/$m^2$ treated)	Annual Unit O&M Cost ($CDN/$m^2$ treated)	References
Bioretention cell	2005 USD	$10,000.00	$925.00	$11,384.12	$1,053.03	2023	$5.63	$0.52	Fairfax County, 2005
Bioretention cell	2006 USD	$62,765.00	No info given	$68,663.93	N/A	10000	$6.87	N/A	CVC & TRCA, 2010
Bio retention in clay soil.	2003 USD	$2,742.12	$143.11	$3,313.38	$172.93	1214	$2.73	$0.14	Wossink & Hunt, 2003
Bio retention in clay soil.	2003 USD	$55,363.28	$217.77	$66,896.84	$263.13	19223	$3.48	$0.01	Wossink & Hunt, 2003
Bio retention in clay soil.	2003 USD	$113,652.85	$240.79	$137,329.60	$290.95	37231	$3.69	$0.01	Wossink & Hunt, 2003
Bioretention cell	2003 USD	$1,688.48	$143.11	$2,040.24	$172.93	1214	$1.68	$0.14	Wossink & Hunt, 2003
Bioretention cell	2003 USD	$5,661.22	$217.77	$6,840.59	$263.13	19223	$0.36	$0.01	Wossink & Hunt, 2003
Bioretention cell	2003 USD	$7,562.35	$240.79	$9,137.78	$290.95	37231	$0.25	$0.01	Wossink & Hunt, 2003
Rain Garden	2003 USD	$11.00	No info given	$13.29	N/A	0.1	$143.06	N/A	CWP, 2003
Bioretention area	2007 USD	$3.00	No info given	$3.22	N/A	0.1	$34.66	N/A	Hathaway & Hunt, 2007
Rain garden	2006 USD	$14,520.00	No info given	$16,013.18	N/A	4047	$3.96	N/A	CWP, 2007
New Bioretention area	2006 USD	$25,400.00	No info given	$28,012.05	N/A	4047	$6.92	N/A	CWP, 2007
Small Bioretention retrofit	2006 USD	$108,900.00	No info given	$120,098.89	N/A	4047	$29.68	N/A	CWP, 2007
Stormwater Planter	2006 USD	$98,010.00	No info given	$108,089.00	N/A	4047	$26.71	N/A	CWP, 2007
Larger Bioretention Retrofits	2006 USD	$38,115.00	No info given	$42,034.61	N/A	4047	$10.39	N/A	CWP, 2007
Bioinfiltration	2003 USD	$3.50	No info given	$4.23	N/A	0.1	$45.53	N/A	City of Chicago, 2003
Rain garden	2008 USD	$658.00	$183.80	$679.48	$189.80	9	$73.14	$20.43	WERF, 2007b
Rain garden	2008 USD	$1,351.89	$193.80	$1,396.03	$200.13	28	$50.09	$7.18	WERF, 2007b
Rain garden	2008 USD	$2,046.00	$203.80	$2,112.79	$210.45	46	$45.49	$4.53	WERF, 2007b
Rain garden	2008 USD	$2,740.00	$213.80	$2,829.45	$220.78	65	$43.51	$3.40	WERF, 2007b
Rain garden	2008 USD	$3,435.00	$223.80	$3,547.14	$231.11	84	$42.42	$2.76	WERF, 2007b
Rain garden	2008 USD	$4,129.00	$402.60	$4,263.80	$415.74	102	$41.72	$4.07	WERF, 2007b
Rain garden	2008 USD	$4,823.00	$412.60	$4,980.45	$426.07	121	$41.24	$3.53	WERF, 2007b
Rain garden	2008 USD	$5,517.00	$422.60	$5,697.11	$436.40	139	$40.88	$3.13	WERF, 2007b
In-curb Planter Vault	2008 USD	$10,000.00	$455.00	$10,722.95	$487.90	40	$264.97	$12.06	WERF, 2007b
In-curb Planter Vault	2008 USD	$10,000.00	$455.00	$10,722.95	$487.90	202	$52.99	$2.41	WERF, 2007b
In-curb Planter Vault	2008 USD	$10,000.00	$455.00	$10,722.95	$487.90	405	$26.50	$1.21	WERF, 2007b
In-curb Planter Vault	2008 USD	$10,000.00	$455.00	$10,722.95	$487.90	1012	$10.60	$0.48	WERF, 2007b
In-curb Planter Vault	2008 USD	$20,000.00	$1,090.00	$21,445.91	$21,909.14	2023	$10.60	$10.83	WERF, 2007b
In-curb Planter Vault	2008 USD	$40,000.00	$2,900.00	$42,891.80	$43,818.26	4047	$10.60	$10.83	WERF, 2007b
Filters/bio-retention	2007 CAD	$390.00	No info given	$405.80	N/A	4	$101.45	N/A	City of Hamilton, 2007

NOTE: Cost estimates apply to bioretention implemented as a lot, linear, and an area based practice

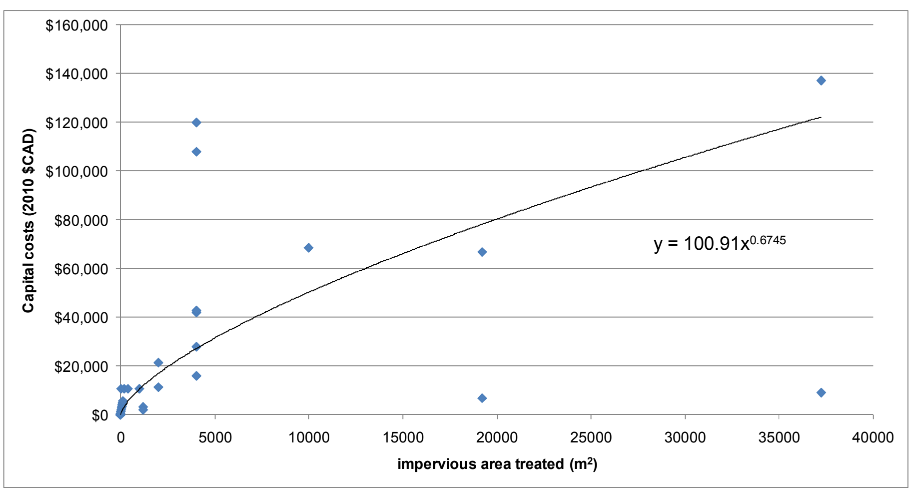

Figure C-9: Estimated capital cost for bioretention installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

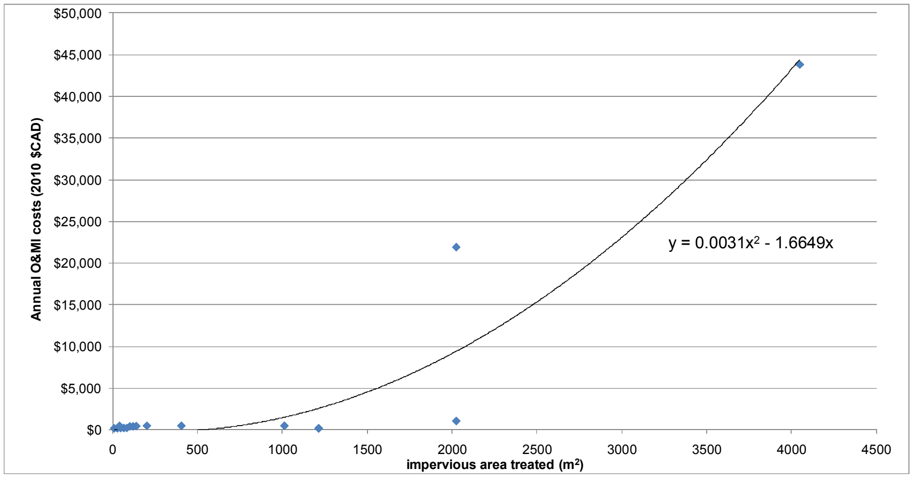

Figure C-10: Estimated O&M cost for bioretention installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Linear-based LID Practices

Table C-8: Summary of cost data for filter strip and level spreaders

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency	Annual O&M costs (in currency	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/$m^2$ treated)	Annual Unit O&M Cost ($CDN/$m^2$ treated)	References
Filter strip	2009 CAD	$6.25	No Info Given	$6.34	No Info Given	1	$6.34	N/A	CVC & TRCA, 2010
Biofiltration strip	1999 USD	$63,037.00	$2,750.00	$84,124.44	$3,669.94	3930	$21.41	$0.93	CALTRANS, 2004
Filter strip	2006 USD	$21,780.00	No Info Given	$24,019.78	No Info Given	4047	$5.94	N/A	CWP, 2007
Vegetated filter strip	2006 USD	$21,500.00	$350.00	$23,752.17	$357.56	4047	$5.87	$0.09	EPA, 2006
Vegetated filter strip	2006 USD	50,000	750	55237.60	828.57	4047	$13.65	$0.20	Pennsylvania Department of Environmental Protection, 2006

Note: No date is given for the costs reported in the Pennsylvania Department of Environment Protection (2006). It is assumed the cost is reported in 2006 USD, which corresponds to the year the document was issued.

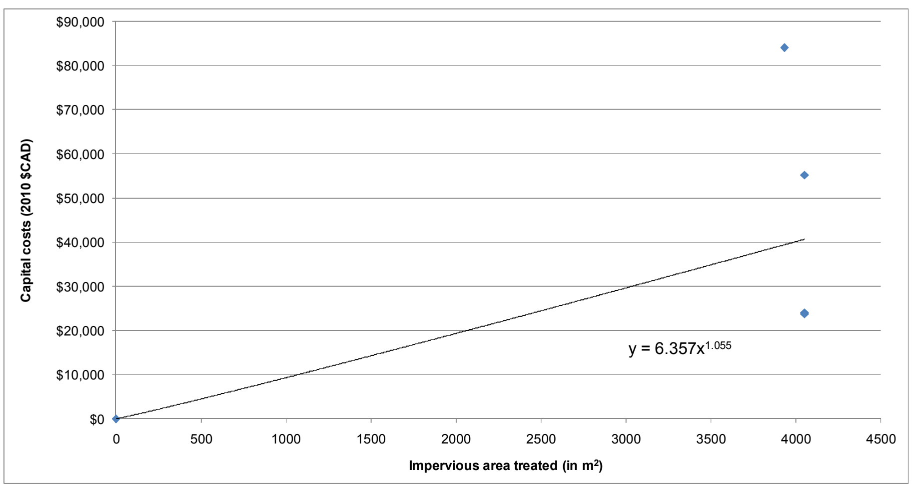

Figure C-11: Estimated capital cost for filter strip or level spreader installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

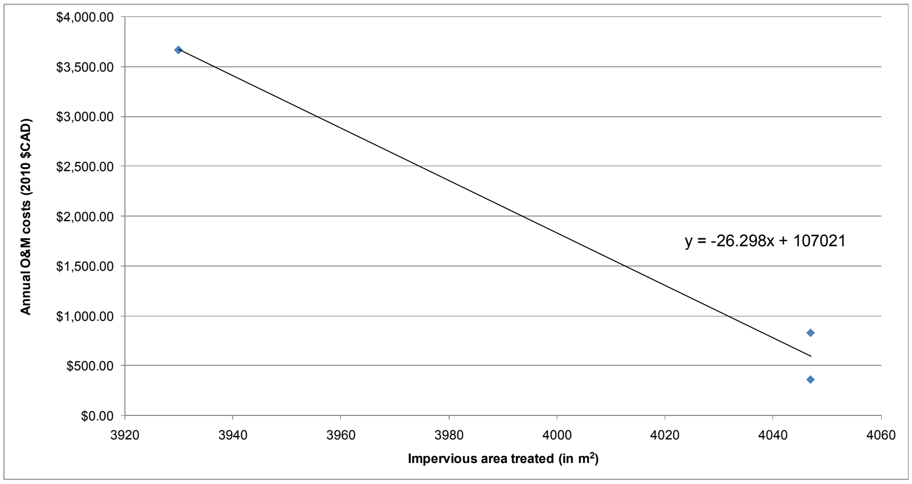

Figure C-12: Estimated O&M cost for filter strip or level spreader installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-9: Summary of cost data for grass channel

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency reported)	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/m^2 treated)	Annual Unit O&M Cost ($CDN/m^2 treated)	References
Grass channel	2006 USD	$44,850.00	No info given	$49,462.21	No info given	10000	$4.95	N/A	CVC & TRCA, 2010
Biofiltration swale	1999 USD	$57,818.00	$2,750.00	$77,159.56	$3,669.94	4500	$17.15	$0.82	CALTRANS, 2004
Grass channel	2007 USD	$0.95	No info given	$1.02	No info given	0.1	$10.98	N/A	Hathaway & Hunt, 2007
Grass channel	2006 USD	$45,375.00	No info given	$50,041.21	No info given	4047	$12.37	N/A	CWP, 2007
Grass Swale (from seed)	2006 USD	$6.50	$0.75 per unit area	$7.18	$0.83	1.4	$5.15	$0.59	Pennsylvania Department of Environmental Protection, 2006
Grass Swale (from sod)	2006 USD	$17.50	$0.75 per unit area	$19.35	$0.83	1.4	$13.89	$0.59	Pennsylvania Department of Environmental Protection, 2006

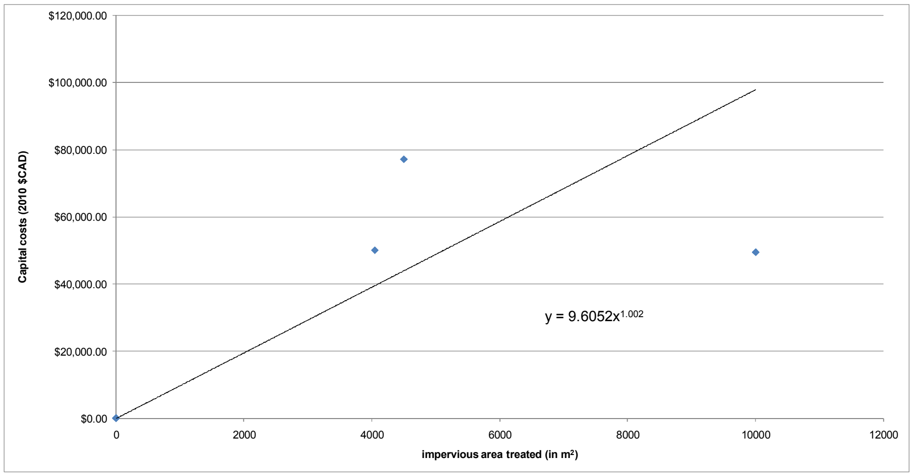

Figure C-13: Estimated capital cost for grass channel installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

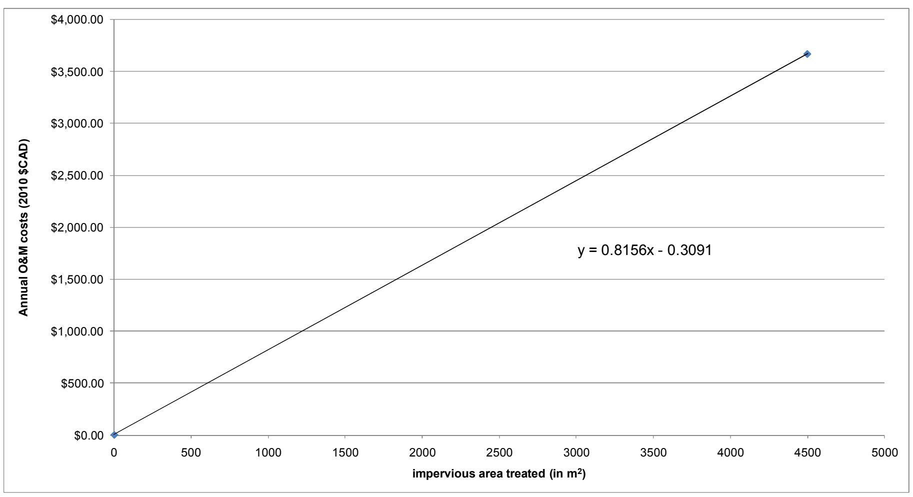

Figure C-14: Estimated O&M cost for grass channel installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-10: Summary of cost data for dry swale

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/m^2 treated)	Annual Unit O&M Cost ($CDN/m^2 treated)	References
Bioslope	2005 USD	$10,000.00	$200.00	$11,384.12	$227.68	2023	$5.63	$0.11	Fairfax County, 2005
Swale	2006 USD	$83,490.00	No Info Given	$92,075.82	No Info Given	4047	$22.75	N/A	CWP, 2007
Swale	2005 USD	$625.00	$246.00	$711.50	$280.05	202	$3.52	$1.38	WERF, 2007b
Swale	2005 USD	$1,125.00	$246.00	$1,280.71	$280.05	405	$3.16	$0.69	WERF, 2007b
Swale	2005 USD	$5,250.00	$246.00	$5,976.67	$280.05	2023	$2.95	$0.14	WERF, 2007b
Swale	2005 USD	$9,750.00	$246.00	$11,099.51	$280.05	4047	$2.74	$0.07	WERF, 2007b
Swale	2005 USD	$18,750.00	$246.00	$21,345.22	$280.05	20235	$1.05	$0.01	WERF, 2007b
Swale	2005 USD	$37,500.00	$246.00	$42,690.45	$280.05	40469	$1.05	$0.01	WERF, 2007b

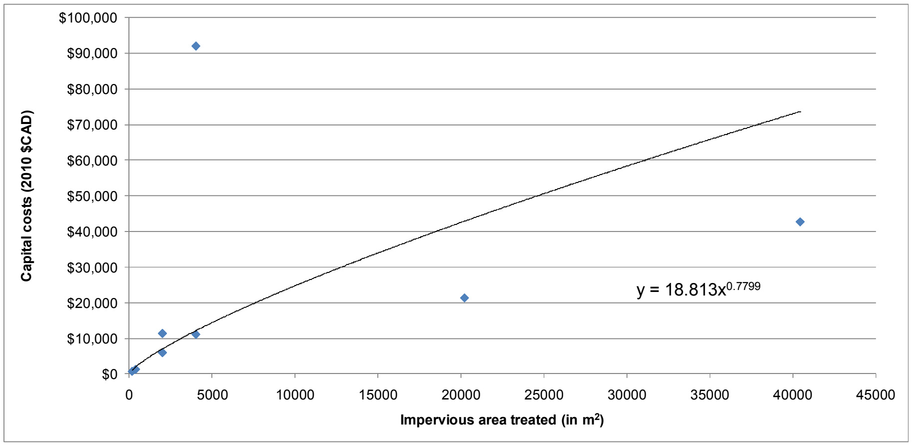

Figure C-15: Estimated capital cost for dry swale installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

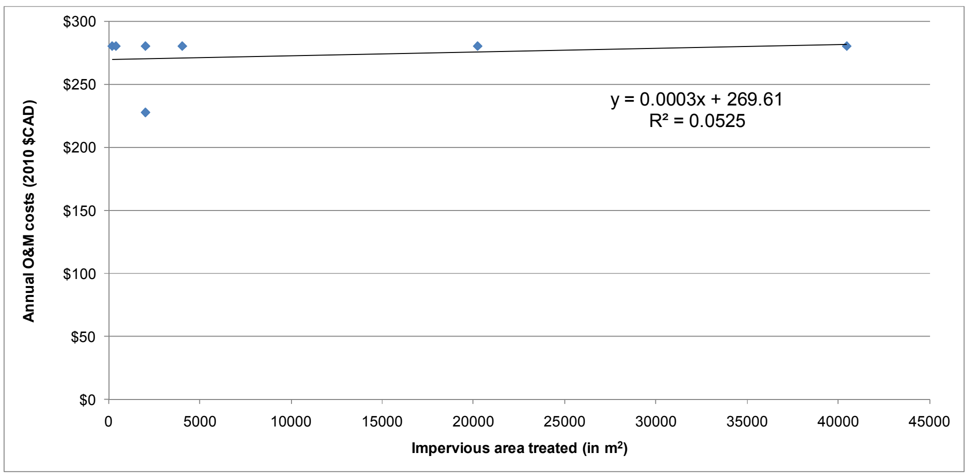

Figure C-16: Estimated O&M cost for dry swale installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

Table C-11: Summary of cost data for soakaway pit or infiltration trench

LID Design Type	Currency in year reported	Avg. capital cost per component (in currency	Annual O&M costs (in currency reported)	Avg. capital cost per LID (in 2010 $CDN)	Annual O&M costs (in 2010 $CDN)	Area treated (m^2)	Unit Capital Cost ($CDN/m^2 treated)	Annual Unit O&M Cost ($CDN/m^2 treated)	References
Infiltration trench	2005 USD	$10,000.00	$650.00	$11,384.12	$739.97	2023	$5.63	$0.37	Fairfax County, 2005
Infiltration trench	2006 USD	$62,765.00	No info given	$68,663.93	N/A	10000	$6.87	N/A	CVC & TRCA, 2010
Large infiltration trench	1993 USD	$13,500.00	$700.00	$20,771.49	$934.17	38	$549.83	$24.73	US EPA, 1999
Small infiltration trench	1993 USD	$5,750.00	$325.00	$8,847.12	$433.72	38	$234.19	$11.48	US EPA, 1999
Infiltration trench	1999 USD	$146,154.00	$2,660.00	$195,046.14	$3,549.84	14000	$13.93	$0.25	CALTRANS, 2004
Soakaway Pit	2007 CAD	$30,000.00	No info given	$31,215.12	N/A	10000	$3.12	N/A	City of Hamilton, 2007

NOTE: Soakaways are similar in construction to infiltration trenches (TRCA, 2007) so the cost data obtained will apply to both practices.

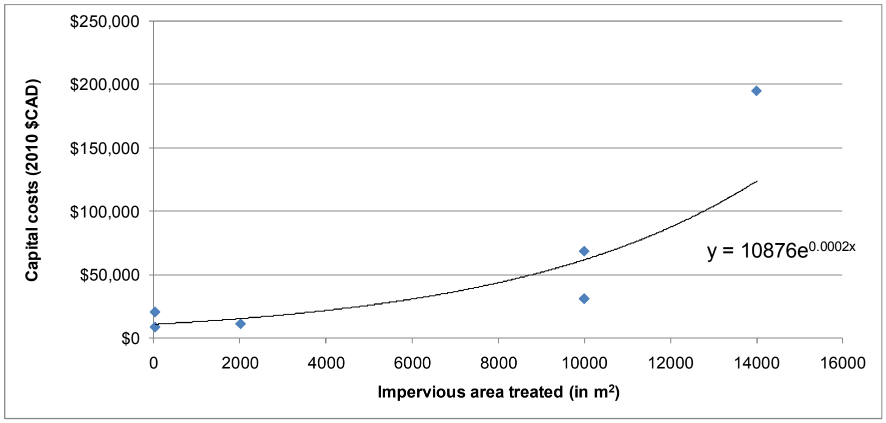

Figure C-17: Estimated capital cost for soakaway pit or infiltration trench installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

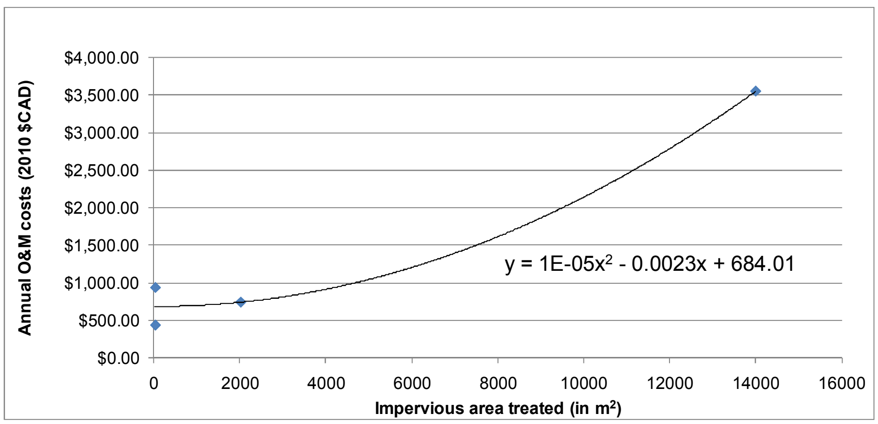

Figure C-18: Estimated O&M cost for soakaway pit or infiltration trench installation (in 2010 $CDN) vs. Impervious area treated (in m^2)

APPENDIX D.1: Case study data and results for hydrological performance evaluation

D.1 LID Planning Framework Component 1: Evaluation of Hydrological Performance

D.1-1. Input Data

Table D.1-1: Screening of the Rainfall Records in Barrie WPCC Rain Gauge Station (adapted from Li et al. (2010))

Year	Monitoring Period			
	Starting Date (Apr 1*)	Ending Date (Nov 1*)	# of Missing Records, in Days	Missing Record Dates
1968	May 1	June 1	183	Apr 1 to 30, June 2 to Nov 1
1978	July 1	Nov 1	92	Apr 1 to June 30, Aug 16
1979	Apr 1	Nov 1	2	June 23 to 24
1980	Apr 1	Nov 1	2	July 21, Oct 5
1981	Apr 1	Oct 31	2	July 19, Nov 1
1982	Apr 1	Nov 1	29	June 2 to 30
1983	Apr 1	Nov 1	0	-----
1984	Apr 1	Nov 1	0	-----
1985	Apr 1	Nov 1	0	-----
1986	Apr 1	Oct 30	5	Oct 13 to 16, Nov 1
1987	Apr 1	Sept 28	34	Sept 29 to Nov 1
1988	July 1	Oct 31	10	July 23, July 26, Oct 6 to 11, Oct 24, Nov 1
1989	Apr 1	Nov 1	0	-----
1990	Apr 1	Nov 1	2	June 23 to 24
1991	Apr 1	Nov 1	1	Apr 7
1992	Apr 1	Oct 1	62	Apr 7, May 2 to 31, Oct 2 to Nov 1
1993	Apr 1	Nov 1	0	-----
1994	Apr 1	Nov 1	0	-----
1995	Apr 1	Nov 1	1	Apr 3
1996	Apr 11	Nov 1	10	Apr 1 to 10
1997	May 1	Nov 1	30	Apr 1 to 30

1998	Apr 2	Nov 1	1	Apr 1
1999	Apr 1	Nov 1	0	-----
2000	Apr 1	Nov 1	0	-----
2001	Apr 1	Nov 1	0	-----
2002	Apr 1	Nov 1	1	Apr 28
2003	Apr 1	Nov 1	2	Apr 3, Aug 6

** Rain season is between April 1 and November 1.*

D.1-2. Identification of number of models to run

Table D.1-2: Distribution of Lots in Lake Simcoe Watershed Suitable for Green Roof Application

Bin	Buildings over 350m^2	
	Frequency	Cumulative %
0	0	0.00%
11	63	11.41%
22	157	39.86%
33	191	74.46%
44	78	88.59%
55	22	92.57%
66	9	94.20%
77	8	95.65%
88	11	97.64%
100	13	100.00%
Total # of Lots	**552**	

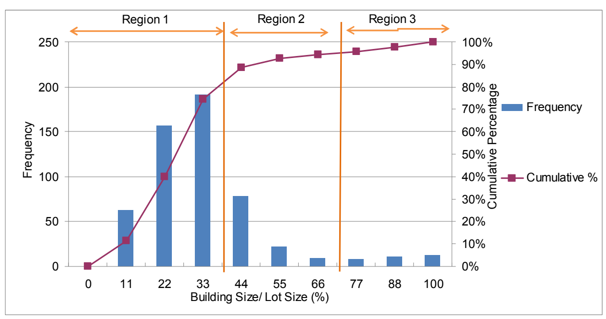

Figure D.1-1: Histogram of building size-to-lot size ratio for Green Roof

Table D.1-3: Distribution of Lots in Lake Simcoe Watershed Suitable for Soakaway Pit Application

Bin	Commercial		Residential	
	Frequency	Cumulative %	Frequency	Cumulative %
0	0	0.00%	0	0.00%
11	13	13.27%	422	5.92%
22	31	44.90%	2536	41.51%
33	36	81.63%	2789	80.65%
44	14	95.92%	1256	98.27%
55	4	100.00%	101	99.69%
66	0	100.00%	10	99.83%
77	0	100.00%	6	99.92%
88	0	100.00%	5	99.99%
100	0	100.00%	1	100.00%
Total # of Lots	**98**		**7126**	

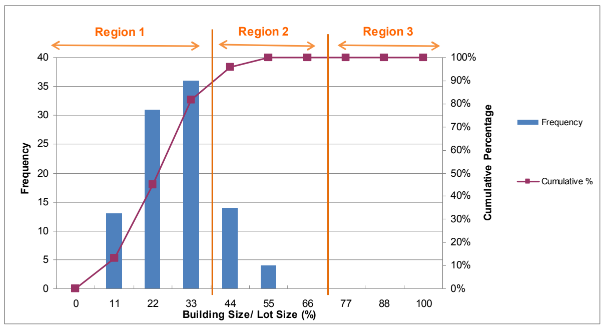

Figure D.1-2: Histogram of building size-to-lot size for soakaway pit application on lots designated as commercial land use

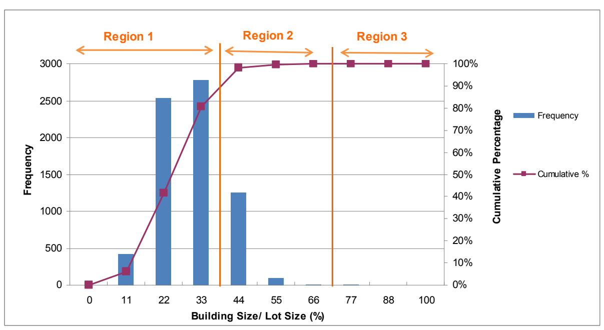

Figure D.1-3: Histogram of building size-to-lot size for soakaway pit application on lots designated as residential land use

Table D.1-4: Distribution of Lots in Lake Simcoe Watershed Suitable for downspout disconnection Application

Bin	Commercial		Industrial		Residential	
	Frequency	Cumulative %	Frequency	Cumulative %	Frequency	Cumulative %
0	0	0.00%	0	0.00%	0	0.00%
11	21	9.25%	96	13.50%	440	5.77%
22	71	40.53%	258	49.79%	2659	40.63%
33	72	72.25%	246	84.39%	2943	79.21%
44	30	85.46%	77	95.22%	1315	96.45%
55	10	89.87%	20	98.03%	147	98.37%
66	9	93.83%	11	99.58%	26	98.72%
77	3	95.15%	2	99.86%	28	99.08%
88	4	96.92%	0	99.86%	27	99.44%
100	7	100.00%	1	100.00%	43	100.00%
Total # of Lots	**227**		**711**		**7628**	

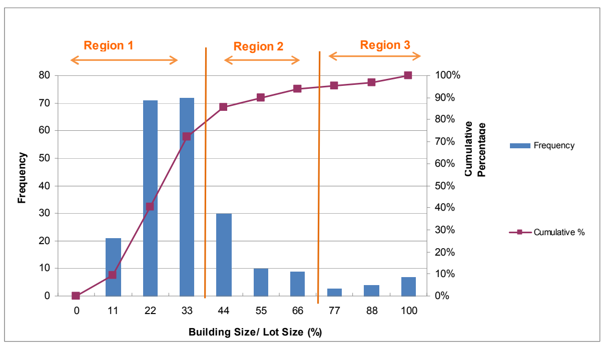

Figure D.1-4: Histogram of building size-to-lot size for downspout disconnection application on lots designated as commercial land use

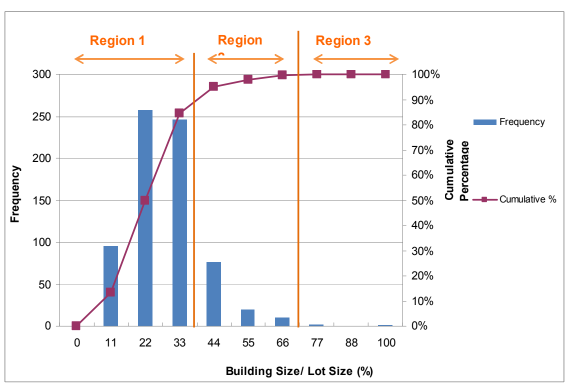

Figure D.1-5: Histogram of building size-to-lot size for downspout disconnection application on lots designated as industrial land use

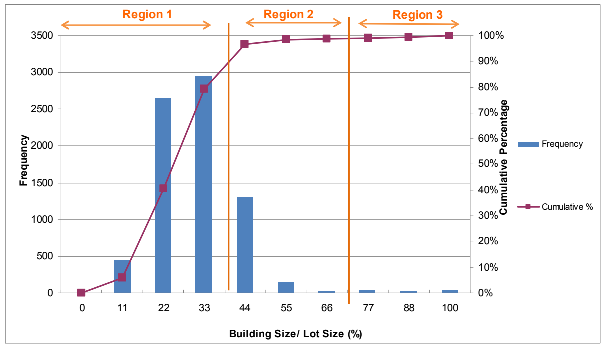

Figure D.1-6: Histogram of building size-to-lot size for downspout disconnection application on lots designated as residential land use

Table D.1-5: Distribution of lots in Lake Simcoe Watershed Suitable for dry well application

Bin	Commercial		Industrial		Residential	
	Frequency	Cumulative %	Frequency	Cumulative %	Frequency	Cumulative %
0	0	0.00%	0	0.00%	0	0.00%
11	23	11.86%	100	14.18%	2368	23.46%
22	61	43.30%	254	50.21%	3328	56.42%
33	67	77.84%	246	85.11%	3043	86.57%
44	31	93.81%	73	95.46%	1238	98.83%
55	9	98.45%	18	98.01%	95	99.77%
66	1	98.97%	11	99.57%	3	99.80%
77	0	98.97%	2	99.86%	4	99.84%
88	1	99.48%	0	99.86%	11	99.95%
100	1	100.00%	1	100.00%	5	100.00%
Total # of Lots	**194**		**705**		**10095**	

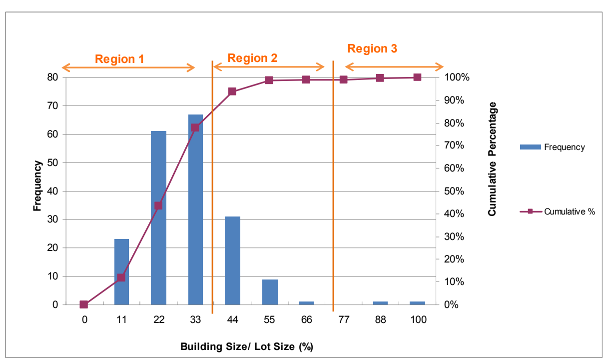

Figure D.1-7: Histogram of building size-to-lot size for dry well application on lots designated as commercial land use

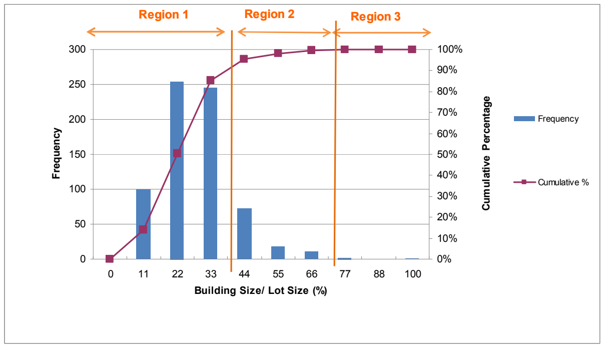

Figure D.1-8: Histogram of building size-to-lot size for dry well application on lots designated as industrial land use

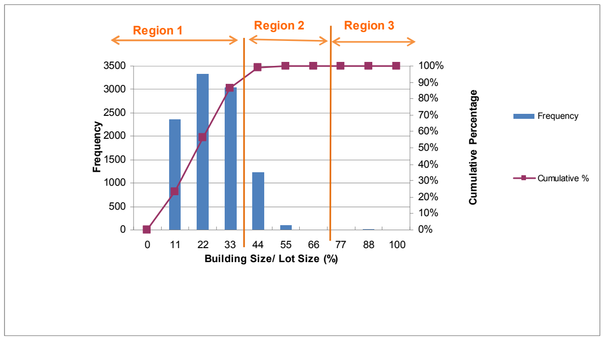

Figure D.1-9: Histogram of building size-to-lot size for dry well application on lots designated as residential land use

Table D.1-6: Distribution of lots in Lake Simcoe Watershed Suitable for rainwater harvesting application

Bin	Commercial		Industrial		Residential	
	Frequency	Cumulative %	Frequency	Cumulative %	Frequency	Cumulative %
0	0	0.00%	0	0.00%	0	0.00%
11	23	11.86%	100	14.18%	530	6.36%
22	61	43.30%	254	50.21%	3053	43.01%
33	67	77.84%	246	85.11%	3268	82.24%
44	31	93.81%	73	95.46%	1307	97.92%
55	9	98.45%	18	98.01%	117	99.33%
66	1	98.97%	11	99.57%	13	99.48%
77	0	98.97%	2	99.86%	12	99.63%
88	1	99.48%	0	99.86%	17	99.83%
100	1	100.00%	1	100.00%	14	100.00%
Total # of Lots	**194**		**705**		**8331**	

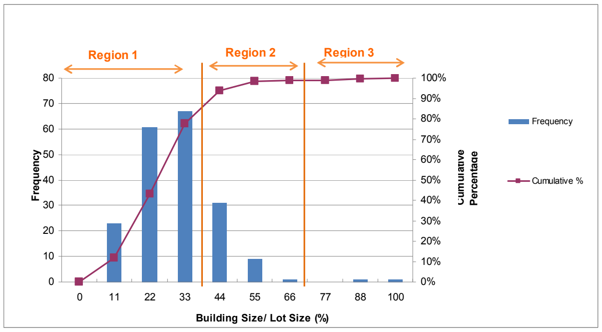

Figure D.1-10: Histogram of building size-to-lot size for rainwater harvesting application on lots designated as commercial land use

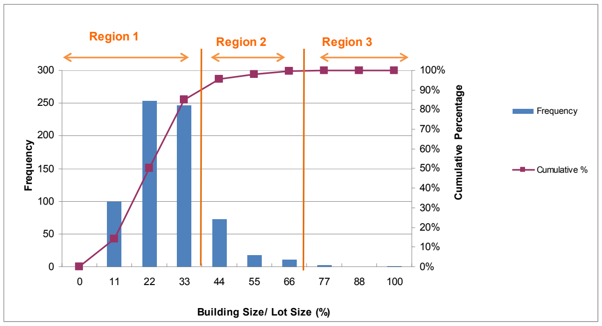

Figure D.1-11: Histogram of building size-to-lot size for rainwater harvesting application on lots designated as industrial land use

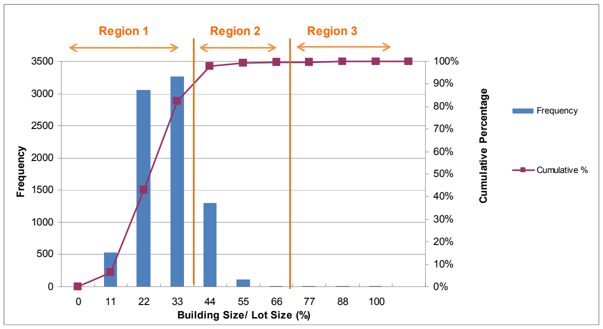

Figure D.1-12: Histogram of building size-to-lot size for rainwater harvesting application on lots designated as residential land use

