DEVELOPMENT OF A STORMWATER LOW IMPACT DEVELOPMENT (LID) PLANNING TOOL

By

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Abstract

Development of a New Low Impact Development Planning Tool

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The purpose of this research is to develop a new planning tool to evaluate the efficiency of Low Impact Development (LID) for single-family homes in Ontario. A comprehensive literature review was conducted to compare major LID planning tool available for public to identify the key features of an ideal LID planning tool. A study across four regions in Ontario was conducted to obtain rainfall, soil, and housing-types data. U.S. EPA Stormwater Management Model (SWMM) was selected to perform all the simulation for establishing a common database for the new tool. With the new tool, users can estimate the runoff reduction, total suspended solids loading reduction, total phosphorus loading reduction and total cost by several clicks and few data inputs. The case study of Bayview Wellington Center in Town of Aurora illustrated that the new tool achieved required accuracy level.

Acknowledgements

I would like to gratefully acknowledge my supervisor Dr. James Li for his guidance, support, and inspiration throughout my thesis work. My acknowledgement also extend to Dr. Darko Joksimovic for his help and guidance in the early stages of this research with respect to data collection. Huge thanks to my colleague Marija Eric at Ryerson University, for her help and advices. My last thanks go to Mr. Matyn Hills for helping me proofread this thesis.

Dedications

I dedicate this thesis to my parents, Ping Zheng and Liqin Jiang, who always supported my every endeavor. Also, this thesis is dedicated to my fiancé, Nan Zi. I cannot finish this thesis without his motivation and inspiration.

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CHAPTER ONE

1 Introduction

1.1 Background

Rapid population growth has become a major driving force of urbanization, which inevitably affects landscape, watershed, and surface and ground water. Urbanization changes runoff quality and affects water quality in receiving water bodies, and generates significant environmental impacts on receiving waters, and their habitats. When a land area is developed, undisturbed pervious surface becomes impervious with the construction of parking lots, buildings, streets, and other structures, which increases the quantity and decreases the quality of stormwater runoff. Figure 1 indicates the general environmental impacts of urban development on an undeveloped site. In a typical moderately developed watershed, the net effect of urbanization is a series of changes to hydrologic conditions. These changes occur progressively with each step in the intensification of development. Such impacts include (Schueler, 1987):

- Peak discharges about two to five times higher than pre-development levels;
- Increased volume of stormwater runoff;
- Reduced time of concentration;
- Increased frequency and severity of flooding;
- Reduced stream flows during prolonged periods of dry weather due to reduced level of infiltration in the watershed; and
- Increased runoff velocity during storms.

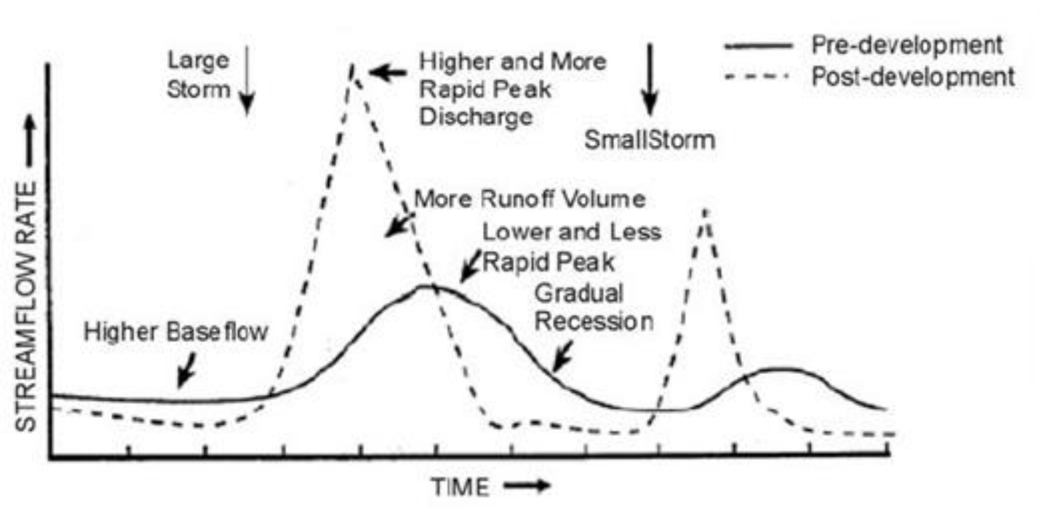


Figure 1: Changes in Watershed Hydrology as a Result of Urbanization (Schueler, 1987)

Most flooding is caused by heavy and intens precipitation in areas where inadequate drainage systems cannot deal with excess amount of runoff effectively. In their well-known publication on water resource engineering, Wurbs and James (2002) suggested that the ultimate objective of storm water management is to enhance the quality of life by:

- Protecting human life and reducing flood safety risks;
- Preventing damage to private and public properties;
- Minimizing the disruption effects of storm water runoff; and
- Protecting water quality.

Poor stormwater management practices in urban area can be even more dangerous than many natural disasters. On July 20th, 2012, Beijing, China, was hit by the heaviest storm since 1951. In some of the worst hit areas such as Fang Shan, the obsolete design of the city's drainage system allowed most stormwater to flood the city's roads submerging or sweeping away large number of vehicles. The storm took 77 lives, damaged more than 66,000 homes, wrecked 466 miles of road, and resulted in a total loss of 1.57 billion Canadian Dollars. More than 1.9 million people are still suffering from post-disaster trauma. (Xinhua News Agency, 2012). The Beijing incident shows that storm water management is not only a basic urban requirement, but is also one of the most critical infrastructure components to be considered at the urban planning and development stage.

A low-impact development (LID) urban drainage uses effective and attractive micro-scale techniques to control stormwater runoff, minimize pollution, and protect developing watersheds; it is employed to address many of the new challenges as well as providing promising outcomes in storm water management. LID is a relatively new concept in stormwater management, which utilizes a site design strategy with a goal of maintaining or replicating the pre-development hydrologic regime using design techniques to create a functionally equivalent hydrologic landscape (U.S. EPA, 2000). Unlike traditional stormwater management methods that convey, manage and treat stormwater by large and expensive drainage systems, LID manages stormwater through smaller and more cost-effective landscape features located at the lot level. LIDs also have the advantages of effectively removing nutrients, pathogens and metals from runoff, and reducing the volume and intensity of stormwater flows.

Stormwater Best Management Practice (BMP) focuses on water quality problems caused by increased impervious surface from land development. US EPA defines BMP as "a technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner". BMP can be used to meet a variety of goals, including reducing stormwater volume, peak flows, and nonpoint source pollution through evapotranspiration, infiltration, detention and filtration or biological and chemical actions. In existing developed areas, BMP can be executed to address a range of water quality and quantity considerations. For new urban development, BMP should be designed and implemented to maintain the pre-development peak discharge rate and volume, sediment loadings to receiving, and runoff quality after development. In order to meet these goals, BMP can be employed to address three main factors: flow control, pollutant removal and pollutant source reduction (U.S. EPA, 1999).

Regardless of the types, stormwater BMP is most effective when implemented as part of a comprehensive stormwater management program that includes proper selection, design, construction, inspection and maintenance. BMP can be grouped into two categories: structural and non-structural. Structural BMP is used to treat the stormwater at point of generation or point of discharge either to the storm sewer system or to receiving waters. Non-structural BMP includes pollution prevention, education, institutional, management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation (U.S. EPA, 1999). This thesis focuses on structural BMP only.

1.2 Problem Definition

Models can be used to facilitate design and policy decision-making by predicting the outcomes of different design and management approaches and alternatives. Models allow users to isolate the receiving water impacts associated with stormwater management approaches, and compare the environmental outcomes of alternative management scenarios to guide the decision makers in meeting sustainable development objectives. A range of models is available to analyze the costs and environmental outcomes associated with LID implementation. In order to identify the features of an ideal planning tool, 16 available planning models were reviewed. Table 1 indicates the models and their download ability. Most models are available for the public to download from government or institution websites, except the ‘Drainage System Selection Tool’, ‘New York State Green Infrastructure Worksheets’, and ‘Phosphorus Budget Tool for the Lake Simcoe Watershed’, which are only for research purposes at this stage. The new tool developed in this thesis would be for use at the planning level, which means the tool should quickly generate performance estimation with a set of simplified assumptions. However, several complex models requiring relatively extensive data and technical expertise, such as SWMM and DURMM, were also reviewed to give a more comprehensive result.

Table 1: List of Reviewed LID Planning Models

Model	Downloadable
Green Build-out Model	Yes
Virginia Runoff Reduction Method	Yes
WERF BMP and LID Whole Life Cost Models	Yes
EPA's Green Long Term Control-EZ Template	Yes
WERF BMP SELECT Model	Yes
Center for Neighborhood Technology Green Values National Stormwater Management Calculator	Yes
North Carolina State University Rainwater Harvesting Model	Yes
SWMM	Yes
Drainage System Selection Tool	No
RECARGA	Yes
Delaware Urban Runoff Management Model(DURMM)	Yes
Phosphorus Budget Tool for the Lake Simcoe Watershed	No
New York State Green Infrastructure Worksheets	No
LID BMP Sizing Calculator for Kitsap County	Yes

Figure 2 shows the scale distribution of 16 available models. Among these models, more than 70% of them are at site or city scale. Models at the stage can allow users to link a site's land cover and stormwater controls to the volume of stormwater discharged by the site and the pollutant loads exported by those discharges. Site designers can use these results to meet mandatory or voluntary performance standards. Only 28% of the models can predict at watershed level. Models at watershed scale can link land cover and stormwater controls throughout a watershed to the hydrological, chemical, and ecological outcomes in receiving water. For planning a new subdivision, site-scale tool can give more appropriate and compatible results. However, most of the site-scale planning tools normalize designate LID to the entire proposed area, so the outputs, especially the cost, vary significantly depending on the land use and percentage of impervious area. Lot-based simulation could be adopted to solve these uncertainties.

In addition, most tools are suitable for modeling drainage characteristics before LID planning and are more useful during the last stages of decision-making. Only a few tools can provide detailed runoff analysis at the early stage of planning. Other than just technical criteria, economics is also a driving factor in prioritizing management strategies. 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 (Lawson, 2010). Figure 3 shows the output distribution of 16 reviewed LID planning models. About one third of the models can calculate the total cost. However, most tools with cost estimation function are based on either complex models, or simple spreadsheets without runoff analysis. In addition, among these sixteen models, only two models are specially designed for Ontario, and one of model outputs do not include cost calculation. It means none of reviewed tools except one can calculate the capital cost, and operation and maintenance cost based on Ontario market prices.

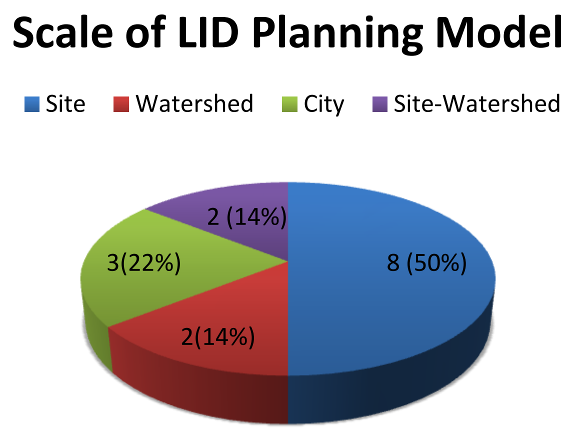


Figure 2: Scale Distribution of Available LID Planning Tool.