Table D.1-7: Modelled Lots for Existing Conditions Function

LID Practice	Land-use Type	Assessment ID Number	Address	Stormwatershed ID	Lot Size (m^2)	Bldg Size (m^2)	Building Size-to-Lot Size Ratio (%)	Impervious Area (%)
Green Roof	Residential	434202200809800	114 DUNLOP ST E	BAR-NE40	642.00	532.43	82.93	96.51
	Industrial	434204000603502	80 MORROW RD	BAR-SW13	1860.14	922.38	49.59	91.20
	Industrial	434203200306100	20 ELLIOTT AVE	BAR-C23	13323.80	2386.12	17.91	91.83
1a)	Resource & Industrial	434203200304101	26 Ferndale Drive	BAR-C23	18939.50	367.81	1.94	24.83
1b)	Resource & Industrial	434203200301800	428 Tiffin St	BAR-C25	5511.15	365.49	6.63	92.80
2a)	Residential	434203102002800	114 Anne St N	BAR-NW12	3749.39	664.66	17.73	49.14
2b)	Resource & Industrial	434204000202100	134 Tiffin St	BAR-C25	2150.79	351.83	16.36	87.62
3a)	Residential	434201201505700	88 Cook St	BAR-NE14	1906.44	455.60	23.90	28.15
3b)	Open Area	434203102200225	500 Dunlop St W	BAR-C16	8981.86	2821.62	31.41	79.58
4a)	Resource & Industrial	434203101902602	36 Lennox Dr	BAR-C16	1,641	553.299	33.72	34.83
4b)	Resource & Industrial	434204000206010	134 Anne St	BAR-C25	1315.11	471.79	35.87	82.56
5a)	Residential	434203200504600	34 Simcoe St	BAR-NE39	2408.77	1145.14	47.54	77.04
5b)	Commercial	434202200306500	89 Collier St	BAR-NE40	792.81	412.19	51.99	88.09
6a)	Resource & Industrial	434204000202500	168 Tiffin St	BAR-C25	15792.20	9367.56	59.32	70.31
6b)	Residential	434202200802200	89 Dunlop St E	BAR-NE40	607.21	358.46	59.03	91.23
7a)	Residential	434202200809700	110 Dunlop St E	BAR-NE40	544.13	390.07	71.69	72.26
7b)	Residential	434203200504100	33 Mary St	BAR-NE39	796.89	564.44	70.83	94.33
8a)	Residential	434202200805700	46 Dunlop St E	BAR-NE39	609.21	469.13	77.01	79.87
8b)	Commercial	434202200802500	105-107 Dunlop St E	BAR-NE40	500.68	398.25	79.54	99.43
9a)	Residential	434202200810700	65-69 Collier St	BAR-NE40	942.12	834.84	88.61	88.96
9b)	Residential	434202200301410	17 Mulcaster St	BAR-NE40	477.39	459.77	96.31	96.31
Soakaway Pit	Commercial	434202200305600	115 COLLIER ST	BAR-NE32	755.20	123.26	16.32	84.08
	Commercial	434202200306000	105 COLLIER ST	BAR-NE40	319.29	106.67	33.41	77.58
	Commercial	434202201003701	44 COLLIER ST	BAR-NE39	2957.15	1218.86	41.22	75.19
	Residential	434201100503600	148 PUGET ST	BAR-NE8	789.48	130.78	16.57	28.88
	Residential	434205000606798	29 STEPHANIE LANE	BAR-SE85	406.85	201.07	49.42	60.75
	Residential	434203200510000	14 HIGH ST	BAR-C5	906.74	706.65	77.93	77.93
Downspout Disconnection	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86
	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62
	Residential	434202200805800	50 DUNLOP ST E	BAR-NE39	497.97	433.71	87.10	87.10
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15
	Residential	434201201613800	12 MELROSE AVE	BAR-NE13	835.64	137.88	16.50	24.80
Dry Well	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86
	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62
	Residential	434202200810700	65-69 COLLIER ST	BAR-NE40	942.12	834.84	88.61	88.96
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15
	Residential	434202101404700	136 OWEN ST	BAR-NE39	1334.87	220.22	16.50	20.29
Rainwater Harvesting	Commercial	434202201002700	35 WORSLEY ST	BAR-NE39	512.52	409.20	79.84	91.92
	Commercial	434202200307200	100 COLLIER ST	BAR-NE40	613.76	245.84	40.06	92.86
	Commercial	434203101904400	125 EDGEHILL DR	BAR-C1	2483.59	414.76	16.70	56.69
	Industrial	434203101005900	8 ECCLES ST N	BAR-C5	337.20	221.70	65.75	85.70
	Industrial	434204000501200	151 TIFFIN ST	BAR-C26	3590.96	1842.12	51.30	88.65
	Industrial	434204000202100	134 TIFFIN ST	BAR-C25	2150.79	351.83	16.36	87.62
	Residential	434202200810700	65-69 COLLIER ST	BAR-NE40	942.12	834.84	88.61	88.96
	Residential	434205000606606	103 ESTHER DR	BAR-SE85	526.08	260.27	49.47	58.15
	Residential	434202101404700	136 OWEN ST	BAR-NE39	1334.87	220.22	16.50	20.29

D.1-3. SWMM Input Parameters for LID Modules

Green Roof Model

To implement the green roof in the SWMM model, a few design assumptions were applied. It was assumed that the green roof was applied on the 75% of the roof area. As a result, the percentage of area in which the LID occupies was determined by the following equation:

$$\%\text{ of subcatchment area} = \frac{75\% \times building\ area}{lot\ area}$$

The percent impervious area in the subcatchment box was also affected as a result of the green roof application. Since the green roof is implemented on the roof, a portion of the impervious area will be decreased upon implementation.

$$\%\text{ of subcatchment area} = \frac{75\% \times building\ area}{lot\ area}$$

$$\text{Revised }\%\text{ impervious area} = \frac{\%Imper_{noLID} - (\%of\ subcatchment\ area)}{1 - \%\ of\ subcatchment\ area}$$

The “%of subcatchment area” is the percentage of lot area in which the LID occupies. This value is located in the “BMP Editor box”

Table D.1-8: Parameters in the “Subcatchment” Box of the SWMM-LID Program for Green Roof Model

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
user-assigned name of subcatchment	Name	GreenRoof		
rain gage assigned to subcatchment	Rain Gage	RainGage		
name of node or another subcatchment that receives runoff	Outlet	O1		
area of subcatchment, in hectares	Area	1.33238	0.1860	0.0642
width of overland flow path, in metres	Width	47.3	30.5	13.3
average surface slope, in %	%Slope	2		
percent of impervious area, in % **(without LID)**	%Imperv	91.83	100	96.51
percent of impervious area, in % **(with LID)**	%Imperv	90.56	100	90.775
Mannings *n* for impervious area	N-Imperv	0.015		
Mannings *n* for pervious area	N-Perv	0.24		
depth of depression storage on impervious area, in mm	Dstore-Imperv	1.524		
depth of depression storage on pervious area, in mm	Dstore-Perv	7.62		

percent of impervious area with no depression storage, in %	%Zero-Imperv	25
choice of internal routing between pervious and impervious sub-areas	Subarea Routing	Outlet
percent of runoff routed between sub-areas, in %	Percent Routed	100
BMP/LID units	BMP Controls	1
Infiltration: Green-Ampt Method		
suction head, in mm	-----	88.9
conductivity, in mm/hr	-----	3.4
initial deficit	-----	0.463

Table D.1-9: Parameters in the "BMP Controls Editor" Box of the SWMM-LID Program for Green Roof Model

Names of Parameters	Parameter Values		
	Region 1	Region 2	Region 3
Process Layer: Surface			
storage depth, in mm	0		
length to width ratio, dimensionless	2.5	2	2
surface slope, in %	2		
surface roughness or Mannings *n*, dimensionless	0.1		
swale side slope (run/rise), dimensionless	5		
Process Layer: Soil			
thickness, in mm	95		
porosity, in volume fraction	0.25		
field capacity, in volume fraction	0.2		
wilting point, in volume fraction	0.1		
conductivity, in mm/hr	12.7		
conductivity slope, dimensionless	10.0		
suction head, in mm	88.9		
Process Layer: Storage			
height or thickness, in mm	300		
void ratio, dimensionless	0.75		
drain height, in mm	0		
drain coefficient, in mm/hr	25.4		
drain exponent, dimensionless	1		
permeable bottom	no		

Soakaway Pit Model

To implement the soakaway pit, a number of design assumptions were made. From existing literature, it was determined that the soakway pit the depth of the stone should be a maximum 1.5 metres (TRCA & CVC, 2010). It was also found that for this LID technology, it can be assumed that the storage layer is filled with a uniformly-graded, washed 50 mm diameter stone with a 40% void capacity (TRCA & CVC, 2010). For the area in which the soakway pit would occupy in the subcatchment, “Table 3.2: Water Quality Storage Requirements based on Receiving Waters” in the OMOE Stormwater Management Design manual (OMOE, 2003) was used as a basis for the sizing criteria. This table is reproduced below for reference.

Table D.1-10: Water quality storage requirements based on receiving waters (adapted from OMOE, 2003)

Protection Level	SWMP Type	Storage Volume (m^3/ha) for Impervious Level			
		35%	55%	70%	85%
Enhanced 80% long-term S.S. removal	Infiltration	25	30	35	40
	Wetlands	80	105	120	140
	Hybrid Wet Pond/Wetland	110	150	175	195
	Wet Pond	140	190	225	250
Normal 70% long-term S.S. removal	Infiltration	20	20	25	30
	Wetlands	60	70	80	90
	Hybrid Wet Pond/Wetland	75	90	105	120
	Wet Pond	90	110	130	150
Basic 60% long-term S.S. removal	Infiltration	20	20	20	20
	Wetlands	60	60	60	60
	Hybrid Wet Pond/Wetland	60	70	75	80
	Wet Pond	60	75	85	95
	Dry Pond (Continuous Flow)	90	150	200	240

In order for the soakaway pit to achieve an enhanced 80% long-term S.S. removal as an infiltration practice, and assuming an 85% impervious level, the storage volume criteria to apply is 40 m^3/ha. Therefore, to determine the soakaway pit based on the drainage area, which is assumed to be the roof area in this case, the following is the sizing criteria that will apply:

$$Storage\ Volume(\frac{m3}{ha}) \times roof_{area(m^2)} = Soakaway\ Pit_{(void_{space})}$$

$$\frac{40m^3}{10000} \times roof_{area(m^2)} = 0.40$$

$$Soakaway\ Pit\ Volume = 0.01 \times roof_{area}(m^2)$$

$$\therefore Area\ of\ Soakaway\ Pit\ = \frac{0.01}{1.5} \times roof_{area} \text{ (depth = 1.5m)}$$

$$\%of\ Lot\ Area\ occupied\ by\ Soakaway\ Pit\ = \frac{0.0067 \times roof_{area}}{Lot\ Size} \times 100$$

The “percent of impervious area, in %” parameter will also change in the subcatchment editor box (Table D.1-10) when applying the dry well. It is assumed that this practice will be placed on a portion of the pervious area of the lot. As a result, the percent imperviousness parameter will change as follows:

$$Revised\ \%\ imperviousness = \frac{\%imperviousness\_noLID}{100} \times \frac{Lot\ Size}{(Lot\ Size - Area\ occupied\ by\ soakaway\ pit)} \times 100$$

There is no underdrain included in this design. Using these design assumptions, the appropriate parameters were calculated for the subcatchment and LID properties implemented within the model developed in SWMM-LID. An “infiltration trench” LID module was selected in SWMM-LID to represent the dry well practice. These design assumptions were applied to all two land-use categories assessment in this study for soakaway pit implementation.

Table D.1-11: Parameters in the “Subcatchment” Box of the SWMM-LID Program for the Soakaway Pit Commercial and Residential Land Use Analysis

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
user-assigned name of subcatchment	Name	SoakawayPit		
rain gage assigned to subcatchment	Rain Gage	RainGage		
name of node or another subcatchment that receives runoff	Outlet	O1		
area of subcatchment, in hectares (Commercial)	Area	0.07552	0.03193	0.2957
area of subcatchment, in hectares (Residential)	Area	0.07895	0.04069	0.09067

width of overland flow path, in metres (Commercial)	Width	16.80	10.00	50.0
width of overland flow path, in metres (Residential)	Width	17.4	12	22
average surface slope, in %	%Slope	2		
percent of impervious area, in % **(without LID) (Commercial)**	%Imperv	84.08	77.58	75.1
percent of impervious area, in % **(with LID) (Commercial)**	%Imperv	84.17	77.75	75.4
percent of impervious area, in % **(without LID) (Residential)**	%Imperv	28.88	60.75	77.9
percent of impervious area, in % **(with LID) (Residential)**	%Imperv	28.91	60.95	78.3
Mannings *n* for impervious area	N-Imperv	0.015		
Mannings *n* for pervious area	N-Perv	0.24		
depth of depression storage on impervious area, in mm	Dstore-Imperv	1.524		
depth of depression storage on pervious area, in mm	Dstore-Perv	7.62		
percent of impervious area with no depression storage, in %	%Zero-Imperv	25		
choice of internal routing between pervious and impervious sub-areas	Subarea Routing	Outlet		
percent of runoff routed between sub-areas, in %	Percent Routed	100		
BMP/LID units	BMP Controls	1		
Infiltration: Green-Ampt Method				
suction head, in mm	-----	88.9		
conductivity, in mm/hr	-----	3.4		
initial deficit	-----	0.463		

Table D.1-12: Parameters in the "BMP Controls Editor" Box of the SWMM-LID Program for the Soakaway Pit Commercial and Residential Land Use Analysis

Names of Parameters	Parameter Values		
	Region 1	Region 2	Region 3
Process Layer: Surface			
storage depth, in mm	0		
length to width ratio, dimensionless	1		
surface slope, in %	5		
surface roughness or Mannings *n*, dimensionless	0.024		

swale side slope (run/rise), dimensionless	5
Process Layer: Storage	
height or thickness, in mm	1500
void ratio, dimensionless	0.40
drain height, in mm	0
drain coefficient, in mm/hr	0
drain exponent, dimensionless	0.5
permeable bottom	yes

Downspout Disconnection Model

The tables below show the properties that are used to describe the downspout disconnection when implemented within the subcatchment for each land-use type. The assumptions regarding the downspout design, routing of runoff after LID application, and SWMM-LID module are the same for all land-use types assessed. In order to calculate the amount of impervious area the LID occupies, a square commonly used downspout design of 76.2mm x 76.2mm was assumed (DVC Aluminum, 2010). It was also assumed that once the downspout is disconnected, any runoff that flows through it will be directed to the pervious area of the subcatchment. Finally, a "rain barrel" LID module was selected in SWMM-LID to represent the downspout disconnection practice. The values used in the "BMP Controls Editor" Box of the SWMM-LID Program for all land-use type modelled are shown in Table D.1-16.

Table D.1-13: Initial general parameters in the "Subcatchment" Box of the SWMM-LID Program used to model Downspout Disconnection for all land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
user-assigned name of subcatchment	Name	Subcatchment_Downspout		
rain gage assigned to subcatchment	Rain Gage	RainGage		
name of node or another subcatchment that receives runoff	Outlet	O1		
average surface slope, in %	%Slope	2		
Mannings *n* for impervious area	N-Imperv	0.011		
Mannings *n* for pervious area	N-Perv	0.15		
depth of depression storage on	Dstore-Imperv	1.524		

impervious area, in mm		
depth of depression storage on pervious area, in mm	Dstore-Perv	7.62
percent of impervious area with no depression storage, in %	%Zero-Imperv	25
choice of internal routing between pervious and impervious sub-areas	Subarea Routing	OUTLET
percent of runoff routed between sub-areas, in %	Percent Routed	100
BMP/LID units	BMP Controls	0
Infiltration: Green-Ampt Method		
suction head, in mm	-----	88.9
conductivity, in mm/hr	-----	3.4
initial deficit	-----	0.463

Table D.1-14: Initial specific parameters in the "Subcatchment" Box of the SWMM-LID Program used to model Downspout Disconnection for each land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
area of subcatchment, in hectares	Commercial	0.2484	0.0614	0.0512
	Industrial	0.2151	0.3591	0.0337
	Residential	0.08356	0.04105	0.04980
width of overland flow path, in metres	Commercial	25.45	12.60	19.47
	Industrial	20.50	40.4	37.00
	Residential	18.50	15.78	10.28
percent of impervious area, in % **(without LID)**	Commercial	56.7	92.9	91.9
	Industrial	87.62	88.65	85.70
	Residential	87.10	58.15	24.80

Table D.1-15: Adjusted parameters in the "Subcatchment" Box of the SWMM-LID Program in the Downspout Disconnection for each Land-Use Model

Land Use Type	Names of Parameters	Symbols	Parameter Values		
			Region 1	Region 2	Region 3
Commercial	percent of impervious area, in % **(takes into account LID)**	%Imperv	56.7	92.9	91.9
	BMP/LID units	BMP Controls	1	1	1
Industrial	percent of impervious area, in % **(takes into account LID)**	%Imperv	87.62	88.65	85.70

	BMP/LID units	BMP Controls	1	1	1
Residential	percent of impervious area, in %**(takes into account LID)**	%Imperv	87.10	58.15	24.80
	BMP/LID units	BMP Controls	1	1	1

Table D.1-16: Parameters in the "BMP Controls Editor" Box of the SWMM-LID Program in the Downspout Disconnection for all Land-Use Models

Names of Parameters	Parameter Values		
	Region 1	Region 2	Region 3
Process Layer: Storage			
Height or Thickness (mm)	1		
Void Ratio	0.99		
Drain Height	0		
Drain Coefficient (C)	75**		
Drain Exponent (n)	0		
Drain Delay	0		

**NOTE: A high value of C was determined through sensitivity testing. A high value of C best simulates the behaviour of a downspout in that the flow going into the technology will equal the flow going out.

Dry Well Model

To implement the dry well in the SWMM model, some design parameters had to be determined. A typical dry well design is described in Government of Prince George's County (1999) LID Manual. Based on this design, the dry well in this model is assumed to have a storage (gravel) depth of 3 feet. Since this LID technology is very similar to a soakaway pit and infiltration trench (TRCA &CVC, 2010), it was assumed that the storage layer is filled with a uniformly-graded, washed 50 mm diameter stone with a 40% void capacity. For the area in which the dry well would occupy in the subcatchment, the Ontario Ministry of Environment (2003) "Table 3.2: Water Quality Storage Requirements based on Receiving Waters" was used as a basis for the sizing criteria. This table is adapted and shown in Table D.1-10.

In order for the dry well to achieve an enhanced 80% long-term S.S. removal as an infiltration practice, and assuming an 85% impervious level, the storage volume criteria to apply is 40

m^3/ha. Therefore, to determine the dry well based on the drainage area, which is assumed to be the roof area in this case, the following is the sizing criteria that will apply:

$$Storage\ Volume(\frac{m3}{ha}) \times roof_{area(m^2)} = Dry\ Well\ Volume_{(void_{space})}$$

$$\frac{40m^3}{10000} \times roof_{area(m^2)} = 0.40$$

$$Dry\ Well\ Volume = 0.01 \times roof_{area}(m^2)$$

$$\therefore Area\ of\ Dry\ Well\ = \frac{0.01}{0.900} \times roof_{area} \text{ (depth = 3ft ~ 0.900m)}$$

$$\%of\ Lot\ Area\ occupied\ by\ dry\ well\ = \frac{0.011 \times roof_{area}}{Lot\ Size} \times 100$$

The "percent of impervious area, in %" parameter will also change in the subcatchment editor box (Table D.1-17) when applying the dry well. It is assumed that this practice will be placed on a portion of the pervious area of the lot. As a result, the percent imperviousness parameter will change as follows:

$$Revised\ \%\ imperviousness = \frac{\%imperviousness\_noLID}{100} \times \frac{Lot\ Size}{(Lot\ Size - Area\ occupied\ by\ dry\ well)} \times 100$$

There is no underdrain included in this design. Using these design assumptions, the appropriate parameters were calculated for the subcatchment and LID properties implemented within the model developed in SWMM-LID. An "infiltration trench" LID module was selected in SWMM-LID to represent the dry well practice. These design assumptions were applied to all three land-use categories assessment in this study for dry well implementation. As well, the values used in the "BMP Controls Editor" Box of the SWMM-LID Program are the same values used for all models regardless of land-use type.

Table D.1-17: Initial general parameters in the "Subcatchment" Box of the Dry Well Model for all land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
user-assigned name of subcatchment	Name	Subcatchment_DryWell		
rain gage assigned to subcatchment	Rain Gage	RainGage		
name of node or another subcatchment that receives runoff	Outlet	O1		
average surface slope, in %	%Slope	2		
Mannings *n* for impervious area	N-Imperv	0.011		

Mannings *n* for pervious area	N-Perv	0.15
depth of depression storage on impervious area, in mm	Dstore-Imperv	1.524
depth of depression storage on pervious area, in mm	Dstore-Perv	7.62
percent of impervious area with no depression storage, in %	%Zero-Imperv	25
choice of internal routing between pervious and impervious sub-areas	Subarea Routing	OUTLET
percent of runoff routed between sub-areas, in %	Percent Routed	100
BMP/LID units	BMP Controls	0
Infiltration: Green-Ampt Method		
suction head, in mm	-----	88.9
conductivity, in mm/hr	-----	3.4
initial deficit	-----	0.463

Table D.1-18: Initial specific parameters in the "Subcatchment" Box of the SWMM-LID Program used to model Dry Well for each land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
area of subcatchment, in hectares	Commercial	0.2483	0.0614	0.0513
	Industrial	0.2151	0.3591	0.0337
	Residential	0.1335	0.0403	0.0942
width of overland flow path, in metres	Commercial	25.45	12.6	19.4709
	Industrial	37	40.4	20.5
	Residential	19	15.5	20
percent of impervious area, in % **(without LID)**	Commercial	56.7	92.86	91.92
	Industrial	87.62	88.65	85.70
	Residential	20.29	58.15	88.96

Table D.1-19: Adjusted parameters in the "Subcatchment" Box of the SWMM-LID Program in the Dry Well for each Land-Use Model

Land Use Type	Names of Parameters	Parameter Values		
		Region 1	Region 2	Region 3
Commercial	% impervious area **(takes into account LID)**	56.80	93.27	92.73
Industrial		87.78	89.16	86.32
Residential		20.33	58.47	89.84

Table D.1-20: Parameters in the "BMP Controls Editor" Box of the SWMM-LID Program

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Names of Parameters	Parameter Values		
	Region 1	Region 2	Region 3
Process Layer: Surface			
Storage depth	0		
Length to Width Ratio	1.0		
Surface Slope	2.0		
Surface Roughness	0.06		
Swale Side Slope	5		
Process Layer: Storage			
Height or Thickness (mm)	914.4		
Void Ratio	0.40		
Drain Height	0		
Drain Coefficient (C)	0		
Drain Exponent (n)	0.5		
Permeable Bottom	Checked		

**NOTE: It was assumed that the "surface roughness" was of the type "cultivated soils - Residue cover < 20%" (Rossman, 2009)

Rainwater Harvesting Model

The sizing criteria for the rain barrels/cisterns used in this model had to account for variation in roof sizes that would be treated. The commonly used practice is to design for a 0.5 inch rainfall/m^2 of roof area (Snyders Industries, Inc., n.d.). Each tank implemented on the modelled lots was sized according to this criterion. The depth of the tanks was assumed to be 2m for commercial and industrial lots, and 1.3m for residential lots based on average industry sizes (The RainWell, n.d.). While there is no underdrain included in this design, it was assumed that the captured rainwater would be directed 100% to a pervious surface at a later time after the rainfall occurred. Using these design assumptions, the appropriate parameters were calculated for the subcatchment and LID properties implemented within the model developed in SWMM-LID. A "rain barrel" LID module was selected in SWMM-LID to represent the rainwater harvesting practice.

Table D.1-21: Initial general parameters in the "Subcatchment" Box of the SWMM-LID Program for all land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3

user-assigned name of subcatchment	Name	Subcatchment_RWH
rain gage assigned to subcatchment	Rain Gage	RainGage
name of node or another subcatchment that receives runoff	Outlet	O1
average surface slope, in %	%Slope	2
Mannings *n* for impervious area	N-Imperv	0.011
Mannings *n* for pervious area	N-Perv	0.15
depth of depression storage on impervious area, in mm	Dstore-Imperv	1.524
depth of depression storage on pervious area, in mm	Dstore-Perv	7.62
percent of impervious area with no depression storage, in %	%Zero-Imperv	25
choice of internal routing between pervious and impervious sub-areas	Subarea Routing	OUTLET
percent of runoff routed between sub-areas, in %	Percent Routed	100
BMP/LID units	BMP Controls	0
Infiltration: Green-Ampt Method		
suction head, in mm	-----	88.9
conductivity, in mm/hr	-----	3.4
initial deficit	-----	0.463

Table D.1-22: Initial specific parameters in the "Subcatchment" Box of the SWMM-LID Program used to model Rainwater Harvesting for each land-use types

Names of Parameters	Symbols	Parameter Values		
		Region 1	Region 2	Region 3
area of subcatchment, in hectares	Commercial	0.248359	0.06137	0.051252
	Industrial	0.2151	0.3591	0.0337
	Residential	0.1335	0.0403	0.0942
width of overland flow path, in metres	Commercial	25.45	12.6	19.4709
	Industrial	37	40.4	20.5
	Residential	19	15.5	20
percent of impervious area, in % **(without LID)**	Commercial	56.69	92.86	91.92
	Industrial	87.62	88.65	85.70
	Residential	20.29	58.15	88.96

Table D.1-23: Adjusted parameters in the "Subcatchment" Box of the Rainwater Harvesting Model for each Land-Use Type

Land Use Type	Names of Parameters	Parameter Values

		Region 1	Region 2	Region 3
Commercial	% impervious area **(takes into account LID)**	56.75	93.09	92.38
Industrial		87.71	88.94	86.05
Residential		20.32	58.43	89.73

Table D.1-24: "BMP Controls Editor" Box for Rainwater Harvesting Model

Names of Parameters	Parameter Values		
	Region 1	Region 2	Region 3
Process Layer: Storage			
Height or Thickness (mm)	2000 (Commercial & Industrial), 1300 (Residential)		
Void Ratio	0.99		
Drain Height	0		
Drain Coefficient (C)	25.4		
Drain Exponent (n)	0.5		
Drain Delay	6		

**NOTE: Default parameter values provided within the example Rain Barrel module for the value of C and n (EPA SWMM Manual, 2009) were used in this case.

D.1-4. Additional lots included for development of runoff volume function without LID application

Land-use Type	Assessment ID Number	Address	Stormwatershed ID	Lot Size (m^2)	Bldg Size (m^2)	Building Size-to-Lot Size Ratio (%)	Impervious Area (%)	Total Runoff without LID application (m^3)
Resource & Industrial	434203200304101	26 Ferndale Drive	BAR-C23	18939.50	367.81	1.94	24.83	2167.00
Resource & Industrial	434203200301800	428 Tiffin St	BAR-C25	5511.15	365.49	6.63	92.80	2139.00
Residential	434203102002800	114 Anne St N	BAR-NW12	3749.39	664.66	17.73	49.14	858.00
Resource & Industrial	434204000202100	134 Tiffin St	BAR-C25	2150.79	351.83	16.36	87.62	811.00
Residential	434201201505700	88 Cook St	BAR-NE14	1906.44	455.60	23.90	28.15	290.00
Open Area	434203102200225	500 Dunlop St W	BAR-C16	8981.86	2821.62	31.41	79.58	3109.00
Resource & Industrial	434203101902602	36 Lennox Dr	BAR-C16	1,641	553.299	33.72	34.83	293.00
Resource & Industrial	434204000206010	134 Anne St	BAR-C25	1315.11	471.79	35.87	82.56	476.00
Residential	434203200504600	34 Simcoe St	BAR-NE39	2408.77	1145.14	47.54	77.04	818.00
Commercial	434202200306500	89 Collier St	BAR-NE40	792.81	412.19	51.99	88.09	305.00
Resource & Industrial	434204000202500	168 Tiffin St	BAR-C25	15792.20	9367.56	59.32	70.31	4910.00
Residential	434202200802200	89 Dunlop St E	BAR-NE40	607.21	358.46	59.03	91.23	241.00
Residential	434202200809700	110 Dunlop St E	BAR-NE40	544.13	390.07	71.69	72.26	177.00
Residential	434203200504100	33 Mary St	BAR-NE39	796.89	564.44	70.83	94.33	325.00
Residential	434202200805700	46 Dunlop St E	BAR-NE39	609.21	469.13	77.01	79.87	215.00
Commercial	434202200802500	105-107 Dunlop St E	BAR-NE40	500.68	398.25	79.54	99.43	214
Residential	434202200810700	65-69 Collier St	BAR-NE40	942.12	834.84	88.61	88.96	365.00
Residential	434202200301410	17 Mulcaster St	BAR-NE40	477.39	459.77	96.31	96.31	199.00

D.1-5. Performance curves developed from the SWMM-LID modelled lots to estimate volumetric runoff reduction

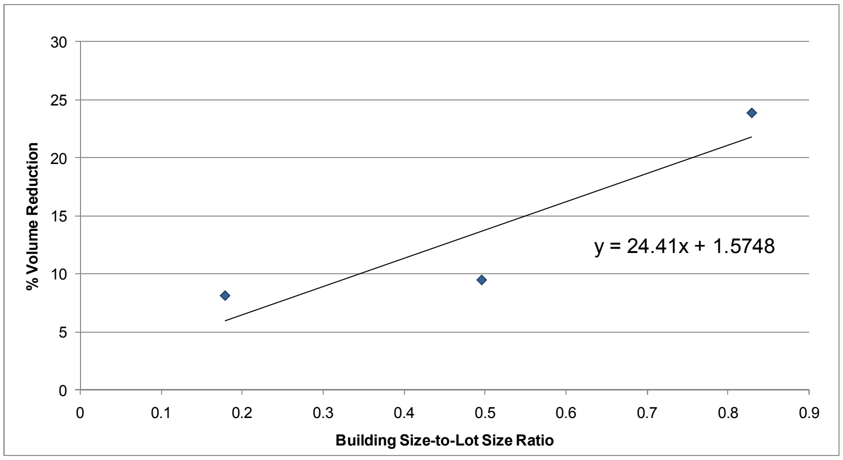

Figure D.1-13: Performance curve for lots modelled with green roof application

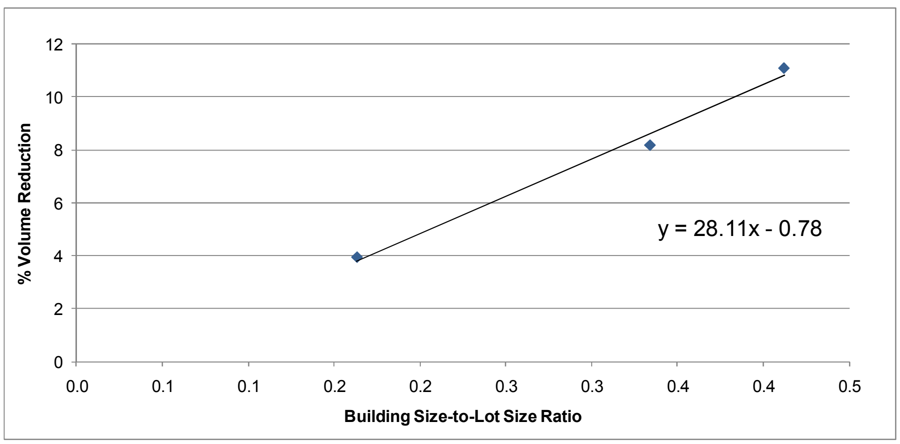

Figure D.1-14: Performance curve for commercial lots modelled with soakaway pit application

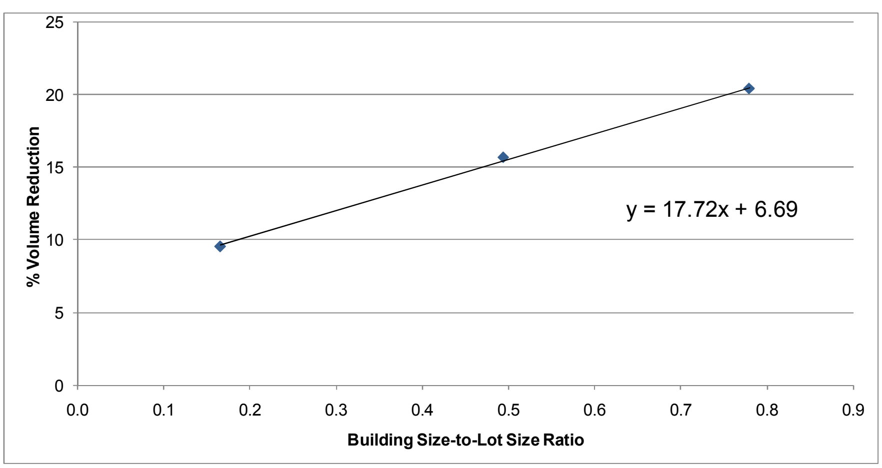

Figure D.1-15: Performance curve for residential lots modelled with soakaway pit application

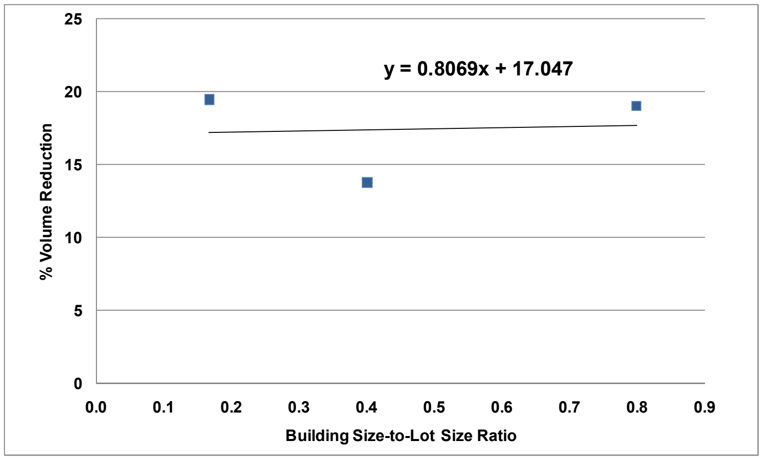

Figure D.1-16: Performance curve for commercial lots modelled with downspout disconnection application

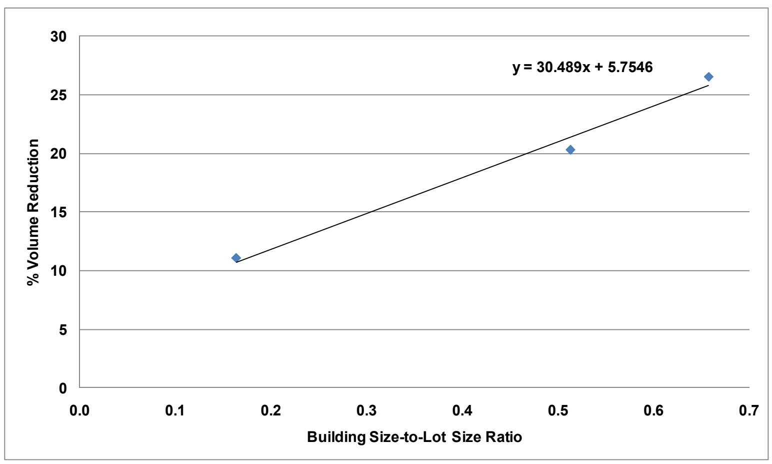

Figure D.1-17: Performance curve for industrial lots modelled with downspout disconnection application

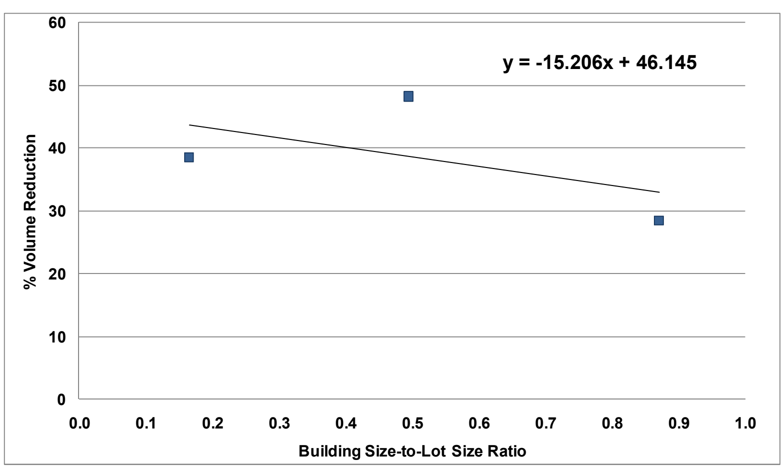

Figure D.1-18: Performance curve for residential lots modelled with downspout disconnection application

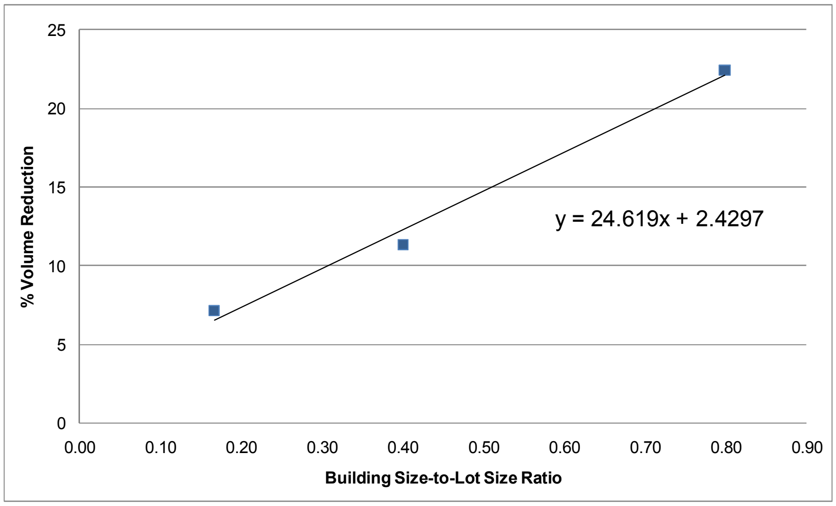

Figure D.1-19: Performance curve for commercial lots modelled with dry well application