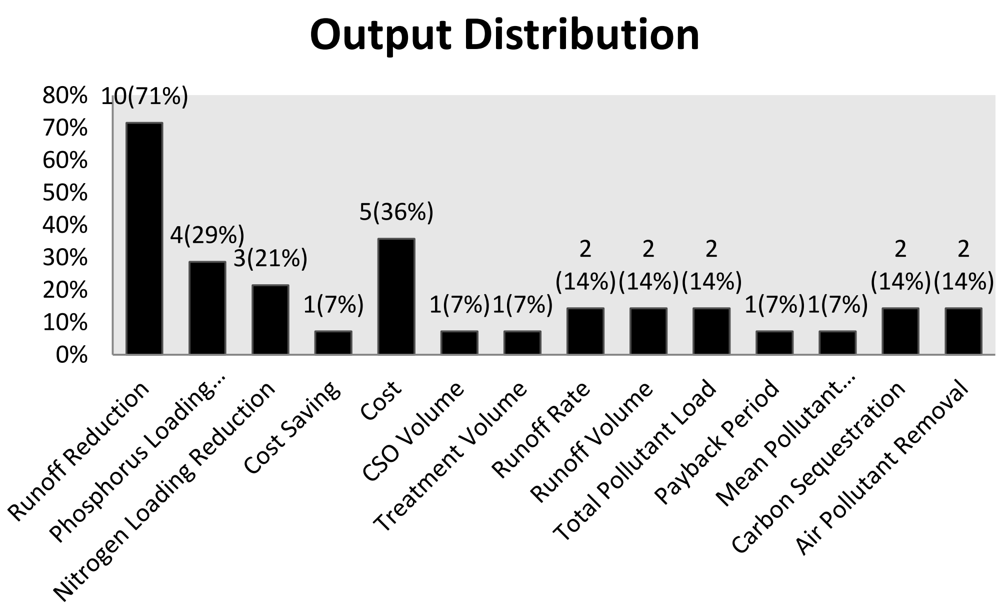


Figure 3: Output Distribution of Available LID Planning Models

An ideal planning tool with appropriate features should allow users to apply regional watershed criteria and local physical constraints to BMP selection. By comparing the performance and cost-efficiency of different LID combinations, users could determine whether or not the LID plan is likely to meet the provincial standards and the most cost-effective combination.

1.3 Research Objective

As a result of the deficiencies discussed above, there is an acute need to devise an innovative lot-based LID planning tool for engineers and decision-makers which will close the gap in determining the performance and cost-efficiency of LID implementation at planning level in Ontario. The objective of this research is to develop an effective LID planning tool for single-family residential areas, which allow users to select LID practices in order to achieve 80% Total Suspended Solids removal standard regulated by Ontario Ministry of Environment (2003). Research tasks are as follows:

- Determine the role and level of stormwater management in Ontario;
- Review available planning models to identify optimum features to be made of a new LID planning tool;
- Develop a new tool with the required features;
- Test the new tool with a series of local rainfall, soil, and land use data; and
- Analyze the model outputs to evaluate the performance of the new tool.

1.4 Research Scope and Methodology

In line with the research objective, the scope of this study was to:

a) Compare available LID planning tools, including simple spreadsheets and complex models, to identify key features of an ideal LID planning tool;

b) Develop and describe the function of each component of the new LID planning tool, where each function is developed from an Ontario perspective; and

c) Demonstrate the new planning tool through a case study for the Bayview Wellington Centre in the Town of Aurora.

The methodology corresponding to the study's objectives is summarized in Table 2 below.

Table 2: List of Goals and Corresponding Methodology

Goal	Methodologies/Activities
To identify needs of study	• Identify the research gap • Identify role of stormwater management in North

	America • Review current applications of LID in Ontario
To determine general design parameters	• Compare available LID planning models • Conclude features of the new LID planning tool
To create tool structure for organizing data	• Identify planning tool scale • Identify most appropriate level of accuracy • Identify the hierarchy of objects required for data input and design representation
To select and apply appropriate data	• Identify features which support steps in integration and selection of LID practices for Ontario Municipalities • Divide Ontario into 4 regions and select one representative station of each region • Obtain rainfall, soil and housing data of each station • Run SWMM to obtain runoff reduction, TSS reduction and TP reduction of each station • Select and add appropriate features wherever feasible
To evaluate the utility of new planning tool in Ontario	• Employ a case study of Bayview Wellington Centre of Town of Aurora in Lake Simcoe Watershed • Compare results with two other available planning tools (New York State Green Infrastructure Worksheets and Phosphorus Budget Tool for the Lake Simcoe Watershed)
To recommend other modifications for future study	• Identify shortages of the new planning tool • Identify emerging trends and requirements in stormwater management decisions at the planning level

1.5 Organization of Thesis

The thesis consists of five chapters. Chapter One begins with a background of the research, as well as the research objectives and scope. Chapter Two provides a literature review of current application of LID in North America, compares available LID planning models, and identifies key features of an ideal LID planning tool. Chapter Three describes structure and functions of each component of the new LID planning tool. Chapter Four demonstrate a case study of Bayview Wellington Centre in the Town of Aurora to evaluate efficiency and accuracy of the new LID planning tool. Chapter Five highlights the conclusions of the research, and proposes recommendations for future study.

CHAPTER TWO

2 Literature Review

2.1 History of Low Impact Development in North American

LID was first adopted and implemented as an alternate design strategy in northeastern United States and the Pacific Northwest (CWP, 2000; Horner *et al.*, 1997) and has been increasingly introduced in other regions of the United States. The practice is still fairly new because the first formal application was launched in Prince George's County, Maryland, in 1999 (Prince George's County Government, 1999). Morzaria-Luna *et al.* (2004) listed 15 LID projects in eight states, of which seven were in new development areas and eight were retrofit projects in established urban areas. Graham *et al.* (2004) described application of LID design in British Columbia. There are now a number of field assessments of individual LID, all of which present successful outcomes: Maryland (Davis *et al.*, 2003), New Hampshire (Rossen *et al.*, 2006), North Carolina (Hunt *et al.*, 2006), Ohio (Sansalone and Teng, 2004), and Pennsylvania (Heasom *et al.*, 2006). In the past decade, over 30 stormwater management manuals and guidelines with most up-to-date approaches and practice have been published (Lawson, 2010). However, most of them are more focused on technical aspect than other aspects, such as economic, cultural, and social impacts.

2.2 Low Impact Development in Ontario

Ontario borders on four of the five Great Lakes, having more than 250 thousands lakes, rivers, and streams with a rich groundwater resource. (Ontario Ministry of Environment, 2003). In order to protect the lush drinking water and fresh water resources at large from pollution, Ontario government released a series of legislative practices including 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) (Lawson, 2010). Ontario Ministry of Environment also created several documents, such as 'Understanding Stormwater Management: An Introduction to Stormwater Management Planning and Design (2003)', 'Stormwater Management Planning and Design Manual (2003)', and 'Stormwater Pollution Prevention Handbook (2001)', for municipalities, community groups, businesses and individuals who are interested in managing stormwater and reducing pollution at its source. Although the Stormwater Management Planning and Design Manual (2003) is considered as the primary reference for LID planning in Ontario, it has not been renewed for almost 10 years so some of the criteria and design guidelines might be out-of-date. According to the current urbanization and population growth situation, an updated version or supplementary document is expected. Two organizations in Ontario, the Credit Valley Conservation (CVC) and the Toronto and Region Conservation Authority (TRCA), published an integrated LID design process and requirement manual in 2010. The manual gives detailed design criteria, BMP sizing and cost estimation of different LID designs.

To be feasible in Ontario cities, infiltration-based stormwater controls must function satisfactorily in winter condition. Hunt *et al.* (2006) proved that LID elements continue to function in colder months with reduced capacity. A reduction of infiltration from 0.93 in summer to 0.46 in winter was observed due to low evapotranspiration in winter. Heason *et al.* (2006) observed that under winter conditions at a site near Philadelphia, the hydraulic conductivity of soil receiving infiltration was about half the summer value. The Connecticut, Pennsylvania, and New Hampshire results (Roseen *et al.*, 2006) demonstrated the capability of infiltration-based BMP to function satisfactorily under winter conditions similar to those of Central Ontario. However, all the Ontario studies are based on Southern Ontario conditions. There is no evidence to prove that LID practices can function in the colder Northern Ontario. In order to maintain the consistency of the new planning tool, only rainfall data from the rain season (from April to November) will be processed, and snow accumulation and melting will not be simulated in this thesis.

LID has not been widely implemented in Ontario because it is still considered as a new approach and is mistakenly assumed to be experimental. Without widespread municipal adoption, professionals in the development business have not invested sufficient time to get familiar with the LID approach. The other reason is that LID does not have as clear design criteria and performance as large end-of-pipe designs. The MOE 2003 Stormwater Management Planning and Design Manual also does not provide guidance on the credit applicable when incorporating LID within the treatment train.(IFC Marbek,2012) Figure 4 shows the various sites implemented LID in Ontario. A total of 38 projects were found. Most of them were applied at public lands, and industrial and commercial lands.

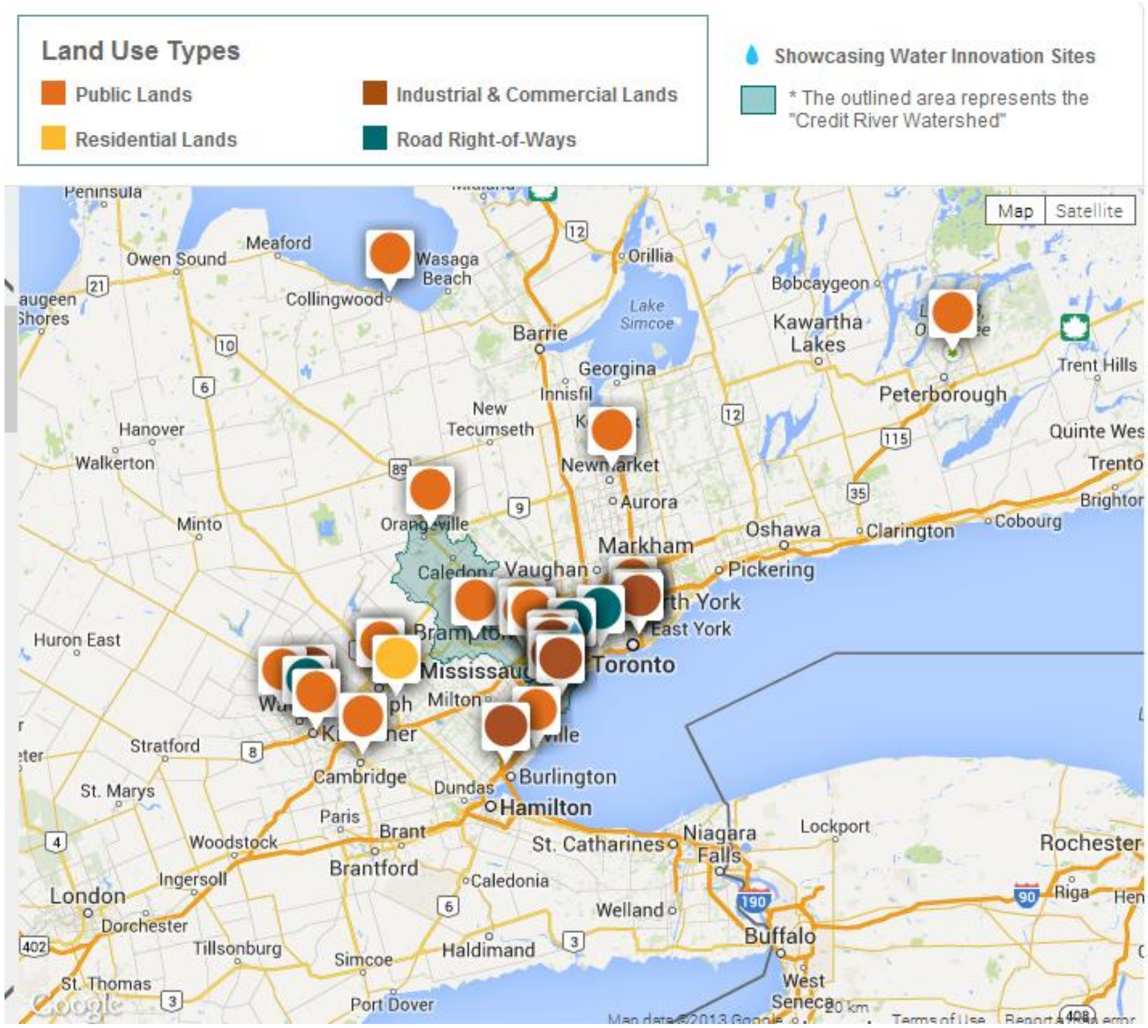


Figure 4 Sites implemented LID in Ontario (Credit Valley Conservation, 2013)

2.3 LID Practices Selection

LID selection is a complex process. There are a number of competing factors that need to be addressed when selecting appropriate LID for an area. Without proper LID selection, design, construction and maintenance, LID will not be able to manage urban runoff effectively. LID selection can be altered to address the various sources of runoff produced from urbanized areas. In established urban communities, a different combination of LID may be more suitable due to space constraints. In these areas, LID may be selected to focus on pollution prevention practices along with retrofit of the established storm drainage system with regional LID. Site suitability for selecting a particular LID strategy is key to successful performance. LID has limitations and therefore cannot be applied nationwide. U.S EPA (1999) listed a few considerations to incorporate into LID selection including:

- drainage area;
- land use;
- average rainfall frequency, duration and intensity;
- runoff volume and flow rates;
- soil types;
- site slopes;
- geology and topography;
- availability of land;
- future development in watershed;
- depth to groundwater table;
- availability of supplemental water to support vegetative BMPs;
- susceptibility to freezing;
- safety and community acceptance;
- maintenance accessibility; and
- periodic and long-term maintenance/rehabilitation needs.

It is impossible to include all LID simulations in one planning tool. Figure 5 demonstrates LID distribution among the sixteen reviewed tools. Only the following top seven LID are incorporated into the new planning tool as follows:

- Green Roof (GR)
- Porous Pavement (PP)
- Dry Well (DW)
- Bioretention Cell (BR)
- Soakaway Pit (SP)
- Rainwater Harvesting (RH)
- Downspout Disconnection (DD)

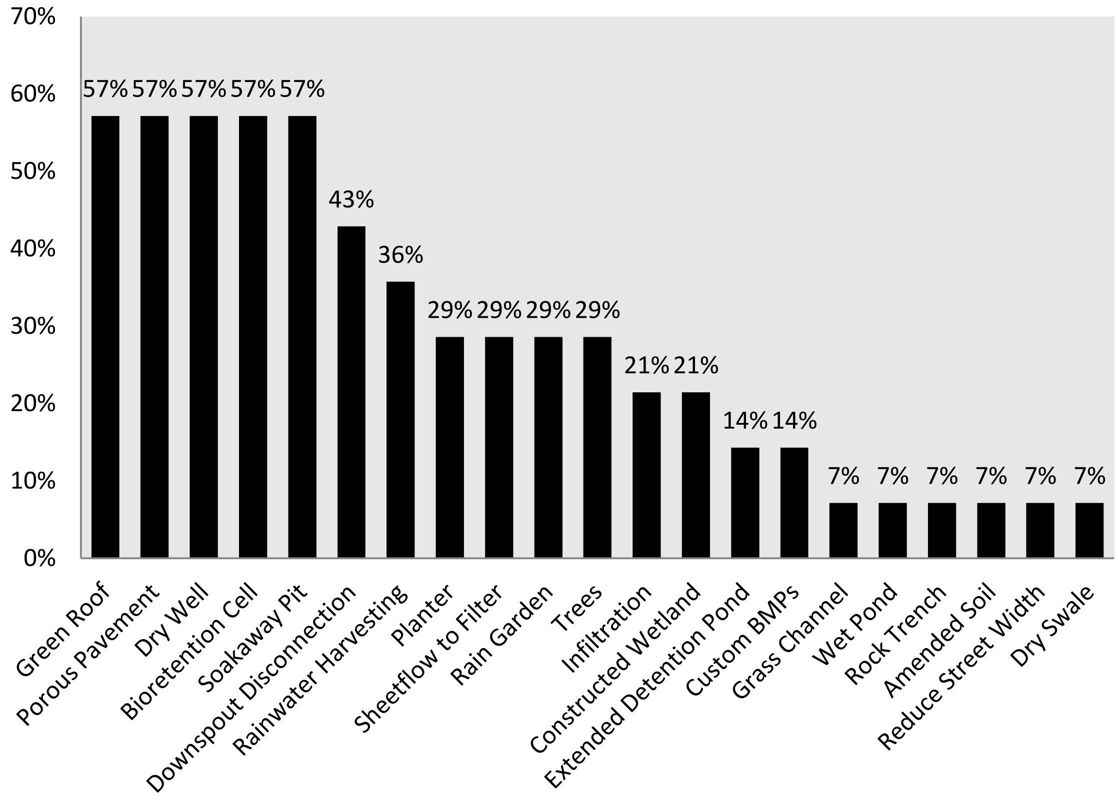


Figure 5: LID Distribution of Available Planning Models

According to Li *et al*. (2010), the seven LID practices could be combined in various ways to yield seventeen reasonable combinations. The combinations depended on the land use of the planned lot, for example, residential, commercial, or institutional. This thesis only analyzes single-family residential homes lots, which means that the roof area of each lot is generally smaller than 200 square meters. One of the assumptions of green roof is "applied on rooftops greater than 350 square meters" (Li *et al*., 2010). Green roofs may not be practicable in this thesis, but all the combinations containing green roofs are reserved in the new tool for further research and development. Combinations of GR+PP+DD and GR+BR+DD were simulated as PP+DD and BR+DD for the residential use. The seventeen combinations consist of:

- Green Roof + Downspout Disconnection (GR+DD)
- Green Roof + Soakaway Pit (GR+SP)
- Green Roof + Dry Well (GR+DW)
- Green Roof + Porous Pavement (GR+PP)
- Green Roof + Porous Pavement + Downspout Disconnection (GR+PP+DD)
- Green Roof + Bioretention Cell + Downspout Disconnection (GR+BR+DD)
- Soakaway Pit + Porous Pavement (SP+PP)
- Green Roof + Rainwater Harvesting (GR+RH)
- Bioretention Cell + Porous Pavement (BR+PP)
- Green Roof + Bioretention Cell (GR+BR)
- Dry Well + Porous Pavement (DW+PP)
- Dry Well + Bioretention Cell (DW+BR)
- Soakaway Pit + Bioretention Cell (SP+BR)
- Rainwater Harvesting + Bioretention Cell (RH+BR)
- Green Roof + Bioretention Cell + Rainwater Harvesting (GR+BR+RH)

- Green Roof + Porous Pavement + Rainwater Harvesting (GR+PP+RH)
- Porous Pavement + Rainwater Harvesting (PP+RH)

2.4 Evaluation of LID Effectiveness

2.4.1 Hydrological Measures

Some traditional stormwater control enhancement in site drainage, such as curbs and gutters, cause an increase in surface runoff volume, frequency, and velocity. This may result in flooding, high erosion, reduction of groundwater infiltration, and habitat degradation. Four hydrological functions should be considered when investigating the effectiveness of LID practices: runoff curve number, time of concentration, retention, and detention. (U.S. EPA, 2000)

Curve number is used to define the runoff potential for a site. Hydrological function on a developed site can be measured by comparing the pre-developed and post-developed curve number. Hawkins (1998) stated that the curve number measures a watershed or subwatershed's hydrological response and is determined based on soil type, land use and amount of impervious surface. One of the goals of LID is to design a system so that the post-developed curve number is as close as possible to the pre-development curve number of the site. Limiting the percentage of impervious surface is one technique to accomplishing the goal. The runoff coefficient, which is derived from the curve number, can be applied to calculate the percentage of rainfall converted to runoff.

Other than Curve Number model, the US EPA SWMM model (Rossman, 2010) has the other two built-in infiltration models: Horton's Equation, and Green-Ampt. Horton's Equation is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to some minimum infiltration rate, a decay coefficient that describes how fast the rate decreases over time, and the time it takes a fully saturated soil to completely dry. Green-Ampt Method for modeling infiltration assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. The input parameters include initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front. The recovery rate of moisture deficit during dry periods is empirically related to the hydraulic conductivity (Rossman, L.A., 2010). Green-Ampt was chosen as the simulation model because it can simulate better on the impacts of land use on runoff. The reason is the infiltration parameters used in the equation are all directly related to the catchment characteristics (Wilcox *et al.*, 1990). Although Green Ampt has limitations on simulating event-based models, specific application models, and field scale models (Wilcox *et al.*, 1990), the new tool is assumed not to have any of these problems. Also, Horton's Equation is mostly used to compute the recovery of infiltration rate, and Curve Number Method is usually applied to calculate the recovery of infiltration capacity during dry periods. (Rossman, 2010)

Time of concentration is defined as the amount of time it takes for water to travel from the most distant point to the watershed outlet. By retaining pre-development concentration time, negative environmental impacts associated with development can be trimmed down. Retention and detention of rainfall are key components to increase concentration time. U.S. EPA (2000) offers methods to maintain concentration time:

- Maintaining flow path length;
- Increasing surface roughness;
- Detaining flows;
- Minimizing disturbances at the site;
- Flattening grades in impact areas;
- Disconnecting impervious surface; and
- Connecting pervious surfaces.

2.4.2 Pollutant Removal Measures

LID provides a high level of water quality treatment control due to runoff volume control of the "first flush" (first 1/2 inch) of runoff, which contains the highest pollutant loadings. Often LID practices control up to the first 2 inches of runoff and therefore treat a much greater volume of annual runoff (Coffman, 2000). By increasing concentration time and decreasing flow velocity, LID results in a reduction in pollutant transport capacity and overall pollutant loadings. LID also supports pollution prevention by changing human activities, which lower the production of pollutants into the environment. (U.S. EPA, 2000)

Total suspended solids (TSS) are solid organic and inorganic materials suspended in water. It is listed as a conventional pollutant by U.S. EPA, which is considered as an important parameter to define water quality. Phosphorus is a necessary plant nutrient presented in many fertilizers (Wurbs & James, 2002). When phosphorous is washed from terrestrial sources into surface water system, it would cause excessive growing of aquatic habitats, aquatic macrophytes, and phytoplankton (Li *et al*., 2010). Due to human activities, Lake Simcoe Watershed in Ontario has faced a significant eutrophication problem. Phosphorus emission from different land use is the main cause of ecosystem decline, which results in excessive aquatic plant growth, raising water temperatures, and reducing dissolved oxygen (LSWMS, 2003). Total Phosphorus Reduction (TP) is a main parameter used to indicate the eutrophication treatment efficiency in stormwater management. Therefore, other than runoff volume reduction, the new tool would also predict TSS reduction and TP reduction to measure the pollutant removal effectiveness.

2.5 LID Evaluation Steps

LID evaluation can be executed using a variety of approaches and analytical techniques. Coffman (2000) devised a typical series of steps for defining the needs for hydrologic control and management, as shown in Figure 6. An ideal planning tool should follow the flow chart to illustrate general LID performance predictions for engineers at the planning level.