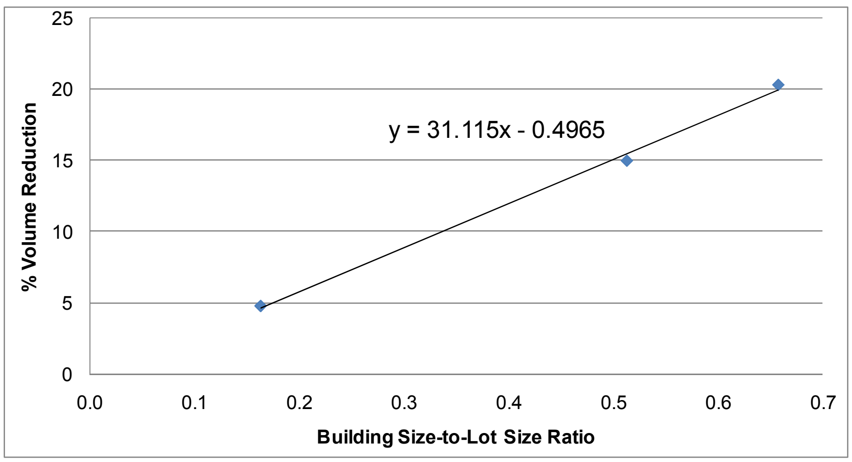

Figure D.1-20: Performance curve for industrial lots modelled with dry well application

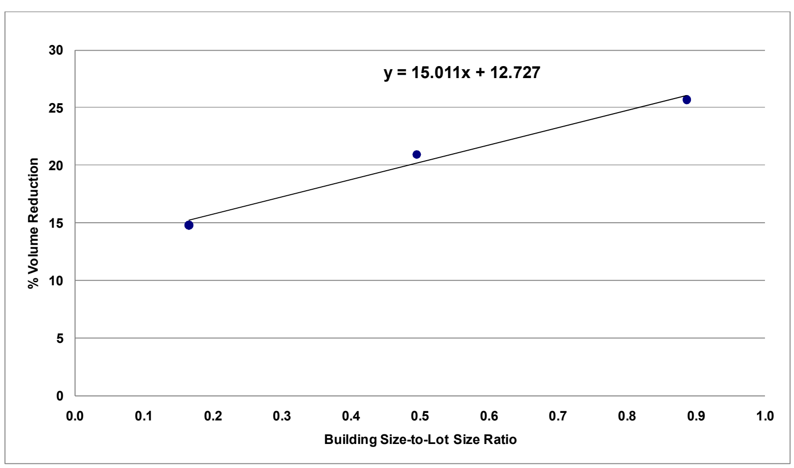

Figure D.1-21: Performance curve for residential lots modelled with dry well application

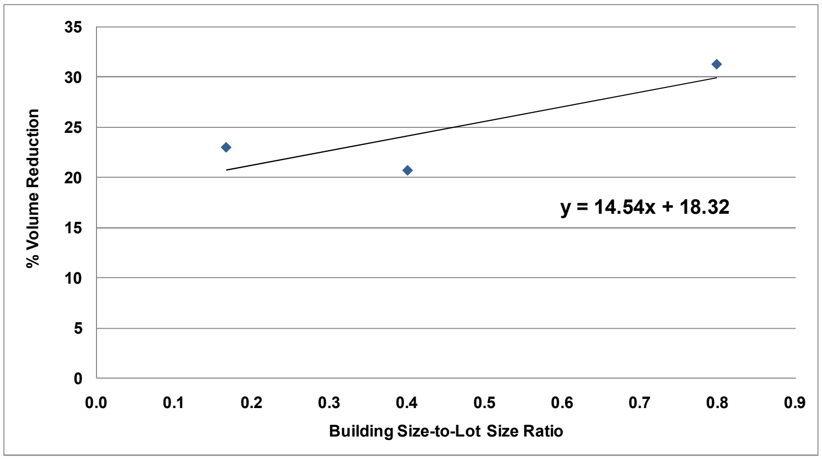

Figure D.1-22: Performance curve for commercial lots modelled with rainwater harvesting application

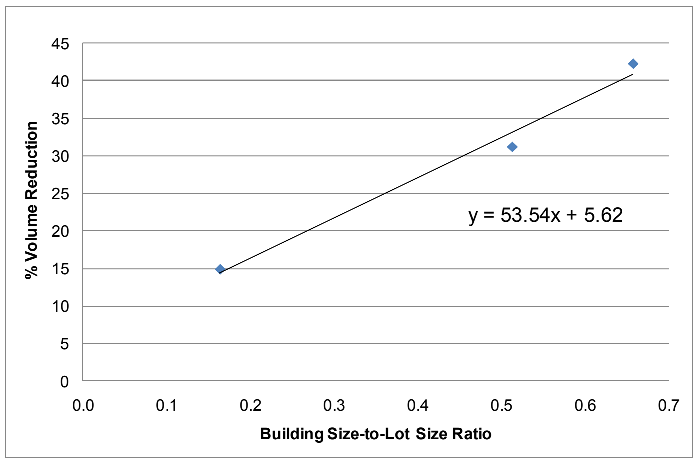

Figure D.1-23: Performance curve for industrial lots modelled with rainwater harvesting application

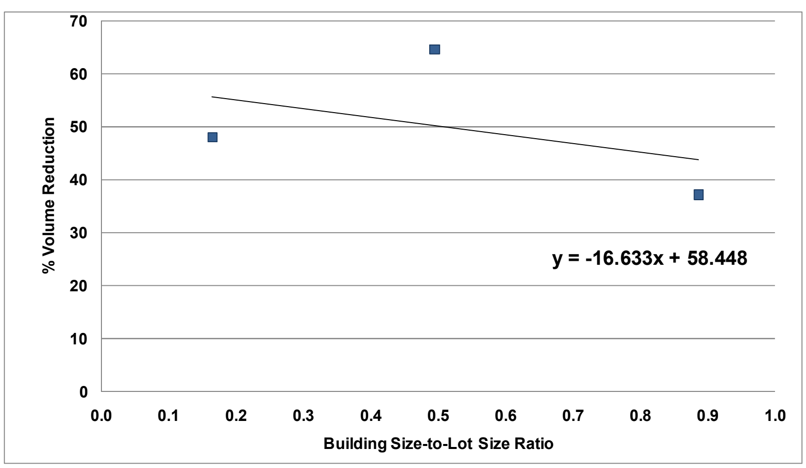

Figure D.1-24: Performance curve for residential lots modelled with rainwater harvesting application

D.1-6. Performance curves developed from the SWMM-LID modelled lots to estimate pollutant loading reduction potential

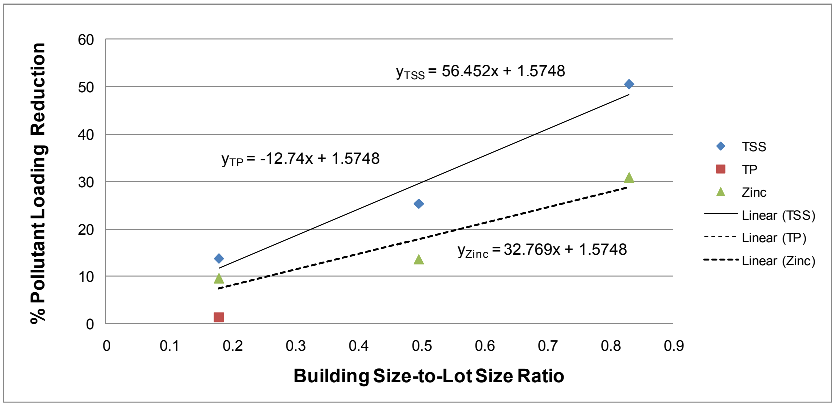

Figure D.1-25: Pollutant loading performance curve for lots modelled with green roof application

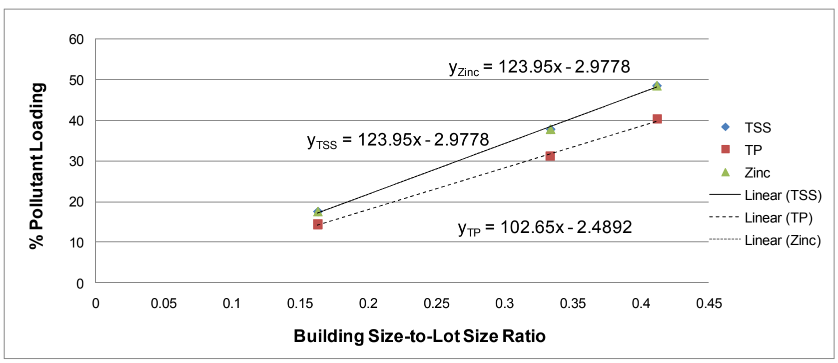

Figure D.1-26: Pollutant loading performance curve for commercial lots modelled with soakaway pit application

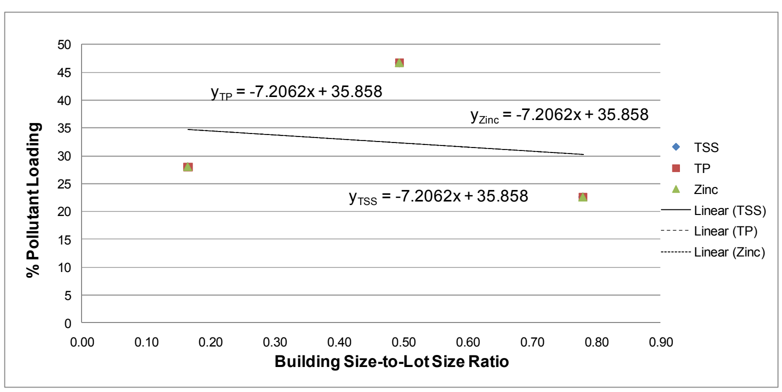

Figure D.1-27: Pollutant loading performance curve for residential lots modelled with soakaway pit application

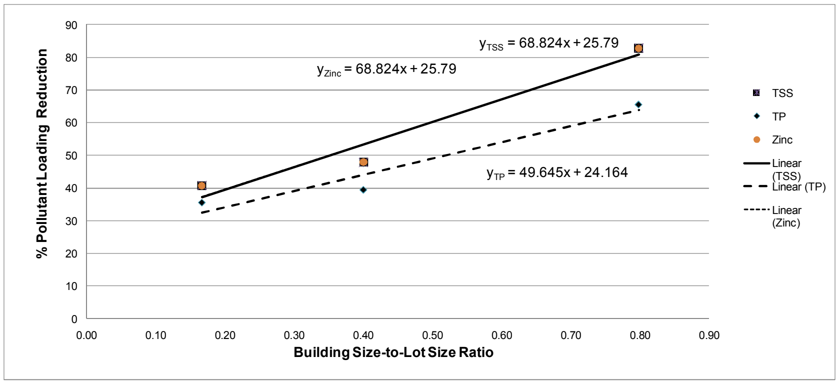

Figure D.1-28: Pollutant loading performance curve for commercial lots modelled with downspout disconnection application

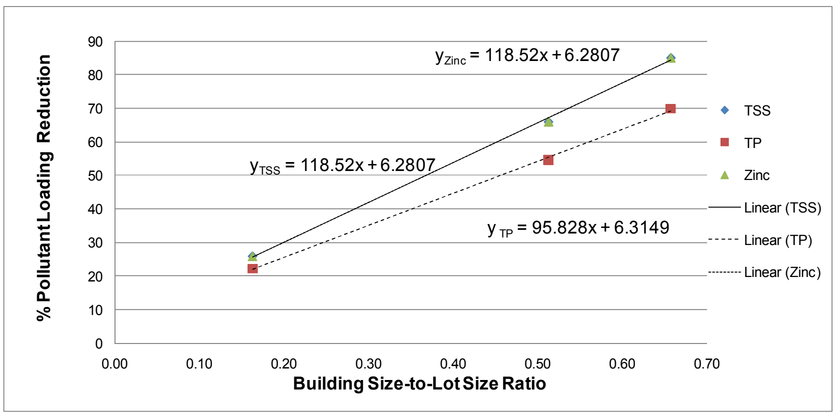

Figure D.1-29: Pollutant loading performance curve for industrial lots modelled with downspout disconnection application

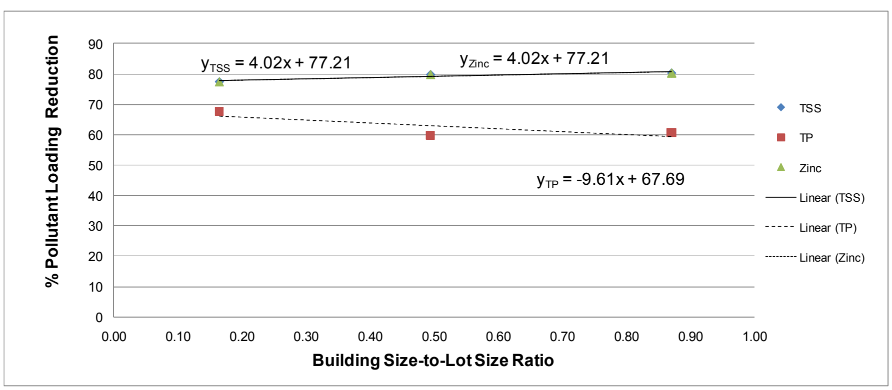

Figure D.1-30: Pollutant loading performance curve for residential lots modelled with downspout disconnection application

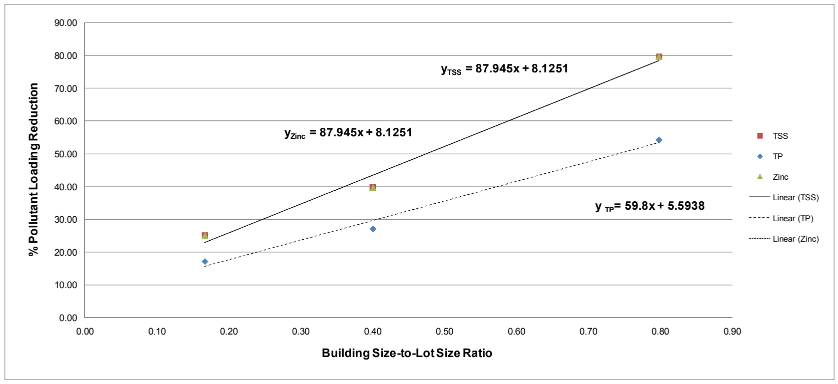

Figure D.1-31: Pollutant loading performance curve for commercial lots modelled with dry well application

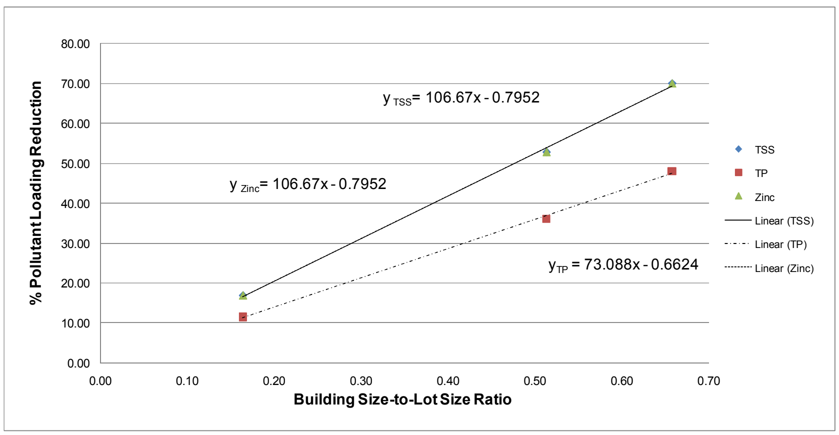

Figure D.1-32: Pollutant loading performance curve for industrial lots modelled with dry well application

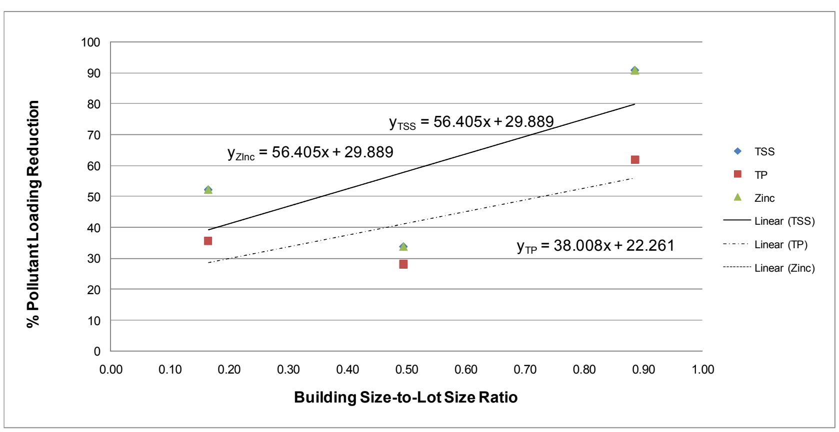

Figure D.1-33: Pollutant loading performance curve for residential lots modelled with dry well application

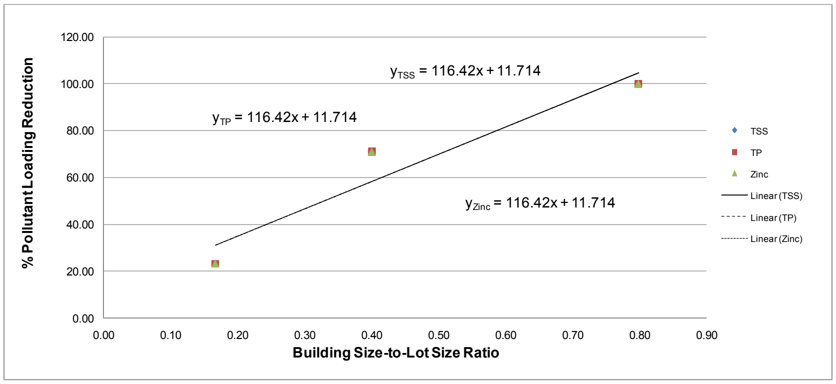

Figure D.1-34: Pollutant loading performance curve for commercial lots modelled with rainwater harvesting application

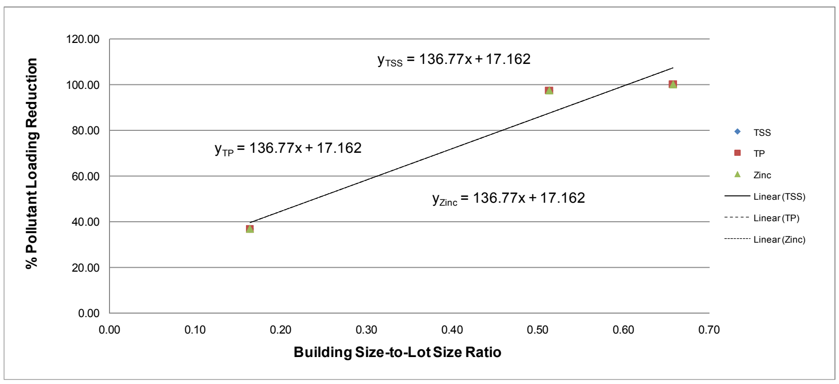

Figure D.1-35: Pollutant loading performance curve for industrial lots modelled with rainwater harvesting application

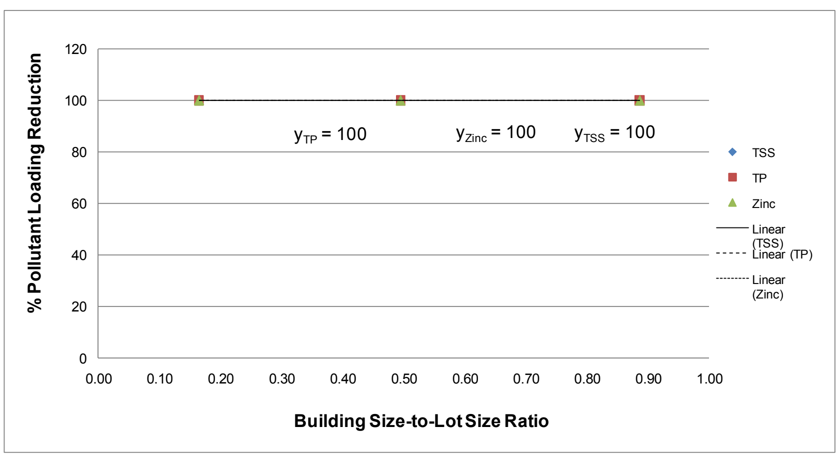

Figure D.1-36: Pollutant loading performance curve for residential lots modelled with rainwater harvesting application

APPENDIX D.2: Application of Cost Estimate Functions for LID Practices in Case Study

Table D.2-1: Example of Total-cost estimates produced for LID practice included in case study

Assessment ID Number	Address	Stormwatershed ID	Lot Size (m^2)	Bldg Size (m^2)	Total-Cost (2010 $CDN)
434204001679900	LAKESHORE DR	BAR-SE80	173405.00	767.11	$313,387
434205000600350	61 BIG BAY POINT RD	BAR-SW33	630790.00	5540.87	$2,037,546
434203200114400	55 LAKESHORE DR	BAR-C15	41166.70	442.60	$186,939
434204001730100	359 TIFFIN ST	BAR-C25	20412.10	382.46	$163,023
434203200304101	26 FERNDALE DR	BAR-C23	18939.50	367.81	$157,165
434205000501900	214 HICKORY LANE	BAR-SE3	11160.60	352.65	$151,089
434204000300201	BRADFORD ST E/S	BAR-SW11	27829.00	891.16	$360,886
434203200302100	452 TIFFIN ST	BAR-C25	14130.40	531.69	$222,043
434203102054000	340 LEACOCK DR	BAR-C1	40507.40	1534.18	$602,529
434205000419500	650 BIG BAY POINT RD	BAR-SE1	11702.00	451.46	$190,446
434203200303900	46 FERNDALE DR	BAR-C23	10127.60	424.46	$179,744
434203200305100	15 SARJEANT DR	BAR-C23	35457.50	1501.49	$590,388
434204001724300	94 PATTERSON RD	BAR-SW45	9785.79	442.24	$186,796
434201100602200	170 STEEL ST	BAR-NE3	8165.45	430.46	$182,128
434205000218400	306 YONGE ST	BAR-SE25	10582.10	566.40	$235,626
434205000417400	601 YONGE ST	BAR-SE7	7107.95	389.01	$165,637
434203200303700	60 FERNDALE DR	BAR-C23	21041.90	1240.66	$493,026

(NOTE: Cost-estimates (in 2010 $CDN) for some lots suitable for green roof installation are shown)

APPENDIX D.3: Stakeholder Involvement in the Lake Simcoe LID Project Case Study

Part One: Questionnaires used in research

LSRCA LID Workshop

Preliminary Questions to Assess the Opinions and Concerns of Stakeholders Regarding LID Implementation

1. Which group of stakeholders do you represent? (e.g., municipal government, developer, private citizen, landscape architect, private (environmental) consulting firm, stormwater manager, local NGOs, etc)

2. Which LID practices were you familiar with before this Workshop? (Please check the appropriate box):

LID practice	Never heard of it	Have some knowledge	Very familiar – Currently implementing LIDs
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable pavement	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Permeable pavement	☐	☐	☐
Home clustering	☐	☐	☐

1

3. Given the information presented in this Workshop, which LID practices would you invest in? (Please check the appropriate box):

LID practice	No chance	Maybe	Definitely!
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable pavement	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Permeable pavement	☐	☐	☐
Home clustering	☐	☐	☐

4. What do you think the benefits (immediate and long term) would be to you if you were to implement LID practices? Please check off and rank accordingly:

Benefits	Check	Rank		
		Low	Medium	High
Possible rebates	☐	☐	☐	☐
Public image	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐
Environmental benefits	☐	☐	☐	☐
Reduction of infrastructure costs	☐	☐	☐	☐
No benefits	☐	☐	☐	☐
Other benefits (please list):				

2

5. Check off your concerns for LID implementation. Rank accordingly:

Concern	Check	Rank		
		Low	Medium	High
Costs - capital	☐	☐	☐	☐
Cost – O&M	☐	☐	☐	☐
Lack of design guidelines/standards	☐	☐	☐	☐
Long payback period	☐	☐	☐	☐
Space	☐	☐	☐	☐
Municipal approval	☐	☐	☐	☐
Liability	☐	☐	☐	☐
Buy-in: gain acceptance from influencing stakeholders	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐
Other concerns (please list all):				

6. Where do you think the drivers of LID implementation will come from? Please check off accordingly:

Drivers	Check
Developers	☐
Municipal programs and policies (rebates, by-laws, education, stormwater charges, etc)	☐
Provincial regulations and guidelines	☐
Private citizens and corporations	☐
Grassroot initiatives	☐
Local NGOs	☐
Other drivers (please list):	

3

7. What type of incentive program do you think needs to be in place to have effective LID implementation? Please check off accordingly:

Incentive	Check
Municipal rebate	☐
Reduced requirements for stormwater management	☐
Recognition program	☐
Streamlined approvals	☐
Other incentives (please list):	

8. Please list any other comments or concerns related to LID implementation that you may have.

Please fill out the ballot below and return the survey to Sarah Lawson (Ryerson University) before the end of the Workshop. Your name will be entered into a draw.

Surveys can also be mailed in to the following address:
Department of Civil Engineering
Faculty of Engineering, Architecture and Science
Ryerson University
350 Victoria Street
Toronto, Ontario,
Canada M5B 2K3
Tel: 1-416-979-5000

Thank you for your participation!

- -

Name:	
Organization:	
Contact Number:	

4

"New Directions '09 in Stormwater Management" Conference ("SWM Conference")

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LID Implementation in a Watershed

Survey to Assess the Opinions and Concerns of Stakeholders

1. Check off the group of stakeholders that best represents you (please select one):

Municipal government	☐
Provincial or Federal government	☐
Conservation Authority	☐
Developer	☐
Scientist (i.e., geoscience, aquatic, biology, botany, ecology)	☐
Planning professional (i.e. architect, landscape architect, urban planning consultant)	☐
Private consulting firm (environmental, construction)	☐
Storm water professional (i.e., manager, engineer, hydrologist, modeller)	☐
Member of local NGOs	☐
Member of School Board	☐
Researcher	☐
Local Business Owner (i.e., restaurant, supermarket, real estate, etc)	☐
Private citizen	☐
Other (please specify): ____________________	☐

2. Do you carry out projects, work, or live (if you've identified yourself as private citizen) within the Lake Simcoe Region Watershed?

Yes	☐
No	☐

1

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3. Which LID practices are you familiar with? (Please check the appropriate box):

LID practice	Never heard of it	Have some knowledge	Very familiar
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable/porous pavements	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Home clustering	☐	☐	☐

2

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4. Based on your current knowledge, check off the LID practices you would most likely implement:

LID practice	Don't know what is!	No chance	Maybe	Definitely!
Soakaway pit	☐	☐	☐	☐
Bioretention	☐	☐	☐	☐
Dry Well	☐	☐	☐	☐
Rainwater harvesting	☐	☐	☐	☐
Green roof	☐	☐	☐	☐
Downspout disconnection	☐	☐	☐	☐
Filter strip	☐	☐	☐	☐
Permeable/porous pavements	☐	☐	☐	☐
Grass channel	☐	☐	☐	☐
Dry Swale	☐	☐	☐	☐
Infiltration trench	☐	☐	☐	☐
Level spreader	☐	☐	☐	☐
Roadway reduction	☐	☐	☐	☐
Soil amendments	☐	☐	☐	☐
Tree clusters	☐	☐	☐	☐
Home clustering	☐	☐	☐	☐

3

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5. For each LID practices you selected to "Maybe" and "Definitely!" implement in Question 4, check off all your reasons:

Reasons for Implementation

LID Practice	Will not implement	Low capital & implementation costs	Low O&M[1] costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits	Other reasons (please specify):
Soakaway pit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bioretention	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dry Well	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rainwater harvesting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Green roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Downspout disconnection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Filter strip	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Permeable/porous pavements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Grass channel	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dry Swale	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Infiltration trench	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Level spreader	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Roadway reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Soil amendments	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tree clusters	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Home clustering	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other Reasons (Please specify):										

[1]O&M – Operating and Maintenance

4

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6. Check off the barriers that are preventing you from implementing LID practices in general. Rank each barrier accordingly:

Barriers	**Not a barrier**	**Barrier Ranking** Low	Medium	High
• Costs – capital	☐	☐	☐	☐
• Cost – O&M	☐	☐	☐	☐
• Time and effort to implement as well as to maintain over time	☐	☐	☐	☐
• Lack of design guidelines/standards/policies	☐	☐	☐	☐
• Possible long payback period	☐	☐	☐	☐
• Lack of Life-cycle-analysis and economic studies	☐	☐	☐	☐
• Space	☐	☐	☐	☐
• Municipal approval	☐	☐	☐	☐
• Liability	☐	☐	☐	☐
• Buy-in: gain acceptance from influencing stakeholders (i.e., support from public, government, upper management, etc.,)	☐	☐	☐	☐
• Aesthetics	☐	☐	☐	☐
• Winter maintenance:	☐	☐	☐	☐
• Lack of existing examples and case studies	☐	☐	☐	☐
• Minimal simulation models and tools to predict performance and effectiveness:	☐	☐	☐	☐
• Other barrier (specify):_______________	☐	☐	☐	☐
• Other barrier (specify):_______________	☐	☐	☐	☐

5

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7. What do you think the benefits (immediate and long term) would be to you if you were to implement LID practices? Please rank the benefits accordingly:

Benefits	**Not a benefit**	**Benefit ranking** Low	Medium	High
Possible rebates	☐	☐	☐	☐
Public image	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐
Environmental benefits	☐	☐	☐	☐
Reduces infrastructure and utility maintenance costs (i.e., streets, curbs, storm sewers)	☐	☐	☐	☐
Can be integrated into existing infrastructure	☐	☐	☐	☐
Assists in meeting regulatory obligations.	☐	☐	☐	☐
Assists in meeting LEED[2] Certification requirements.	☐	☐	☐	☐
Reduces stormwater management construction costs.	☐	☐	☐	☐
Increased property value	☐	☐	☐	☐
Potentially increases lot yields/amount of developable land	☐	☐	☐	☐
Provides environmental education opportunities	☐	☐	☐	☐
Other benefit (specify):_________________	☐	☐	☐	☐
Other benefits (specify):_________________	☐	☐	☐	☐

8. Where do you think the drivers of LID implementation will come from? Please check off accordingly:

Drivers	**Check**
Developers	☐
Municipal programs and policies (rebates, by-laws, education, stormwater charges, etc)	☐
Provincial regulations and guidelines	☐
Private citizens and corporations	☐
Grassroot initiatives	☐
Local NGOs[3]	☐
Community Groups	
Market – Strong desire for environmental responsibility	

[2] (Leadership in Energy and Environmental Design)
[3] Non-Governmental Organizations

6

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9. What type of incentive program do you think needs to be in place to have effective LID implementation? Please check off all that apply:

Incentive	
• Reduced requirements for stormwater management	☐
• Recognition program	☐
• Streamlined approvals (e.g., accelerated reviews for site plans)	☐
• Tax credit for qualifying LID techniques	☐
• Bonus (i.e., municipal rebate, increased floor area (ratio), etc) if LID practices are used that accomplish stormwater management goals.	☐
• Reduce fees (e.g., plan review fees, utility fees) for site plans	☐
• Grants for funding LID projects including for demonstration and educational purposes	☐
• Credits for stormwater utility fees	☐
• Regulatory-based schemes (i.e., ordinances, policies, etc)	
• Other incentive (please specify):_____________	☐

10. What is your perception of the cost of implementing and maintaining each LID listed below? Rank each cost according to low, medium, high.

LID Practice	**Cost Ranking** Low	Medium	High
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable/porous pavements	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Home clustering	☐	☐	☐

7

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11. Rank each LID on cost effectiveness relative to the other LIDs (1 = most cost effective, 16 = least cost effective).

LID Practice	**Cost Effectiveness Ranking**
• Soakaway pit	_____
• Bioretention	_____
• Dry Well	_____
• Rainwater harvesting	_____
• Green roof	_____
• Downspout disconnection	_____
• Filter strip	_____
• Permeable/porous pavements	_____
• Grass channel	_____
• Dry Swale	_____
• Infiltration trench	_____
• Level spreader	_____
• Roadway reduction	_____
• Soil amendments	_____
• Tree clusters	_____
• Home clustering	_____

12. Please list any other comments or concerns related to LID implementation that you may have.

Please fill out the information below and return the survey to a Ryerson University Representative before the end of the Conference.

Thank you for your participation!

Name:	
Organization:	
Contact Number:	

8

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LID Implementation in a Watershed

Survey to Assess the Opinions and Concerns of Stakeholders

Study Description

The concept of Low Impact Development (LID) has emerged in recent years as a sustainable approach to traditional forms of stormwater management practices. Despite the effort that has been made to incorporate this new approach into existing frameworks and guidelines, a particular challenge that is being faced is planning for LID implementation on a large scale. To address some of these emerging issues, the objective of this study is to develop a comprehensive planning framework for LID implementation on a watershed level. The framework is being created based on data from the Lake Simcoe watershed, and will include the development of a modelling approach, incorporation of stakeholders' interests (traditional and non-traditional), as well as application of a cost-benefit analysis.

The objective of this survey is to assess the opinions and concerns of affected stakeholder groups regarding the planning and application of LID practices. As a result, a greater understanding into the mechanisms required to facilitate wide spread implementation, as well insight into the capacity of those applying LID systems will be achieved.

1. Check off the group of stakeholders that best represents you (please select one):

Municipal government	☐
Provincial or Federal government	☐
Conservation Authority	☐
Developer	☐
Scientist (i.e., geoscience, aquatic, biology, botany, ecology)	☐
Planning professional (i.e. architect, landscape architect, urban planning consultant)	☐
Private consulting firm (environmental, construction)	☐
Storm water professional (i.e., manager, engineer, hydrologist, modeller)	☐
Member of local NGOs	☐
Member of School Board	☐
Researcher	☐
Local Business Owner (i.e., restaurant, supermarket, real estate, etc)	☐
Private citizen	☐
Other (please specify): ____________	☐

1

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2. Have you taken a similar survey (i.e., at the LID Workshop – Sept 28, 2009 or Stormwater Management Conference - Nov. 30 – Dec 2nd)?

Yes ☐
No ☐

3. Do you carry out projects, work, or live (if you've identified yourself as private citizen) within the Lake Simcoe Region Watershed?

Yes ☐
No ☐

4. Which LID practices are you familiar with? (Please check the appropriate box):

LID practice	Never heard of it	Have some knowledge	Very familiar
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable/porous pavements	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Home clustering	☐	☐	☐

2

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5. Based on your current knowledge, check off the LID practices you would most likely implement:

LID practice	Don't know what is!	No chance	Maybe	Definitely!
Soakaway pit	☐	☐	☐	☐
Bioretention	☐	☐	☐	☐
Dry Well	☐	☐	☐	☐
Rainwater harvesting	☐	☐	☐	☐
Green roof	☐	☐	☐	☐
Downspout disconnection	☐	☐	☐	☐
Filter strip	☐	☐	☐	☐
Permeable/porous pavements	☐	☐	☐	☐
Grass channel	☐	☐	☐	☐
Dry Swale	☐	☐	☐	☐
Infiltration trench	☐	☐	☐	☐
Level spreader	☐	☐	☐	☐
Roadway reduction	☐	☐	☐	☐
Soil amendments	☐	☐	☐	☐
Tree clusters	☐	☐	☐	☐
Home clustering	☐	☐	☐	☐

3

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6. For each LID practices you selected to "Maybe" and "Definitely!" implement in Question 4, check off all your reasons:

LID Practice	Will not implement	Low capital & implementation costs	Low O&M[1] costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits	Other reasons (please specify):
	Reasons for Implementation									
Soakaway pit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bioretention	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dry Well	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rainwater harvesting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Green roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Downspout disconnection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Filter strip	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Permeable/porous pavements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Grass channel	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dry Swale	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Infiltration trench	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Level spreader	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Roadway reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Soil amendments	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tree clusters	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Home clustering	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other Reasons (Please specify):										

[1]O&M – Operating and Maintenance

4

7. Check off the barriers that are preventing you from implementing LID practices in general. Rank each barrier accordingly:

Barriers	Not a barrier	Low	Medium	High
		Barrier Ranking		
• Costs – capital	☐	☐	☐	☐
• Cost – O&M	☐	☐	☐	☐
• Time and effort to implement as well as to maintain over time	☐	☐	☐	☐
• Lack of design guidelines/standards/policies	☐	☐	☐	☐
• Possible long payback period	☐	☐	☐	☐
• Lack of Life-cycle-analysis and economic studies	☐	☐	☐	☐
• Space	☐	☐	☐	☐
• Municipal approval	☐	☐	☐	☐
• Liability	☐	☐	☐	☐
• Buy-in: gain acceptance from influencing stakeholders (i.e., support from public, government, upper management, etc.,)	☐	☐	☐	☐
• Aesthetics	☐	☐	☐	☐
• Winter maintenance:	☐	☐	☐	☐
• Lack of existing examples and case studies	☐	☐	☐	☐
• Minimal simulation models and tools to predict performance and effectiveness:	☐	☐	☐	☐
• Other barrier (specify):_______________	☐	☐	☐	☐
• Other barrier (specify):_______________	☐	☐	☐	☐

5

8. What do you think the benefits (immediate and long term) would be to you if you were to implement LID practices? Please rank the benefits accordingly:

Benefits	Not a benefit	Benefit ranking		
		Low	Medium	High
Possible rebates	☐	☐	☐	☐
Public image	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐
Environmental benefits	☐	☐	☐	☐
Reduces infrastructure and utility maintenance costs (i.e., streets, curbs, storm sewers)	☐	☐	☐	☐
Can be integrated into existing infrastructure	☐	☐	☐	☐
Assists in meeting regulatory obligations.	☐	☐	☐	☐
Assists in meeting LEED[2] Certification requirements.	☐	☐	☐	☐
Reduces stormwater management construction costs.	☐	☐	☐	☐
Increased property value	☐	☐	☐	☐
Potentially increases lot yields/amount of developable land	☐	☐	☐	☐
Provides environmental education opportunities	☐	☐	☐	☐
Other benefit (specify):__________________	☐	☐	☐	☐
Other benefits (specify):_________________	☐	☐	☐	☐

9. Where do you think the drivers of LID implementation will come from? Please check off accordingly:

Drivers	Check
Developers	☐
Municipal programs and policies (rebates, by-laws, education, stormwater charges, etc)	☐
Provincial regulations and guidelines	☐
Private citizens and corporations	☐
Grassroot initiatives	☐
Local NGOs[3]	☐
Community Groups	
Market – Strong desire for environmental responsibility	

[2] (Leadership in Energy and Environmental Design)
[3] Non-Governmental Organizations

6

10. What type of incentive program do you think needs to be in place to have effective LID implementation? Please check off all that apply:

Incentive	
• Reduced requirements for stormwater management	☐
• Recognition program	☐
• Streamlined approvals (e.g., accelerated reviews for site plans)	☐
• Tax credit for qualifying LID techniques	☐
• Bonus (i.e., municipal rebate, increased floor area (ratio), etc) if LID practices are used that accomplish stormwater management goals.	☐
• Reduce fees (e.g., plan review fees, utility fees) for site plans	☐
• Grants for funding LID projects including for demonstration and educational purposes	☐
• Credits for stormwater utility fees	☐
• Regulatory-based schemes (i.e., ordinances, policies, etc)	
• Other incentive (please specify):______________	☐

11. What is your perception of the cost of implementing and maintaining each LID listed below? Rank each cost according to low, medium, high.

LID Practice	Cost Ranking		
	Low	Medium	High
Soakaway pit	☐	☐	☐
Bioretention	☐	☐	☐
Dry Well	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Green roof	☐	☐	☐
Downspout disconnection	☐	☐	☐
Filter strip	☐	☐	☐
Permeable/porous pavements	☐	☐	☐
Grass channel	☐	☐	☐
Dry Swale	☐	☐	☐
Infiltration trench	☐	☐	☐
Level spreader	☐	☐	☐
Roadway reduction	☐	☐	☐
Soil amendments	☐	☐	☐
Tree clusters	☐	☐	☐
Home clustering	☐	☐	☐

7

12. Rank each LID on cost effectiveness relative to the other LIDs (1 = most cost effective, 16 = least cost effective).

LID Practice	Cost Effectiveness Ranking
• Soakaway pit	_____
• Bioretention	_____
• Dry Well	_____
• Rainwater harvesting	_____
• Green roof	_____
• Downspout disconnection	_____
• Filter strip	_____
• Permeable/porous pavements	_____
• Grass channel	_____
• Dry Swale	_____
• Infiltration trench	_____
• Level spreader	_____
• Roadway reduction	_____
• Soil amendments	_____
• Tree clusters	_____
• Home clustering	_____

13. Please list any other comments or concerns related to LID implementation that you may have.

If you have any more questions regarding the study or this survey,
please contact Sarah Lawson at:

Department of Civil Engineering c/o Dr. James Li or Dr. Darko Joksimovic
Faculty of Engineering, Architecture and Science
Ryerson University
350 Victoria Street
Toronto, Ontario,
Canada M5B 2K3
Tel: 1-416-979-5000
Email: sarah.o.lawson@ryerson.ca

Thank you for your participation!

8

Part Two: Questionnaire Results

Main Stakeholder Groups Represented

Table D.3-1: Representation of stakeholders groups that participated in Questionnaire

Stakeholder groups	# of Representatives Present	# of Representatives Present (%)
Municipal Governments	18	50%
Federal Governments	1	3%
School board	1	3%
Provincial Government (Ontario)	3	8%
Stormwater manager	1	3%
Private Consulting Firm	5	14%
Private Citizen	1	3%
Conservation Authority	5	14%
Student	1	3%
Total	**36**	**100%**

Sample 1

Stakeholder groups	# of Representatives Present	# of Representatives Present (%)
Municipal government	13	34.21%
Provincial or Federal government	1	2.63%
Conservation Authority	1	2.63%
Developer	1	2.63%
Scientist (i.e., geoscience, aquatic, biology,	1	2.63%
Planning professional (i.e. architect, landsc	1	2.63%
Private consulting firm (environmental, con	6	15.79%
Storm water professional (i.e., manager, en	13	34.21%
Member of local NGOs	0	0.00%
Member of School Board	0	0.00%
Researcher	1	2.63%
Local Business Owner (i.e., restaurant, supe	0	0.00%
Private citizen	0	0.00%
Other (please specify)	0	0.00%
Total	**38**	**100.00%**

Sample 2

Stakeholder groups	# of Representatives Present	# of Representatives Present (%)
Municipal government	6	27.27%
Provincial or Federal government	0	0.00%
Conservation Authority	2	9.09%
Developer	1	4.55%
Scientist (i.e., geoscience, aquatic, biology, botany, ecology)	1	4.55%
Planning professional (i.e. architect, landscape architect, urban planning consultant)	1	4.55%
Private consulting firm (environmental, construction)	3	13.64%
Storm water professional (i.e., manager, engineer, hydrologist, modeller)	7	31.82%
Member of local NGOs	0	0.00%
Member of School Board	0	0.00%
Researcher	0	0.00%
Local Business Owner (i.e., restaurant, supermarket, real estate, etc)	0	0.00%
Private citizen	0	0.00%
Other (please specify)	1	4.55%
Total	22	100.00%

Sample 3

Current knowledge of LID practices

Table D.3-2: Knowledge of LID practices indicated by survey participants in each sample

LID Practices	Sample 1: LSRCA LID Workshop			Sample 2: SWM Conference			Sample 3: TRCA/CSA LID Training Course		
	Never heard of it	Have some knowledge	Very Familiar	Never heard of it	Have some knowledge	Very Familiar	Never heard of it	Have some knowledge	Very Familiar
Soakaway Pit	4.44%	68.89%	26.67%	2.70%	32.43%	64.86%	10.00%	50.00%	40.00%
Biorention	6.82%	77.27%	15.91%	8.11%	51.35%	40.54%	4.55%	59.09%	36.36%
Dry Well	13.95%	69.77%	16.28%	8.11%	54.05%	37.84%	10.53%	52.63%	36.84%
Rainwater Harvesting	4.55%	70.45%	25.00%	5.41%	51.35%	43.24%	0.00%	54.55%	45.45%
Green Roofs	2.22%	77.78%	20.00%	2.70%	43.24%	54.05%	5.00%	50.00%	45.00%
Downspout Disconnection	2.27%	63.64%	34.09%	0.00%	24.32%	75.68%	0.00%	38.10%	61.90%
Filter Strips	16.67%	59.52%	23.81%	5.41%	40.54%	54.05%	4.55%	50.00%	45.45%
Permeable Pavements	2.22%	77.78%	20.00%	0.00%	45.95%	54.05%	0.00%	50.00%	50.00%
Grass Channel	2.27%	61.36%	36.36%	0.00%	27.03%	72.97%	9.09%	45.45%	45.45%
Dry Swale	9.30%	55.81%	34.88%	2.70%	29.73%	67.57%	0.00%	50.00%	50.00%
Infiltration Trench	4.55%	59.09%	36.36%	0.00%	27.03%	72.97%	4.76%	33.33%	61.90%
Level Spreader	27.91%	46.51%	25.58%	16.22%	37.84%	45.95%	42.11%	26.32%	31.58%
Roadway Reduction	20.93%	67.44%	11.63%	16.22%	45.95%	37.84%	20.00%	65.00%	15.00%
Soil Amendments	27.50%	60.00%	12.50%	32.43%	40.54%	27.03%	38.10%	47.62%	14.29%
Tree Clusters	15.91%	68.18%	15.91%	29.73%	54.05%	16.22%	33.33%	57.14%	9.52%
Home Clustering	34.88%	53.49%	11.63%	32.43%	48.65%	18.92%	65.00%	25.00%	10.00%

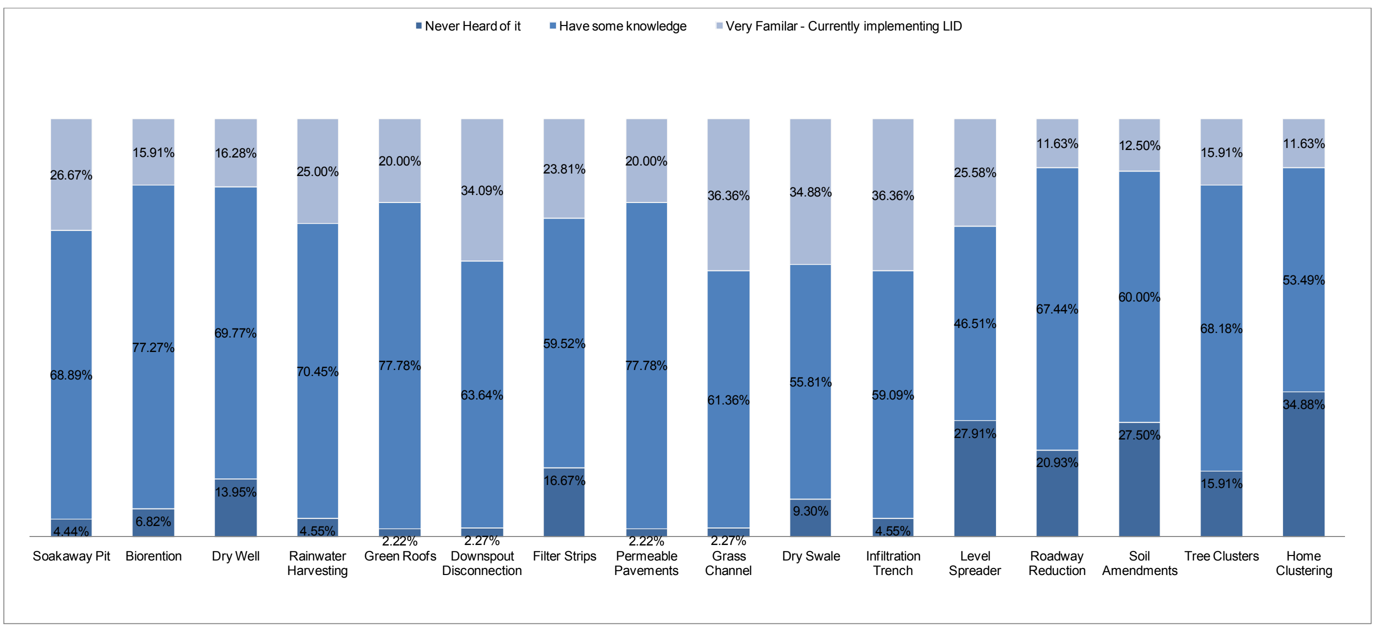

Figure D.3-1: Knowledge of LID practices held by LID Workshop Attendees (Sample #1 Results)

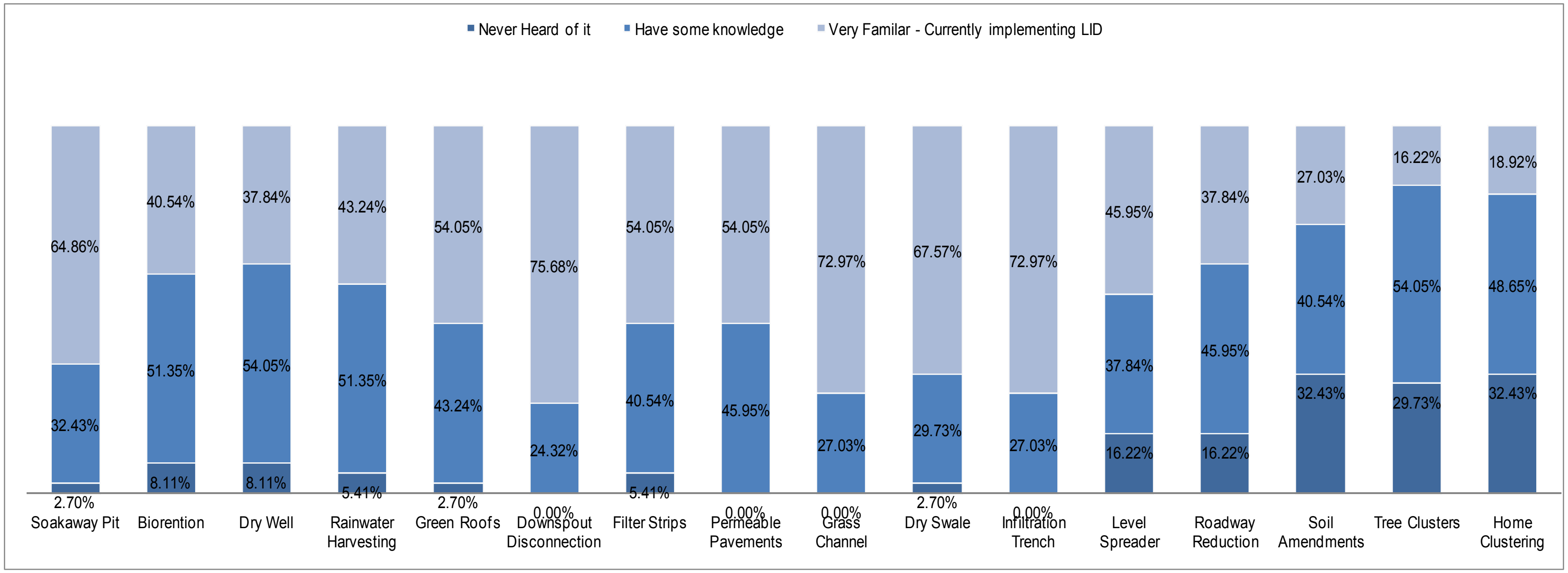

Figure D.3-2: Knowledge of LID practices by SWM Conference Attendees (Sample 2 Results)

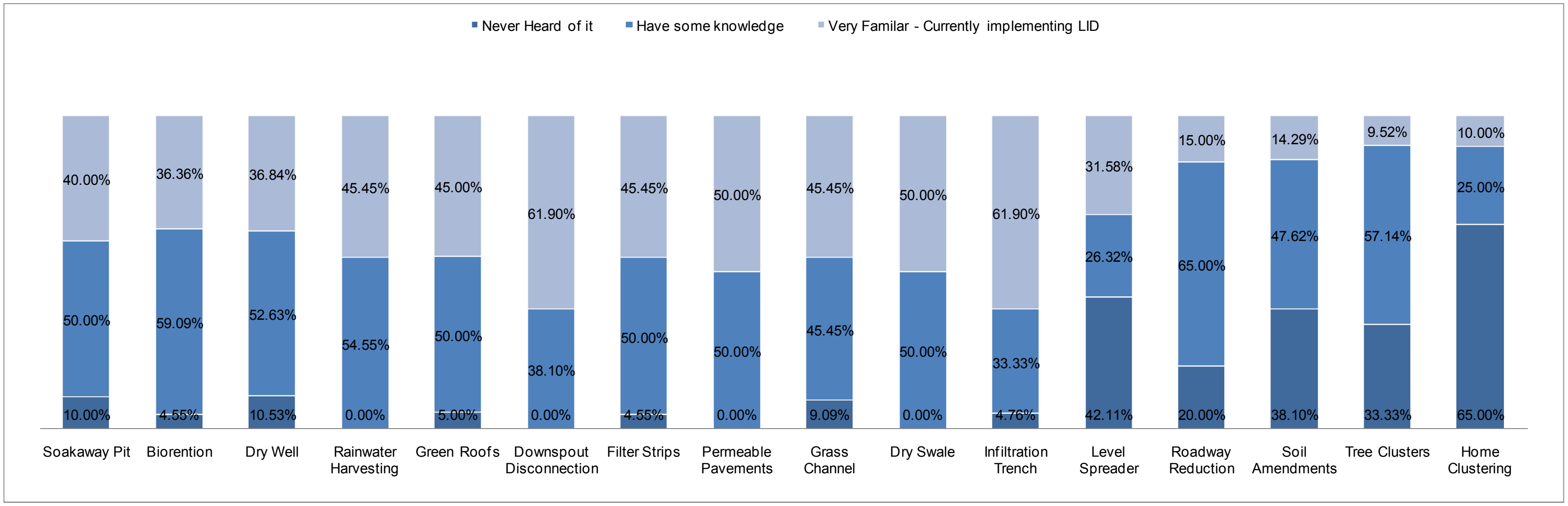

Figure D.3-3: Knowledge of LID practices by Training Workshop Attendees (Sample 3 Results)

Table D.3-3: Percentage of survey participants that "have some knowledge" or "very familiar" with LID practices in each sample

LID Practices	Sample 1: LSRCA LID Workshop	Sample 2: SWM Conference	Sample 3: TRCA/CSA LID Training Course	Average
Soakaway Pit	95.56%	97.30%	90.00%	94.29%
Biorention	93.18%	91.89%	95.45%	93.51%
Dry Well	86.05%	91.89%	89.47%	89.14%
Rainwater Harvesting	95.45%	94.59%	100.00%	96.68%
Green Roofs	97.78%	97.30%	95.00%	96.69%
Downspout Disconnection	97.73%	100.00%	100.00%	99.24%
Filter Strips	83.33%	94.59%	95.45%	91.13%
Permeable Pavements	97.78%	100.00%	100.00%	99.26%
Grass Channel	97.72%	100.00%	90.91%	96.21%
Dry Swale	90.69%	97.30%	100.00%	96.00%
Infiltration Trench	95.45%	100.00%	95.24%	96.90%
Level Spreader	72.09%	83.78%	57.89%	71.26%
Roadway Reduction	79.07%	83.78%	80.00%	80.95%
Soil Amendments	72.50%	67.57%	61.90%	67.32%
Tree Clusters	84.09%	70.27%	66.67%	73.68%
Home Clustering	65.12%	67.57%	35.00%	55.90%

Table D.3-4: Percentage of survey participants that indicated to be "very familiar" with LID practices in each sample

LID Practices	Sample 1: LSRCA LID Workshop	Sample 2: SWM Conference	Sample 3: TRCA/CSA LID Training Course	Average
Soakaway Pit	26.67%	64.86%	40.00%	43.84%
Biorention	15.91%	40.54%	36.36%	30.94%
Dry Well	16.28%	37.84%	36.84%	30.32%
Rainwater Harvesting	25.00%	43.24%	45.45%	37.90%
Green Roofs	20.00%	54.05%	45.00%	39.68%
Downspout Disconnection	34.09%	75.68%	61.90%	57.22%
Filter Strips	23.81%	54.05%	45.45%	41.11%
Permeable Pavements	20.00%	54.05%	50.00%	41.35%
Grass Channel	36.36%	72.97%	45.45%	51.60%
Dry Swale	34.88%	67.57%	50.00%	50.82%
Infiltration Trench	36.36%	72.97%	61.90%	57.08%
Level Spreader	25.58%	45.95%	31.58%	34.37%
Roadway Reduction	11.63%	37.84%	15.00%	21.49%
Soil Amendments	12.50%	27.03%	14.29%	17.94%
Tree Clusters	15.91%	16.22%	9.52%	13.88%
Home Clustering	11.63%	18.92%	10.00%	13.52%

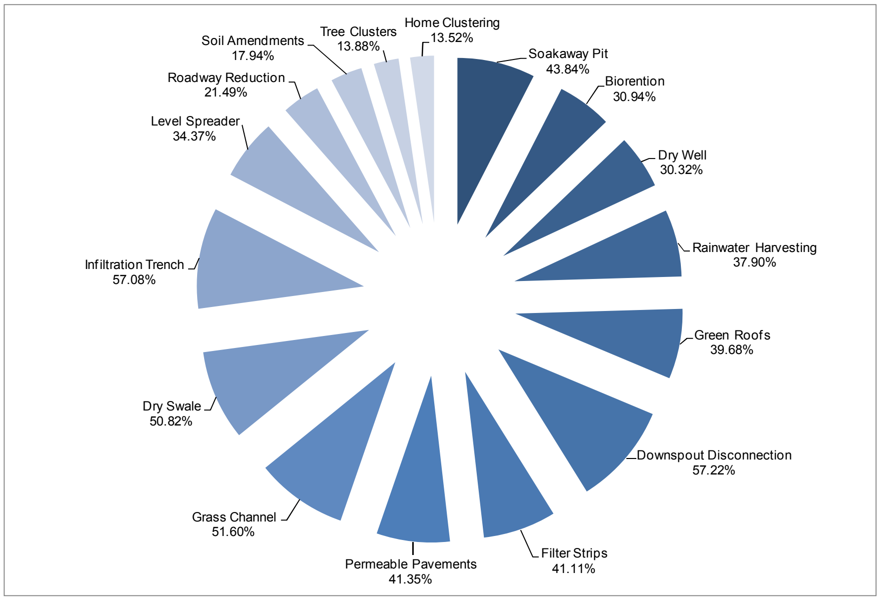

Figure D.3-4: Average percentage of respondents among all samples who are "very familiar" with LID practices

LID practices most likely to be supported by stakeholders in watershed

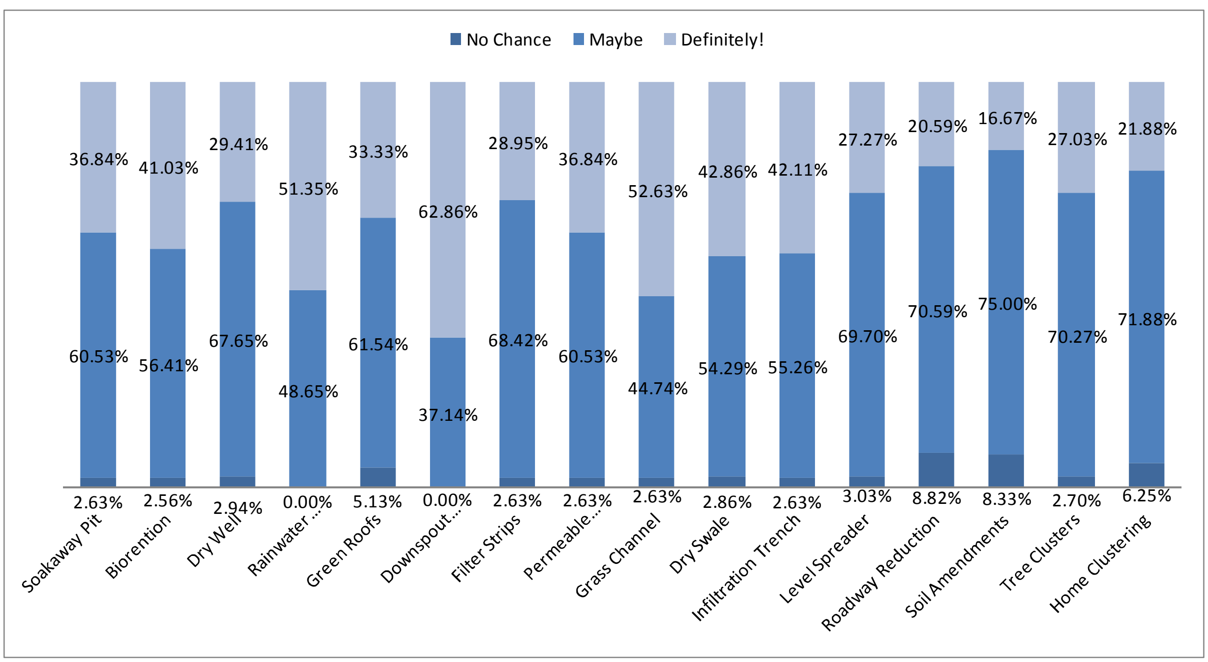

Figure D.3-5: Likeliness to invest in LID practices (Sample 1)

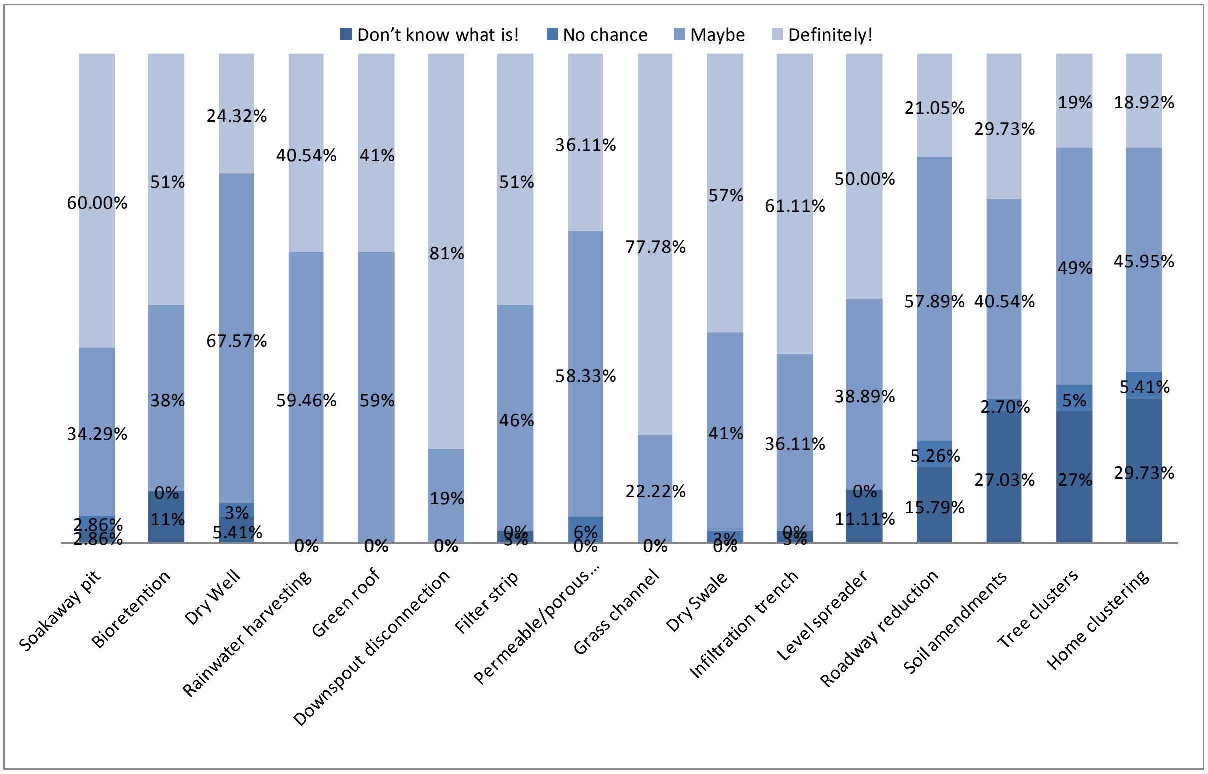

Figure D.3-6: LID practices most likely to implement by stakeholder groups in watershed (Sample 2)

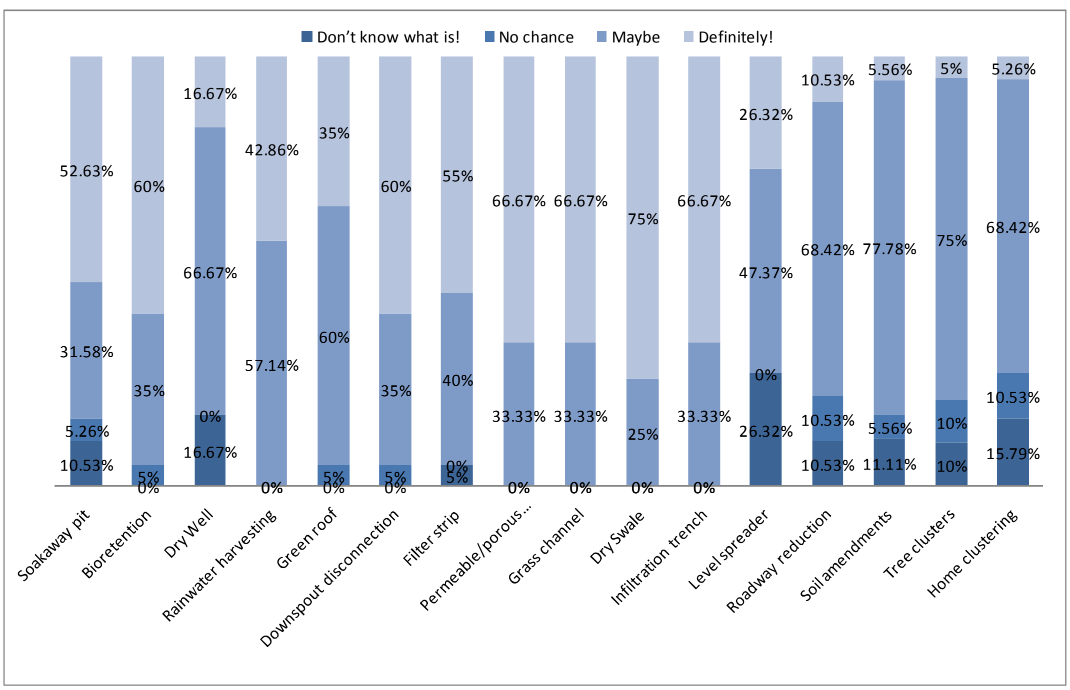

Figure D.3-7: LID practices most likely to implement by stakeholder groups in watershed (Sample 3)

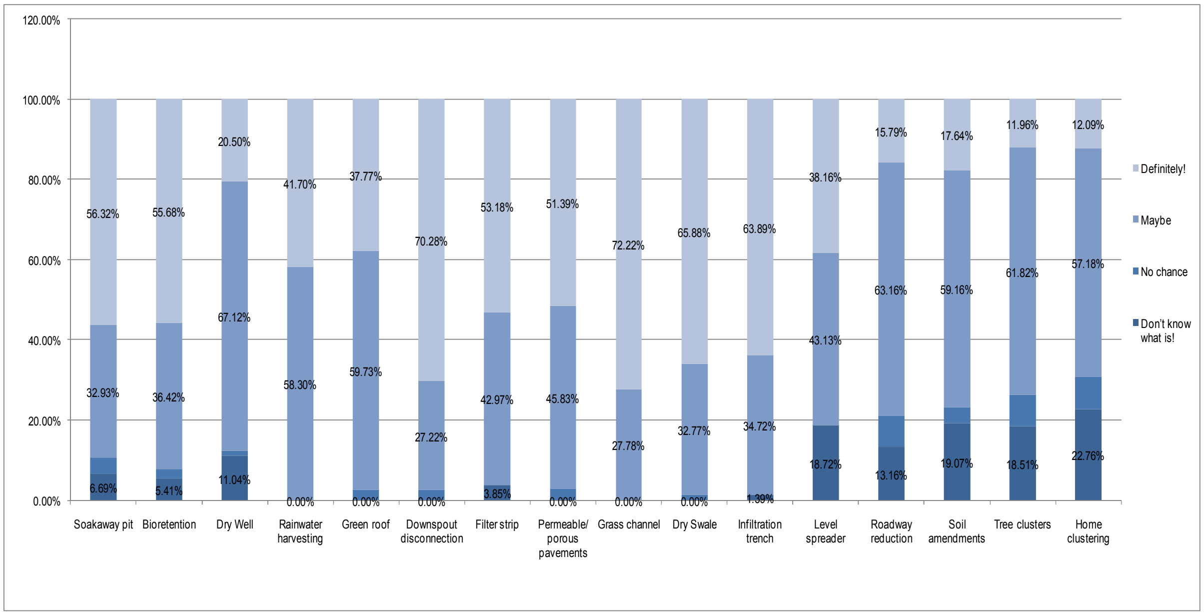

Figure D.3-8: Average results of Sample 2 and Sample 3 of LID practices most likely to implement by stakeholder groups in watershed

Table D.3-5: LID practice most likely to implement (Sample 2 and Sample3)

LID Practices	Sample 2: SWM Conference					Sample 3: TRCA/CSA LID Training Co			
	Likeliness to implement ranking								
	Don't know what is!	No chance	Maybe	Definitely!	Maybe +Definitely	Don't know what is!	No chance	Maybe	Definitely!
Soakaway pit	2.86%	2.86%	34.29%	60.00%	94.29%	10.53%	5.26%	31.58%	52.63%
Bioretention	10.81%	0.00%	37.84%	51.35%	89.19%	0.00%	5.00%	35.00%	60.00%
Dry Well	5.41%	2.70%	67.57%	24.32%	91.89%	16.67%	0.00%	66.67%	16.67%
Rainwater harvesting	0.00%	0.00%	59.46%	40.54%	100.00%	0.00%	0.00%	57.14%	42.86%
Green roof	0.00%	0.00%	59.46%	40.54%	100.00%	0.00%	5.00%	60.00%	35.00%
Downspout disconnection	0.00%	0.00%	19.44%	80.56%	100.00%	0.00%	5.00%	35.00%	60.00%
Filter strip	2.70%	0.00%	45.95%	51.35%	97.30%	5.00%	0.00%	40.00%	55.00%
Permeable/ porous pavements	0.00%	5.56%	58.33%	36.11%	94.44%	0.00%	0.00%	33.33%	66.67%
Grass channel	0.00%	0.00%	22.22%	77.78%	100.00%	0.00%	0.00%	33.33%	66.67%
Dry Swale	0.00%	2.70%	40.54%	56.76%	97.30%	0.00%	0.00%	25.00%	75.00%
Infiltration trench	2.78%	0.00%	36.11%	61.11%	97.22%	0.00%	0.00%	33.33%	66.67%
Level spreader	11.11%	0.00%	38.89%	50.00%	88.89%	26.32%	0.00%	47.37%	26.32%
Roadway reduction	15.79%	5.26%	57.89%	21.05%	78.95%	10.53%	10.53%	68.42%	10.53%
Soil amendments	27.03%	2.70%	40.54%	29.73%	70.27%	11.11%	5.56%	77.78%	5.56%
Tree clusters	27.03%	5.41%	48.65%	18.92%	67.57%	10.00%	10.00%	75.00%	5.00%
Home clustering	29.73%	5.41%	45.95%	18.92%	64.86%	15.79%	10.53%	68.42%	5.26%

Table D.3-6: Average results for Sample 2 and 3

LID Practices	Average results of Sample 2 and Sample 3				
	Likeliness to implement ranking				
	Don't know what is!	No chance	Maybe	Definitely!	Maybe +Definitely
Soakaway pit	6.69%	4.06%	32.93%	56.32%	89.25%
Bioretention	5.41%	2.50%	36.42%	55.68%	92.09%
Dry Well	11.04%	1.35%	67.12%	20.50%	87.62%
Rainwater harvesting	0.00%	0.00%	58.30%	41.70%	100.00%
Green roof	0.00%	2.50%	59.73%	37.77%	97.50%
Downspout disconnection	0.00%	2.50%	27.22%	70.28%	97.50%
Filter strip	3.85%	0.00%	42.97%	53.18%	96.15%
Permeable/ porous pavements	0.00%	2.78%	45.83%	51.39%	97.22%
Grass channel	0.00%	0.00%	27.78%	72.22%	100.00%
Dry Swale	0.00%	1.35%	32.77%	65.88%	98.65%
Infiltration trench	1.39%	0.00%	34.72%	63.89%	98.61%
Level spreader	18.72%	0.00%	43.13%	38.16%	81.29%
Roadway reduction	13.16%	7.90%	63.16%	15.79%	78.95%
Soil amendments	19.07%	4.13%	59.16%	17.64%	76.81%
Tree clusters	18.51%	7.70%	61.82%	11.96%	73.78%
Home clustering	22.76%	7.97%	57.18%	12.09%	69.27%

Reasons for Implementation

Table D.3-7: Reason for implementation indicated by survey participants of Sample 2

LID Practice	Reasons for Implementation									
	Will not implement	Low capital & implementation costs	Low O&M costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits	Other reasons
Soakaway pit	1.10%	10.99%	12.09%	10.99%	15.38%	7.69%	0.00%	19.78%	19.78%	2.20%
Bioretention	1.30%	6.49%	7.79%	6.49%	18.18%	15.58%	0.00%	23.38%	18.18%	2.60%
Dry Well	0.00%	11.11%	11.11%	8.89%	11.11%	6.67%	0.00%	17.78%	28.89%	4.44%
Rainwater harvesting	0.00%	7.84%	11.76%	0.00%	9.80%	1.96%	5.88%	29.41%	29.41%	3.92%
Green roof	1.09%	1.09%	3.26%	5.43%	15.22%	20.65%	6.52%	26.09%	17.39%	3.26%
Downspout disconnection	0.00%	20.19%	17.31%	9.62%	13.46%	1.92%	2.88%	14.42%	18.27%	1.92%
Filter strip	0.00%	11.69%	16.88%	7.79%	9.09%	15.58%	0.00%	22.08%	14.29%	2.60%
Permeable/porous pavements	5.66%	1.89%	0.00%	3.77%	16.98%	9.43%	1.89%	26.42%	28.30%	5.66%
Grass channel	0.00%	15.89%	17.76%	12.15%	9.35%	14.02%	0.93%	14.02%	14.02%	1.87%
Dry Swale	0.00%	15.85%	18.29%	8.54%	7.32%	13.41%	1.22%	13.41%	19.51%	2.44%
Infiltration trench	1.41%	7.04%	8.45%	14.08%	15.49%	4.23%	1.41%	25.35%	19.72%	2.82%
Level spreader	0.00%	21.82%	20.00%	9.09%	9.09%	7.27%	0.00%	10.91%	18.18%	3.64%
Roadway reduction	5.26%	12.28%	8.77%	1.75%	14.04%	10.53%	0.00%	14.04%	28.07%	5.26%
Soil amendments	6.38%	12.77%	19.15%	2.13%	12.77%	4.26%	0.00%	17.02%	21.28%	4.26%
Tree clusters	1.92%	11.54%	13.46%	3.85%	9.62%	23.08%	3.85%	17.31%	11.54%	3.85%
Home clustering	2.94%	14.71%	11.76%	2.94%	8.82%	8.82%	0.00%	26.47%	17.65%	5.88%
Total number of reason selected		6.00	9.00	0.00	6.00	4.00	0.00	13.00	14.00	
Total number of reason selected (%)		37.50%	56.25%	0.00%	37.50%	25.00%	0.00%	81.25%	87.50%	

Table D.3-8: Reason for implementation indicated by survey participants of Sample 3

LID Practice	Reasons for Implementation									
	Will not implement	Low capital & implementation costs	Low O&M costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits	Other reasons
Soakaway pit	0.00%	17.07%	12.20%	14.63%	19.51%	2.44%	0.00%	17.07%	17.07%	0.00%
Bioretention	0.00%	13.04%	6.52%	6.52%	19.57%	13.04%	2.17%	23.91%	15.22%	0.00%
Dry Well	0.00%	12.00%	12.00%	12.00%	24.00%	0.00%	0.00%	20.00%	16.00%	4.00%
Rainwater harvesting	0.00%	15.63%	12.50%	12.50%	25.00%	0.00%	3.13%	15.63%	15.63%	0.00%
Green roof	6.06%	0.00%	0.00%	12.12%	27.27%	18.18%	6.06%	15.15%	15.15%	0.00%
Downspout disconnection	0.00%	21.28%	12.77%	10.64%	19.15%	2.13%	4.26%	17.02%	12.77%	0.00%
Filter strip	0.00%	17.39%	15.22%	10.87%	21.74%	4.35%	2.17%	15.22%	13.04%	0.00%
Permeable/porous pavements	2.38%	0.00%	4.76%	14.29%	28.57%	9.52%	4.76%	19.05%	16.67%	0.00%
Grass channel	0.00%	22.22%	15.56%	8.89%	22.22%	8.89%	2.22%	13.33%	6.67%	0.00%
Dry Swale	0.00%	19.51%	17.07%	9.76%	19.51%	7.32%	2.44%	14.63%	9.76%	0.00%
Infiltration trench	0.00%	16.67%	14.29%	11.90%	16.67%	4.76%	0.00%	21.43%	14.29%	0.00%
Level spreader	5.26%	26.32%	5.26%	10.53%	15.79%	0.00%	0.00%	15.79%	15.79%	5.26%
Roadway reduction	6.25%	6.25%	6.25%	6.25%	18.75%	6.25%	0.00%	25.00%	25.00%	0.00%
Soil amendments	4.76%	14.29%	14.29%	4.76%	23.81%	0.00%	0.00%	19.05%	14.29%	4.76%
Tree clusters	0.00%	10.00%	16.67%	3.33%	16.67%	13.33%	0.00%	23.33%	13.33%	3.33%
Home clustering	9.52%	9.52%	14.29%	4.76%	14.29%	14.29%	0.00%	14.29%	19.05%	0.00%
Total number of reason selected		9	6	0	16	2	0	14	10	
Total number of reason selected (%)		56%	38%	0%	100%	13%	0%	88%	63%	0%

Table D.3-9: Average results for reasons (Sample 2 and 3)