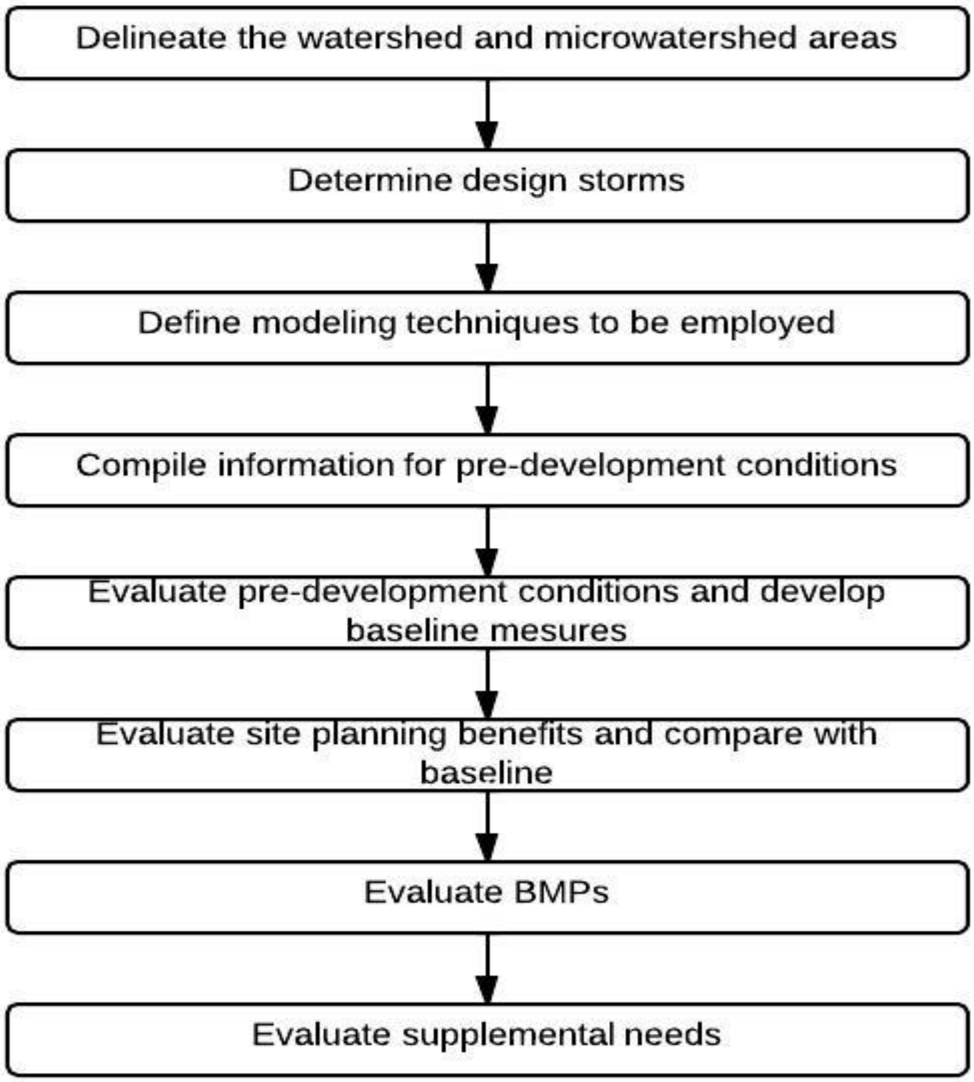


Figure 6: Flow Chart of LID Evaluation

2.6 Review of Available LID Planning Tools

2.6.1 Introduction

Among the sixteen reviewed models, five representative simple tools were chosen for detailed evaluation. The five tools include Phosphorus Budget Tool for the Lake Simcoe Watershed, New York State Green Infrastructure Worksheets, Drainage System Selection

Tool (DSST), LID BMP Sizing Calculator for Kitsap County, and Virginia Runoff Reduction Method. Selected key features, such as tool structure, computation methods, outputs and result presentation, were compared. Features of an ideal LID planning tool were identified by synthesizing advantages and eliminating disadvantages of different tools. This process is described at the end of this section.

2.6.2 Phosphorus Budget Tool for the Lake Simcoe Watershed

Lake Simcoe is located in Southern Ontario, which is the fourth-largest lake in the province. The lake is about 30km long and 25km wide, covering roughly 722 square kilometers. The land and water surface is 3576 square kilometers (LSEMS, 2003). As mentioned before, Lake Simcoe Watershed has suffered from severe environmental problems. In order to achieve sustainable development to reduce the phosphorus loading from this area, Hutchinson Environmental Sciences Ltd., Greenland International Consulting Ltd. and Stoneleigh Associates developed the *Phosphorus Budget Guidance Tool* to guide new development in the Lake Simcoe watershed in 2012. This tool is used to estimate and compare the pre-, post-, and construction phase phosphorus loading from stormwater runoff of new developments in the Lake Simcoe watershed. The tool can also estimate the post-development and construction loading with BMP to predict the phosphorus reduction efficiencies of BMP and LID techniques for stormwater management. The tool calculates the net phosphorus budget of the proposed site. The site can be approved, if:

(a) post-development loading is smaller than or equal to the pre-development loading; and

(b) post-development and amortized construction loading is smaller or equal to the pre-development loading; or

(c) if post-development and amortized construction loading is larger than the pre-development loading, all reasonable and feasible BMP is identified for implementation, documented and accounted for in the application.

This tool is based on Microsoft Access. It consists of four modules: Pre-Development Load, Post- Development Load, Implementation of BMP, and Construction Phase Load. The layout of this tool is clear and user-friendly. After choosing the sub-watershed, users just need to key in several parameters: area of each land use, types of BMP, soil class, site slope and construction duration. The loading is normalized for the whole subdivision as kilogram per hectare per year. However, this tool can calculate only phosphorus loadings and simulate single BMP for each land use, because the main task of this tool is to help engineers screen phosphorus released to the surface water system.

For calculating pre-development and post-development conditions, an export coefficient approach is employed. This approach was developed to predict nutrient inputs to lakes and streams, and is now a well-established method for computing phosphorus export when total phosphorus concentration data is missing. The annual phosphorus loading can be calculated by knowing land use, land area, and amount of nutrients exported per unit area using Equation 1 (Hutchinson Environmental Sciences Ltd. *et al.*, 2012):

$$L = \sum E_i A_i \quad (1)$$

where L is the total phosphorus load of development site (kg)

Ei is the export coefficient selected for a specific land use (kg/ha)

Ai is the area of that land use (ha)

The export coefficients were generalized from results of:

- CANWET™ modeling by Louis Berger Group Inc. (Berger, 2010);
- monitoring under the Stormwater Assessment Monitoring and Performance Program of MOE (SWAMP, 2005); and
- analysis, review and refinement by the Hutchinson Environmental Sciences Ltd., Greenland International Consulting Ltd. and Stoneleigh Associates study team.

After choosing the land use classifications and providing the area in hectares of each identified land use, the tool will link the database and compute annual phosphorus loading of each land use and total loading of the entire site. Also, the database would make a summary of pre-development and post-development phosphorus loadings and the difference between them in kg/yr and as a % (Hutchinson Environmental Sciences Ltd.*et al.*, 2012).

Selection of appropriate BMP phosphorus removal efficiencies of this tool is derived from a range of studies. A table of recommended phosphorus reduction efficiencies for major classes of BMP is summarized. All the data have sufficient documentations to demonstrate their effectiveness in Ontario's climate. However, they are only representative numbers under assumption that they are built to design specifications and maintained to design standards. (Hutchinson Environmental Sciences Ltd.*et al.*, 2012)

Because the phosphorus loading varies site to site, and depends on the timing of construction, storm timing and frequency, and site characteristics, phosphorus reduction during construction period is estimated by soil loss. For example, if a BMP can reduce soil loss during construction by 65%, the phosphorus loss is assumed to be 65%, regardless of the actual concentration of phosphorus in the soil. Universal Soil Loss Equation (Equation 2) (Stone and Hilborn, 2000) is applied to find the average annual estimated soil loss:

$$S_{L} = \Sigma 2241.7 \times R \times K \times L_{S} \times C \times P \times Ai \qquad (2)$$

where 2241.7 is a unit conversion from tons/acre to kg/ha

R is the rainfall and runoff factor by geographic location with a value of 90 for Lake Simcoe (mm)

K is the soil erodibility factor based on soil class

L is the slope length gradient factor

C is the C factor, which is the product of a crop type factor and a tillage method factor

P is the support practice factor and represents BMP

Ai is the area of slope i (ha)

The phosphorus loading (P_L) is the product of soil loss (S_L), subwatershed soil phosphorus concentration ($Soil_p$), and the duration of construction phase in years (D_{yrs}) (Hutchinson Environmental Sciences Ltd.*et al.*, 2012).

2.6.3 New York State Green Infrastructure Worksheets

New York State Green Infrastructure Worksheets are developed based on the New York State Stormwater Design to help select, locate, size, and design BMP at a development site to comply with the State stormwater performance standards. After a development site layout is determined, the site is divided into subcatchments according to the different land uses, and the areas of each subcatchment and soil types are identified. Based on different types of BMP and percentage of impervious, the runoff reduction volume can be calculated for each subcatchment. This tool covers a wide range of BMP, including bioretention, infiltration bioretention, rain barrel, dry swale, green roof, infiltration basin, infiltration trench, porous pavement, planter, rain garden, vegetated swale, dry well, conservation of natural areas, riparian buffer, filter strips, roof disconnection and tree planting-tree pits. However, the structure of this tool is relatively complicated and confusing. Users may need a detail users' guide to operate the tool. Total water quality storage volume for each area (WQv) is calculated by Equation 3:

$$\text{WQv} = \left(\frac{AR_V P}{12}\right) \times 43560 \tag{3}$$

where A is the total area of each subcatchment (acre)

R_v is runoff coefficient

P is the precipitation (in)

12 and 43560 is the unit conversion from in to ft and acres to square feet.

The removal efficiencies and impervious area deductions of each BMP are demonstrated in Table 3 and Table 4. Some numbers do not seem to meet certain levels of accuracy. For example, the removal efficiency of porous pavement is assumed 100%. Based on

SWMM results, the removal efficiency is only 80% under the same setting. Because the design manual is missing, how to assign removal efficiencies remain unclear. A required BMP area would be displayed by selecting subcatchment and BMP, and entering BMP parameters (soil depth, conductivity, void ratio, etc.). If the available area were smaller than required area, an output of zero would be shown. No analysis would be done. In addition, this tool can only simulate single BMP for each subcatchment. However, this tool is still under development, all the background information and computation methods willbe released and modified in future.

Table 3: LID Runoff Removal Efficiency of New York State Green Infrastructure Worksheets

LID	Removal Efficiency
Bioretention	40% without underdrain 80% with underdrain
Infiltration Bioretention	80%
Rain Barrel	100%
Dry Swale	20% with underdrain 40% without underdrain
Green Roof	100%
Infiltration Basin	90%
Infiltration Trench	90% of storage volume
Porous Pavement	100%
Planter	100%
Rain Garden	100% soil group A&B 40% soil group C&D
Vegetated Swale	20% soil group A&B 10% soil group C&D 15% soil group Modified C& Modified D
Dry Well	90% of storage volume

Table 4: Impervious Area Deduction of New York State Green Infrastructure Worksheets (meets all development criteria)

LID	Impervious Area Deduction
Conservation of Natural Areas	100%
Riparian Buffer	100%
Filter Strips	100%
Tree Planting	100%
Rooftop Disconnection	100%

2.6.4 Drainage System Selection Tool (DSST)

DSST is a selection tool based on Microsoft Excel to evaluate roadside ditches and other related stormwater management practices. The tool has a very logical layout. By checking a series of boxes, and clicking a few buttons, the tool can conceptualize and cost various potential drainage systems (J.F. Sabourin and Associates Inc, 2000). The new planning tool would adopt the logistic of DSST because it is the only tool providing a clear approach to choose appropriate BMP combinations. Selecting an effective BMP is the first step to success, and extremely important at the planning level. However, DSST focuses more on traditional stormwater management practices other than LID practices. For LID planning, this tool may not offer a satisfactory estimation. Also, the area of each stormwater management practice is normalized for the whole subdivision. It may sometimes cause the total cost to go dramatically high, which would influence the decision-making due to low cost-efficiency.

DSST mainly consists of six tables: Table A, B,C,D,E, and a cost comparison table. Table A and Table B are used to determine which drainage features are compatible based on site physical and development characteristics by using check boxes to match the site conditions. Any "X" appearing below a checked characteristic eliminates the potential use of the alternative drainage feature on that line. The line would be highlighted by a red background with a solid line through it, and given a score of 0. Any "0" appearing below a checked characteristic alerts the designer to check the comments to determine if there is a valid concern. The line would be highlighted as conditional by a yellow background with a dashed line through it, and given a score of 0.5. All other alternatives would be given a score of 1. Both Table A and B have comment tables, which users can review to decide whether the features are compatible or not. Table C is an identification of compatible features, which is used to summarize the results obtained from Table A and B. Features which end up with a final score of 1 are fully compatible with both site characteristics and development characteristics. Features with a final score of 0.5 or 0.25 are potentially incompatible with either or both site characteristics and development characteristics. This scoring system would also be implemented in the new tool (J.F. Sabourin and Associates Inc, 2000).

Table D was prepared for reference purposes only and indicates how well a particular drainage feature can respond to a particular stormwater management objective. Stormwater management objectives cover five groups: groundwater recharge, erosion control, quality control, flood control, and thermal reduction. The water quality control objective was further divided into sediment removal, nutrient removal, bacterial die-off, and oil and grease removal. The numbers provided in Table D refer to "Stormwater Management Function Potential (SWM-FP) values. SWM-FP values vary from 0 to 1. A value of 0 indicates that the corresponding feature provides no valuable benefits. In contrast, a value of 1 means the feature achieves 100% of the target stormwater management objective if designed and constructed properly.