LID Practice	Reasons for Implementation									
	Will not implement	Low capital & implementation costs	Low O&M costs	Clear existing guidelines & standards	Proven case studies of effectiveness & performance	Aesthetics	Existing rebates & financial support programs	Significant environmental benefits	Reduces infrastructure required to achieve stormwater benefits	Other reasons
Soakaway pit	0.55%	14.03%	12.14%	12.81%	17.45%	5.07%	0.00%	18.43%	18.43%	1.10%
Bioretention	0.65%	9.77%	7.16%	6.51%	18.87%	14.31%	1.09%	23.64%	16.70%	1.30%
Dry Well	0.00%	11.56%	11.56%	10.44%	17.56%	3.33%	0.00%	18.89%	22.44%	4.22%
Rainwater harvesting	0.00%	11.73%	12.13%	6.25%	17.40%	0.98%	4.50%	22.52%	22.52%	1.96%
Green roof	3.57%	0.54%	1.63%	8.78%	21.25%	19.42%	6.29%	20.62%	16.27%	1.63%
Downspout disconnection	0.00%	20.73%	15.04%	10.13%	16.31%	2.03%	3.57%	15.72%	15.52%	0.96%
Filter strip	0.00%	14.54%	16.05%	9.33%	15.42%	9.97%	1.09%	18.65%	13.66%	1.30%
Permeable/porous pavements	4.02%	0.94%	2.38%	9.03%	22.78%	9.48%	3.32%	22.73%	22.48%	2.83%
Grass channel	0.00%	19.06%	16.66%	10.52%	15.78%	11.45%	1.58%	13.68%	10.34%	0.93%
Dry Swale	0.00%	17.68%	17.68%	9.15%	13.41%	10.37%	1.83%	14.02%	14.63%	1.22%
Infiltration trench	0.70%	11.85%	11.37%	12.99%	16.08%	4.49%	0.70%	23.39%	17.00%	1.41%
Level spreader	2.63%	24.07%	12.63%	9.81%	12.44%	3.64%	0.00%	13.35%	16.99%	4.45%
Roadway reduction	5.76%	9.27%	7.51%	4.00%	16.39%	8.39%	0.00%	19.52%	26.54%	2.63%
Soil amendments	5.57%	13.53%	16.72%	3.44%	18.29%	2.13%	0.00%	18.03%	17.78%	4.51%
Tree clusters	0.96%	10.77%	15.06%	3.59%	13.14%	18.21%	1.92%	20.32%	12.44%	3.59%
Home clustering	6.23%	12.11%	13.03%	3.85%	11.55%	11.55%	0.00%	20.38%	18.35%	2.94%
Total number of reason selected		4	5	0	11	2	0	13	10	
Total number of reason selected (%)		25%	31%	0%	69%	13%	0%	81%	63%	0%

Main Concerns and Barriers to LID Implementation

Table D.3-10: Concerns and barriers for LID implementation in each sample

Barriers	Sample 1: LSRCA LID Workshop			Sample 2: SWM Conference				Sample 3: TRCA/CSA LID Training Course			
	Barrier Ranking										
	Low	Medium	High	Not a barrier	Low	Medium	High	Not a barrier	Low	Medium	High
Costs – capital	7.14%	30.95%	61.90%	5.71%	11.43%	34.29%	48.57%	0.00%	10.53%	52.63%	36.84%
Cost – O&M	2.44%	17.07%	80.49%	8.57%	8.57%	40.00%	42.86%	0.00%	11.76%	58.82%	29.41%
Time and effort to implement as well as to maintain over	Option not included in survey			5.71%	8.57%	57.14%	28.57%	0.00%	5.88%	70.59%	23.53%
Lack of design guidelines/standards/policies	0.00%	54.76%	45.24%	2.78%	19.44%	41.67%	36.11%	5.88%	11.76%	41.18%	41.18%
Possible long payback period	22.86%	34.29%	42.86%	8.57%	28.57%	48.57%	14.29%	10.53%	36.84%	31.58%	21.05%
Lack of Life-cycle-analysis and economic studies	Option not included in survey			14.71%	23.53%	23.53%	38.24%	5.88%	17.65%	35.29%	41.18%
Space	22.86%	51.43%	25.71%	10.53%	18.42%	42.11%	28.95%	0.00%	16.67%	44.44%	38.89%
Municipal approval	19.44%	50.00%	30.56%	20.59%	23.53%	14.71%	41.18%	5.56%	27.78%	16.67%	50.00%
Liability	15.00%	40.00%	45.00%	13.89%	22.22%	30.56%	33.33%	0.00%	31.58%	26.32%	42.11%
Buy-in: gain acceptance from influencing stakeholders (i.e., support from public, government, upper management, etc.,)	0.00%	65.79%	34.21%	11.43%	8.57%	28.57%	51.43%	5.26%	15.79%	26.32%	52.63%
Aesthetics	29.03%	54.84%	16.13%	44.44%	36.11%	19.44%	0.00%	15.79%	52.63%	15.79%	15.79%
Winter maintenance:	Option not included in survey			11.11%	25.00%	47.22%	16.67%	5.56%	22.22%	44.44%	27.78%
Lack of existing examples and case studies	Option not included in survey			8.33%	30.56%	41.67%	19.44%	6.25%	31.25%	37.50%	25.00%
Minimal simulation models and tools to predict performance and effectiveness	Option not included in survey			8.11%	24.32%	40.54%	27.03%	12.50%	12.50%	56.25%	18.75%

Table D.3-11: Main concerns identified by each stakeholder group in Sample 2 and 3

Barriers	Main Stakeholder Groups											
	Municipal Governments			Conservation Authorities			Private Consulting Firms			Stormwater Professionals		
	Sample 2	Sample 3	Average	Sample 2	Sample 3	Average	Sample 2	Sample 3	Average	Sample 2	Sample 3	Average
Costs – capital	57.85%	54.29%	56.07%	5.88%	10.00%	7.94%	30.88%	28.57%	29.73%	82.85%	54.29%	68.57%
Cost – O&M	68.10%	60.00%	64.05%	6.67%	10.00%	8.34%	20.96%	40.00%	30.48%	90.00%	60.00%	75.00%
Time and effort to implement and maintain over time	65.00%	83.33%	74.17%	5.00%	8.33%	6.67%	40.00%	41.67%	40.84%	70.00%	25.00%	47.50%
Lack of design guidelines/ standards/policies	75.90%	57.15%	66.53%	6.67%	14.29%	10.48%	28.71%	42.86%	35.79%	68.71%	42.86%	55.79%
Space	89.20%	66.07%	77.64%	6.25%	28.57%	17.41%	12.50%	37.50%	25.00%	79.55%	42.86%	61.21%
Buy-in: gain acceptance from influencing stakeholders	67.78%	Not selected	67.78%	0.00%	Not selected	0.00%	22.22%	Not selected	22.22%	80.00%	Not selected	80.00%

Table D.3-12: Perception of benefits in Sample 2 and 3

Benefits	Sample 1: LSRCA LID Workshop				Sample 2: SWM Conference					Sample 3: TRCA/CSA LID Training Course				
	Benefit Ranking													
	Low	Medium	High	Medium & High	Not a benefit	Low	Medium	High	Medium & High	Not a benefit	Low	Medium	High	Medium & High
Possible rebates	25.71%	40.00%	34.29%	74.29%	14.71%	38.24%	26.47%	20.59%	47.06%	5.88%	17.65%	35.29%	41.18%	76.47%
Public image	11.63%	51.16%	37.21%	88.37%	0.00%	8.33%	47.22%	44.44%	91.67%	0.00%	16.67%	44.44%	38.89%	83.33%
Aesthetics	17.50%	55.00%	27.50%	82.50%	0.00%	16.67%	44.44%	38.89%	83.33%	5.56%	5.56%	50.00%	38.89%	88.89%
Environmental benefits	2.17%	21.74%	76.09%	97.83%	0.00%	0.00%	11.11%	88.89%	100.00%	0.00%	5.26%	26.32%	68.42%	94.74%
Reduces infrastructure and utility maintenance costs (i.e., streets, curbs, storm sewers)	25.00%	32.50%	42.50%	75.00%	2.63%	18.42%	36.84%	42.11%	78.95%	5.56%	0.00%	50.00%	44.44%	94.44%
Can be integrated into existing infrastructure	Option not included in survey				2.78%	25.00%	44.44%	27.78%	72.22%	0.00%	16.67%	55.56%	27.78%	83.33%
Assists in meeting regulatory obligations.	Option not included in survey				7.89%	21.05%	36.84%	34.21%	71.05%	5.56%	5.56%	38.89%	50.00%	88.89%
Assists in meeting LEED certification requirements.	Option not included in survey				11.11%	11.11%	44.44%	33.33%	77.78%	5.56%	16.67%	33.33%	44.44%	77.78%
Reduces stormwater management construction costs.	Option not included in survey				7.89%	21.05%	34.21%	36.84%	71.05%	16.67%	5.56%	38.89%	38.89%	77.78%
Increased property value	Option not included in survey				21.62%	27.03%	32.43%	18.92%	51.35%	0.00%	11.11%	38.89%	50.00%	88.89%
Potentially increases lot yields/amount of developable land	Option not included in survey				5.41%	27.03%	32.43%	35.14%	67.57%	11.11%	27.78%	16.67%	44.44%	61.11%
Provides environmental education opportunities	Option not included in survey				0.00%	26.47%	41.18%	32.35%	73.53%	0.00%	35.29%	35.29%	29.41%	64.71%
No benefits	66.67%	33.33%	0.00%	33.33%	Option not included in survey					Option not included in survey				

Table D.3-13: Perception of benefits held by main stakeholder in Sample 2 and 3

Top Benefits	Main Stakeholder Groups							
	Municipal Governments		Conservation Authorities		Private Consulting Firms		Stormwater Professionals	
	Sample 2	Sample 3	Sample 2	Sample 3	Sample 2	Sample 3	Sample 2	Sample 3
Public image	100.00%	Not selected	100.00%	Not selected	83.33%	Not selected	83.34%	Not selected
Aesthetics	91.66%	100.00%	100.00%	100.00%	66.67%	100.00%	91.66%	80.00%
Environmental benefits	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Reduces infrastructure and utility maintenance costs (i.e., streets, curbs, storm sewers)	Not selected	100.00%	Not selected	100.00%	Not selected	100.00%	Not selected	80.00%
Assists in meeting regulatory obligations.	Not selected	83.33%	Not selected	100.00%	Not selected	100.00%	Not selected	100.00%
Increased property value	Not selected	80.00%	Not selected	100.00%	Not selected	10.00%	Not selected	100.00%

Table D.3-14: Drivers identified by survey participants in each sample group

Drivers	Sample 1: LSRCA LID Workshop	Sample 2: SWM Conference	Sample 3: TRCA/CSA LID Training Course
Developers	14.62%	13.86%	7.69%
Municipal programs and policies (rebates, by-laws, education, stormwater charges,	**31.54%**	**29.70%**	**30.77%**
Provincial regulations and guidelines	**31.54%**	**30.69%**	**34.62%**
Private citizens and corporations	8.46%	4.95%	3.85%
Grassroot initiatives	10.77%	7.92%	5.77%
Local NGOs	3.08%	5.94%	7.69%
Community Groups	Option not included in survey	0.99%	7.69%
Market – Strong desire for environmental responsibility	Option not included in survey	5.94%	1.92%

Table D.3-15: Incentive programs identified by survey participants

Incentives	Sample 1: LSRCA LID Workshop	Sample 2: SWM Conference	Sample 3: TRCA/CSA LID Training Course	Average
Reduced requirements for stormwater management	25.66%	12.09%	8.43%	15.39%
Recognition program	16.81%	9.89%	14.46%	13.72%
Streamlined approvals (e.g., accelerated reviews for site	25.66%	14.29%	12.05%	17.33%
Tax credit for qualifying LID techniques*	Option not included in survey	11.54%	13.25%	12.39%
Bonus (i.e., municipal rebate, increased floor area (ratio), etc)	28.32%	13.74%	14.46%	18.84%
Reduce fees (e.g., plan review fees, utility fees) for site plans*	Option not included in survey	9.34%	9.64%	9.49%
Grants for funding LID projects including for demonstration and	Option not included in survey	9.89%	12.05%	10.97%
Credits for stormwater utility fees*	Option not included in survey	13.19%	0.08	10.81%
Regulatory-based schemes (i.e., ordinances, policies, etc)*	Option not included in survey	5.49%	7.23%	6.36%

Table D.3-16: Perception of costs indicated by survey participants in Sample 2 and Sample 3

LID Practice	Sample 2: SWM Conference			Sample 3: TRCA/CSA LID Training Course		
	Cost Ranking					
	Low	Medium	High	Low	Medium	High
Soakaway pit	55.56%	38.89%	5.56%	70.59%	29.41%	0.00%
Bioretention	29.41%	38.24%	32.35%	23.53%	58.82%	17.65%
Dry Well	47.22%	41.67%	11.11%	56.25%	43.75%	0.00%
Rainwater harvesting	27.03%	48.65%	24.32%	41.18%	23.53%	35.29%
Green roof	2.86%	14.29%	82.86%	11.76%	0.00%	88.24%
Downspout disconnection	94.59%	5.41%	0.00%	94.12%	5.88%	0.00%
Filter strip	64.86%	29.73%	5.41%	58.82%	35.29%	5.88%
Permeable/porous pavements	0.00%	41.67%	58.33%	11.76%	52.94%	35.29%
Grass channel	81.58%	15.79%	2.63%	70.59%	29.41%	0.00%
Dry Swale	82.86%	17.14%	0.00%	76.47%	23.52%	0.00%
Infiltration trench	19.44%	69.44%	11.11%	23.53%	76.47%	0.00%
Level spreader	56.25%	43.75%	0.00%	60.00%	33.33%	6.67%
Roadway reduction	51.52%	39.39%	9.09%	43.75%	37.50%	18.75%
Soil amendments	35.71%	35.71%	28.57%	33.33%	33.33%	33.33%
Tree clusters	57.69%	38.46%	3.85%	50.00%	21.43%	28.57%
Home clustering	44.00%	32.00%	24.00%	53.85%	30.77%	15.38%

APPENDIX D.4: Overall case study results and decision-making data

Table D.4-1: Runoff Volume Assessment Case Study Results

Stormsewershed ID	Stormsewershed Area (m^2)	Total Runoff of Stormsewershed (m^3)	Maximum Potential of Stormsewershed Volume Reduction (%)	LID Type	Applicable Area (m^2)	Total Runoff, in m^3		Volume Reduction of Applicable Area (%)	Stormsewershed Volume Reduction (%)	Runoff Volume Removed by LID (mm/m^2) in Stormwatershed
						(without LID)	(with LID)			
BAR-C1	1,071,530	704,193	10	Green Roof	48,736.71	65,825	61,352	6.79	0.64	4.17
				Soakaway Pit	154,211.36	130,252	116,930	10.23	1.89	12.43
				Downspout Disconnection	185,079.53	165,787	109,738	33.81	7.96	52.31
				Dry Well	184,156.56	176,182	153,240	13.02	3.26	21.41
				Rainwater Harvesting	184,340.67	166,147	99,015	40.41	9.53	62.65
BAR-C11	26,627	12,340	14	Green Roof	-	-	-	-----	-----	-
				Soakaway Pit	3,410.03	3,011	2,702	10.25	2.50	11.59
				Downspout Disconnection	3,693.08	3,011	1,623	46.11	11.25	52.14
				Dry Well	3,280.65	3,308	2,799	-	-	19.13
				Rainwater Harvesting	2,997.60	3,011	1,340	55.50	13.54	62.75
BAR-C12	171,839	220,580	4	Green Roof	41,020.11	41,489	37,477	9.67	1.82	23.35
				Soakaway Pit	20,022.10	25,736	23,762	7.67	0.90	11.49
				Downspout Disconnection	38,059.69	48,470	42,091	13.16	2.89	37.13
				Dry Well	39,902.77	52,985	50,240	5.18	1.24	15.97
				Rainwater Harvesting	39,964.05	51,900	42,380	18.34	4.32	55.40
BAR-C15	79,906	2,038	2	Green Roof	442.60	2,038	2,001	1.84	1.84	0.47
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-C16	234,508	150,250	5	Green Roof	29,179.50	42,169	38,833	7.91	2.22	14.23
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	23,917.30	36,027	31,219	13.35	3.20	20.50
				Dry Well	24,145.22	36,027	33,390	7.32	1.75	11.24
				Rainwater Harvesting	24,145.22	36,027	29,169	19.04	4.56	29.25
BAR-C17	52,794	-	0	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-C18	622,619	658,739	6	Green Roof	148,776.26	151,927	137,614	9.42	2.17	22.99
				Soakaway Pit	2,142.23	3,730	3,342	10.41	0.06	0.62
				Downspout Disconnection	157,043.21	170,177	143,703	15.56	4.02	42.52
				Dry Well	154,798.05	166,452	151,174	9.18	2.32	24.54
				Rainwater Harvesting	154,798.05	166,452	128,885	22.57	5.70	60.34
BAR-C19	132,171	151,991	8	Green Roof	21,343.66	21,880	19,559	10.61	1.53	17.56
				Soakaway Pit	8,545.94	7,137	6,214	12.93	0.61	6.98
				Downspout Disconnection	38,490.49	33,820	24,893	26.40	5.87	67.54
				Dry Well	38,416.14	55,238	47,882	13.32	4.84	55.66
				Rainwater Harvesting	38,416.14	33,916	22,259	34.37	7.67	88.20
BAR-C21	103,637	71,403	12	Green Roof	3,124.66	3,625	3,283	9.43	0.48	3.30
				Soakaway Pit	10,653.00	9,818	8,753	10.85	1.49	10.28
				Downspout Disconnection	18,317.60	16,717	10,938	34.57	8.09	55.77
				Dry Well	18,428.50	22,398	19,269	13.97	4.38	30.19
				Rainwater Harvesting	20,417.19	18,844	10,514	44.20	11.67	80.37
BAR-C22	46,207	29,738	5	Green Roof	7,441.89	5,763	5,251	8.87	1.72	11.06
				Soakaway Pit	5,718.65	4,029	3,698	8.20	1.11	7.15
				Downspout Disconnection	6,334.06	4,575	4,242	7.28	1.12	7.20
				Dry Well	9,441.62	7,006	6,796	2.99	0.70	4.53
				Rainwater Harvesting	9,554.09	8,366	6,906	17.45	4.91	31.59
BAR-C23	350,832	317,061	3	Green Roof	25,238.91	70,187	67,019	4.51	1.00	9.03
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	28,368.05	77,075	69,807	9.43	2.29	20.72
				Dry Well	28,697.94	84,899	82,372	2.98	0.80	7.20
				Rainwater Harvesting	28,697.94	84,899	75,094	11.55	3.09	27.95
BAR-C25	612,525	499,394	5	Green Roof	76,496.34	110,243	102,334	7.17	1.58	12.91
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	88,563.25	124,568	108,409	12.97	3.24	26.38
				Dry Well	90,111.20	132,291	123,568	6.59	1.75	14.24
				Rainwater Harvesting	90,111.20	132,291	108,760	17.79	4.71	38.42
BAR-C26	187,583	201,842	5	Green Roof	30,799.74	38,793	36,209	6.66	1.28	13.78
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	48,011.56	54,350	47,373	12.84	3.46	37.19
				Dry Well	48,011.56	54,350	50,637	6.83	1.84	19.79
				Rainwater Harvesting	48,011.56	54,350	44,498	18.13	4.88	52.52
BAR-C28	103,023	112,895	9	Green Roof	2,762.22	4,566	4,259	6.72	0.27	2.98
				Soakaway Pit	7,261.01	7,291	6,510	10.71	0.69	7.58
				Downspout Disconnection	18,534.14	29,775	23,002	22.75	6.00	65.74
				Dry Well	20,065.53	38,568	34,909	9.49	3.24	35.51
				Rainwater Harvesting	20,065.53	32,696	22,744	30.44	8.81	96.59
BAR-C3	144,361	17,435	14	Green Roof	-	-	-	-----	-----	-
				Soakaway Pit	1,762.28	4,267	3,878	9.12	2.23	2.70
				Downspout Disconnection	1,925.88	4,389	2,421	44.84	11.29	13.63
				Dry Well	195.45	4,389	3,845	12.41	3.12	3.77
				Rainwater Harvesting	195.45	4,389	1,897	56.78	14.29	17.26

BAR-C30	98,969	73,148	5	Green Roof	7,560.38	10,492	10,069	4.03	0.58	4.28
				Soakaway Pit	4,060.58	3,870	3,453	10.77	0.57	4.21
				Downspout Disconnection	5,055.30	12,315	10,394	15.60	2.63	19.42
				Dry Well	11,495.32	23,998	22,976	4.26	1.40	10.32
				Rainwater Harvesting	11,949.14	22,473	19,177	14.67	4.51	33.31
BAR-C32	33,480	-	0	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-C4	287,256	239,541	8	Green Roof	27,666.78	38,407	35,735	6.96	1.12	9.30
				Soakaway Pit	20,915.96	22,553	20,247	10.23	0.96	8.03
				Downspout Disconnection	55,079.07	54,636	39,686	27.36	6.24	52.05
				Dry Well	45,026.42	68,303	61,021	10.66	3.04	25.35
				Rainwater Harvesting	45,677.44	55,642	37,381	32.82	7.62	63.57
BAR-C5	491,364	315,463	8	Green Roof	29,262.84	37,071	34,758	6.24	0.73	4.71
				Soakaway Pit	40,184.00	36,265	32,681	9.88	1.14	7.29
				Downspout Disconnection	76,396.39	74,549	54,271	27.20	6.43	41.27
				Dry Well	58,233.36	93,313	83,946	10.04	2.97	19.06
				Rainwater Harvesting	70,473.72	74,265	48,936	34.11	8.03	51.55
BAR-C8	30,677	29,611	12	Green Roof	4,627.79	3,969	3,466	12.68	1.70	16.41
				Soakaway Pit	1,666.03	1,672	1,512	9.55	0.54	5.21
				Downspout Disconnection	12,153.00	6,006	3,241	46.04	9.34	90.14
				Dry Well	7,478.47	11,459	9,657	-	-	58.74
				Rainwater Harvesting	6,886.27	6,506	3,065	52.89	11.62	112.17
BAR-C9	64,846	56,361	8	Green Roof	5,201.64	7,464	6,903	7.52	1.00	8.65
				Soakaway Pit	1,537.87	1,742	1,565	10.14	0.31	2.73
				Downspout Disconnection	10,976.82	15,114	12,207	19.24	5.16	44.83
				Dry Well	10,908.38	15,907	14,482	8.96	2.53	21.97
				Rainwater Harvesting	11,868.53	16,134	11,747	27.20	7.79	67.67
BAR-NE11	80,042	13,746	16	Green Roof	1,033.24	1,207	1,148	4.89	0.43	0.74
				Soakaway Pit	2,427.99	2,050	1,838	10.35	1.54	2.65
				Downspout Disconnection	5,628.12	4,644	2,502	46.11	15.58	26.75
				Dry Well	2,766.11	3,171	2,694	-	-	5.96
				Rainwater Harvesting	2,766.11	2,674	1,193	55.40	10.78	18.51
BAR-NE12	24,306	2,740	33	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-	-	-----
				Downspout Disconnection	2,749.47	1,972	1,063	46.11	33.19	37.41
				Dry Well	191.37	365	316	-	-	2.01
				Rainwater Harvesting	589.14	403	179	55.44	8.15	9.18
BAR-NE13	592,055	275,581	7	Green Roof	26,066.88	23,233	21,542	7.28	0.61	2.86
				Soakaway Pit	53,911.00	43,689	39,497	9.59	1.52	7.08
				Downspout Disconnection	57,155.05	47,095	31,396	33.33	5.70	26.52
				Dry Well	99,687.86	109,481	95,575	12.70	5.05	23.49
				Rainwater Harvesting	65,135.73	52,083	33,638	35.41	6.69	31.15
BAR-NE14	302,098	117,227	12	Green Roof	2,713.19	3,275	3,122	4.68	0.13	0.51
				Soakaway Pit	34,619.88	27,476	24,640	10.32	2.42	9.39
				Downspout Disconnection	36,495.78	27,077	14,591	46.11	10.65	41.33
				Dry Well	32,616.27	32,806	27,836	15.15	4.24	16.45
				Rainwater Harvesting	33,598.37	26,593	11,954	55.05	12.49	48.46
BAR-NE17	84,721	20,389	28	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	12,656.47	9,994	8,378	16.17	7.92	19.07
				Rainwater Harvesting	14,207.63	10,395	4,746	54.34	27.71	66.68
BAR-NE18	120,072	34,356	24	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	20,107.63	19,003	16,041	15.59	8.62	9.80
				Rainwater Harvesting	20,144.03	15,354	6,985	54.51	24.36	27.70
BAR-NE19	146,146	55,012	19	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	5,223.43	5,169	4,633	10.38	0.98	3.67
				Downspout Disconnection	5,736.45	5,532	2,981	46.11	4.64	17.45
				Dry Well	22,488.48	25,312	21,460	15.22	7.00	26.36
				Rainwater Harvesting	22,566.01	18,999	8,596	54.76	18.91	71.18
BAR-NE20	289,305	143,148	10	Green Roof	7,852.35	9,288	8,718	6.14	0.40	1.97
				Soakaway Pit	33,352.81	31,316	28,392	9.34	2.04	10.11
				Downspout Disconnection	36,393.16	32,594	19,030	41.62	9.48	46.88
				Dry Well	31,549.46	39,892	34,467	13.60	3.79	18.75
				Rainwater Harvesting	30,662.08	30,058	15,154	49.58	10.41	51.51
BAR-NE24	43,481	11,818	24	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	6,291.26	6,722	5,692	15.32	8.72	23.69
				Rainwater Harvesting	6,326.47	5,096	2,312	54.63	23.56	64.02
BAR-NE25	130,886	33,691	22	Green Roof	1,066.92	1,114	1,018	8.63	0.29	0.73
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	-	-	-	-----	-----	-
				Dry Well	16,034.58	17,363	14,869	14.36	7.40	19.05
				Rainwater Harvesting	17,910.87	15,214	7,696	49.42	22.32	57.45
BAR-NE26	43,582	12,348	25	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	7,151.65	6,619	5,582	15.67	8.40	23.80
				Rainwater Harvesting	7,317.22	5,729	2,603	54.56	25.31	71.72
BAR-NE27	143,390	86,442	5	Green Roof	13,110.18	14,380	13,517	6.00	1.00	6.59
				Soakaway Pit	10,052.70	13,302	12,628	5.07	0.78	5.15
				Downspout Disconnection	9,468.07	12,933	11,338	12.34	1.85	12.19
				Dry Well	23,224.83	23,906	22,432	6.17	1.71	11.26
				Rainwater Harvesting	23,286.92	21,921	17,903	18.33	4.65	30.70
BAR-NE28	111,963	35,795	24	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	17,772.65	20,108	17,015	15.38	8.64	27.62
				Rainwater Harvesting	17,893.28	15,687	7,115	54.65	23.95	76.57

BAR-NE29	323,137	203,135	13	Green Roof	7,307.83	8,112	7,474	7.85	0.31	1.97
				Soakaway Pit	42,166.82	39,002	34,853	10.64	2.04	12.84
				Downspout Disconnection	44,426.46	42,549	22,929	46.11	9.66	60.72
				Dry Well	47,668.22	66,341	56,386	15.01	4.90	30.81
				Rainwater Harvesting	48,808.23	47,131	21,306	54.79	12.71	79.92
BAR-NE3	790,414	441,644	9	Green Roof	28,544.35	38,261	35,830	6.35	0.55	3.07
				Soakaway Pit	95,389.12	84,440	75,924	10.08	1.93	10.77
				Downspout Disconnection	103,372.64	95,756	59,920	37.42	8.11	45.34
				Dry Well	99,925.43	131,439	114,285	13.05	3.88	21.70
				Rainwater Harvesting	97,732.89	91,750	51,394	43.98	9.14	51.06
BAR-NE30	123,729	64,211	8	Green Roof	4,767.94	7,327	6,993	4.56	0.52	2.70
				Soakaway Pit	13,164.67	12,202	11,266	7.67	1.46	7.56
				Downspout Disconnection	13,908.96	12,833	9,379	26.91	5.38	27.92
				Dry Well	12,017.09	17,339	15,613	9.96	2.69	13.95
				Rainwater Harvesting	14,479.86	14,510	9,445	34.91	7.89	40.94
BAR-NE31	202,077	140,746	7	Green Roof	16,768.27	15,189	13,852	8.80	0.95	6.62
				Soakaway Pit	32,545.27	29,398	26,574	9.61	2.01	13.97
				Downspout Disconnection	26,317.06	30,998	22,358	27.87	6.14	42.75
				Dry Well	26,351.23	35,194	31,642	10.09	2.52	17.58
				Rainwater Harvesting	25,119.43	29,966	20,256	32.40	6.90	48.05
BAR-NE32	59,077	49,467	5	Green Roof	1,995.77	1,522	1,349	11.39	0.35	2.93
				Soakaway Pit	4,882.07	4,259	3,795	10.90	0.94	7.86
				Downspout Disconnection	11,228.26	14,713	13,021	11.50	3.42	28.64
				Dry Well	10,280.73	14,009	13,496	3.67	1.04	8.69
				Rainwater Harvesting	11,170.33	14,964	12,698	15.14	4.58	38.35
BAR-NE39	1,219,320	742,846	10	Green Roof	69,396.63	63,024	56,265	10.73	0.91	5.54
				Soakaway Pit	112,135.83	106,202	95,050	10.50	1.50	9.15
				Downspout Disconnection	244,381.09	197,152	121,976	38.13	10.12	61.65
				Dry Well	149,183.93	220,101	191,279	13.10	3.88	23.64
				Rainwater Harvesting	161,976.05	156,366	85,899	45.07	9.49	57.79
BAR-NE40	169,460	143,416	5	Green Roof	13,454.01	10,615	9,291	12.47	0.92	7.81
				Soakaway Pit	9,378.73	7,385	6,472	12.36	0.64	5.39
				Downspout Disconnection	45,302.33	32,976	25,494	22.69	5.22	44.15
				Dry Well	27,041.20	67,453	59,951	11.12	5.23	44.27
				Rainwater Harvesting	25,404.14	24,988	19,878	20.45	3.56	30.15
BAR-NE8	495,746	182,824	16	Green Roof	3,384.65	2,731	2,552	6.56	0.10	0.36
				Soakaway Pit	31,805.66	26,019	23,375	10.16	1.45	5.33
				Downspout Disconnection	37,559.94	30,627	16,503	46.11	7.73	28.49
				Dry Well	63,880.64	70,801	60,302	14.83	5.74	21.18
				Rainwater Harvesting	63,880.64	52,645	23,780	54.83	15.79	58.23
BAR-NE9	62,083	15,890	17	Green Roof	2,506.74	2,357	2,129	9.71	1.44	3.69
				Soakaway Pit	1,110.29	1,676	1,521	9.24	0.98	2.50
				Downspout Disconnection	6,301.32	6,211	3,507	43.54	17.02	43.56
				Dry Well	1,569.92	2,884	2,517	12.70	2.31	5.90
				Rainwater Harvesting	2,292.65	2,762	1,417	48.68	8.46	21.66
BAR-NW10	134,366	-	0	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-NW12	545,142	297,107	12	Green Roof	11,623.17	14,109	13,250	6.09	0.29	1.58
				Soakaway Pit	84,950.63	68,826	61,505	10.64	2.46	13.43
				Downspout Disconnection	86,769.56	68,794	39,585	42.46	9.83	53.58
				Dry Well	85,820.55	75,634	64,283	15.01	3.82	20.82
				Rainwater Harvesting	86,748.01	69,743	34,869	50.00	11.74	63.97
BAR-NW28	11,383	23,548	10	Green Roof	1,753.57	3,925	3,787	3.52	0.59	12.13
				Soakaway Pit	1,828.70	3,925	3,604	8.16	1.36	28.14
				Downspout Disconnection	1,828.70	3,925	2,114	46.13	7.69	159.05
				Dry Well	1,828.70	7,849	6,802	13.35	4.45	92.06
				Rainwater Harvesting	1,828.70	3,925	1,685	57.07	9.51	196.76
BAR-NW29	63,588	-	0	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-SE1	29,787	8,814	12	Green Roof	451.46	1,763	1,718	2.52	0.50	3.90
				Soakaway Pit	451.46	1,763	1,633	7.37	1.47	11.42
				Downspout Disconnection	451.46	1,763	949	46.14	9.23	71.45
				Dry Well	451.46	1,763	1,528	13.31	2.66	20.60
				Rainwater Harvesting	451.46	1,763	744	57.81	11.56	89.51
BAR-SE10	12,707	1,265	11	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	259.64	253	230	9.17	1.83	1.83
				Downspout Disconnection	259.64	253	136	46.12	9.22	9.18
				Dry Well	259.64	506	436	13.78	5.51	5.48
				Rainwater Harvesting	259.64	253	111	56.12	11.22	11.17
BAR-SE14	163,266	38,144	13	Green Roof	356.71	332	320	3.90	0.03	0.08
				Soakaway Pit	9,666.78	8,712	7,921	9.07	2.07	4.84
				Downspout Disconnection	9,666.78	8,712	4,693	46.12	10.53	24.61
				Dry Well	9,666.78	11,677	10,015	14.23	4.36	10.18
				Rainwater Harvesting	9,666.78	8,712	3,815	56.21	12.84	29.99
BAR-SE16	8,996	-	0	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
BAR-SE17	146,317	47,855	13	Green Roof	1,930.69	1,303	1,216	6.67	0.18	0.59
				Soakaway Pit	15,264.36	11,199	10,132	9.53	2.23	7.30
				Downspout Disconnection	15,604.97	11,421	6,154	46.12	11.01	36.00
				Dry Well	15,604.97	12,511	10,643	14.93	3.90	12.76
				Rainwater Harvesting	15,604.97	11,421	5,051	55.78	13.31	43.54
BAR-SE21	34,663	1,237	12	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	271.95	273	249	8.88	1.96	0.70
				Downspout Disconnection	271.95	273	147	46.13	10.19	3.64
				Dry Well	271.95	417	359	13.94	4.70	1.68
				Rainwater Harvesting	271.95	273	119	56.39	12.46	4.45
BAR-SE24	23,807	34,196	9	Green Roof	4,599.54	5,228	4,948	5.37	0.82	11.79
				Soakaway Pit	4,635.74	5,228	4,733	9.46	1.45	20.78
				Downspout Disconnection	4,635.74	5,228	2,817	46.12	7.05	101.29
				Dry Well	4,635.74	13,283	11,470	13.65	5.30	76.17
				Rainwater Harvesting	4,635.74	5,228	2,309	55.85	8.54	122.64
BAR-SE25	288,566	176,374	11	Green Roof	11,593.68	23,822	22,391	6.01	0.81	4.96
				Soakaway Pit	21,013.51	25,017	22,627	9.56	1.36	8.29
				Downspout Disconnection	35,704.27	34,014	18,333	46.10	8.89	54.34
				Dry Well	25,812.17	59,577	51,084	14.26	4.82	29.43
				Rainwater Harvesting	25,812.17	33,944	15,113	55.48	10.68	65.26

BAR-SE26	55,054	23,079	14	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	6,631.19	5,174	4,661	9.91	2.22	9.32
				Downspout Disconnection	6,918.60	5,321	2,867	46.12	10.63	44.57
				Dry Well	6,680.99	6,803	5,795	14.82	4.37	18.31
				Rainwater Harvesting	7,409.12	5,781	2,576	55.44	13.89	58.22
BAR-SE28	27,308	11,077	20	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	2,783.59	3,291	2,969	9.77	2.90	1.11
				Downspout Disconnection	2,379.91	1,852	998	46.11	7.71	2.96
				Dry Well	1,418.49	2,008	1,707	14.98	2.72	1.04
				Rainwater Harvesting	3,176.34	3,926	1,735	55.80	19.78	7.59
BAR-SE29	73,451	43,400	14	Green Roof	391.20	271	251	7.48	0.05	0.28
				Soakaway Pit	10,815.80	8,516	7,618	10.54	2.07	12.23
				Downspout Disconnection	11,675.56	10,157	5,473	46.11	10.79	63.77
				Dry Well	11,070.83	13,600	11,584	14.82	4.64	27.44
				Rainwater Harvesting	11,871.71	10,856	4,852	55.30	13.83	81.74
BAR-SE3	52,587	18,975	12	Green Roof	352.65	694	678	2.35	0.09	0.31
				Soakaway Pit	3,857.37	4,069	3,735	8.22	1.76	6.36
				Downspout Disconnection	3,857.37	4,069	2,192	46.13	9.89	35.70
				Dry Well	3,857.37	6,074	5,248	13.59	4.35	15.70
				Rainwater Harvesting	3,857.37	4,069	1,749	57.01	12.23	44.12
BAR-SE30	74,648	43,026	12	Green Roof	3,408.37	3,004	2,759	8.18	0.57	0.20
				Soakaway Pit	9,727.12	8,664	7,791	10.08	2.03	0.72
				Downspout Disconnection	10,054.31	8,408	4,531	46.12	9.01	3.18
				Dry Well	9,432.52	13,667	11,697	14.41	4.58	1.62
				Rainwater Harvesting	10,628.11	9,283	4,161	55.18	11.90	4.20
BAR-SE38	29,550	58,282	14	Green Roof	1,739.99	1,943	1,749	9.98	0.33	6.56
				Soakaway Pit	2,463.07	13,868	12,732	8.19	1.95	38.45
				Downspout Disconnection	2,703.02	14,087	7,588	46.13	11.15	219.91
				Dry Well	2,463.07	14,299	12,302	13.96	3.43	67.56
				Rainwater Harvesting	2,703.02	14,087	6,056	57.01	13.78	271.78
BAR-SE42	38,608	12,950	11	Green Roof	-	-	-	-----	-----	-
				Soakaway Pit	1,943.33	1,637	1,491	8.89	1.12	3.77
				Downspout Disconnection	4,049.54	3,288	2,194	33.27	8.45	28.34
				Dry Well	4,049.54	4,737	4,160	12.19	4.46	14.95
				Rainwater Harvesting	4,049.54	3,288	1,925	41.46	10.53	35.31
BAR-SE47	181,324	149,370	7	Green Roof	6,078.20	8,204	7,875	4.01	0.22	1.81
				Soakaway Pit	13,812.51	11,457	10,257	10.48	0.80	6.62
				Downspout Disconnection	26,827.12	25,159	16,662	33.77	5.69	46.86
				Dry Well	26,827.12	79,391	69,514	12.44	6.61	54.47
				Rainwater Harvesting	26,827.12	25,159	14,772	41.28	6.95	57.28
BAR-SE51	14,846	5,885	8	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	3,005.08	1,962	1,660	15.38	5.13	20.32
				Dry Well	3,005.08	1,962	1,779	9.33	3.11	12.32
				Rainwater Harvesting	3,005.08	1,962	1,520	22.52	7.51	29.76
BAR-SE59	61,683	115,150	6	Green Roof	37,507.85	28,787	25,748	10.56	2.64	49.27
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	37,705.29	28,787	23,884	17.03	4.26	79.49
				Dry Well	37,705.29	28,787	25,617	11.01	2.75	51.40
				Rainwater Harvesting	37,705.29	28,787	21,468	25.43	6.36	118.66
BAR-SE61	43,327	23,175	6	Green Roof	6,942.53	5,794	5,267	9.09	2.27	12.16
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	6,942.53	5,794	4,916	15.15	3.79	20.25
				Dry Well	6,942.53	5,794	5,267	9.09	2.27	12.15
				Rainwater Harvesting	6,942.53	5,794	4,513	22.11	5.53	29.57
BAR-SE63	66,392	115,962	2	Green Roof	6,279.84	8,734	8,258	5.44	0.41	7.16
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	8,184.20	35,743	33,239	7.01	2.16	37.71
				Dry Well	8,184.20	35,743	35,355	1.08	0.33	5.83
				Rainwater Harvesting	8,184.20	35,743	32,949	7.82	2.41	42.08
BAR-SE64	111,448	152,519	9	Green Roof	5,234.39	12,710	12,108	4.73	0.39	5.40
				Soakaway Pit	6,102.70	12,710	11,520	9.36	0.78	10.68
				Downspout Disconnection	6,366.22	12,710	6,848	46.12	3.84	52.60
				Dry Well	6,102.70	101,679	88,451	13.01	8.67	118.70
				Rainwater Harvesting	6,102.70	12,710	5,600	55.94	4.66	63.79
BAR-SE67	43,956	46,347	6	Green Roof	11,308.42	10,394	9,227	11.23	2.52	26.56
				Soakaway Pit	-	-	-	-----	-----	-
				Downspout Disconnection	11,582.01	11,984	10,010	16.48	4.26	44.92
				Dry Well	11,582.01	11,984	10,733	10.44	2.70	28.48
				Rainwater Harvesting	11,582.01	11,984	9,055	24.45	6.32	66.65
BAR-SE7	407,245	198,491	8	Green Roof	21,396.55	28,005	26,570	5.12	0.72	3.52
				Soakaway Pit	22,198.12	26,349	23,882	9.36	1.24	6.06
				Downspout Disconnection	26,919.73	32,861	20,617	37.26	6.17	30.07
				Dry Well	24,957.48	78,415	68,723	12.36	4.88	23.80
				Rainwater Harvesting	24,957.48	32,861	17,907	45.51	7.53	36.72
BAR-SE74	244,253	132,859	9	Green Roof	8,668.17	6,589	6,138	6.85	0.34	1.85
				Soakaway Pit	19,671.74	16,848	15,319	9.07	1.15	6.26
				Downspout Disconnection	25,608.19	22,918	12,347	46.12	7.96	43.28
				Dry Well	23,235.79	64,976	56,274	13.39	6.55	35.63
				Rainwater Harvesting	23,502.95	21,528	9,427	56.21	9.11	49.54
BAR-SE80	196,535	47,758	11	Green Roof	2,691.83	6,982	6,716	3.81	0.56	1.35
				Soakaway Pit	11,195.84	9,624	8,551	11.16	2.25	5.46
				Downspout Disconnection	11,237.43	10,048	5,415	46.11	9.70	23.57
				Dry Well	9,163.65	11,281	9,572	15.15	3.58	8.70
				Rainwater Harvesting	11,288.60	9,824	4,487	54.33	11.17	27.15
BAR-SE81	39,023	13,211	11	Green Roof	975.39	2,642	2,548	3.55	0.71	0.48
				Soakaway Pit	975.39	2,642	2,427	8.13	1.63	1.09
				Downspout Disconnection	975.39	2,642	1,423	46.13	9.23	6.20
				Dry Well	975.39	2,642	2,274	-	-	1.87
				Rainwater Harvesting	975.39	2,642	1,134	57.10	11.42	7.68
BAR-SE82	11,789	2,069	17	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-	-----	-----
				Downspout Disconnection	1,095.49	690	372	46.08	15.36	1.62
				Dry Well	1,095.49	690	560	18.79	6.26	0.66
				Rainwater Harvesting	1,095.49	690	333	51.73	17.24	1.82
BAR-SE85	751,111	356,903	13	Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	131,449.54	89,562	77,899	13.02	3.27	59.35
				Downspout Disconnection	132,912.44	88,753	47,847	46.09	11.46	208.14
				Dry Well	132,007.49	89,834	73,580	18.09	4.55	82.70
				Rainwater Harvesting	150,607.61	88,753	42,222	52.43	13.04	236.76
BAR-SW10	113,968	118,876	12	Green Roof	9,851.41	10,793	9,783	9.36	0.85	8.87
				Soakaway Pit	16,331.96	19,468	17,545	9.88	1.62	16.87
				Downspout Disconnection	19,598.08	23,704	14,421	39.16	7.81	81.45
				Dry Well	18,197.45	34,612	30,113	13.00	3.78	39.48
				Rainwater Harvesting	36,828.53	30,300	15,751	48.02	12.24	127.66
BAR-SW11	572,529	372,726	9	Green Roof	22,812.98	27,753	26,018	6.25	0.47	3.03
				Soakaway Pit	71,911.64	59,789	53,630	10.30	1.65	10.76
				Downspout Disconnection	87,363.32	67,141	38,772	42.25	7.61	49.55
				Dry Well	81,397.22	149,806	129,162	13.78	5.54	36.06
				Rainwater Harvesting	157,877.13	68,238	33,908	50.31	9.21	59.96
BAR-SW13	234,634	211,849	5	Green Roof	46,596.04	52,244	48,066	8.00	1.97	17.81
				Soakaway Pit	-	-	-	-----	-----	-----
				Downspout Disconnection	47,495.27	53,202	45,880	13.76	3.46	31.20
				Dry Well	47,495.27	53,202	49,118	7.68	1.93	17.40
				Rainwater Harvesting	47,495.27	53,202	42,731	19.68	4.94	44.63

				Green Roof	1,505.35	2,003	1,892	5.53	0.32	0.98
				Soakaway Pit	1,805.83	2,325	2,122	8.72	0.58	1.79
BAR-SW23	113,062	34,833	6	Downspout Disconnection	7,145.35	8,297	6,613	20.30	4.84	14.90
				Dry Well	7,145.35	13,910	12,616	9.30	3.71	11.45
				Rainwater Harvesting	8,951.17	8,297	6,176	25.56	6.09	18.76
				Green Roof	1,788.16	3,514	3,400	3.24	3.24	5.16
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW27	22,115	3,514	3	Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	2,918.99	2,133	1,898	11.01	2.24	3.42
BAR-SW30	68,702	10,478	11	Downspout Disconnection	3,411.92	2,505	1,501	40.10	9.59	14.62
				Dry Well	3,411.92	3,335	2,866	14.07	4.48	6.83
				Rainwater Harvesting	6,240.97	2,505	1,309	47.76	11.42	17.41
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW31	21,103	-	0	Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW32	56,175	-	0	Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
				Green Roof	41,511.73	71,336	67,472	5.42	1.89	15.87
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW33	243,566	204,317	2	Downspout Disconnection	436.62	44,327	41,735	5.85	1.27	10.64
				Dry Well	436.62	44,327	44,327	-	-	-
				Rainwater Harvesting	436.62	44,327	41,764	5.78	1.25	10.52
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW39	10,171	-	0	Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW40	351,744	81,027	2	Downspout Disconnection	1,323.17	27,009	25,438	5.82	1.94	4.47
				Dry Well	1,323.17	27,009	27,009	-	-	-
				Rainwater Harvesting	1,323.17	27,009	25,461	5.73	1.91	4.40
				Green Roof	2,731.98	4,989	4,732	5.14	0.13	0.52
				Soakaway Pit	57,919.44	46,868	41,990	10.41	2.39	9.92
BAR-SW45	491,948	204,348	12	Downspout Disconnection	60,261.76	49,316	27,232	44.78	10.81	44.89
				Dry Well	59,972.24	57,839	49,090	15.13	4.28	17.78
				Rainwater Harvesting	112,944.29	45,336	21,106	53.44	11.86	49.25
				Green Roof	3,084.72	3,513	3,396	3.34	0.34	2.42
				Soakaway Pit	8,873.33	3,530	3,170	10.18	1.03	7.40
BAR-SW48	48,602	34,879	6	Downspout Disconnection	3,450.24	3,479	1,875	46.11	4.60	33.01
				Dry Well	8,367.34	20,877	18,117	-	-	56.77
				Rainwater Harvesting	11,877.22	3,479	1,559	55.19	5.51	39.51
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW51	68,869	-	0	Downspout Disconnection	-	-	-	-----	-----	-----
				Dry Well	-	-	-	-----	-----	-----
				Rainwater Harvesting	-	-	-	-----	-----	-----
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW7	64,790	53,902	5	Downspout Disconnection	17,198.58	17,967	15,980	11.06	3.69	30.67
				Dry Well	17,198.58	17,967	17,084	4.92	1.64	13.64
				Rainwater Harvesting	17,198.58	17,967	15,284	14.94	4.98	41.42
				Green Roof	-	-	-	-----	-----	-----
				Soakaway Pit	-	-	-	-----	-----	-----
BAR-SW8	17,096	7,612	6	Downspout Disconnection	2,826.09	2,537	2,202	13.20	4.40	19.60
				Dry Well	2,826.09	2,537	2,357	7.11	2.37	10.55
				Rainwater Harvesting	2,826.09	2,537	2,063	18.70	6.23	27.75
				Green Roof	24,682.79	31,552	29,456	6.64	0.42	2.49
				Soakaway Pit	94,148.73	78,765	70,699	10.24	1.61	9.58
BAR-SW9	841,651	501,649	10	Downspout Disconnection	124,623.34	104,248	64,207	38.41	7.98	47.57
				Dry Well	117,348.94	181,326	157,185	13.31	4.81	28.68
				Rainwater Harvesting	215,555.95	105,759	56,873	46.22	9.74	58.08

Note: (1) TSS stands for Total Suspended Solids.
(2) TP stands for Total Phosphorus.

Table D.4-2: Pollutant Loading Assessment Case Study Results

Stormsewershed ID	Stormsewershed Area (m^2)	Total Pollutant Loading of Stormsewershed Before LID Application (kg/yr)			LID Type	Applicable Area (m^2)	Pollutant Loading, in kg/yr						Pollutant Loading Reduction of Applicable Area (%)			Stormsewershed Pollutant Loading Reduction (%)			Pollutant Removed by LID ($kg/yr/m^2$) in Stormwatershed			Maximum Potential Pollutant Loading Reduction in Stormsewershed (%)		
							without LID			(with LID)														
		TSS (1)	TP (2)	Zinc			TSS (1)	TP (2)	Zinc	TSS (1)	TP (2)	Zinc	TSS (1)	TP (2)	Zinc	TSS (1)	TP (2)	Zinc	TSS (1)	TP (2)	Zinc	TSS (1)	TP (2)	Zinc
BAR-C1	1,071,530	187,315.34	288.72	154.92	Green Roof	48,736.71	17,509.35	26.99	14.48	15,120.10	27.30	13.24	13.65	-1.15	8.58	1.28	-0.11	0.80	2.23	-0.00	0.00	18.37	20.93	23.59
					Soakaway Pit	154,211.36	34,647.10	53.40	28.66	23,524.99	36.80	36.80	32.10	31.09	-28.43	5.94	5.75	-5.26	10.38	0.02	-0.01			
					Downspout Disconnection	185,079.53	44,099.29	67.97	36.47	16,697.65	32.69	13.81	62.14	51.91	62.14	14.63	12.22	14.63	25.57	0.03	0.02			
					Dry Well	184,156.56	62,393.10	72.23	38.76	41,696.72	53.20	24.41	33.17	26.35	37.01	11.05	6.59	9.26	19.31	0.02	0.01			
					Rainwater Harvesting	184,340.67	44,195.17	68.12	36.55	9,780.35	7.70	-	77.87	88.69	100.00	18.37	20.93	23.59	32.12	0.06	0.03			
BAR-C11	26,627	3,282.56	5.06	2.71	Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.40	24.40	24.40
					Soakaway Pit	154,211.36	800.89	1.23	0.66	525.31	0.81	0.81	34.41	34.41	-22.24	8.40	8.40	-5.43	10.35	0.02	-0.01			
					Downspout Disconnection	185,079.53	800.89	1.23	0.66	175.47	0.42	0.15	78.09	65.59	78.09	19.05	16.00	19.05	23.49	0.03	0.02			
					Dry Well	184,156.56	879.89	1.36	0.73	528.66	0.96	0.44	39.92	29.02	39.92	10.70	7.78	10.70	13.19	0.01	0.01			
					Rainwater Harvesting	184,340.67	800.89	1.23	0.66	-	-	-	100.00	100.00	100.00	24.40	24.40	24.40	30.08	0.05	0.02			
BAR-C12	171,839	58,674.34	90.44	48.53	Green Roof	48,736.71	11,036.12	17.01	9.13	8,796.31	17.46	7.99	20.30	-2.65	12.44	3.82	-0.50	2.34	13.03	-0.00	0.01	7.84	23.23	23.53
					Soakaway Pit	154,211.36	6,845.82	10.55	5.66	4,729.43	7.53	7.53	30.92	28.62	-33.03	3.61	3.34	-3.85	12.32	0.02	-0.01			
					Downspout Disconnection	185,079.53	12,893.11	19.87	10.66	9,987.67	16.07	8.26	22.53	19.15	22.53	4.95	4.21	4.95	16.91	0.02	0.01			
					Dry Well	184,156.56	14,947.78	21.72	11.66	12,857.87	19.60	10.09	13.98	9.76	13.43	3.56	2.35	3.23	12.16	0.01	0.01			
					Rainwater Harvesting	184,340.67	13,805.31	21.28	11.42	9,207.75	0.27	-	33.30	98.74	100.00	7.84	23.23	23.53	26.76	0.12	0.07			
BAR-C15	79,906	542.10	0.84	0.45	Green Roof	48,736.71	542.10	0.84	0.45	530.28	0.82	0.44	2.18	1.44	1.93	2.18	1.44	1.93	0.15	0.00	0.00	2.18	1.44	1.93
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-C16	234,508	39,966.44	61.60	33.05	Green Roof	48,736.71	11,216.90	17.29	9.28	9,396.60	17.59	8.34	16.23	-1.73	10.08	4.55	-0.49	2.83	7.76	-0.00	0.00	20.70	12.33	23.98
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Downspout Disconnection	185,079.53	9,583.18	14.77	7.93	6,153.30	10.31	5.09	35.79	30.17	35.79	8.58	7.24	8.58	14.63	0.02	0.01			
					Dry Well	184,156.56	33,390.26	14.77	7.93	25,115.62	12.16	5.87	24.78	17.65	25.93	20.70	4.23	6.22	35.29	0.01	0.01			
					Rainwater Harvesting	184,340.67	9,583.18	14.77	7.93	4,654.10	7.17	-	51.43	51.43	100.00	12.33	12.33	23.98	21.02	0.03	0.03			
BAR-C17	52,794	-	-	-	Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-C18	622,619	175,224.62	270.08	144.92	Green Roof	48,736.71	40,412.59	62.29	33.42	32,442.89	63.86	29.38	19.72	-2.52	12.11	4.55	-0.58	2.79	12.80	-0.00	0.01	26.57	15.69	25.27
					Soakaway Pit	154,211.36	992.24	1.53	0.82	651.46	1.00	1.00	34.34	34.34	-22.36	0.19	0.19	-0.13	0.55	0.00	-0.00			
					Downspout Disconnection	185,079.53	45,267.20	69.77	37.44	25,829.78	44.69	21.36	42.94	35.95	42.94	11.09	9.29	11.09	31.22	0.04	0.03			
					Dry Well	184,156.56	145,769.13	68.25	36.62	99,206.22	53.31	24.88	31.94	21.88	32.04	26.57	5.53	8.10	74.79	0.02	0.02			
					Rainwater Harvesting	184,340.67	44,276.29	68.25	36.62	17,968.36	25.87	-	59.42	62.09	100.00	15.01	15.69	25.27	42.25	0.07	0.06			
BAR-C19	132,171	40,429.48	62.32	33.44	Green Roof	48,736.71	5,820.17	8.97	4.81	4,512.43	9.25	4.15	22.47	-3.14	13.70	3.23	-0.45	1.97	9.89	-0.00	0.00	28.02	17.71	22.31
					Soakaway Pit	154,211.36	1,898.32	2.93	1.57	1,265.77	1.95	1.95	33.32	33.32	-24.26	1.56	1.56	-1.14	4.79	0.01	-0.00			
					Downspout Disconnection	185,079.53	8,996.07	13.87	7.44	3,565.35	6.97	2.95	60.37	49.75	60.37	13.43	11.07	13.43	41.09	0.05	0.03			
					Dry Well	184,156.56	29,125.70	22.65	12.15	17,796.51	16.47	7.48	38.90	27.28	38.46	28.02	9.92	13.98	85.72	0.05	0.04			
					Rainwater Harvesting	184,340.67	9,021.62	13.91	7.46	1,859.71	2.87	-	79.39	79.39	100.00	17.71	17.71	22.31	54.19	0.08	0.06			
BAR-C21	103,637	18,993.12	29.28	15.71	Green Roof	48,736.71	964.25	1.49	0.80	773.95	1.52	0.70	19.74	-2.52	12.12	1.00	-0.13	0.62	1.84	-0.00	0.00	23.36	24.01	26.39
					Soakaway Pit	154,211.36	2,611.71	4.03	2.16	1,725.81	2.67	2.67	33.92	33.70	-23.55	4.66	4.63	-3.24	8.55	0.01	-0.00			
					Downspout Disconnection	185,079.53	4,446.85	6.85	3.68	1,460.26	3.02	1.21	67.16	56.01	67.16	15.72	13.11	15.72	28.82	0.04	0.02			
					Dry Well	184,156.56	9,698.05	9.18	4.93	5,844.63	6.62	3.01	39.73	27.86	38.98	20.29	8.74	12.23	37.18	0.02	0.02			
					Rainwater Harvesting	184,340.67	5,012.40	7.73	4.15	576.43	0.70	-	88.50	91.00	100.00	23.36	24.01	26.39	42.80	0.07	0.04			
BAR-C22	46,207	7,910.43	12.19	6.54	Green Roof	48,736.71	1,532.88	2.36	1.27	1,250.07	2.42	1.12	18.45	-2.23	11.37	3.58	-0.43	2.20	6.12	-0.00	0.00	8.75	28.13	28.13
					Soakaway Pit	154,211.36	1,071.70	1.65	0.89	692.17	1.16	1.16	35.41	29.58	-31.24	4.80	4.01	-4.23	8.21	0.01	-0.01			
					Downspout Disconnection	185,079.53	1,216.93	1.88	1.01	1,065.06	1.69	0.88	12.48	10.00	12.48	1.92	1.54	1.92	3.29	0.00	0.00			
					Dry Well	184,156.56	1,863.50	2.87	1.54	1,714.43	2.71	1.42	8.00	5.77	8.00	1.88	1.36	1.88	3.23	0.00	0.00			
					Rainwater Harvesting	184,340.67	2,225.41	3.43	1.84	1,532.88	-	-	31.12	100.00	100.00	8.75	28.13	28.13	14.99	0.07	0.04			
BAR-C23	350,832	84,338.24	130.00	69.75	Green Roof	48,736.71	18,669.75	28.78	15.44	17,106.95	28.76	14.59	8.37	0.04	5.52	1.85	0.01	1.22	4.45	0.00	0.00	10.54	8.65	26.78
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Downspout Disconnection	185,079.53	20,502.02	31.60	16.96	16,285.13	25.95	13.47	20.57	17.87	20.57	5.00	4.34	5.00	12.02	0.02	0.01			
					Dry Well	184,156.56	82,371.75	34.81	18.68	73,485.89	32.22	16.62	10.79	7.43	11.02	10.54	1.99	2.95	25.33	0.01	0.01			
					Rainwater Harvesting	184,340.67	22,583.24	34.81	18.68	15,287.03	23.56	-	32.31	32.31	100.00	8.65	8.65	26.78	20.80	0.03	0.05			

					Green Roof	48,736.71	29,324.75	45.20	24.25	25,065.36	45.81	22.05	14.52	-1.35	9.09	3.21	-0.30	2.01	6.95	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-C25	612,525	132,838.89	204.75	109.87	Downspout Disconnection	185,079.53	78,102.10	51.07	27.40	64,329.52	36.23	17.97	17.63	29.05	34.41	10.37	7.25	8.58	22.48	0.02	0.02	21.06	12.89	26.49
					Dry Well	184,156.56	123,142.80	54.24	29.10	95,173.20	45.57	22.26	22.71	15.98	23.50	21.06	4.23	6.23	45.66	0.01	0.01			
					Rainwater Harvesting	184,340.67	35,189.54	54.24	29.10	18,216.60	27.84	-	48.23	48.67	100.00	12.78	12.89	26.49	27.71	0.04	0.05			
					Green Roof	48,736.71	10,318.91	15.91	8.53	8,942.61	16.08	7.82	13.34	-1.08	8.40	2.56	-0.21	1.61	7.34	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-C26	187,583	53,689.90	82.76	44.41	Downspout Disconnection	185,079.53	53,727.91	22.28	11.96	46,751.30	15.88	7.88	12.99	28.76	34.06	12.99	7.74	9.17	37.19	0.03	0.02	22.26	13.63	26.93
					Dry Well	184,156.56	50,015.67	22.28	11.96	38,062.58	18.60	9.05	23.90	16.54	24.31	22.26	4.45	6.55	63.72	0.02	0.02			
					Rainwater Harvesting	184,340.67	14,457.00	22.28	11.96	7,363.58	11.00	-	49.07	50.62	100.00	13.21	13.63	26.93	37.81	0.06	0.06			
					Green Roof	48,736.71	1,214.43	1.87	1.00	1,050.88	1.89	0.92	13.47	-1.11	8.48	0.54	-0.04	0.34	1.59	-0.00	0.00			
					Soakaway Pit	154,211.36	1,939.28	2.99	1.60	1,275.61	1.97	1.97	34.22	34.22	-22.59	2.21	2.21	-1.46	6.44	0.01	-0.00			
BAR-C28	103,023	30,029.94	46.29	24.84	Downspout Disconnection	185,079.53	21,341.35	12.21	6.55	17,259.12	7.81	3.77	19.13	36.00	42.47	13.59	9.50	11.20	39.62	0.04	0.03	18.05	18.83	28.96
					Dry Well	184,156.56	22,887.13	15.81	8.48	18,440.73	12.87	6.28	19.43	18.62	26.01	14.81	6.36	8.88	43.16	0.03	0.02			
					Rainwater Harvesting	184,340.67	8,697.05	13.41	7.19	3,276.35	4.69	-	62.33	65.00	100.00	18.05	18.83	28.96	52.62	0.08	0.07			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	1,134.98	1.75	0.94	739.24	1.14	1.14	34.87	34.87	-21.38	8.53	8.53	-5.23	2.74	0.00	-0.00			
BAR-C3	144,361	4,637.59	7.15	3.84	Downspout Disconnection	185,079.53	1,167.54	1.80	0.97	284.95	0.64	0.24	75.59	64.52	75.59	19.03	16.24	19.03	6.11	0.01	0.01	24.47	25.18	25.18
					Dry Well	184,156.56	1,167.54	1.80	0.97	826.71	1.41	0.68	29.19	21.73	29.19	7.35	5.47	7.35	2.36	0.00	0.00			
					Rainwater Harvesting	184,340.67	1,167.54	1.80	0.97	32.56	-	-	97.21	100.00	100.00	24.47	25.18	25.18	7.86	0.01	0.01			
					Green Roof	48,736.71	2,790.88	4.30	2.31	2,588.16	4.29	2.20	7.26	0.29	4.88	1.04	0.04	0.70	2.05	0.00	0.00			
					Soakaway Pit	154,211.36	1,029.39	1.59	0.85	677.34	1.04	1.04	34.20	34.20	-22.63	1.81	1.81	-1.20	3.56	0.01	-0.00			
BAR-C30	98,969	19,457.46	29.99	16.09	Downspout Disconnection	185,079.53	9,669.65	5.05	2.71	8,490.37	3.95	2.03	12.20	21.78	25.21	6.06	3.67	4.24	11.92	0.01	0.01	9.32	22.15	30.72
					Dry Well	184,156.56	12,605.70	9.84	5.28	11,383.71	9.01	4.66	9.69	8.38	11.68	6.28	2.75	3.83	12.35	0.01	0.01			
					Rainwater Harvesting	184,340.67	5,977.89	9.21	4.94	4,164.12	2.57	-	30.34	72.09	100.00	9.32	22.15	30.72	18.33	0.07	0.05			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-C32	33,480	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	10,216.15	15.75	8.45	8,783.83	15.94	7.71	14.02	-1.23	8.80	2.25	-0.20	1.41	4.99	-0.00	0.00			
					Soakaway Pit	154,211.36	5,999.19	9.25	4.96	3,934.30	6.06	6.06	34.42	34.42	-22.22	3.24	3.24	-2.09	7.19	0.01	-0.00			
BAR-C4	287,256	63,717.99	98.21	52.70	Downspout Disconnection	185,079.53	36,504.93	22.40	12.02	27,149.91	11.78	5.21	25.63	47.43	56.67	14.68	10.82	12.93	32.57	0.04	0.02	16.26	16.96	23.23
					Dry Well	184,156.56	38,061.89	28.00	15.03	27,701.69	22.00	10.51	27.22	21.44	30.07	16.26	6.11	8.57	36.07	0.02	0.02			
					Rainwater Harvesting	184,340.67	14,800.68	22.81	12.24	4,687.30	6.16	-	68.33	73.02	100.00	15.87	16.96	23.23	35.21	0.06	0.04			
					Green Roof	48,736.71	9,860.99	15.20	8.16	8,642.01	15.33	7.52	12.36	-0.86	7.84	1.45	-0.10	0.92	2.48	-0.00	0.00			
					Soakaway Pit	154,211.36	9,646.40	14.87	7.98	6,302.49	9.86	9.86	34.66	33.70	-23.57	3.98	3.87	-2.71	6.81	0.01	-0.00			
BAR-C5	491,364	83,913.26	129.34	69.40	Downspout Disconnection	185,079.53	30,759.25	30.57	16.40	20,703.34	18.28	8.56	32.69	40.18	47.78	11.98	9.50	11.29	20.47	0.02	0.02	15.14	21.03	23.54
					Dry Well	184,156.56	33,871.10	38.26	20.53	25,972.60	31.07	15.23	23.32	18.79	25.79	9.41	5.56	7.63	16.07	0.01	0.01			
					Rainwater Harvesting	184,340.67	19,754.48	30.45	16.34	7,048.19	3.25	-	64.32	89.32	100.00	15.14	21.03	23.54	25.86	0.06	0.03			
					Green Roof	48,736.71	1,055.79	1.63	0.87	768.00	1.70	0.73	27.26	-4.22	16.48	3.65	-0.57	2.21	9.38	-0.00	0.00			
					Soakaway Pit	154,211.36	444.69	0.69	0.37	290.41	0.45	0.45	34.69	34.69	-21.71	1.96	1.96	-1.23	5.03	0.01	-0.00			
BAR-C8	30,677	7,876.62	12.14	6.51	Downspout Disconnection	185,079.53	1,597.60	2.46	1.32	320.45	0.96	0.27	79.94	61.16	79.94	16.21	12.40	16.21	41.63	0.05	0.03	21.97	21.97	21.97
					Dry Well	184,156.56	3,047.97	4.70	2.52	1,793.61	3.30	1.48	41.15	29.85	41.15	15.93	11.55	15.93	40.89	0.05	0.03			
					Rainwater Harvesting	184,340.67	1,730.56	2.67	1.43	-	-	-	100.00	100.00	100.00	21.97	21.97	21.97	56.41	0.09	0.05			
					Green Roof	48,736.71	1,985.35	3.06	1.64	1,681.32	3.11	1.49	15.31	-1.53	9.55	2.03	-0.20	1.26	4.69	-0.00	0.00			
					Soakaway Pit	154,211.36	463.41	0.71	0.38	303.75	0.47	0.47	34.45	34.45	-22.16	1.06	1.06	-0.68	2.46	0.00	-0.00			
BAR-C9	64,846	14,992.08	23.11	12.40	Downspout Disconnection	185,079.53	12,489.95	6.20	3.33	10,323.07	3.96	1.90	17.35	36.12	42.93	14.45	9.69	11.51	33.42	0.03	0.02	21.30	18.79	28.63
					Dry Well	184,156.56	11,844.26	6.52	3.50	8,650.98	5.24	2.51	26.96	19.73	28.35	21.30	5.57	8.00	49.24	0.02	0.02			
					Rainwater Harvesting	184,340.67	4,291.74	6.62	3.55	1,647.50	2.27	-	61.61	65.65	100.00	17.64	18.79	28.63	40.78	0.07	0.05			
					Green Roof	48,736.71	321.00	0.49	0.27	291.33	0.50	0.25	9.24	-0.16	6.03	0.81	-0.01	0.53	0.37	-0.00	0.00			
					Soakaway Pit	154,211.36	545.35	0.84	0.45	357.92	0.55	0.55	34.37	34.37	-22.31	5.13	5.13	-3.33	2.34	0.00	-0.00			
BAR-NE11	80,042	3,656.55	5.64	3.02	Downspout Disconnection	185,079.53	1,235.26	1.90	1.02	271.42	0.65	0.22	78.03	65.74	78.03	26.36	22.21	26.36	12.04	0.02	0.01	26.36	22.21	26.36
					Dry Well	184,156.56	843.56	1.30	0.70	517.80	0.93	0.43	38.62	28.14	38.62	8.91	6.49	8.91	4.07	0.00	0.00			
					Rainwater Harvesting	184,340.67	711.39	1.10	0.59	-	-	-	100.00	100.00	100.00	19.46	19.46	19.46	8.89	0.01	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE12	24,306	728.91	1.12	0.60	Downspout Disconnection	185,079.53	524.61	0.81	0.43	114.64	0.28	0.09	78.15	65.45	78.15	56.24	47.10	56.24	16.87	0.02	0.01	56.24	47.10	56.24
					Dry Well	184,156.56	97.20	0.15	0.08	65.69	0.11	0.05	32.42	23.97	32.42	4.32	3.20	4.32	1.30	0.00	0.00			
					Rainwater Harvesting	184,340.67	107.10	0.17	0.09	-	-	-	100.00	100.00	100.00	14.69	14.69	14.69	4.41	0.01	0.00			
					Green Roof	48,736.71	6,179.98	9.53	5.11	5,267.33	9.66	4.64	14.77	-1.40	9.23	1.25	-0.12	0.78	1.54	-0.00	0.00			
					Soakaway Pit	154,211.36	11,621.20	17.91	9.61	8,048.96	12.55	12.55	30.74	29.95	-30.54	4.87	4.75	-4.84	6.03	0.01	-0.00			
BAR-NE13	592,055	73,304.63	112.99	60.63	Downspout Disconnection	185,079.53	15,493.74	19.31	10.36	8,137.04	10.05	4.41	47.48	47.98	57.48	10.04	8.20	9.82	12.43	0.02	0.01	13.89	18.11	18.90
					Dry Well	184,156.56	31,841.40	44.89	24.09	21,657.63	34.14	16.15	31.98	23.94	32.94	13.89	9.51	13.09	17.20	0.02	0.01			
					Rainwater Harvesting	184,340.67	13,854.21	21.35	11.46	4,675.59	0.89	-	66.25	95.83	100.00	12.52	18.11	18.90	15.50	0.03	0.02			
					Green Roof	48,736.71	871.23	1.34	0.72	794.88	1.34	0.68	8.76	-0.05	5.75	0.24	-0.00	0.16	0.25	-0.00	0.00			
					Soakaway Pit	154,211.36	7,308.49	11.26	6.04	4,795.69	7.39	7.39	34.38	34.38	-22.29	8.06	8.06	-5.22	8.32	0.01	-0.00			
BAR-NE14	302,098	31,182.38	48.06	25.79	Downspout Disconnection	185,079.53	7,202.61	11.10	5.96	1,578.81	3.82	1.31	78.08	65.61	78.08	18.04	15.15	18.04	18.62	0.02	0.02	22.68	22.68	22.68
					Dry Well	184,156.56	8,726.41	13.45	7.22	5,323.90	9.63	4.40	38.99	28.39	38.99	10.91	7.95	10.91	11.26	0.01	0.01			
					Rainwater Harvesting	184,340.67	7,073.65	10.90	5.85	-	-	-	100.00	100.00	100.00	22.68	22.68	22.68	23.42	0.04	0.02			

					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE17	84,721	5,423.46	8.36	4.49	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.99	50.99	50.99
					Dry Well	184,156.56	2,658.31	4.10	2.20	1,520.24	2.83	1.26	42.81	30.97	42.81	20.98	15.18	20.98	13.43	0.01	0.01			
					Rainwater Harvesting	184,340.67	2,765.16	4.26	2.29	-	-	-	100.00	100.00	100.00	50.99	50.99	50.99	32.64	0.05	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE18	120,072	9,138.82	14.09	7.56	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44.69	44.69	44.69
					Dry Well	184,156.56	5,054.70	7.79	4.18	3,000.96	5.49	2.48	40.63	29.50	40.63	22.47	16.32	22.47	17.10	0.02	0.01			
					Rainwater Harvesting	184,340.67	4,084.13	6.30	3.38	-	-	-	100.00	100.00	100.00	44.69	44.69	44.69	34.01	0.05	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	1,375.04	2.12	1.14	902.59	1.39	1.39	34.36	34.36	-22.33	3.23	3.23	-2.10	3.23	0.00	-0.00			
BAR-NE19	146,146	14,633.11	22.55	12.10	Downspout Disconnection	185,079.53	1,471.48	2.27	1.22	322.39	0.78	0.27	78.09	65.58	78.09	7.85	6.60	7.85	7.86	0.01	0.01	34.54	34.54	34.54
					Dry Well	184,156.56	6,732.86	10.38	5.57	4,090.22	7.41	3.38	39.25	28.57	39.25	18.06	13.14	18.06	18.08	0.02	0.01			
					Rainwater Harvesting	184,340.67	5,053.72	7.79	4.18	-	-	-	100.00	100.00	100.00	34.54	34.54	34.54	34.58	0.05	0.03			
					Green Roof	48,736.71	2,470.62	3.81	2.04	2,171.04	3.84	1.89	12.13	-0.81	7.70	0.79	-0.05	0.50	1.04	-0.00	0.00			
					Soakaway Pit	154,211.36	8,330.14	12.84	6.89	5,687.74	8.78	8.78	31.72	31.61	-27.45	6.94	6.92	-6.01	9.13	0.01	-0.01			
BAR-NE20	289,305	38,077.29	58.69	31.49	Downspout Disconnection	185,079.53	8,669.91	13.36	7.17	2,564.87	5.44	2.12	70.42	59.32	70.42	16.03	13.51	16.03	21.10	0.03	0.02	18.78	21.00	21.00
					Dry Well	184,156.56	10,611.32	16.36	8.78	6,940.28	12.22	5.74	34.60	25.26	34.60	9.64	7.04	9.64	12.69	0.01	0.01			
					Rainwater Harvesting	184,340.67	7,995.30	12.32	6.61	845.79	-	-	89.42	100.00	100.00	18.78	21.00	21.00	24.71	0.04	0.02			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE24	43,481	3,143.51	4.85	2.60	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	43.12	43.12	43.12
					Dry Well	184,156.56	1,788.03	2.76	1.48	1,079.26	1.96	0.89	39.64	28.83	39.64	22.55	16.40	22.55	16.30	0.02	0.01			
					Rainwater Harvesting	184,340.67	1,355.48	2.09	1.12	-	-	-	100.00	100.00	100.00	43.12	43.12	43.12	31.17	0.05	0.03			
					Green Roof	48,736.71	296.32	0.46	0.25	243.31	0.47	0.22	17.89	-2.11	11.05	0.59	-0.07	0.37	0.41	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE25	130,886	8,961.92	13.81	7.41	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41.96	41.96	45.16
					Dry Well	184,156.56	6,044.82	7.12	3.82	3,937.12	5.16	2.37	34.87	27.54	38.08	23.52	14.19	19.62	16.10	0.01	0.01			
					Rainwater Harvesting	184,340.67	4,047.04	6.24	3.35	286.66	0.44	-	92.92	92.92	100.00	41.96	41.96	45.16	28.73	0.04	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE26	43,582	3,284.52	5.06	2.72	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46.39	46.39	46.39
					Dry Well	184,156.56	1,760.69	2.71	1.46	1,039.88	1.91	0.86	40.94	29.71	40.94	21.95	15.92	21.95	16.54	0.02	0.01			
					Rainwater Harvesting	184,340.67	1,523.84	2.35	1.26	-	-	-	100.00	100.00	100.00	46.39	46.39	46.39	34.97	0.05	0.03			
					Green Roof	48,736.71	3,825.01	5.90	3.16	3,373.63	5.94	2.93	11.80	-0.73	7.51	1.96	-0.12	1.25	3.15	-0.00	0.00			
					Soakaway Pit	154,211.36	3,538.24	5.45	2.93	2,920.92	4.58	4.58	17.45	16.10	-56.35	2.68	2.48	-8.67	4.31	0.01	-0.01			
BAR-NE27	143,390	22,993.58	35.44	19.02	Downspout Disconnection	185,079.53	3,440.25	5.30	2.85	2,718.73	4.38	2.25	20.97	17.36	20.97	3.14	2.60	3.14	5.03	0.01	0.00	8.57	25.36	25.36
					Dry Well	184,156.56	6,358.98	9.80	5.26	5,333.65	8.65	4.41	16.12	11.70	16.12	4.46	3.24	4.46	7.15	0.01	0.01			
					Rainwater Harvesting	184,340.67	5,831.10	8.99	4.82	3,861.06	-	-	33.79	100.00	100.00	8.57	25.36	25.36	13.74	0.06	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NE28	111,963	9,521.55	14.68	7.87	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	43.82	43.82	43.82
					Dry Well	184,156.56	5,348.75	8.24	4.42	3,216.85	5.86	2.66	39.86	28.98	39.86	22.39	16.28	22.39	19.04	0.02	0.02			
					Rainwater Harvesting	184,340.67	4,172.79	6.43	3.45	-	-	-	100.00	100.00	100.00	43.82	43.82	43.82	37.27	0.06	0.03			
					Green Roof	48,736.71	2,157.68	3.33	1.78	1,810.35	3.38	1.61	16.10	-1.70	10.00	0.64	-0.07	0.40	1.07	-0.00	0.00			
					Soakaway Pit	154,211.36	10,374.45	15.99	8.58	6,820.92	10.51	10.51	34.25	34.25	-22.53	6.58	6.58	-4.33	11.00	0.02	-0.01			
BAR-NE29	323,137	54,033.78	83.29	44.69	Downspout Disconnection	185,079.53	11,318.08	17.45	9.36	2,478.90	6.01	2.05	78.10	65.57	78.10	16.36	13.73	16.36	27.35	0.04	0.02	23.20	23.20	23.20
					Dry Well	184,156.56	17,646.63	27.20	14.59	10,861.52	19.58	8.98	38.45	28.03	38.45	12.56	9.15	12.56	21.00	0.02	0.02			
					Rainwater Harvesting	184,340.67	12,536.94	19.32	10.37	-	-	-	100.00	100.00	100.00	23.20	23.20	23.20	38.80	0.06	0.03			
					Green Roof	48,736.71	10,177.36	15.69	8.42	8,892.73	15.83	7.75	12.62	-0.92	7.99	1.09	-0.08	0.69	1.63	-0.00	0.00			
					Soakaway Pit	154,211.36	22,460.91	34.62	18.58	15,150.39	23.55	23.55	32.55	31.98	-26.77	6.22	6.11	-5.12	9.25	0.01	-0.01			
BAR-NE3	790,414	117,477.31	181.07	97.16	Downspout Disconnection	185,079.53	30,452.76	39.26	21.07	13,884.39	18.20	7.58	54.41	53.65	64.01	14.10	11.63	13.88	20.96	0.03	0.02	16.95	19.87	20.77
					Dry Well	184,156.56	39,608.35	53.89	28.92	26,990.79	40.66	19.16	31.86	24.55	33.75	10.74	7.31	10.04	15.96	0.02	0.01			
					Rainwater Harvesting	184,340.67	24,405.43	37.62	20.18	4,490.06	1.64	-	81.60	95.64	100.00	16.95	19.87	20.77	25.20	0.05	0.03			
					Green Roof	48,736.71	1,949.04	3.00	1.61	1,783.99	3.00	1.52	8.47	0.02	5.58	0.97	0.00	0.64	1.33	0.00	0.00			
					Soakaway Pit	154,211.36	3,245.70	5.00	2.68	2,375.41	3.72	3.72	26.81	25.56	-38.72	5.10	4.86	-7.36	7.03	0.01	-0.01			
BAR-NE30	123,729	17,080.08	26.33	14.13	Downspout Disconnection	185,079.53	3,413.50	5.26	2.82	1,856.84	3.25	1.54	45.60	38.23	45.60	9.11	7.64	9.11	12.58	0.02	0.01	14.28	22.60	22.60
					Dry Well	184,156.56	4,612.28	7.11	3.81	3,459.03	5.81	2.86	25.00	18.32	25.00	6.75	4.95	6.75	9.32	0.01	0.01			
					Rainwater Harvesting	184,340.67	3,859.56	5.95	3.19	1,421.02	-	-	63.18	100.00	100.00	14.28	22.60	22.60	19.71	0.05	0.03			
					Green Roof	48,736.71	4,040.33	6.23	3.34	3,301.16	6.36	2.96	18.29	-2.20	11.28	1.97	-0.24	1.22	3.66	-0.00	0.00			
					Soakaway Pit	154,211.36	7,819.95	12.05	6.47	5,109.67	8.16	8.16	34.66	32.31	-26.14	7.24	6.75	-5.46	13.41	0.02	-0.01			
BAR-NE31	202,077	37,438.39	57.71	30.96	Downspout Disconnection	185,079.53	8,245.42	12.71	6.82	4,351.27	7.68	3.60	47.23	39.58	47.23	10.40	8.72	10.40	19.27	0.02	0.02	12.58	21.29	21.29
					Dry Well	184,156.56	9,361.63	14.43	7.74	6,904.82	11.68	5.71	26.24	19.07	26.24	6.56	4.77	6.56	12.16	0.01	0.01			
					Rainwater Harvesting	184,340.67	7,971.07	12.29	6.59	3,261.52	-	-	59.08	100.00	100.00	12.58	21.29	21.29	23.31	0.06	0.03			
					Green Roof	48,736.71	404.85	0.62	0.33	306.57	0.65	0.29	24.28	-3.55	14.75	0.75	-0.11	0.45	1.66	-0.00	0.00			
					Soakaway Pit	154,211.36	1,132.92	1.75	0.94	679.95	1.11	1.11	39.98	36.22	-18.86	3.44	3.12	-1.62	7.67	0.01	-0.00			
BAR-NE32	59,077	13,158.10	20.28	10.88	Downspout Disconnection	185,079.53	3,913.53	6.03	3.24	3,148.95	5.05	2.60	19.54	16.21	19.54	5.81	4.82	5.81	12.94	0.02	0.01	8.41	30.25	30.25
					Dry Well	184,156.56	3,726.45	5.74	3.08	3,366.13	5.34	2.78	9.67	7.00	9.67	2.74	1.98	2.74	6.10	0.01	0.01			
					Rainwater Harvesting	184,340.67	3,980.35	6.14	3.29	2,873.65	-	-	27.80	100.00	100.00	8.41	30.25	30.25	18.73	0.10	0.06			
					Green Roof	48,736.71	16,764.48	25.84	13.87	12,952.86	26.67	11.94	22.74	-3.20	13.86	1.93	-0.27	1.18	3.13	-0.00	0.00			
					Soakaway Pit	154,211.36	28,249.81	43.54	23.36	18,575.37	28.74	28.74	34.25	33.99	-23.01	4.90	4.86	-3.29	7.93	0.01	-0.00			
BAR-NE39	1,219,320	197,597.02	304.57	163.43	Downspout Disconnection	185,079.53	63,128.24	80.83	43.37	27,929.02	37.32	14.72	55.76	53.84	66.06	17.81	14.29	17.53	28.87	0.04	0.02	17.81	20.07	21.05
					Dry Well	184,156.56	68,211.75	90.24	48.42	46,055.80	68.07	32.08	32.48	24.57	33.76	11.21	7.28	10.00	18.17	0.02	0.01			
					Rainwater Harvesting	184,340.67	41,593.46	64.11	34.40	6,471.35	2.97	-	84.44	95.36	100.00	17.77	20.07	21.05	28.80	0.05	0.03			
					Green Roof	48,736.71	2,823.56	4.35	2.34	2,067.44	4.53	1.96	26.78	-4.11	16.21	1.98	-0.30	1.20	4.46	-0.00	0.00			
					Soakaway Pit	154,211.36	1,964.34	3.03	1.62	1,302.65	2.04	2.04	33.69	32.52	-25.75	1.73	1.67	-1.33	3.90	0.01	-0.00			
BAR-NE40	169,460	38,148.75	58.80	31.55	Downspout Disconnection	185,079.53	8,771.59	13.52	7.25	5,312.20	9.46	4.39	39.44	30.05	39.44	9.07	6.91	9.07	20.41	0.02	0.02	13.08	17.42	17.42
					Dry Well	184,156.56	17,942.49	27.66	14.84	12,952.88	22.02	10.71	27.81	20.39	27.81	13.08	9.59	13.08	29.44	0.03	0.02			
					Rainwater Harvesting	184,340.67	6,646.77	10.25	5.50	3,953.45	-	-	40.52	100.00	100.00	7.06	17.42	17.42	15.89	0.06	0.03			