According to results of Table C and design experience, various alternative drainage systems, which may include one, or some, or all of the potential drainage features, could be conceived. To further compare each alternative, the cost of each system and how well it would meet the objectives of the project would be evaluated. Once a drainage system is defined, Table E can do the further evaluation. It could be done by first listing the system's individual components, and entering the system's objectives in the columns under the heading of "Drainage System Objectives and Compliance". The system objectives include stormwater management objective as well as other specific requirements that may have been requested by the public. SWM-FP values would be adjusted based on drainage areas accordingly. The total cost for each feature can also be calculated and entered in the last column. The result score of overall SWM-FP for each system objective will show whether the system could meet the individual requirement. Any score lower than 1 would demonstrate a potential deficiency and the need to re-evaluate the system.

A cost comparison table aims to provide the necessary information to allow comparative cost analysis to be undertaken in the comparison of alternative drainage systems. The table provides capital, maintenance, and total present value costs for the construction and maintenance of various drainage system components. The Amortized Capital Cost (ACC), Present Value of (Capital + Annual Repairs), and Amortized Maintenance Cost (AAMC) is computed by the following equations:

$$\mathbf{ACC} = \frac{\mathbf{C_R \times i\%}}{\mathbf{1-(1+i\%)^{-L}}} \tag{4}$$

where C_R is the construction or replacement cost (Canadian Dollar)

i% is the annual discount rate

L is the life expectancy of the component

$$\mathbf{Present\ Value\ of\ Capital + Annual\ Repairs = TACC} \times \frac{\mathbf{[1-(1+i\%)^{-LC}]}}{\mathbf{i\%}} \tag{5}$$

where TACC is total of the Amortized Capital and Annual Repair Cost (Canadian Dollar)

LC is the life cycle being considered (years)

$$\mathbf{AAMC} = \frac{\dfrac{\mathbf{AMUC}}{(\mathbf{1+i\%})^{\frac{\mathbf{1}}{\mathbf{FREQ}}}} \times \mathbf{i\%}}{\mathbf{1-(1+i\%)^{-[LONG \times (LONG \times FREQ-1)^{-1}]}}} \tag{6}$$

where AMUC is the average maintenance unit cost (Canadian Dollar)

FREQ is the frequency of maintenance activity

LONG is the longevity of the associated drainage component

2.6.5 LID BMP Sizing Calculator for Kitsap County

Kitsap County is located in Washington, United States. According to the US Census Bureau, the total area of Kitsap County is 566 square miles, of which 170 square miles (30.04%) is water. According to Puget Sound Partnership, the county has over 250 miles of saltwater shoreline. The presentation of this tool is very simple and clear. Relatively little pre-designed BMP is included, which are bioretention, porous pavement, trees, partial dispersion and green roof. The advantage of this tool is that it can simulate more than one BMP at a time. This tool includes a Flow Control Calculator and a Treatment Calculator, both of which allow user to develop a site design to satisfy the flow control and water quality standards. For both calculators, site mean annual precipitation can be read from Precipitation Sheet. The tool also provides a BMP Design Requirement Sheet (Herrera Environmental Consultants, 2010).

The Western Washington Hydrology Model, Professional Version 3 (WWHM3 Pro) was used for this tool. WWHM3 can simulate runoff based on topography, soil types, and vegetation. The soil type was assumed to be Till (group C) and moderate slope were assumed (Herrera Environmental Consultants, 2010). Soil type is a sensitive parameter in runoff simulation, which means this tool may not be able to provide rational results for the Ontario perspective due to the fact that the main soil type in Ontario is different from the assumption. Also, BMP was evaluated by mean annual precipitation of 32, 36, 44, and 52 inches per year, which does not represent Ontario's rainfall condition (Herrera Environmental Consultants, 2010).

The following Equation 7 sized infiltration BMP (bioretention and porous pavement in this case):

$$\mathbf{BMP\ Area}(\mathbf{ft^2}) = \frac{\mathbf{Impervious\ Area} \times \mathbf{Sizing\ Factor}(\%)}{\mathbf{100}} \tag{7}$$

The following sizing factors were derived from a series of scenarios simulation:

- contributing impervious area: 2000, 5000, and 10000 square feet;
- soil design infiltration rate: 0.13, 0.25, 0.5,1.0, and 2.0 inches per hour; and

- annual precipitation depth: 32, 36, 44, and 52 inches per year.

For a BMP that does not fully meet the Ecology pre-development forest flow control standard, flow control credits were employed other than sizing factors or sizing equations. The flow control credit values are based on the extent to which these facilities achieve the flow control standard. Flow control performance was evaluated by various methods, including literature review and continuous simulation hydrologic modeling (Herrera Environmental Consultants, 2010).

2.6.6 Virginia Runoff Reduction Method

The Virginia Runoff Reduction Method is developed by the Center for Watershed Protection (CWP), the Chesapeake Stormwater Network (CSN), and the Virginia Department of Conservation and Recreation. The method uses two spreadsheets, which are for new development and redevelopment respectively. A technical memo showing the older version of the method is also provided to serve as background research. Only new development spreadsheet was reviewed in detail because the main target of the new tool is new subdivisions in Ontario. The method can predict the capacity of BMP to reduce the overall volume and pollutant of runoff and help users design best combination of BMP for a specific site to meet the standards. Although this tool covers a wide range of BMP, the logic remains understandable. Different colored cells (blue for input, grey for calculation, and yellow for constants) are also easy to follow. Other than runoff reduction, total phosphorus and total nitrogen were used as target pollutants to address the removal efficiencies of different BMP. This tool has five tabs for multiple drainage areas (CWP *et al.*, 2011).

This tool has generally three categories of tabs: site data, drainage area analysis, and water quality compliance. For site data tab, precipitation and area of post-development impervious, managed turf, and forest/open space for different soil groups are required. Target phosphorus loading of 0.41 pounds per acre per year is indicated. A weighted site runoff coefficient would be calculated using Equations 8 and 9 and be used to find the post development treatment volume (Equation 10).

$$\mathbf{R_V(F)} = \frac{\mathbf{A(f_A)\times 0.02 + A(f_B)\times 0.03 + A(f_C)\times 0.04 + A(f_D)\times 0.05}}{\mathbf{SA}}$$

$$R_v(T) = \frac{A(t_A)\times 0.15 + A(t_B)\times 0.2 + A(t_C)\times 0.22 + A(t_D)\times 0.25}{SA} \quad (8)$$

$$R_V(I) = 0.95$$

where $R_v(F)$, $R_v(T)$, and $R_v(I)$ are weighted forest, turf, and impervious cover runoff coefficients

$A(f_A)$, $A(f_B)$, $A(f_C)$, and $A(f_D)$ are areas of post-development forest in A,B,C, and D soils (acre)

$A(t_A)$, $A(t_B)$, $A(t_C)$, and $A(t_D)$ are areas of post-development managed turf in A,B,C, and D soils (acre)

SA is surface area (acre)

$$\mathbf{R_V(S) = R_V(F) \times \%Forest + R_v(T) \times \%Turf + R_v(I) \times \%Impervious} \quad (9)$$

where $R_v(S)$ is runoff coefficient for the site

$$\mathbf{T_V(S)} = \frac{\mathbf{R_d \times R_v(S) \times SA}}{\mathbf{12}} \quad (10)$$

where $T_v(S)$ is post-development treatment volume for site (acre-ft)

R_d is rainfall depth (in)

S_A is total site area (acre)

Equation 11 and Equation 12 calculate TP loading and TP loading reduction.

$$\mathbf{L = P \times P_J \times \frac{T_v(S)}{R_d} \times C \times 2.72} \tag{11}$$

where L is post-development pollutant loading for site

P is average annual rainfall depth (in)

P_j is fraction of rainfall events that produce runoff

C is flow-weighted mean concentration of pollutant in urban runoff (mg/acre-ft)

2.72 is unit conversion from milligram to pound and acre-feet to liter

$$\mathbf{L_{reduction} = L - P_{target} \times SA} \tag{12}$$

where $L_{reduction}$ is required TP loading Reduction (lb/yr)

P_{target} is target phosphorus loading (lb/yr)

If the site has more than one discharge points, it can be divided into several drainage areas. For each drainage area, the post-development impervious, managed turf, and frost/open space is required. After selecting the BMP for each case, the runoff reduction is calculated by Equation 13:

$$\mathbf{C_V(x) = [R_d \times R_v(land\ cover) \times C_A \times 3630 + V_{upstream}] \times CR} \tag{13}$$

where $C_v(X)$ is adjustment of treatment volume (ft^3)

R_v(land cover) is weighted runoff coefficient for land cover being treated

C_A is credit area (acre)

3630 is unit conversion from acre-inches to cubic feet

$V_{upstream}$ is upstream runoff volume (ft^3)

CR is credit (fraction of runoff eliminated by the credit practice)

Pollutants loading and loading reduction would be computed by Equation 14 and Equation 15.

$$\mathbf{L(x) = L_{upstream} + \frac{R_V(land\ cover) \times C_A \times P \times \frac{P_i}{12} - C_V(x)}{43560} \times 2.72 \times EMC} \tag{14}$$

where L(x) is pollutant load to practice (lbs/yr)

$L_{upstream}$ is pollutant load from upstream treatment practices (lbs/yr)

12 is the unit conversion from acre-inch to acre-ft

EMC is weighted mean concentration of pollutant in urban runoff

2.72 is unit conversion from milligram to pound and acre-feet to liter

$$\mathbf{LR(x) = L(x) \times \frac{C_v(x) + \frac{AT_V(x) \times EFF_{tp}}{100}}{C_V(x) + AT_V(x)}} \tag{15}$$

where LR(x) is loading reduction (lbs/yr)

$C_v(x)$ is adjustment to treatment volume based on application of BMP credit

$AT_v(x)$ is remaining runoff volume after credit x is applied

EFF_{tp} is total phosphorus pollutant removal efficiency

The water quality compliance summarizes the runoff reduction and pollutant reduction for this site. The credits of each BMP are shown in Table 5 below.

Table 5: Credits of BMP Used in Virginia Runoff Reduction Method

BMP	Description	Credit
Green Roof	Type 1	45%
	Type 2	60%
Rooftop Disconnection	to soil group A&B	50%
	to soil group C&D	25%
	to filter path	50%
	to dry well type 1	50%
	to dry well type 2	90%
	to rain garden type 1	40%
	to rain garden type 2	80%
	to rainwater harvesting	0%
	to planter	40%
Porous Pavement	Type 1	45%
	Type 2	75%
Grass Channel	Soil Group A&B	20%
	Soil Group C&D	10%
	grass channels with compost amended soil	30%
Dry Swale	Type 1	40%
	Type 2	60%
Bioretention	Type 1/ Urban Bioretention	40%
	Type 2	80%
Infiltration	Type 1	50%
	Type 2	90%
Extended Detention Pond	Type 1	0%
	Type 2	15%
Sheetflow to Filter/Open	Soil Group A&B	75%

Space	Soil Group C&D	50%
	Sheetflow to compost amended B/C/D Soils	50%

2.6.7 Conclusions of Available Model Comparison

The literature reviewed for the five available LID planning tools reveals that none of them can fulfill the needs of LID planning for a new subdivision in Ontario. Based on the comparison of available LID planning tools, key features of an ideal LID planning tool suitable for Ontario can be identified as being:

- based on Microsoft Excel;
- site scale lot-based tool;
- outputs include runoff volume reduction, total suspended solids reduction, total phosphorus loading reduction and total cost estimation;
- seven LID practices and seventeen possible combination are simulated;
- using SWMM to generalize runoff reduction, TSS reduction, and TP reduction database;
- follow the DSST logic to identify whether or not a BMP or BMP combination is compatible with the site characteristics;
- allow users to choose a BMP or BMP combination based on the site characteristics;
- report-ready analysis can be made with the click of a few buttons; and
- uncertainties lie within an acceptable range.