					Green Roof	48,736.71	726.54	1.12	0.60	631.41	1.13	0.55	13.09	-1.02	8.26	0.20	-0.02	0.12	0.19	-0.00	0.00			
					Soakaway Pit	154,211.36	6,921.14	10.67	5.72	4,537.10	6.99	6.99	34.45	34.45	-22.17	4.90	4.90	-3.16	4.81	0.01	-0.00			
BAR-NE8	495,746	48,631.18	74.96	40.22	Downspout Disconnection	185,079.53	8,146.73	12.56	6.74	1,791.80	4.30	1.48	78.01	65.79	78.01	13.07	11.02	13.07	12.82	0.02	0.01	28.60	28.80	28.80
					Dry Well	184,156.56	18,833.10	29.03	15.58	11,699.94	21.01	9.68	37.88	27.63	37.88	14.67	10.70	14.67	14.39	0.02	0.01			
					Rainwater Harvesting	184,340.67	14,003.68	21.58	11.58	93.70	-	-	99.33	100.00	100.00	28.60	28.80	28.80	28.06	0.04	0.02			
					Green Roof	48,736.71	627.07	0.97	0.52	499.24	0.99	0.45	20.38	-2.67	12.49	3.02	-0.40	1.85	2.06	-0.00	0.00			
					Soakaway Pit	154,211.36	445.89	0.69	0.37	290.63	0.45	0.45	34.82	34.82	-21.47	3.67	3.67	-2.27	2.50	0.00	-0.00			
BAR-NE9	62,083	4,226.72	6.51	3.50	Downspout Disconnection	185,079.53	1,652.07	2.55	1.37	432.82	0.97	0.36	73.80	61.77	73.80	28.85	24.14	28.85	19.64	0.03	0.02	28.85	24.14	28.85
					Dry Well	184,156.56	767.05	1.18	0.63	521.98	0.91	0.43	31.95	23.39	31.95	5.80	4.25	5.80	3.95	0.00	0.00			
					Rainwater Harvesting	184,340.67	734.64	1.13	0.61	92.12	-	-	87.46	100.00	100.00	15.20	17.38	17.38	10.35	0.02	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NW10	134,366	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	3,752.92	5.78	3.10	3,302.16	5.83	2.87	12.01	-0.78	7.63	0.57	-0.04	0.36	0.83	-0.00	0.00			
					Soakaway Pit	154,211.36	18,307.82	28.22	15.14	12,284.57	19.01	19.01	32.90	32.64	-25.53	7.62	7.56	-5.92	11.05	0.02	-0.01			
BAR-NW12	545,142	79,030.41	121.81	65.36	Downspout Disconnection	185,079.53	18,299.33	28.21	15.13	5,112.82	11.27	4.23	72.06	60.05	72.06	16.69	13.90	16.69	24.19	0.03	0.02	21.64	23.47	23.47
					Dry Well	184,156.56	20,118.67	31.01	16.64	12,121.72	22.09	10.03	39.75	28.75	39.75	10.12	7.32	10.12	14.67	0.02	0.01			
					Rainwater Harvesting	184,340.67	18,551.67	28.59	15.34	1,447.50	-	-	92.20	100.00	100.00	21.64	23.47	23.47	31.38	0.05	0.03			
					Green Roof	48,736.71	1,043.97	1.61	0.86	980.62	1.60	0.83	6.07	0.56	4.18	1.01	0.09	0.70	5.57	0.00	0.00			
					Soakaway Pit	154,211.36	1,043.97	1.61	0.86	675.87	1.04	1.04	35.26	35.26	-20.65	5.88	5.88	-3.44	32.34	0.05	-0.02			
BAR-NW28	11,383	6,263.84	9.65	5.18	Downspout Disconnection	185,079.53	1,043.97	1.61	0.86	234.44	0.53	0.19	77.54	66.89	77.54	12.92	11.15	12.92	71.12	0.09	0.06	16.67	16.67	16.67
					Dry Well	184,156.56	2,087.95	3.22	1.73	1,415.00	2.45	1.17	32.23	23.84	32.23	10.74	7.95	10.74	59.12	0.07	0.05			
					Rainwater Harvesting	184,340.67	1,043.97	1.61	0.86	-	-	-	100.00	100.00	100.00	16.67	16.67	16.67	91.71	0.14	0.08			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-NW29	63,588	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	468.88	0.72	0.39	451.29	0.71	0.38	3.75	1.08	2.84	0.75	0.22	0.57	0.59	0.00	0.00			
					Soakaway Pit	154,211.36	468.88	0.72	0.39	302.05	0.47	0.47	35.58	35.58	-20.06	7.12	7.12	-4.01	5.60	0.01	-0.00			
BAR-SE1	29,787	2,344.41	3.61	1.94	Downspout Disconnection	185,079.53	468.88	0.72	0.39	106.13	0.24	0.09	77.37	67.32	77.37	15.47	13.46	15.47	12.18	0.02	0.01	20.00	20.00	20.00
					Dry Well	184,156.56	468.88	0.72	0.39	318.53	0.55	0.26	32.07	23.73	32.07	6.41	4.75	6.41	5.05	0.01	0.00			
					Rainwater Harvesting	184,340.67	468.88	0.72	0.39	-	-	-	100.00	100.00	100.00	20.00	20.00	20.00	15.74	0.02	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	67.27	0.10	0.06	43.83	0.07	0.07	34.85	34.85	-21.42	6.97	6.97	-4.28	1.84	0.00	-0.00			
BAR-SE10	12,707	336.37	0.52	0.28	Downspout Disconnection	185,079.53	67.27	0.10	0.06	14.95	0.03	0.01	77.77	66.34	77.77	15.55	13.27	15.55	4.12	0.01	0.00	20.00	20.00	20.00
					Dry Well	184,156.56	134.55	0.21	0.11	89.01	0.16	0.07	33.84	24.93	33.84	13.54	9.97	13.54	3.58	0.00	0.00			
					Rainwater Harvesting	184,340.67	67.27	0.10	0.06	-	-	-	100.00	100.00	100.00	20.00	20.00	20.00	5.29	0.01	0.00			
					Green Roof	48,736.71	88.44	0.14	0.07	82.29	0.14	0.07	6.95	0.36	4.70	0.06	0.00	0.04	0.04	0.00	0.00			
					Soakaway Pit	154,211.36	2,317.29	3.57	1.92	1,508.80	2.33	2.33	34.89	34.89	-21.34	7.97	7.97	-4.87	4.95	0.01	-0.00			
BAR-SE14	163,266	10,146.25	15.64	8.39	Downspout Disconnection	185,079.53	2,317.29	3.57	1.92	515.59	1.20	0.43	77.75	66.40	77.75	17.76	15.16	17.76	11.04	0.01	0.01	22.84	22.84	22.84
					Dry Well	184,156.56	3,105.95	4.79	2.57	2,001.92	3.54	1.66	35.55	26.07	35.55	10.88	7.98	10.88	6.76	0.01	0.01			
					Rainwater Harvesting	184,340.67	2,317.29	3.57	1.92	-	-	-	100.00	100.00	100.00	22.84	22.84	22.84	14.19	0.02	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE16	8,996	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	346.67	0.53	0.29	300.37	0.54	0.26	13.35	-1.08	8.41	0.36	-0.03	0.23	0.32	-0.00	0.00			
					Soakaway Pit	154,211.36	2,978.94	4.59	2.46	1,945.19	3.00	3.00	34.70	34.70	-21.69	8.12	8.12	-5.08	7.07	0.01	-0.00			
BAR-SE17	146,317	12,729.54	19.62	10.53	Downspout Disconnection	185,079.53	3,037.99	4.68	2.51	672.74	1.59	0.56	77.86	66.15	77.86	18.58	15.79	18.58	16.17	0.02	0.01	23.87	23.87	23.87
					Dry Well	184,156.56	3,327.94	5.13	2.75	2,057.93	3.70	1.70	38.16	27.84	38.16	9.98	7.28	9.98	8.68	0.01	0.01			
					Rainwater Harvesting	184,340.67	3,037.99	4.68	2.51	-	-	-	100.00	100.00	100.00	23.87	23.87	23.87	20.76	0.03	0.02			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	72.68	0.11	0.06	47.27	0.07	0.07	34.97	34.97	-21.20	7.72	7.72	-4.68	0.73	0.00	-0.00			
BAR-SE21	34,663	329.03	0.51	0.27	Downspout Disconnection	185,079.53	72.68	0.11	0.06	16.20	0.04	0.01	77.71	66.50	77.71	17.17	14.69	17.17	1.63	0.00	0.00	22.09	22.09	22.09
					Dry Well	184,156.56	110.99	0.17	0.09	72.74	0.13	0.06	34.46	25.34	34.46	11.62	8.55	11.62	1.10	0.00	0.00			
					Rainwater Harvesting	184,340.67	72.68	0.11	0.06	-	-	-	100.00	100.00	100.00	22.09	22.09	22.09	2.10	0.00	0.00			
					Green Roof	48,736.71	1,390.71	2.14	1.15	1,246.84	2.15	1.07	10.35	-0.40	6.67	1.58	-0.06	1.02	6.04	-0.00	0.00			
					Soakaway Pit	154,211.36	1,390.71	2.14	1.15	907.71	1.40	1.40	34.73	34.73	-21.64	5.31	5.31	-3.31	20.29	0.03	-0.01			
BAR-SE24	23,807	9,096.10	14.02	7.52	Downspout Disconnection	185,079.53	1,390.71	2.14	1.15	308.19	0.72	0.25	77.84	66.19	77.84	11.90	10.12	11.90	45.47	0.06	0.04	15.29	15.29	15.29
					Dry Well	184,156.56	3,533.25	5.45	2.92	2,354.44	4.11	1.95	33.36	24.60	33.36	12.96	9.56	12.96	49.52	0.06	0.04			
					Rainwater Harvesting	184,340.67	1,390.71	2.14	1.15	-	-	-	100.00	100.00	100.00	15.29	15.29	15.29	58.42	0.09	0.05			
					Green Roof	48,736.71	6,336.75	9.77	5.24	5,587.43	9.84	4.85	11.83	-0.74	7.52	1.60	-0.10	1.02	2.60	-0.00	0.00			
					Soakaway Pit	154,211.36	6,654.63	10.26	5.50	4,345.99	6.70	6.70	34.69	34.69	-21.71	4.92	4.92	-3.08	8.00	0.01	-0.00			
BAR-SE25	288,566	46,915.51	72.31	38.80	Downspout Disconnection	185,079.53	9,047.61	13.95	7.48	1,959.03	4.89	1.62	78.35	64.97	78.35	15.11	12.53	15.11	24.56	0.03	0.02	19.25	19.25	19.25
					Dry Well	184,156.56	15,847.43	24.43	13.11	10,200.74	18.04	8.44	35.63	26.13	35.63	12.04	8.83	12.04	19.57	0.02	0.02			
					Rainwater Harvesting	184,340.67	9,029.08	13.92	7.47	-	-	-	100.00	100.00	100.00	19.25	19.25	19.25	31.29	0.05	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	1,376.40	2.12	1.14	900.90	1.39	1.39	34.55	34.55	-21.98	7.75	7.75	-4.93	8.64	0.01	-0.00			
BAR-SE26	55,054	6,139.15	9.46	5.08	Downspout Disconnection	185,079.53	1,415.33	2.18	1.17	312.18	0.74	0.26	77.94	65.94	77.94	17.97	15.20	17.97	20.04	0.03	0.02	25.05	25.05	25.05
					Dry Well	184,156.56	1,809.66	2.79	1.50	1,126.76	2.02	0.93	37.74	27.55	37.74	11.12	8.12	11.12	12.40	0.01	0.01			
					Rainwater Harvesting	184,340.67	1,537.75	2.37	1.27	-	-	-	100.00	100.00	100.00	25.05	25.05	25.05	27.93	0.04	0.02			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	875.35	1.35	0.72	572.43	0.88	0.88	34.61	34.61	-21.87	10.28	10.28	-6.50	11.09	0.02	-0.01			
BAR-SE28	27,308	2,946.43	4.54	2.44	Downspout Disconnection	185,079.53	492.50	0.76	0.41	107.20	0.26	0.09	78.23	65.25	78.23	13.08	10.91	13.08	14.11	0.02	0.01	35.44	35.44	35.44
					Dry Well	184,156.56	534.22	0.82	0.44	329.31	0.59	0.27	38.36	27.97	38.36	6.95	5.07	6.95	7.50	0.01	0.01			
					Rainwater Harvesting	184,340.67	1,044.36	1.61	0.86	-	-	-	100.00	100.00	100.00	35.44	35.44	35.44	38.24	0.06	0.03			
					Green Roof	48,736.71	72.09	0.11	0.06	61.11	0.11	0.05	15.22	-1.51	9.50	0.10	-0.01	0.06	0.15	-0.00	0.00			
					Soakaway Pit	154,211.36	2,265.35	3.49	1.87	1,488.55	2.29	2.29	34.29	34.29	-22.46	6.73	6.73	-4.41	10.58	0.02	-0.01			
BAR-SE29	73,451	11,544.46	17.79	9.55	Downspout Disconnection	185,079.53	2,701.77	4.16	2.23	593.91	1.43	0.49	78.02	65.76	78.02	18.26	15.39	18.26	28.70	0.04	0.02	25.01	25.01	25.01
					Dry Well	184,156.56	3,617.49	5.58	2.99	2,251.65	4.04	1.86	37.76	27.56	37.76	11.83	8.64	11.83	18.60	0.02	0.02			
					Rainwater Harvesting	184,340.67	2,887.77	4.45	2.39	-	-	-	100.00	100.00	100.00	25.01	25.01	25.01	39.32	0.06	0.03			
					Green Roof	48,736.71	184.59	0.28	0.15	178.39	0.28	0.15	3.36	1.17	2.61	0.12	0.04	0.10	0.12	0.00	0.00			
					Soakaway Pit	154,211.36	1,082.36	1.67	0.90	700.97	1.08	1.08	35.24	35.24	-20.70	7.56	7.56	-4.44	7.25	0.01	-0.00			
BAR-SE3	52,587	5,047.41	7.78	4.17	Downspout Disconnection	185,079.53	1,082.36	1.67	0.90	242.92	0.55	0.20	77.56	66.86	77.56	16.63	14.34	16.63	15.96	0.02	0.01	21.44	21.44	21.44
					Dry Well	184,156.56	1,615.75	2.49	1.34	1,080.16	1.88	0.89	33.15	24.46	33.15	10.61	7.83	10.61	10.18	0.01	0.01			
					Rainwater Harvesting	184,340.67	1,082.36	1.67	0.90	-	-	-	100.00	100.00	100.00	21.44	21.44	21.44	20.58	0.03	0.02			
					Green Roof	48,736.71	799.16	1.23	0.66	664.57	1.25	0.59	16.84	-1.87	10.44	1.18	-0.13	0.73	1.80	-0.00	0.00			
					Soakaway Pit	154,211.36	2,304.59	3.55	1.91	1,509.94	2.33	2.33	34.48	34.48	-22.10	6.94	6.94	-4.45	10.65	0.02	-0.01			
BAR-SE30	74,648	11,444.85	17.64	9.47	Downspout Disconnection	185,079.53	2,236.55	3.45	1.85	492.56	1.18	0.41	77.98	65.86	77.98	15.24	12.87	15.24	23.36	0.03	0.02	21.57	21.57	21.57
					Dry Well	184,156.56	3,635.38	5.60	3.01	2,318.81	4.12	1.92	36.22	26.52	36.22	11.50	8.43	11.50	17.64	0.02	0.01			
					Rainwater Harvesting	184,340.67	2,469.17	3.81	2.04	-	-	-	100.00	100.00	100.00	21.57	21.57	21.57	33.08	0.05	0.03			

					Green Roof	48,736.71	516.71	0.80	0.43	408.15	0.82	0.37	21.01	-2.81	12.86	0.70	-0.09	0.43	3.67	-0.00	0.00			
					Soakaway Pit	154,211.36	3,688.88	5.69	3.05	2,388.67	3.68	3.68	35.25	35.25	-20.68	8.39	8.39	-4.92	44.00	0.07	-0.02			
BAR-SE38	29,550	15,503.14	23.90	12.82	Downspout Disconnection	185,079.53	3,747.03	5.78	3.10	840.94	1.91	0.70	77.56	66.86	77.56	18.75	16.16	18.75	98.35	0.13	0.08	24.17	24.17	24.17
					Dry Well	184,156.56	3,803.50	5.86	3.15	2,490.19	4.37	2.06	34.53	25.39	34.53	8.47	6.23	8.47	44.44	0.05	0.04			
					Rainwater Harvesting	184,340.67	3,747.03	5.78	3.10	-	-	-	100.00	100.00	100.00	24.17	24.17	24.17	126.80	0.20	0.10			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	435.42	0.67	0.36	283.19	0.44	0.44	34.96	34.96	-21.21	4.42	4.42	-2.68	3.94	0.01	-0.00			
BAR-SE42	38,608	3,444.83	5.31	2.85	Downspout Disconnection	185,079.53	1,821.63	1.35	0.72	1,235.56	0.65	0.28	32.17	52.14	61.37	17.01	13.24	15.58	15.18	0.02	0.01	20.54	20.54	25.39
					Dry Well	184,156.56	2,113.23	1.94	1.04	1,485.15	1.49	0.71	29.72	23.38	32.34	18.23	8.55	11.83	16.27	0.01	0.01			
					Rainwater Harvesting	184,340.67	874.62	1.35	0.72	166.97	0.26	-	80.91	80.91	100.00	20.54	20.54	25.39	18.33	0.03	0.02			
					Green Roof	48,736.71	2,182.23	3.36	1.80	2,025.00	3.35	1.72	7.21	0.30	4.84	0.40	0.02	0.27	0.87	0.00	0.00			
					Soakaway Pit	154,211.36	3,047.55	4.70	2.52	2,001.68	3.09	3.09	34.32	34.32	-22.41	2.63	2.63	-1.72	5.77	0.01	-0.00			
BAR-SE47	181,324	39,732.30	61.24	32.86	Downspout Disconnection	185,079.53	13,270.97	10.32	5.53	8,885.76	5.04	2.20	33.04	51.11	60.32	11.04	8.61	10.16	24.18	0.03	0.02	19.19	13.41	16.84
					Dry Well	184,156.56	27,218.67	32.55	17.47	19,593.32	25.19	12.10	28.02	22.61	30.74	19.19	12.02	16.34	42.05	0.04	0.03			
					Rainwater Harvesting	184,340.67	6,692.24	10.32	5.53	1,363.90	2.10	-	79.62	79.62	100.00	13.41	13.41	16.84	29.39	0.05	0.03			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE51	14,846	1,565.33	2.41	1.29	Downspout Disconnection	185,079.53	1,961.57	0.80	0.43	1,659.87	0.51	0.24	15.38	36.57	43.70	19.27	12.19	14.57	20.32	0.02	0.01	37.00	20.11	33.33
					Dry Well	184,156.56	1,778.61	0.80	0.43	1,199.36	0.62	0.29	32.57	22.41	32.88	37.00	7.47	10.96	39.02	0.01	0.01			
					Rainwater Harvesting	184,340.67	521.78	0.80	0.43	206.92	0.32	-	60.34	60.34	100.00	20.11	20.11	33.33	21.21	0.03	0.03			
					Green Roof	48,736.71	7,657.47	11.80	6.33	5,946.13	12.17	5.47	22.35	-3.11	13.63	5.59	-0.78	3.41	27.74	-0.01	0.01			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE59	61,683	30,629.86	47.21	25.33	Downspout Disconnection	185,079.53	28,787.47	11.80	6.33	23,884.00	6.87	3.16	17.03	41.76	50.12	16.01	10.44	12.53	79.49	0.08	0.05	32.34	16.94	25.00
					Dry Well	184,156.56	25,616.87	11.80	6.33	15,712.10	8.69	3.88	38.67	26.37	38.67	32.34	6.59	9.67	160.58	0.05	0.04			
					Rainwater Harvesting	184,340.67	7,657.47	11.80	6.33	2,468.99	3.81	-	67.76	67.76	100.00	16.94	16.94	25.00	84.11	0.13	0.10			
					Green Roof	48,736.71	1,541.14	2.38	1.27	1,248.91	2.43	1.13	18.96	-2.35	11.67	4.74	-0.59	2.92	6.74	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE61	43,327	6,164.56	9.50	5.10	Downspout Disconnection	185,079.53	5,793.76	2.38	1.27	4,916.29	1.52	0.73	15.15	35.83	42.78	14.23	8.96	10.70	20.25	0.02	0.01	27.39	14.82	25.00
					Dry Well	184,156.56	5,267.30	2.38	1.27	3,578.67	1.86	0.87	32.06	21.85	32.06	27.39	5.46	8.01	38.97	0.01	0.01			
					Rainwater Harvesting	184,340.67	1,541.14	2.38	1.27	627.45	0.97	-	59.29	59.29	100.00	14.82	14.82	25.00	21.09	0.03	0.03			
					Green Roof	48,736.71	2,323.17	3.58	1.92	2,078.71	3.60	1.79	10.52	-0.44	6.77	0.79	-0.03	0.51	3.68	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE63	66,392	30,845.97	47.54	25.51	Downspout Disconnection	185,079.53	35,742.86	14.65	7.86	33,239.07	13.15	6.99	7.01	10.25	11.14	8.12	3.16	3.43	37.71	0.02	0.01	8.12	7.02	30.82
					Dry Well	184,156.56	35,355.48	14.65	7.86	34,138.46	14.31	7.58	3.44	2.34	3.58	3.95	0.72	1.10	18.33	0.01	0.00			
					Rainwater Harvesting	184,340.67	9,507.60	14.65	7.86	7,342.60	11.32	-	22.77	22.77	100.00	7.02	7.02	30.82	32.61	0.05	0.12			
					Green Roof	48,736.71	3,380.84	5.21	2.80	3,080.66	5.21	2.63	8.88	-0.07	5.81	0.74	-0.01	0.48	2.69	-0.00	0.00			
					Soakaway Pit	154,211.36	3,380.84	5.21	2.80	2,205.29	3.40	3.40	34.77	34.77	-21.56	2.90	2.90	-1.80	10.55	0.02	-0.01			
BAR-SE64	111,448	40,570.08	62.53	33.55	Downspout Disconnection	185,079.53	3,380.84	5.21	2.80	749.11	1.76	0.62	77.84	66.18	77.84	6.49	5.51	6.49	23.61	0.03	0.02	20.64	15.32	20.64
					Dry Well	184,156.56	27,046.72	41.69	22.37	18,675.06	32.11	15.45	30.95	22.98	30.95	20.64	15.32	20.64	75.12	0.09	0.06			
					Rainwater Harvesting	184,340.67	3,380.84	5.21	2.80	-	-	-	100.00	100.00	100.00	8.33	8.33	8.33	30.34	0.05	0.03			
					Green Roof	48,736.71	2,764.90	4.26	2.29	2,103.80	4.41	1.95	23.91	-3.47	14.54	5.36	-0.78	3.26	15.04	-0.00	0.01			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE67	43,956	12,328.41	19.00	10.20	Downspout Disconnection	185,079.53	11,984.35	4.91	2.64	10,009.87	2.95	1.37	16.48	40.01	47.96	16.02	10.35	12.40	44.92	0.04	0.03	31.11	16.87	25.86
					Dry Well	184,156.56	10,732.64	4.91	2.64	6,897.46	3.68	1.67	35.73	25.04	36.71	31.11	6.47	9.49	87.25	0.03	0.02			
					Rainwater Harvesting	184,340.67	3,187.84	4.91	2.64	1,107.62	1.71	-	65.25	65.25	100.00	16.87	16.87	25.86	47.33	0.07	0.06			
					Green Roof	48,736.71	7,449.20	11.48	6.16	6,720.44	11.51	5.77	9.78	-0.28	6.34	1.38	-0.04	0.89	1.79	-0.00	0.00			
					Soakaway Pit	154,211.36	7,008.89	10.80	5.80	4,571.87	7.05	7.05	34.77	34.77	-21.56	4.62	4.62	-2.86	5.98	0.01	-0.00			
BAR-SE7	407,245	52,798.49	81.38	43.67	Downspout Disconnection	185,079.53	9,429.56	13.47	7.23	3,891.13	6.22	2.68	58.73	53.81	62.94	10.49	8.91	10.42	13.60	0.02	0.01	13.44	16.25	16.56
					Dry Well	184,156.56	21,514.61	32.15	17.25	15,174.18	25.03	12.08	29.47	22.16	30.00	12.01	8.75	11.85	15.57	0.02	0.01			
					Rainwater Harvesting	184,340.67	8,740.96	13.47	7.23	1,645.84	0.25	-	81.17	98.13	100.00	13.44	16.25	16.56	17.42	0.03	0.02			
					Green Roof	48,736.71	1,752.73	2.70	1.45	1,511.30	2.73	1.32	13.77	-1.18	8.66	0.68	-0.06	0.43	0.99	-0.00	0.00			
					Soakaway Pit	154,211.36	4,481.67	6.91	3.71	2,918.10	4.50	4.50	34.89	34.89	-21.34	4.42	4.42	-2.71	6.40	0.01	-0.00			
BAR-SE74	244,253	35,340.60	54.47	29.23	Downspout Disconnection	185,079.53	6,096.09	9.40	5.04	1,354.45	3.16	1.12	77.78	66.32	77.78	13.42	11.44	13.42	19.41	0.03	0.02	16.20	16.20	16.20
					Dry Well	184,156.56	17,283.72	26.64	14.29	11,685.45	20.26	9.66	32.39	23.95	32.39	15.84	11.71	15.84	22.92	0.03	0.02			
					Rainwater Harvesting	184,340.67	5,726.39	8.83	4.74	-	-	-	100.00	100.00	100.00	16.20	16.20	16.20	23.44	0.04	0.02			
					Green Roof	48,736.71	1,857.12	2.86	1.54	1,731.96	2.85	1.47	6.74	0.41	4.57	0.99	0.06	0.67	0.64	0.00	0.00			
					Soakaway Pit	154,211.36	2,560.05	3.95	2.12	1,688.57	2.60	2.60	34.04	34.04	-22.92	6.86	6.86	-4.62	4.43	0.01	-0.00			
BAR-SE80	196,535	12,703.61	19.58	10.51	Downspout Disconnection	185,079.53	2,672.68	4.12	2.21	585.12	1.42	0.48	78.11	65.54	78.11	16.43	13.79	16.43	10.62	0.01	0.01	20.57	20.57	20.57
					Dry Well	184,156.56	3,000.68	4.63	2.48	1,830.63	3.31	1.51	38.99	28.40	38.99	9.21	6.71	9.21	5.95	0.01	0.00			
					Rainwater Harvesting	184,340.67	2,613.08	4.03	2.16	-	-	-	100.00	100.00	100.00	20.57	20.57	20.57	13.30	0.02	0.01			
					Green Roof	48,736.71	702.83	1.08	0.58	659.58	1.08	0.56	6.15	0.54	4.23	1.23	0.11	0.85	1.11	0.00	0.00			
					Soakaway Pit	154,211.36	702.83	1.08	0.58	454.92	0.70	0.70	35.27	35.27	-20.63	7.05	7.05	-4.13	6.35	0.01	-0.00			
BAR-SE81	39,023	3,514.14	5.42	2.91	Downspout Disconnection	185,079.53	702.83	1.08	0.58	157.88	0.36	0.13	77.54	66.91	77.54	15.51	13.38	15.51	13.96	0.02	0.01	20.00	20.00	20.00
					Dry Well	184,156.56	702.83	1.08	0.58	460.60	0.81	0.38	34.46	25.34	34.46	6.89	5.07	6.89	6.21	0.01	0.01			
					Rainwater Harvesting	184,340.67	702.83	1.08	0.58	-	-	-	100.00	100.00	100.00	20.00	20.00	20.00	18.01	0.03	0.01			

					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SE82	11,789	550.43	0.85	0.46	Downspout Disconnection	185,079.53	183.48	0.28	0.15	38.84	0.10	0.03	78.83	63.81	78.83	26.28	21.27	26.28	12.27	0.02	0.01	33.33	33.33	33.33
					Dry Well	184,156.56	183.48	0.28	0.15	86.86	0.18	0.07	52.66	37.60	52.66	17.55	12.53	17.55	8.20	0.01	0.01			
					Rainwater Harvesting	184,340.67	183.48	0.28	0.15	-	-	-	100.00	100.00	100.00	33.33	33.33	33.33	15.56	0.02	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	23,823.62	36.72	19.70	15,894.49	24.50	24.50	33.28	33.28	-24.34	8.35	8.35	-6.11	10.56	0.02	-0.01			
BAR-SE85	751,111	94,936.12	146.33	78.52	Downspout Disconnection	185,079.53	23,608.39	36.39	19.53	5,034.13	13.03	4.16	78.68	64.18	78.68	19.57	15.96	19.57	24.73	0.03	0.02	24.87	24.87	24.87
					Dry Well	184,156.56	23,895.71	36.83	19.76	11,935.87	23.63	9.87	50.05	35.85	50.05	12.60	9.02	12.60	15.92	0.02	0.01			
					Rainwater Harvesting	184,340.67	23,608.39	36.39	19.53	-	-	-	100.00	100.00	100.00	24.87	24.87	24.87	31.43	0.05	0.03			
					Green Roof	48,736.71	2,870.91	4.43	2.37	2,308.71	4.54	2.09	19.58	-2.49	12.03	1.78	-0.23	1.09	4.93	-0.00	0.00			
					Soakaway Pit	154,211.36	5,178.39	7.98	4.28	3,417.46	5.30	5.30	34.01	33.61	-23.73	5.57	5.50	-3.89	15.45	0.02	-0.01			
BAR-SW10	113,968	31,621.07	48.74	26.15	Downspout Disconnection	185,079.53	6,305.20	9.72	5.21	2,125.69	4.30	1.76	66.29	55.77	66.29	13.22	11.12	13.22	36.67	0.05	0.03	22.18	25.49	25.49
					Dry Well	184,156.56	9,206.71	14.19	7.61	6,173.37	10.77	5.11	32.95	24.08	32.95	9.59	7.01	9.59	26.62	0.03	0.02			
					Rainwater Harvesting	184,340.67	8,059.86	12.42	6.67	1,045.74	-	-	87.03	100.00	100.00	22.18	25.49	25.49	61.54	0.11	0.06			
					Green Roof	48,736.71	7,382.29	11.38	6.11	6,467.46	11.48	5.63	12.39	-0.87	7.85	0.92	-0.06	0.58	1.60	-0.00	0.00			
					Soakaway Pit	154,211.36	15,903.86	24.51	13.15	10,533.84	16.29	16.29	33.77	33.55	-23.83	5.42	5.38	-3.82	9.38	0.01	-0.01			
BAR-SW11	572,529	99,145.21	152.82	82.00	Downspout Disconnection	185,079.53	20,075.50	27.53	14.77	6,984.80	10.87	4.04	65.21	60.53	72.67	13.20	10.90	13.09	22.86	0.03	0.02	17.05	18.05	18.31
					Dry Well	184,156.56	41,732.89	61.42	32.96	27,254.24	45.85	21.56	34.69	25.34	34.60	14.60	10.19	13.91	25.29	0.03	0.02			
					Rainwater Harvesting	184,340.67	18,151.19	27.98	15.01	1,245.28	0.40	-	93.14	98.57	100.00	17.05	18.05	18.31	29.53	0.05	0.03			
					Green Roof	48,736.71	13,896.89	21.42	11.49	11,613.78	21.80	10.32	16.43	-1.78	10.20	4.05	-0.44	2.51	9.73	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW13	234,634	56,351.82	86.86	46.61	Downspout Disconnection	185,079.53	53,201.66	21.81	11.70	45,880.02	14.95	7.33	13.76	31.48	37.41	12.99	7.91	9.39	31.20	0.03	0.02	23.46	13.33	25.11
					Dry Well	184,156.56	49,118.24	21.81	11.70	35,896.45	17.77	8.52	26.92	18.53	27.22	23.46	4.65	6.84	56.35	0.02	0.01			
					Rainwater Harvesting	184,340.67	14,151.64	21.81	11.70	6,639.60	10.23	-	53.08	53.08	100.00	13.33	13.33	25.11	32.02	0.05	0.05			
					Green Roof	48,736.71	532.81	0.82	0.44	475.69	0.83	0.41	10.72	-0.49	6.88	0.62	-0.03	0.40	0.51	-0.00	0.00			
					Soakaway Pit	154,211.36	618.49	0.95	0.51	401.81	0.62	0.62	35.03	35.03	-21.07	2.34	2.34	-1.41	1.92	0.00	-0.00			
BAR-SW23	113,062	9,265.52	14.28	7.66	Downspout Disconnection	185,079.53	6,590.70	3.40	1.83	5,498.61	2.27	1.12	16.57	33.36	38.84	11.79	7.95	9.25	9.66	0.01	0.01	16.39	13.07	23.82
					Dry Well	184,156.56	7,839.73	5.70	3.06	6,320.96	4.69	2.31	19.37	17.76	24.53	16.39	7.09	9.80	13.43	0.01	0.01			
					Rainwater Harvesting	184,340.67	2,207.10	3.40	1.83	996.15	1.54	-	54.87	54.87	100.00	13.07	13.07	23.82	10.71	0.02	0.02			
					Green Roof	48,736.71	934.69	1.44	0.77	883.87	1.43	0.74	5.44	0.70	3.82	5.44	0.70	3.82	2.30	0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW27	22,115	934.69	1.44	0.77	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.44	0.70	3.82
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	567.29	0.87	0.47	373.83	0.58	0.58	34.10	34.10	-22.81	6.94	6.94	-4.64	2.82	0.00	-0.00			
BAR-SW30	68,702	2,787.15	4.30	2.31	Downspout Disconnection	185,079.53	989.80	1.03	0.55	507.66	0.43	0.17	48.71	58.42	69.79	17.30	13.97	16.69	7.02	0.01	0.01	21.60	21.60	23.91
					Dry Well	184,156.56	1,184.69	1.37	0.73	792.94	1.00	0.46	33.07	26.90	37.16	14.06	8.56	11.83	5.70	0.01	0.00			
					Rainwater Harvesting	184,340.67	666.40	1.03	0.55	64.39	0.10	-	90.34	90.34	100.00	21.60	21.60	23.91	8.76	0.01	0.01			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW31	21,103	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW32	56,175	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	18,975.40	29.25	15.69	16,990.49	29.37	14.64	10.46	-0.43	6.73	3.65	-0.15	2.35	8.15	-0.00	0.00			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW33	243,566	54,348.31	83.77	44.95	Downspout Disconnection	185,079.53	44,326.96	18.17	9.75	41,735.44	16.97	9.10	5.85	6.60	6.64	4.77	1.43	1.44	10.64	0.00	0.00	4.77	3.81	21.70
					Dry Well	184,156.56	44,326.96	18.17	9.75	44,537.13	18.25	9.80	-0.47	-0.44	-0.47	(0.39)	-0.10	-0.10	-0.86	-0.00	-0.00			
					Rainwater Harvesting	184,340.67	11,790.97	18.17	9.75	9,718.87	14.98	-	17.57	17.57	100.00	3.81	3.81	21.70	8.51	0.01	0.04			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW39	10,171	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW40	351,744	21,553.30	33.22	17.83	Downspout Disconnection	185,079.53	27,009.14	11.07	5.94	25,437.60	10.35	5.55	5.82	6.52	6.53	7.29	2.17	2.18	4.47	0.00	0.00	7.29	5.82	33.33
					Dry Well	184,156.56	27,009.14	11.07	5.94	27,163.48	11.13	5.98	-0.57	-0.51	-0.57	(0.72)	-0.17	-0.19	-0.44	-0.00	-0.00			
					Rainwater Harvesting	184,340.67	7,184.43	11.07	5.94	5,930.83	9.14	-	17.45	17.45	100.00	5.82	5.82	33.33	3.56	0.01	0.02			
					Green Roof	48,736.71	1,327.02	2.05	1.10	1,196.63	2.05	1.03	9.83	-0.29	6.36	0.24	-0.01	0.16	0.27	-0.00	0.00			
					Soakaway Pit	154,211.36	12,466.98	19.22	10.31	8,185.14	12.62	12.62	34.35	34.35	-22.36	7.88	7.88	-5.13	8.70	0.01	-0.00			
BAR-SW45	491,948	54,356.47	83.78	44.96	Downspout Disconnection	185,079.53	14,603.01	20.22	10.85	4,507.20	7.23	2.56	69.14	64.25	76.37	18.57	15.51	18.43	20.52	0.03	0.02	21.72	21.72	22.19
					Dry Well	184,156.56	16,717.00	23.71	12.72	10,286.73	16.92	7.70	38.47	28.65	39.48	11.83	8.11	11.17	13.07	0.01	0.01			
					Rainwater Harvesting	184,340.67	12,059.28	18.59	9.97	255.16	0.39	-	97.88	97.88	100.00	21.72	21.72	22.19	23.99	0.04	0.02			
					Green Roof	48,736.71	934.50	1.44	0.77	881.56	1.43	0.74	5.66	0.65	3.95	0.57	0.07	0.40	1.09	0.00	0.00			
					Soakaway Pit	154,211.36	938.98	1.45	0.78	615.62	0.95	0.95	34.44	34.44	-22.19	3.49	3.49	-2.25	6.65	0.01	-0.00			
BAR-SW48	48,602	9,277.72	14.30	7.67	Downspout Disconnection	185,079.53	925.53	1.43	0.77	203.06	0.49	0.17	78.06	65.66	78.06	7.79	6.55	7.79	14.86	0.02	0.01	18.99	14.07	18.99
					Dry Well	184,156.56	5,553.18	8.56	4.59	3,791.13	6.55	3.14	31.73	23.50	31.73	18.99	14.07	18.99	36.25	0.04	0.03			
					Rainwater Harvesting	184,340.67	925.53	1.43	0.77	-	-	-	100.00	100.00	100.00	9.98	9.98	9.98	19.04	0.03	0.02			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW51	68,869	-	-	-	Downspout Disconnection	185,079.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					Dry Well	184,156.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Rainwater Harvesting	184,340.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW7	64,790	14,338.01	22.10	11.86	Downspout Disconnection	185,079.53	17,967.43	7.37	3.95	15,980.21	5.67	2.89	11.06	22.99	26.90	13.86	7.66	8.97	30.67	0.03	0.02	21.14	13.65	33.33
					Dry Well	184,156.56	17,083.80	7.37	3.95	14,052.72	6.48	3.25	17.74	12.06	17.77	21.14	4.02	5.92	46.78	0.01	0.01			
					Rainwater Harvesting	184,340.67	4,779.34	7.37	3.95	2,821.63	4.35	-	40.96	40.96	100.00	13.65	13.65	33.33	30.22	0.05	0.06			
					Green Roof	48,736.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
					Soakaway Pit	154,211.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
BAR-SW8	17,096	2,024.69	3.12	1.67	Downspout Disconnection	185,079.53	2,537.21	1.04	0.56	2,202.20	0.73	0.36	13.20	29.73	35.24	16.55	9.91	11.75	19.60	0.02	0.01	28.97	16.86	33.33
					Dry Well	184,156.56	2,356.92	1.04	0.56	1,770.44	0.86	0.42	24.88	17.19	25.27	28.97	5.73	8.42	34.31	0.01	0.01			
					Rainwater Harvesting	184,340.67	674.90	1.04	0.56	333.55	0.51	-	50.58	50.58	100.00	16.86	16.86	33.33	19.97	0.03	0.03			
					Green Roof	48,736.71	8,392.70	12.94	6.94	7,277.10	13.07	6.36	13.29	-1.07	8.38	0.84	-0.07	0.53	1.33	-0.00	0.00			
					Soakaway Pit	154,211.36	20,951.38	32.29	17.33	13,975.40	21.61	21.61	33.30	33.08	-24.71	5.23	5.19	-3.88	8.29	0.01	-0.01			
BAR-SW9	841,651	133,438.56	205.68	110.36	Downspout Disconnection	185,079.53	40,338.35	42.74	22.93	21,056.42	18.72	7.53	47.80	56.19	67.16	14.45	11.68	13.96	22.91	0.03	0.02	18.34	19.35	21.08
					Dry Well	184,156.56	59,664.44	74.34	39.89	40,473.53	55.83	26.26	32.16	24.90	34.16	14.38	9.00	12.35	22.80	0.02	0.02			
					Rainwater Harvesting	184,340.67	28,131.81	43.36	23.27	3,654.06	3.56	-	87.01	91.79	100.00	18.34	19.35	21.08	29.08	0.05	0.03			

Note: [(1)] TSS stands for Total Suspended Solids.
[(2)] TP stands for Total Phosphorus.

Table D.4-3: Decision-Making Input Data

Stormsewershed ID	LID Type	Runoff Volume Removed by LID (mm/m^2) in Stormwatershed	Pollutant Removed by LID ($kg/yr/m^2$) in Stormwatershed			Total-Cost (2010, $CDN)	Stakeholder Acceptance Level Rank
			TSS (1)	TP (2)	Zinc		
BAR-C1	Green Roof	4.17	2.23	0.00	0.00	$18,492,478	4
	Soakaway Pit	12.43	10.38	0.02	-0.01	$11,634,699	2
	Downspout Disconnection	52.31	25.57	0.03	0.02	$4,384,606	1
	Dry Well	21.41	19.31	0.02	0.01	$2,235,134	5
	Rainwater Harvesting	62.65	32.12	0.06	0.03	$27,211,253	3
BAR-C11	Green Roof	-	0.00	0.00	0.00	$0	0
	Soakaway Pit	11.59	10.35	0.02	-0.01	$346,683	2
	Downspout Disconnection	52.14	23.49	0.03	0.02	$6,435	1
	Dry Well	19.13	13.19	0.01	0.01	$41,601	5
	Rainwater Harvesting	62.75	30.08	0.05	0.02	$730,115	3
BAR-C12	Green Roof	23.35	13.03	0.00	0.01	$14,623,362	4
	Soakaway Pit	11.49	12.32	0.02	-0.01	$690,065	2
	Downspout Disconnection	37.13	16.91	0.02	0.01	$13,311,989	1
	Dry Well	15.97	12.16	0.01	0.01	$171,926	5
	Rainwater Harvesting	55.40	26.76	0.12	0.07	$2,586,240	3
BAR-C15	Green Roof	0.47	0.15	0.00	0.00	$186,939	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-C16	Green Roof	14.23	7.76	0.00	0.00	$11,527,664	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	20.50	14.63	0.02	0.01	$711,429	1
	Dry Well	11.24	35.29	0.01	0.01	$288,752	5
	Rainwater Harvesting	29.25	21.02	0.03	0.03	$1,099,413	3
BAR-C17	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-C18	Green Roof	22.99	12.80	0.00	0.01	$54,014,084	4
	Soakaway Pit	0.62	0.55	0.00	0.00	$63,405	2
	Downspout Disconnection	42.52	31.22	0.04	0.03	$46,507,289	1
	Dry Well	24.54	74.79	0.02	0.02	$816,079	5
	Rainwater Harvesting	60.34	42.25	0.07	0.06	$5,657,472	3
BAR-C19	Green Roof	17.56	9.89	0.00	0.00	$8,106,524	4
	Soakaway Pit	6.98	4.79	0.01	0.00	$482,117	2
	Downspout Disconnection	67.54	41.09	0.05	0.03	$3,888,026	1
	Dry Well	55.66	85.72	0.05	0.04	$396,281	5
	Rainwater Harvesting	88.20	54.19	0.08	0.06	$2,124,639	3
BAR-C21	Green Roof	3.30	1.84	0.00	0.00	$1,250,077	4
	Soakaway Pit	10.28	8.55	0.01	0.00	$1,043,932	2
	Downspout Disconnection	55.77	28.82	0.04	0.02	$238,736	1
	Dry Well	30.19	37.18	0.02	0.02	$228,500	5
	Rainwater Harvesting	80.37	42.80	0.07	0.04	$3,099,420	3
BAR-C22	Green Roof	11.06	6.12	0.00	0.00	$2,846,909	4
	Soakaway Pit	7.15	8.21	0.01	-0.01	$97,284	2
	Downspout Disconnection	7.20	3.29	0.00	0.00	$290,545	1
	Dry Well	4.53	3.23	0.00	0.00	$108,142	5
	Rainwater Harvesting	31.59	14.99	0.07	0.04	$398,712	3
BAR-C23	Green Roof	9.03	4.45	0.00	0.00	$9,805,671	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	20.72	12.02	0.02	0.01	$1,286,451	1
	Dry Well	7.20	25.33	0.01	0.01	$332,241	5
	Rainwater Harvesting	27.95	20.80	0.03	0.05	$1,155,823	3
BAR-C25	Green Roof	12.91	6.95	0.00	0.00	$28,672,719	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	26.38	22.48	0.02	0.02	$11,631,990	1
	Dry Well	14.24	45.66	0.01	0.01	$853,886	5
	Rainwater Harvesting	38.42	27.71	0.04	0.05	$3,743,853	3

BAR-C26	Green Roof	13.78	7.34	0.00	0.00	$11,431,616	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	37.19	37.19	0.03	0.02	$7,212,712	1
	Dry Well	19.79	63.72	0.02	0.02	$429,996	5
	Rainwater Harvesting	52.52	37.81	0.06	0.06	$2,191,511	3
BAR-C28	Green Roof	2.98	1.59	0.00	0.00	$1,149,029	4
	Soakaway Pit	7.58	6.44	0.01	0.00	$610,420	2
	Downspout Disconnection	65.74	39.62	0.04	0.03	$1,360,010	1
	Dry Well	35.51	43.16	0.03	0.02	$221,114	5
	Rainwater Harvesting	96.59	52.62	0.08	0.07	$2,085,775	3
BAR-C3	Green Roof	-	0.00	0.00	0.00	$0	0
	Soakaway Pit	2.70	2.74	0.00	0.00	$27,252	2
	Downspout Disconnection	13.63	6.11	0.01	0.01	$57,880	1
	Dry Well	3.77	2.36	0.00	0.00	$2,480	5
	Rainwater Harvesting	17.26	7.86	0.01	0.01	$50,231	3
BAR-C30	Green Roof	4.28	2.05	0.00	0.00	$2,810,918	4
	Soakaway Pit	4.21	3.56	0.01	0.00	$157,077	2
	Downspout Disconnection	19.42	11.92	0.01	0.01	$102,256	1
	Dry Well	10.32	12.35	0.01	0.01	$121,672	5
	Rainwater Harvesting	33.31	18.33	0.07	0.05	$669,075	3
BAR-C32	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-C4	Green Roof	9.30	4.99	0.00	0.00	$10,377,152	4
	Soakaway Pit	8.03	7.19	0.01	0.00	$1,377,758	2
	Downspout Disconnection	52.05	32.57	0.04	0.02	$9,239,123	1
	Dry Well	25.35	36.07	0.02	0.02	$472,687	5
	Rainwater Harvesting	63.57	35.21	0.06	0.04	$3,848,369	3
BAR-C5	Green Roof	4.71	2.48	0.00	0.00	$11,175,345	4
	Soakaway Pit	7.29	6.81	0.01	0.00	$2,021,918	2
	Downspout Disconnection	41.27	20.47	0.02	0.02	$3,521,743	1
	Dry Well	19.06	16.07	0.01	0.01	$672,103	5
	Rainwater Harvesting	51.55	25.86	0.06	0.03	$7,417,911	3
BAR-C8	Green Roof	16.41	9.38	0.00	0.00	$1,716,610	4
	Soakaway Pit	5.21	5.03	0.01	0.00	$156,671	2
	Downspout Disconnection	90.14	41.63	0.05	0.03	$1,715,969	1
	Dry Well	58.74	40.89	0.05	0.03	$88,750	5
	Rainwater Harvesting	112.17	56.41	0.09	0.05	$558,399	3
BAR-C9	Green Roof	8.65	4.69	0.00	0.00	$2,100,525	4
	Soakaway Pit	2.73	2.46	0.00	0.00	$122,873	2
	Downspout Disconnection	44.83	33.42	0.03	0.02	$216,192	1
	Dry Well	21.97	49.24	0.02	0.02	$133,136	5
	Rainwater Harvesting	67.67	40.78	0.07	0.05	$847,660	3
BAR-NE11	Green Roof	0.74	0.37	0.00	0.00	$414,874	4
	Soakaway Pit	2.65	2.34	0.00	0.00	$152,795	2
	Downspout Disconnection	26.75	12.04	0.02	0.01	$8,276	1
	Dry Well	5.96	4.07	0.00	0.00	$35,031	5
	Rainwater Harvesting	18.51	8.89	0.01	0.01	$423,008	3
BAR-NE12	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	37.41	16.87	0.02	0.01	$5,754	1
	Dry Well	2.01	1.30	0.00	0.00	$2,429	5
	Rainwater Harvesting	9.18	4.41	0.01	0.00	$57,315	3
BAR-NE13	Green Roof	2.86	1.54	0.00	0.00	$9,912,091	4
	Soakaway Pit	7.08	6.03	0.01	0.00	$3,328,575	2
	Downspout Disconnection	26.52	12.43	0.02	0.01	$1,234,901	1
	Dry Well	23.49	17.20	0.02	0.01	$1,221,156	5
	Rainwater Harvesting	31.15	15.50	0.03	0.02	$7,414,750	3

BAR-NE14	Green Roof	0.51	0.25	0.00	0.00	$1,143,992	4
	Soakaway Pit	9.39	8.32	0.01	0.00	$2,351,522	2
	Downspout Disconnection	41.33	18.62	0.02	0.02	$67,331	1
	Dry Well	16.45	11.26	0.01	0.01	$413,136	5
	Rainwater Harvesting	48.46	23.42	0.04	0.02	$4,827,558	3
BAR-NE17	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	19.07	13.43	0.01	0.01	$160,479	5
	Rainwater Harvesting	66.68	32.64	0.05	0.03	$2,354,692	3
BAR-NE18	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	9.80	17.10	0.02	0.01	$255,035	5
	Rainwater Harvesting	27.70	34.01	0.05	0.03	$3,301,245	3
BAR-NE19	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	3.67	3.23	0.00	0.00	$417,706	2
	Downspout Disconnection	17.45	7.86	0.01	0.01	$6,547	1
	Dry Well	26.36	18.08	0.02	0.01	$285,285	5
	Rainwater Harvesting	71.18	34.58	0.05	0.03	$3,764,512	3
BAR-NE20	Green Roof	1.97	1.04	0.00	0.00	$3,120,958	4
	Soakaway Pit	10.11	9.13	0.01	-0.01	$2,112,366	2
	Downspout Disconnection	46.88	21.10	0.03	0.02	$252,756	1
	Dry Well	18.75	12.69	0.01	0.01	$395,392	5
	Rainwater Harvesting	51.51	24.71	0.04	0.02	$4,500,559	3
BAR-NE24	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	23.69	16.30	0.02	0.01	$79,833	5
	Rainwater Harvesting	64.02	31.17	0.05	0.03	$1,070,044	3
BAR-NE25	Green Roof	0.73	0.41	0.00	0.00	$444,423	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-	0.00	0.00	0.00	$0	0
	Dry Well	19.05	16.10	0.01	0.01	$203,017	5
	Rainwater Harvesting	57.45	28.73	0.04	0.03	$2,816,971	3
BAR-NE26	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	23.80	16.54	0.02	0.01	$90,640	5
	Rainwater Harvesting	71.72	34.97	0.05	0.03	$1,134,641	3
BAR-NE27	Green Roof	6.59	3.15	0.00	0.00	$4,763,032	4
	Soakaway Pit	5.15	4.31	0.01	-0.01	$476,555	2
	Downspout Disconnection	12.19	5.03	0.01	0.00	$518,129	1
	Dry Well	11.26	7.15	0.01	0.01	$232,629	5
	Rainwater Harvesting	30.70	13.74	0.06	0.03	$2,069,062	3
BAR-NE28	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	27.62	19.04	0.02	0.02	$225,693	5
	Rainwater Harvesting	76.57	37.27	0.06	0.03	$3,703,085	3
BAR-NE29	Green Roof	1.97	1.07	0.00	0.00	$2,968,766	4
	Soakaway Pit	12.84	11.00	0.02	-0.01	$3,182,414	2
	Downspout Disconnection	60.72	27.35	0.04	0.02	$218,928	1
	Dry Well	30.81	21.00	0.02	0.02	$602,116	5
	Rainwater Harvesting	79.92	38.80	0.06	0.03	$7,810,978	3
BAR-NE3	Green Roof	3.07	1.63	0.00	0.00	$11,361,638	4
	Soakaway Pit	10.77	9.25	0.01	-0.01	$5,500,639	2
	Downspout Disconnection	45.34	20.96	0.03	0.02	$970,974	1
	Dry Well	21.70	15.96	0.02	0.01	$1,251,480	5
	Rainwater Harvesting	51.06	25.20	0.05	0.03	$11,465,960	3
BAR-NE30	Green Roof	2.70	1.33	0.00	0.00	$1,895,936	4
	Soakaway Pit	7.56	7.03	0.01	-0.01	$556,622	2
	Downspout Disconnection	27.92	12.58	0.02	0.01	$222,076	1
	Dry Well	13.95	9.32	0.01	0.01	$148,136	5
	Rainwater Harvesting	40.94	19.71	0.05	0.03	$1,411,547	3

BAR-NE31	Green Roof	6.62	3.66	0.00	0.00	$6,371,050	4
	Soakaway Pit	13.97	13.41	0.02	-0.01	$1,540,814	2
	Downspout Disconnection	42.75	19.27	0.02	0.02	$156,420	1
	Dry Well	17.58	12.16	0.01	0.01	$330,952	5
	Rainwater Harvesting	48.05	23.31	0.06	0.03	$3,279,142	3
BAR-NE32	Green Roof	2.93	1.66	0.00	0.00	$796,848	4
	Soakaway Pit	7.86	7.67	0.01	0.00	$240,810	2
	Downspout Disconnection	28.64	12.94	0.02	0.01	$550,348	1
	Dry Well	8.69	6.10	0.01	0.01	$116,893	5
	Rainwater Harvesting	38.35	18.73	0.10	0.06	$967,179	3
BAR-NE39	Green Roof	5.54	3.13	0.00	0.00	$27,732,730	4
	Soakaway Pit	9.15	7.93	0.01	0.00	$8,078,096	2
	Downspout Disconnection	61.65	28.87	0.04	0.02	$5,918,083	1
	Dry Well	23.64	18.17	0.02	0.01	$1,859,660	5
	Rainwater Harvesting	57.79	28.80	0.05	0.03	$21,412,641	3
BAR-NE40	Green Roof	7.81	4.46	0.00	0.00	$5,427,723	4
	Soakaway Pit	5.39	3.90	0.01	0.00	$317,001	2
	Downspout Disconnection	44.15	20.41	0.02	0.02	$1,366,993	1
	Dry Well	44.27	29.44	0.03	0.02	$328,963	5
	Rainwater Harvesting	30.15	15.89	0.06	0.03	$1,726,869	3
BAR-NE8	Green Roof	0.36	0.19	0.00	0.00	$1,360,425	4
	Soakaway Pit	5.33	4.81	0.01	0.00	$2,108,440	2
	Downspout Disconnection	28.49	12.82	0.02	0.01	$218,892	1
	Dry Well	21.18	14.39	0.02	0.01	$807,860	5
	Rainwater Harvesting	58.23	28.06	0.04	0.02	$9,550,308	3
BAR-NE9	Green Roof	3.69	2.06	0.00	0.00	$1,017,514	4
	Soakaway Pit	2.50	2.50	0.00	0.00	$75,444	2
	Downspout Disconnection	43.56	19.64	0.03	0.02	$44,181	1
	Dry Well	5.90	3.95	0.00	0.00	$19,885	5
	Rainwater Harvesting	21.66	10.35	0.02	0.01	$321,286	3
BAR-NW10	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-NW12	Green Roof	1.58	0.83	0.00	0.00	$4,477,287	4
	Soakaway Pit	13.43	11.05	0.02	-0.01	$5,948,829	2
	Downspout Disconnection	53.58	24.19	0.03	0.02	$954,857	1
	Dry Well	20.82	14.67	0.02	0.01	$1,070,346	5
	Rainwater Harvesting	63.97	31.38	0.05	0.03	$12,853,153	3
BAR-NW28	Green Roof	12.13	5.57	0.00	0.00	$683,696	4
	Soakaway Pit	28.14	32.34	0.05	-0.02	$27,881	2
	Downspout Disconnection	159.05	71.12	0.09	0.06	$62,392	1
	Dry Well	92.06	59.12	0.07	0.05	$21,790	5
	Rainwater Harvesting	196.76	91.71	0.14	0.08	$58,451	3
BAR-NW29	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SE1	Green Roof	3.90	0.59	0.00	0.00	$190,446	4
	Soakaway Pit	11.42	5.60	0.01	0.00	$15,025	2
	Downspout Disconnection	71.45	12.18	0.02	0.01	$2,906	1
	Dry Well	20.60	5.05	0.01	0.00	$5,658	5
	Rainwater Harvesting	89.51	15.74	0.02	0.01	$31,553	3
BAR-SE10	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	1.83	1.84	0.00	0.00	$13,259	2
	Downspout Disconnection	9.18	4.12	0.01	0.00	$670	1
	Dry Well	5.48	3.58	0.00	0.00	$3,289	5
	Rainwater Harvesting	11.17	5.29	0.01	0.00	$28,017	3
BAR-SE14	Green Roof	0.08	0.04	0.00	0.00	$152,719	4
	Soakaway Pit	4.84	4.95	0.01	0.00	$610,758	2
	Downspout Disconnection	24.61	11.04	0.01	0.01	$18,117	1
	Dry Well	10.18	6.76	0.01	0.01	$122,420	5
	Rainwater Harvesting	29.99	14.19	0.02	0.01	$1,293,906	3

BAR-SE16	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SE17	Green Roof	0.59	0.32	0.00	0.00	$822,160	4
	Soakaway Pit	7.30	7.07	0.01	0.00	$770,934	2
	Downspout Disconnection	36.00	16.17	0.02	0.01	$47,134	1
	Dry Well	12.76	8.68	0.01	0.01	$196,950	5
	Rainwater Harvesting	43.54	20.76	0.03	0.02	$1,658,445	3
BAR-SE21	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	0.70	0.73	0.00	0.00	$24,247	2
	Downspout Disconnection	3.64	1.63	0.00	0.00	$210	1
	Dry Well	1.68	1.10	0.00	0.00	$3,455	5
	Rainwater Harvesting	4.45	2.10	0.00	0.00	$51,532	3
BAR-SE24	Green Roof	11.79	6.04	0.00	0.00	$1,765,208	4
	Soakaway Pit	20.78	20.29	0.03	-0.01	$65,235	2
	Downspout Disconnection	101.29	45.47	0.06	0.04	$217,286	1
	Dry Well	76.17	49.52	0.06	0.04	$54,911	5
	Rainwater Harvesting	122.64	58.42	0.09	0.05	$137,758	3
BAR-SE25	Green Roof	4.96	2.60	0.00	0.00	$4,517,235	4
	Soakaway Pit	8.29	8.00	0.01	0.00	$1,260,840	2
	Downspout Disconnection	54.34	24.56	0.03	0.02	$3,464,631	1
	Dry Well	29.43	19.57	0.02	0.02	$314,749	5
	Rainwater Harvesting	65.26	31.29	0.05	0.03	$2,840,096	3
BAR-SE26	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	9.32	8.64	0.01	0.00	$528,503	2
	Downspout Disconnection	44.57	20.04	0.03	0.02	$7,438	1
	Dry Well	18.31	12.40	0.01	0.01	$84,768	5
	Rainwater Harvesting	58.22	27.93	0.04	0.02	$1,252,778	3
BAR-SE28	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	1.11	11.09	0.02	-0.01	$199,556	2
	Downspout Disconnection	2.96	14.11	0.02	0.01	$2,622	1
	Dry Well	1.04	7.50	0.01	0.01	$18,013	5
	Rainwater Harvesting	7.59	38.24	0.06	0.03	$523,635	3
BAR-SE29	Green Roof	0.28	0.15	0.00	0.00	$166,511	4
	Soakaway Pit	12.23	10.58	0.02	-0.01	$762,690	2
	Downspout Disconnection	63.77	28.70	0.04	0.02	$24,741	1
	Dry Well	27.44	18.60	0.02	0.02	$140,317	5
	Rainwater Harvesting	81.74	39.32	0.06	0.03	$1,823,197	3
BAR-SE3	Green Roof	0.31	0.12	0.00	0.00	$151,089	4
	Soakaway Pit	6.36	7.25	0.01	0.00	$198,553	2
	Downspout Disconnection	35.70	15.96	0.02	0.01	$12,568	1
	Dry Well	15.70	10.18	0.01	0.01	$48,754	5
	Rainwater Harvesting	44.12	20.58	0.03	0.02	$419,671	3
BAR-SE30	Green Roof	0.20	1.80	0.00	0.00	$1,382,497	4
	Soakaway Pit	0.72	10.65	0.02	-0.01	$546,203	2
	Downspout Disconnection	3.18	23.36	0.03	0.02	$56,861	1
	Dry Well	1.62	17.64	0.02	0.01	$119,042	5
	Rainwater Harvesting	4.20	33.08	0.05	0.03	$1,266,364	3
BAR-SE38	Green Roof	6.56	3.67	0.00	0.00	$678,687	4
	Soakaway Pit	38.45	44.00	0.07	-0.02	$77,180	2
	Downspout Disconnection	219.91	98.35	0.13	0.08	$58,114	1
	Dry Well	67.56	44.44	0.05	0.04	$29,853	5
	Rainwater Harvesting	271.78	126.80	0.20	0.10	$190,623	3
BAR-SE42	Green Roof	-	0.00	0.00	0.00	$0	0
	Soakaway Pit	3.77	3.94	0.01	0.00	$126,593	2
	Downspout Disconnection	28.34	15.18	0.02	0.01	$6,545	1
	Dry Well	14.95	16.27	0.01	0.01	$51,375	5
	Rainwater Harvesting	35.31	18.33	0.03	0.02	$626,478	3
BAR-SE47	Green Roof	1.81	0.87	0.00	0.00	$2,299,382	4
	Soakaway Pit	6.62	5.77	0.01	0.00	$975,955	2
	Downspout Disconnection	46.86	24.18	0.03	0.02	$623,387	1
	Dry Well	54.47	42.05	0.04	0.03	$332,523	5
	Rainwater Harvesting	57.28	29.39	0.05	0.03	$3,237,383	3
BAR-SE51	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	20.32	20.32	0.02	0.01	$3,681	1
	Dry Well	12.32	39.02	0.01	0.01	$38,065	5
	Rainwater Harvesting	29.76	21.21	0.03	0.03	$465,309	3

BAR-SE59	Green Roof	49.27	27.74	-0.01	0.01	$12,708,853	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	79.49	79.49	0.08	0.05	$28,476,450	1
	Dry Well	51.40	160.58	0.05	0.04	-$229,801	5
	Rainwater Harvesting	118.66	84.11	0.13	0.10	$1,694,223	3
BAR-SE61	Green Roof	12.16	6.74	0.00	0.00	$2,526,007	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	20.25	20.25	0.02	0.01	$950,476	1
	Dry Well	12.15	38.97	0.01	0.01	$64,473	5
	Rainwater Harvesting	29.57	21.09	0.03	0.03	$181,081	3
BAR-SE63	Green Roof	7.16	3.68	0.00	0.00	$2,295,636	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	37.71	37.71	0.02	0.01	$843,971	1
	Dry Well	5.83	18.33	0.01	0.00	$82,882	5
	Rainwater Harvesting	42.08	32.61	0.05	0.12	$222,590	3
BAR-SE64	Green Roof	5.40	2.69	0.00	0.00	$1,930,094	4
	Soakaway Pit	10.68	10.55	0.02	-0.01	$73,040	2
	Downspout Disconnection	52.60	23.61	0.03	0.02	$797,830	1
	Dry Well	118.70	75.12	0.09	0.06	$68,019	5
	Rainwater Harvesting	63.79	30.34	0.05	0.03	$158,830	3
BAR-SE67	Green Roof	26.56	15.04	0.00	0.01	$4,305,105	4
	Soakaway Pit	-	0.00	0.00	0.00	$0	0
	Downspout Disconnection	44.92	44.92	0.04	0.03	$745,396	1
	Dry Well	28.48	87.25	0.03	0.02	$128,461	5
	Rainwater Harvesting	66.65	47.33	0.07	0.06	$371,746	3
BAR-SE7	Green Roof	3.52	1.79	0.00	0.00	$7,944,362	4
	Soakaway Pit	6.06	5.98	0.01	0.00	$946,231	2
	Downspout Disconnection	30.07	13.60	0.02	0.01	$1,276,166	1
	Dry Well	23.80	15.57	0.02	0.01	$301,114	5
	Rainwater Harvesting	36.72	17.42	0.03	0.02	$2,225,726	3
BAR-SE74	Green Roof	1.85	0.99	0.00	0.00	$3,214,147	4
	Soakaway Pit	6.26	6.40	0.01	0.00	$1,333,363	2
	Downspout Disconnection	43.28	19.41	0.03	0.02	$456,638	1
	Dry Well	35.63	22.92	0.03	0.02	$293,782	5
	Rainwater Harvesting	49.54	23.44	0.04	0.02	$2,906,405	3
BAR-SE80	Green Roof	1.35	0.64	0.00	0.00	$1,082,238	4
	Soakaway Pit	5.46	4.43	0.01	0.00	$798,963	2
	Downspout Disconnection	23.57	10.62	0.01	0.01	$14,218	1
	Dry Well	8.70	5.95	0.01	0.00	$116,287	5
	Rainwater Harvesting	27.15	13.30	0.02	0.01	$1,743,886	3
BAR-SE81	Green Roof	0.48	1.11	0.00	0.00	$392,940	4
	Soakaway Pit	1.09	6.35	0.01	0.00	$19,872	2
	Downspout Disconnection	6.20	13.96	0.02	0.01	$16,549	1
	Dry Well	1.87	6.21	0.01	0.01	$11,968	5
	Rainwater Harvesting	7.68	18.01	0.03	0.01	$41,472	3
BAR-SE82	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	1.62	12.27	0.02	0.01	$21,231	1
	Dry Well	0.66	8.20	0.01	0.01	$13,376	5
	Rainwater Harvesting	1.82	15.56	0.02	0.01	$43,800	3
BAR-SE85	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	59.35	10.56	0.02	-0.01	$10,439,678	2
	Downspout Disconnection	208.14	24.73	0.03	0.02	$164,326	1
	Dry Well	82.70	15.92	0.02	0.01	$1,672,881	5
	Rainwater Harvesting	236.76	31.43	0.05	0.03	$21,990,454	3
BAR-SW10	Green Roof	8.87	4.93	0.00	0.00	$3,857,830	4
	Soakaway Pit	16.87	15.45	0.02	-0.01	$889,658	2
	Downspout Disconnection	81.45	36.67	0.05	0.03	$130,529	1
	Dry Well	39.48	26.62	0.03	0.02	$228,959	5
	Rainwater Harvesting	127.66	61.54	0.11	0.06	$2,482,153	3
BAR-SW11	Green Roof	3.03	1.60	0.00	0.00	$8,814,771	4
	Soakaway Pit	10.76	9.38	0.01	-0.01	$4,168,595	2
	Downspout Disconnection	49.55	22.86	0.03	0.02	$2,696,574	1
	Dry Well	36.06	25.29	0.03	0.02	$1,013,949	5
	Rainwater Harvesting	59.96	29.53	0.05	0.03	$9,682,028	3

BAR-SW13	Green Roof	17.81	9.73	0.00	0.00	$17,994,231	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	31.20	31.20	0.03	0.02	$2,404,796	1
	Dry Well	17.40	56.35	0.02	0.01	$543,006	5
	Rainwater Harvesting	44.63	32.02	0.05	0.05	$1,624,946	3
BAR-SW23	Green Roof	0.98	0.51	0.00	0.00	$591,823	4
	Soakaway Pit	1.79	1.92	0.00	0.00	$49,290	2
	Downspout Disconnection	14.90	9.66	0.01	0.01	$89,398	1
	Dry Well	11.45	13.43	0.01	0.01	$89,117	5
	Rainwater Harvesting	18.76	10.71	0.02	0.02	$749,816	3
BAR-SW27	Green Roof	5.16	2.30	0.00	0.00	$696,446	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SW30	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	3.42	2.82	0.00	0.00	$266,050	2
	Downspout Disconnection	14.62	7.02	0.01	0.01	$5,713	1
	Dry Well	6.83	5.70	0.01	0.00	$43,252	5
	Rainwater Harvesting	17.41	8.76	0.01	0.01	$596,886	3
BAR-SW31	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SW32	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SW33	Green Roof	15.87	8.15	0.00	0.00	$14,245,123	4
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	10.64	10.64	0.00	0.00	$2,680	1
	Dry Well	-	-0.86	0.00	0.00	$5,475	5
	Rainwater Harvesting	10.52	8.51	0.01	0.04	$30,799	3
BAR-SW39	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SW40	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	4.47	4.47	0.00	0.00	$31,699	1
	Dry Well	-	-0.44	0.00	0.00	$16,006	5
	Rainwater Harvesting	4.40	3.56	0.01	0.02	$47,790	3
BAR-SW45	Green Roof	0.52	0.27	0.00	0.00	$1,119,287	4
	Soakaway Pit	9.92	8.70	0.01	0.00	$4,773,065	2
	Downspout Disconnection	44.89	20.52	0.03	0.02	$109,910	1
	Dry Well	17.78	13.07	0.01	0.01	$759,702	5
	Rainwater Harvesting	49.25	23.99	0.04	0.02	$9,306,093	3
BAR-SW48	Green Roof	2.42	1.09	0.00	0.00	$1,238,578	4
	Soakaway Pit	7.40	6.65	0.01	0.00	$127,327	2
	Downspout Disconnection	33.01	14.86	0.02	0.01	$230,170	1
	Dry Well	56.77	36.25	0.04	0.03	$104,539	5
	Rainwater Harvesting	39.51	19.04	0.03	0.02	$116,800	3
BAR-SW51	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	-----	0.00	0.00	0.00	$0	0
	Dry Well	-----	0.00	0.00	0.00	$0	0
	Rainwater Harvesting	-----	0.00	0.00	0.00	$0	0
BAR-SW7	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	30.67	30.67	0.03	0.02	$4,730,471	1
	Dry Well	13.64	46.78	0.01	0.01	$100,644	5
	Rainwater Harvesting	41.42	30.22	0.05	0.06	$794,415	3
BAR-SW8	Green Roof	-----	0.00	0.00	0.00	$0	0
	Soakaway Pit	-----	0.00	0.00	0.00	$0	0
	Downspout Disconnection	19.60	19.60	0.02	0.01	$3,035	1
	Dry Well	10.55	34.31	0.01	0.01	$35,828	5
	Rainwater Harvesting	27.75	19.97	0.03	0.03	$484,868	3
BAR-SW9	Green Roof	2.49	1.33	0.00	0.00	$9,761,658	4
	Soakaway Pit	9.58	8.29	0.01	-0.01	$6,251,876	2
	Downspout Disconnection	47.57	22.91	0.03	0.02	$2,405,213	1
	Dry Well	28.68	22.80	0.02	0.02	$1,470,786	5
	Rainwater Harvesting	58.08	29.08	0.05	0.03	$15,952,086	3

Note: (1) TSS stands for Total Suspended Solids.
(2) TP stands for Total Phosphorus.