Therefore, the new tool should provide an approach that is:

- workable: allow users to complete the necessary runoff quantity, quality and cost estimation without the need for undue additional expense or access to complicated software or modeling capabilities;
- timely: produces the analysis within a reasonable time frame for timely review and approval;
- defensible: strong and providing reliable outputs that can meet certain level of accuracy; and
- adaptable: the new LID techniques or other land use applications can be plugged in for further research.

The methodology is comprised of the following stages, each of which is discussed in the following chapters:

1. Data collection
2. Running SWMM to model the representative lots without and with a LID or a combination of LIDs
3. Uncertainty Analysis
4. Development of a common database
5. Development of the new LID planning tool

CHAPTER THREE

3 Database Development

3.1 Introduction

Since all the simulations of the new tool would be done by SWMM, before developing the tool, SWMM modeling methodology should be introduced. A database would be generated to store all the results for lot planning. Before developing the database, the attributes used for hydrological modeling were chosen (Eric, 2012). Based on a case study by Li *et al.* (2010) and the suitability of available data, five major attributes were selected:

1. Lot area (m^2)
2. Lot width (m)
3. Imperviousness (%)
4. Average slope (%)
5. Soil type

The imperviousness could further be decomposed into driveway area (%) and roof area (%). This chapter demonstrates lot-based modeling methodology, data collection, data gaps, data standardization, SWMM results and uncertainty analysis.

3.2 Regions of Ontario and Representative Stations

According to Ministry of Environment, the Province of Ontario, shown in Figure 7, was divided into four regions: Central, North, East, and West. One representative station was picked for each region. All of the representative stations, shown in Table 6, meet WMO standards for temperature and precipitation. twenty years ofhourly rainfall data was used for SWMM simulation. A housing survey was conducted to identify typical single-family lot width, lot area, and imperviousness in each region.

Table 6: Representative Stations

Region	Station	Climate ID
West	Windsor A	6139525
Central	Barrie WPCC	6110557
North	North Bay A	6085700
East	Ottawa Macdonald-Cartier Int'L A	6106000

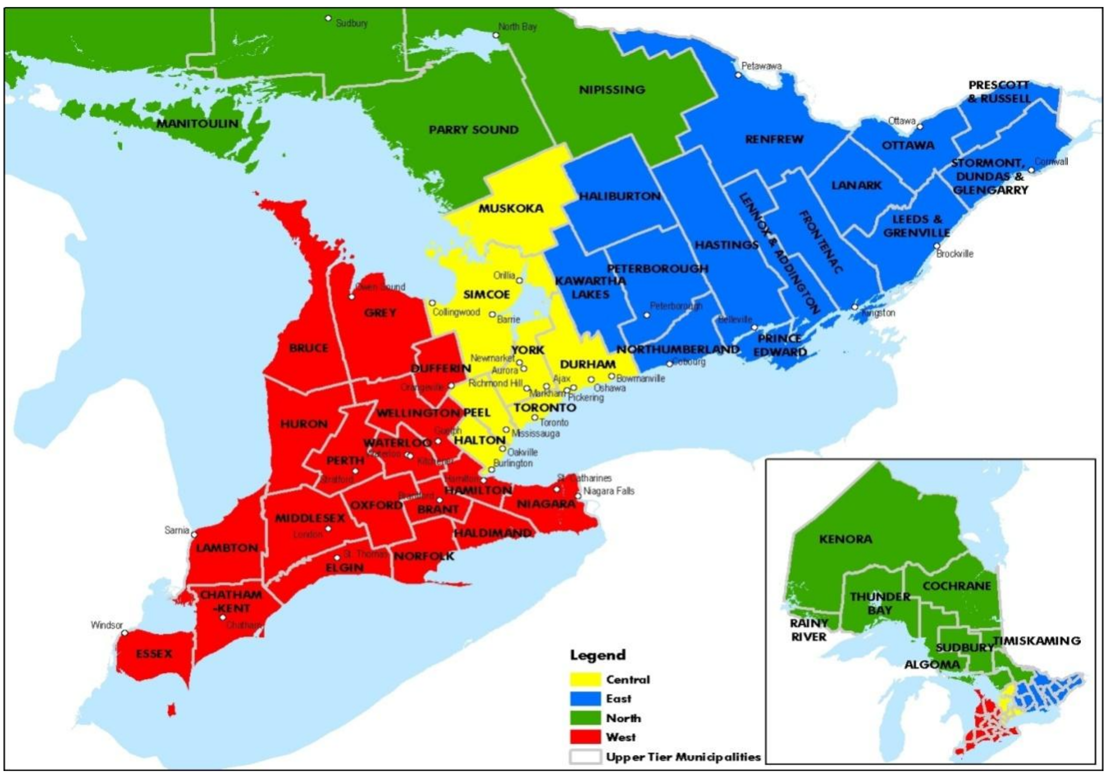


Figure 7: Regions of Ontario (Ontario Ministry of Environment, 2012)

3.3 Climate Analysis of Ontario Regions According to Their Representative Stations

Western Ontario is bounded on three sides by water: Lake Huron to the north and northwest, the St. Clair River, Lake St. Clair, and Detroit River to the west, and Lake Erie to the south. The climate in this region is among the mildest in Canada. It brings warm summers with normal thunderstorm occurrences. Some of these storms are severe, with damaging winds and hail all possible during the peak season. The most likely areas for these kinds of weather events are within the Windsor-London corridor and north up to about Huron County. Winters are cold with less snowfall in the south towards Essex County and higher amount north towards Bruce County.

The City of Windsor's northern boundary is Detroit River, which is part of Canada's border with the United States. Regional surface water in Windsor's rivers, creeks and streams is rated "poor" to "very poor" (DPRA Canada, 2006). The Environment Canada weather station located at Windsor Airport has been monitoring and recording weather data since 1941. As air temperature increases, so does the capacity of the air to hold more water leading to more intense rainfall events. The average annual temperature has increased by almost 1^{o}C since that time. Figure 8 shows the average annual precipitation in Windsor from 1941 to 2011. The data is obtained from the Windsor Airport station, indicating an increasing trend in annual precipitation. 2011 rainfall hit the highest record (City of Windsor, 2012). Table 7 summarizes the average trends in the amount of annual maximum rain events.

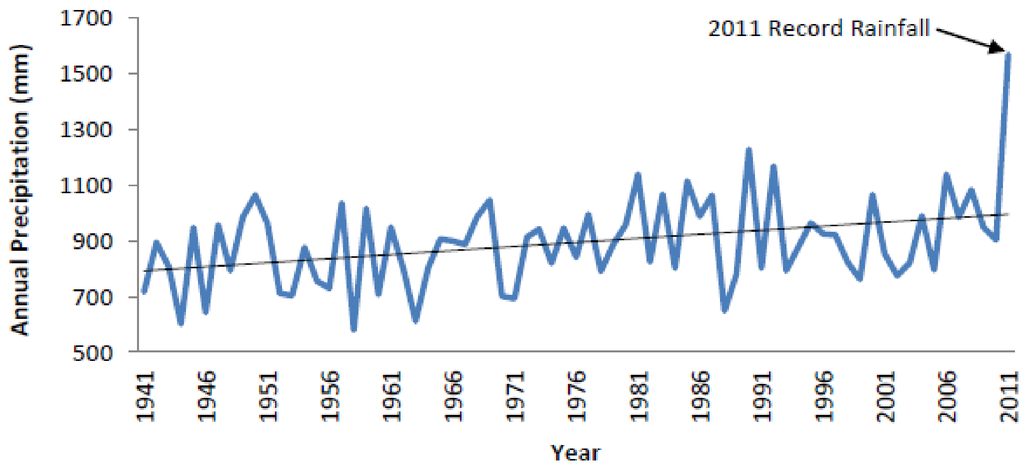


Figure 8: Total Annual Precipitation in Windsor (City of Windsor, 2012)

Table 7: Summary of the Observed and Projected Increase in Rainfall over Time in Windsor (Bruce *et al.*, 2006)

	Observed trends 1970 – 2000	Projected trends to 2050
30 minute extremes	• 5% increase per decade (Adamowski) • 4.5% increase per decade to 1996 (Soil and Water Conservation Society)	• 5% increase per decade
Daily extremes	• 7% per decade (May, June, July) (Stone) • 5% increase per decade (over the year) to 1996 (Soil and Water Conservation Society)	• 3% per decade over the year (20 year return period) • 2.5 to 6% increase per decade (rainfall with probability <5 %)
Annual rainfall	• 1% to 3% increase per decade	• 1% increase per decade

The southern part of Central Ontariohas higher population density than the northern part, as this area is closer to the Greater Toronto Area. The climate of Central Ontario is a humid continental climate with large seasonal variation moderated somewhat by great lakes. Summers are warm and humid, but are shorter than further south with generally cooler nights. Winters are cold with significant snow. Some snowbelt areas receive an average of over 300 cm per year. Severe summer storms are also commonplace, particularly in Simcoe County.

Barrie is located in the Greater Toronto Area. Toronto is the largest city in Canada and the provincial capital of Ontario. Since the late 1800s, the average temperature of Toronto has increased by 2.7℃, which is much higher than surrounding rural sites due to the urban heat island effect. Figure 9 indicates the Toronto average annual precipitation from 1895 to 2002. Average annual precipitation has changed relatively little in Toronto since late 1800s. However, Toronto has recently experienced rains more intense that can overwhelm stormwater systems and cause flash flooding (Environment Canada, 2006). According to Wieditz and Penney (2006), more precipitation is expected to occur in future because warmer air is able to hold more moisture thereby increasing the probability of intense rain events.

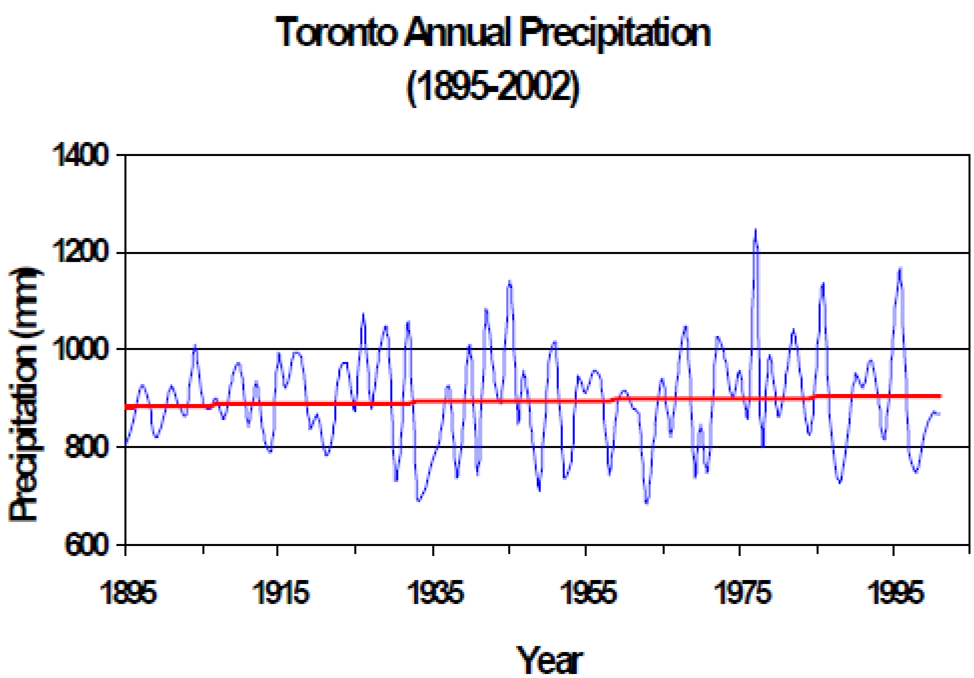


Figure 9: Total Annual Precipitation in Toronto (Wieditz and Penney, 2006)

In order to obtain a more accurate result for the case study of Bayview Wellington Center in Town of Aurora, Barrie WPCC was selected as the representative station other than Toronto Pearson International Airport. Although Udora is the nearest rain gauge around Town of Aurora, it only has daily flow records. Barrie WPCC is the only station within Lake Simcoe Watershed that can provide hourly rainfall data.

Eastern Ontario is also a portion of Southern Ontario. The climate of this region is humid continental with large seasonal variations. Snow and ice are dominant during the winter season. Ice storms are relatively common, especially on lower terrain if compared with other parts of Ontario. Winters are more severe and longer along the Ottawa River than further south along the Upper St. Lawrence River shoreline. Summers are fairly warm and humid in Ottawa and the St. Lawrence valleys, usually lasting a little longer than winter does in duration. Thunderstorms are common and sometimes severe, causing tree and property damages (OCCIAR, 2011).

Ottawa is the fourth largest city in Canada, and is the capital of the country. The annual average temperature of Ottawa has increased 1.1℃ (OCCIAR, 2011). Figure 10 and Figure 11 display the average annual temperature and precipitation data from 1939 to 2010, which was captured from the Ottawa Airport weather station. There has been an increasing trend in total annual precipitation since the 1930s, but a decrease in the annual amount of snowfall. Ottawa is experiencing more days with precipitation rather than more precipitation on individual days. An increasing trend is observed in three measures:

multi-day accumulation of precipitation, the total number of days of precipitation, and the duration of precipitation events.

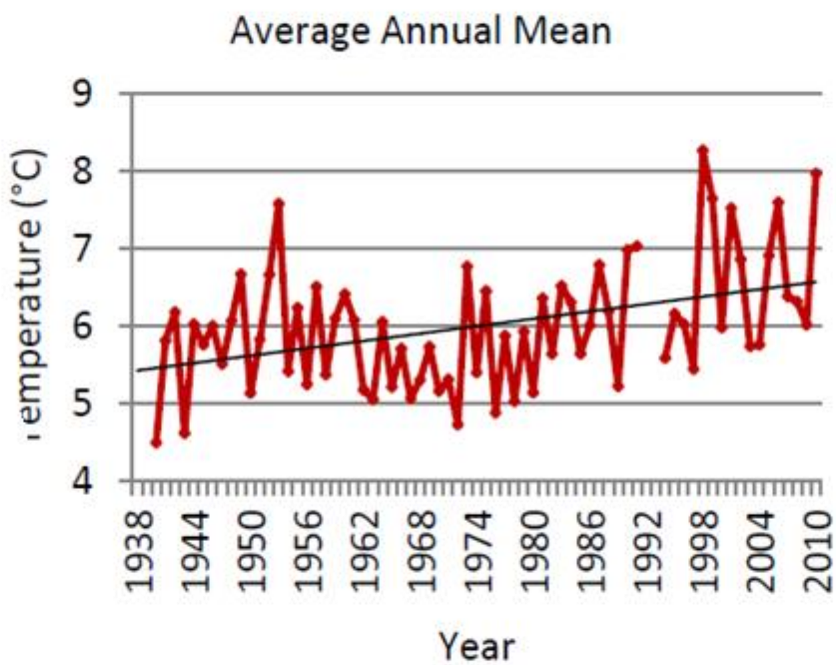


Figure 10: Ottawa average annual temperature (OCCIAR, 2011)

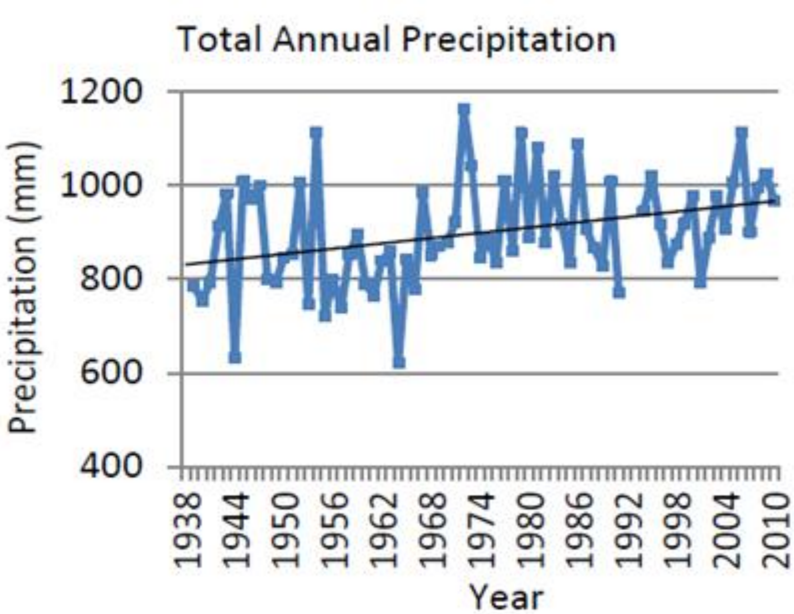


Figure 11: Total Annual Precipitation in Ottawa (OCCIAR, 2011)

Northern Ontario is a geographic and administrative region of Ontario. It lies north of Lake Huron, the French River, Lake Nipissing, and the Mattawa River. Although it covers almost 87% of the total area of Ontario, it contains only about 6% of the population. The climate of this region is characterized by extremes of temperature, which is extremely cold in winter and hot in summer. The principal industries in this region are mining, forestry, and hydroelectricity. North Bay is located on the shore of Lake Nipissing, and is positioned on the Canadian Shield, which gives rise to a different and more rugged landscape. The city is geographically unique because it straddles both the Ottawa River watershed to the east and the Great Lakes Basin to the west. Daily climate data has been collected from North Bay Airport weather station since 1939 where the annual average temperature has increased 1.0ºC over the 69 years that records have been kept (OCCIAR, 2009). Figures 12show the annual average rainfall from 1939 to 2008.

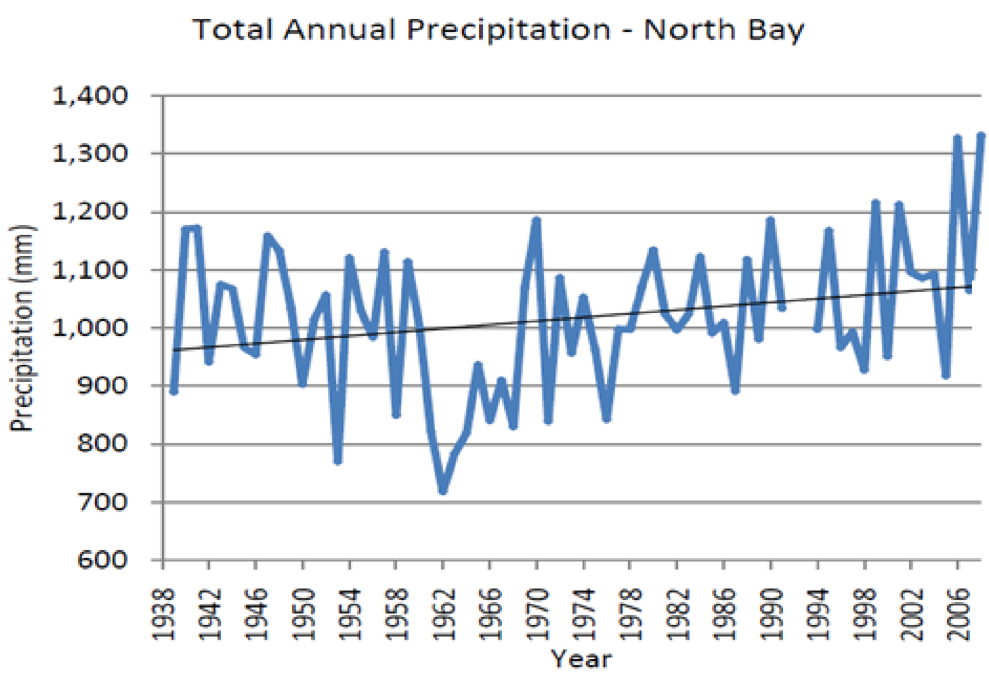


Figure 12: Total Annual Precipitation in North Bay (OCCIAR, 2009)

3.4 Data Collection

3.4.1 Soil Type of Each Representative Station

According to Ontario Soil Map (Ontario Institute of Pedology, & Land Resource Research Centre, 1986; Marshall *et al.,* 1979; Caldwell *et al.,* 1947; Sharpe *et al.,* 1980), the soil type of each station is shown as Table 8:

Table 8: Soil Types of Representation Stations

Station	Soil Series	Soil Type
Windsor A	Brookston Clay	Clay Loam
Barrie WPCC	Otonabee	Loam
North Bay A	Rockland	Loam
Ottawa Macdonald-Cartier Int'L A	Dalhousie	Clay Loam

Brookston Clay series is the poorly drained member of the Huron catena. This series has high organic matter content in the surface soil, and it exhibits the characteristic of the Dark Grey Gleisolie soils. There is usually a certain amount of grit and small stones throughout the profile but occasionally there is none in the top 2 to 3 feet. The topography is level to slightly undulating and the natural drainage is poor. The natural forest vegetation is elm with considerable ash, red oak, soft maple, and occasional hard maple, sycamore, and hickory (Caldwell *et al.,* 1947).

Otonabee loam has developed on high lime parent materials derived largely from Trenton limestone. Occurring on drumlinized till plains, the type has a smooth moderately sloping to hilly topography. The soil is well drained due to free percolation and good runoff. The natural vegetation consists chiefly of sugar maple and beech (Hoffman and Richards, 1955).

Rockland series consist of well-drained soils formed in loamy colluviums from rotational landslides on slopes of stream valleys and dissections of ground moraines. Saturated hydraulic conductivity is moderate in the upper part of the profile and moderately slow in the lower part. Drainage water saturation do not occur a depth of 203cm year round (well drained). The major vegetation species include sugar maple, white pine, green ash, quaking aspen, eastern hemlock, yellow birth, white birch, and balsam fir (USDA-NRCS).

Dalhousie association consists of soils developed in fine-textured, modified marine materials. Soil profiles are Gleyed Orthic Melanic Brunisols, Orthic Humic Gleysols and Rego Gleysols. The Dalhousie association contains the Dalhousie and Brandon soil series. The Dalhousie series is an imperfectly drained soil that is subject to saturation for only a short time during the growing season. The soils have very dark grayish brown, granular surface horizons, 10 to 16cm thick. The Brandon series, which is poorly drained, is found on level to very gently sloping positions, subject to water saturation for a much longer part of the growing season. The granular surface horizons have a higher organic content, and vary in color from very dark brown to dark grayish brown. The underlying subsoil is gray to very dark grayish brown with structures similar to that of the Dalhousie series (Marshall *et al.,* 1979).

SWMM provide a soil characteristics table, but all the units are in inches. The new planning tool will use SI unit, so a unit conversion was necessary. Table 9 shows soil characteristics in mm.

Table 9: Soil Characteristics (SI Unit)

Soil Type	Hydraulic Conductivity (mm/hr)	Suction Head (mm)	Porosity	Field Capacity	Wilting Point
Loam	3.302	88.9	0.463	0.232	0.116
Clay Loam	1.016	210.058	0.464	0.31	0.187

3.4.3 Housing Survey

In order to obtain lot width, lot area, and imperviousness, a single-family housing survey of Ontario was conducted. A total of 58, 21, 34 and 14 new subdivisions were reviewed in the Greater Toronto Area (GTA), Windsor, Ottawa, and North Bay respectively. The standard deviations and 95% confidence intervals show that imperviousness varies slightly for a specific lot width. All these numbers can be found in the Appendix. Therefore, the average lot area and imperviousness are used for SWMM simulation. Figures 13,14, 15 and 16 describe the relationship between imperviousness and lot width.

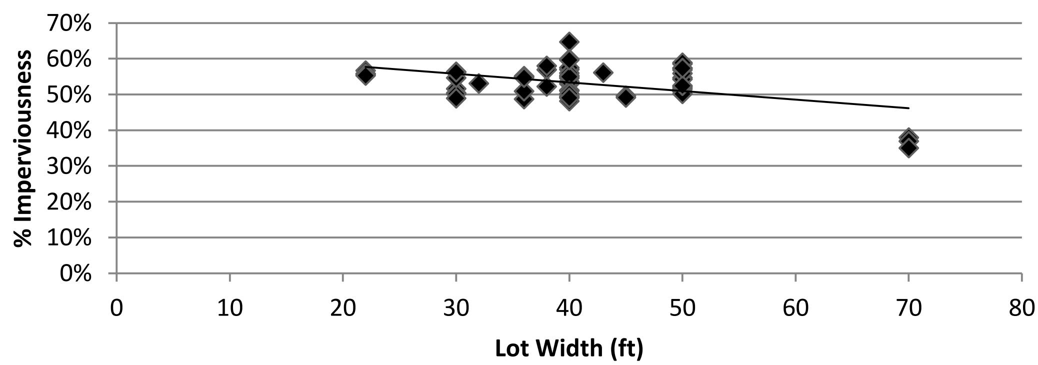


Figure 13: Relationship between imperviousness and lot width (GTA)

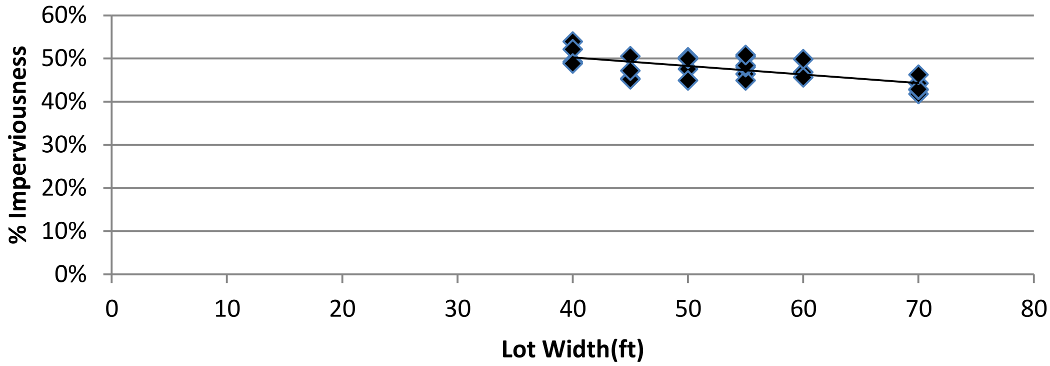


Figure 14: Relationship between Imperviousness and Lot Width (Windsor)

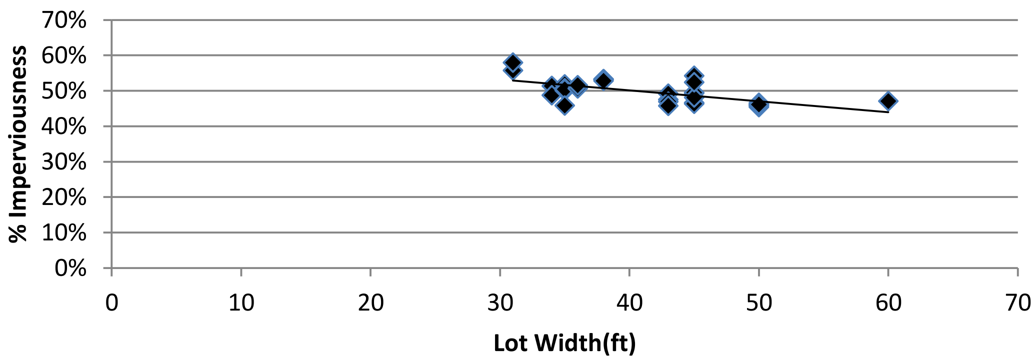


Figure 15: Relationship between Imperviousness and Lot Width (Ottawa)

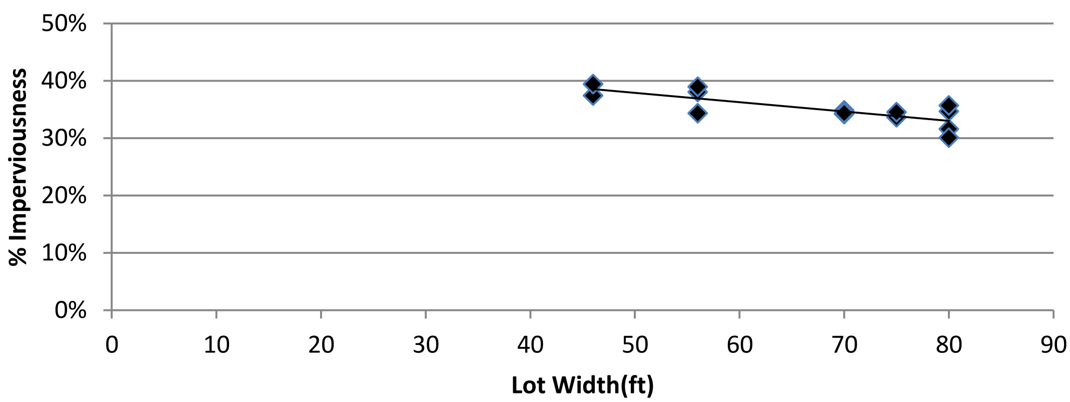


Figure 16: Relationship between Imperviousness and Lot Width (North Bay)

Only the GTA showed a relatively weak major correlation, because 70-ft lots are not common in the GTA. These three lots could be considered as luxury housing with larger lot area and lower imperviousness, which cannot represent the current estate market trend in the GTA. If the 70-ft lot was treated as marginal point, all the figures showed a strong regression relation between lot width and imperviousness. The figures also illustrate that Southern Ontario has comparatively higher density housing than Northern Ontario. Tables 10, 11, 12 and 13 indicate the housing data of each region.

Table 10: Toronto Housing Data

Lot Width (m)/(ft)	Number of Sample	Average Lot Area (ha)/(ft^2)	% Impervious	Average Roof Area (m^2)/(ft^2)	Average Driveway Area (m^2)/(ft^2)
6.7(22)	4	0.02(2200)	54%	80(858)	35(370)
9.1(30)	16	0.03(3273)	53%	121(1301)	42(450)
12.2(40)	22	0.04(4147)	54%	135(1456)	72(770)
15.2(50)	13	0.05(4884)	55%	166(1789)	81(870)
21.3(70)	3	0.13(13860)	37%	245(2642)	142(1530)

Table 11: Windsor Housing Data

Lot Width (m)/(ft)	Number of Sample	Average Lot Area (ha)/(ft^2)	% Impervious	Average Roof Area (m^2)/(ft^2)	Average Driveway Area (m^2)/ft^2)
12.2(40)	4	0.04(4325)	51%	144(1546)	58(620)
13.7(45)	4	0.045(4837)	47%	149(1602)	64(690)
15.2(50)	5	0.05(5440)	48%	160(1717)	83(898)
18.3(60)	3	0.06(6880)	47%	176(1898)	97(1044)
21.3(70)	5	0.07(8036)	43%	220(2373)	114(1235)

Table 12: Ottawa Housing Data

Lot Width (m)/(ft)	Number of Sample	Average Lot Area (ha)/(ft^2)	% Impervious	Average Roof Area (m^2)/(ft^2)	Average Driveway Area (m^2)/(ft^2)
10.6(35)	16	0.03(3331)	52%	110(1191)	49(526)
13.7(45)	11	0.04(4274)	49%	132(1420)	61(661)
15.2(50)	6	0.046(4960)	46%	139(1491)	74(792)
18.3(60)	1	0.053(5700)	47%	161(1736)	88(950)

Table 13: North Bay Housing Data

Lot Width (m)/(ft)	Number of Sample	Average Lot Area (ha)/(ft^2)	% Impervious	Average Roof Area (m^2)/(ft^2)	Average Driveway Area (m^2)/(ft^2)
14(46)	2	0.05(5014)	38%	110(1200)	67(725)
17.1(56)	3	0.06(6050)	37%	143(1543)	65(700)
21.3(70)	5	0.07(7684)	34%	174(1877)	70(756)
24.4(80)	4	0.08(8590)	33%	187(2018)	80(862)

This thesis only applied average lot area and lot width as a typical lot. However, difference in driveway area would influence the placement and performance of LID (Li *et al*., 2010). An uncertainty analysis should be established to make sure that all the results of typical lot method were in an acceptable range. It was not complicated to access new subdivision information in Southern Ontario, especially in the GTA. However, for North Bay, it was very difficult to explore more samples because of a smaller population and a developing economy. The sample size may not be sufficient to illustrate whole region. More research is recommended to conclude a better coverage by reviewing more cities' new subdivision planning in each region.

3.4.4 Rainfall Input Data

All the rainfall input data was obtained from the Ontario Climate Center of Environment Canada and was used in the numerical modeling. The thesis assumed that LID was ineffective during winter. That is why only the rainy season, which is from April to November, was considered. No snow accumulation or snowmelt was taken into account in thisresearch. In order to achieve a more accurate result, 20-year continuous hourly rainfall from 1984 to 2003 was simulated rather than choosing the average year or median year. Tables 14, 15, 16, and 17 summarize the missing records of each station, where the red highlights identify years that were not included in the further modeling due to a large number of missing records.

Table 14: Screening of the Rainfall Records of Barrie WPCC (Li *et al.*, 2010)

Year	Starting Date	Ending Date	Monitoring Period # of Missing Records, in Days	Missing Record Dates
1987	Apr-01	Sep-28	34	Sep 29 to Nov 1
1992	Apr-01	Oct-01	62	Apr 7, May 2 to 31
1997	May-01	Nov-01	30	Apr 1 to 30

Table 15: Screening of the Rainfall Records of Windsor

Year	Starting Date	Ending Date	Monitoring Period # of Missing Records, in Days	Missing Record Dates
1985	Apr-01	Sep-30	32	Oct 1 to Nov 1

1992	Apr-01	Nov-01	94	Apr 29 to May 31, Jul 1 to 31, Sep 1 to 30
1995	Apr-01	Nov-01	30	Sep 2 to Oct 1
1996	Apr-01	Nov-01	61	Sep 2 to Oct 31
1997	Apr-01	Nov-01	61	Jun 1 to Jul 31
1998	Jun-01	Nov-01	61	Apr 1 to May 31

Table 16: Screening of the Rainfall Records of Ottawa

Year	**Starting Date**	**Ending Date**	**Monitoring Period # of Missing Records, in Days**	**Missing Record Dates**
1984	Jun-01	Nov-01	61	Apr 1 to May 31
1991	Jun-01	Nov-01	61	Apr 1 to May 31
1994	Apr-01	Oct-01	31	Aug 2, Oct 2 to Nov 1
1995	Apr-01	Nov-01	63	Jul 17 to 18, Aug 2 to Oct 1
1996	Apr-01	Nov-01	60	May 2 to 31, Jul 2 to 31

Table 17: Screening of the Rainfall Records of North Bay

Year	Starting Date	Ending Date	Monitoring Period # of Missing Records, in Days	Missing Record Dates
1992	Apr-01	Nov-01	32	May 1 to 31, Jul 16,
1995	Apr-01	Nov-01	36	Apr 18 to 20, May 2, May 19, Jun 1, Sep1 to 30
1996	Apr-01	Aug-31	68	Apr 15 to 16, May 22, Jun 11 to 12, Jun 19, Sep 1 to Nov1
1998	May-01	Nov-01	37	Apr 1 to 30, Sep 6, Sep 20, Oct 16 to 20
2000	-	-	215	Apr 1 to Nov 1
2001	May-01	Nov-01	63	Apr 1 to 30, May 8 to 9, Oct 1 to Nov 1
2002	May-09	Nov-01	161	Apr 1 to May 8, Jul 1 to Nov 1
2003	May-02	Nov-01	32	Apr 1 to May 1

3.4.7 Evapotranspiration Input Data

Table 18 shows the average total daily evapotranspiration for Barrie Creeks Subwatershed. All the numbers were provided by LSRCA. However, because of data unavailability, the average total daily evapotranspiration of the other three regions were assumed to the same as Barrie Creeks Subwatershed. Further research is recommended to obtain evapotranspiration rate of each region and modify the SWMM setting.

Table 18: Average Total Daily Evapotranspiration (Li *et al.*, 2010)

Month	Average Daily Evapotranspiration, in mm/day	Month	Average Daily Evapotranspiration, in 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

3.4.8 LID Sizing Assumptions

After gathering all the required input data, the next important step was to determine sizing assumptions for each types of LID practices. All the assumptions were based on the study by Li *et al.* (2010). Table 19 below illustrates a summary of the various sizing assumptions.

Table 19: Summary of LID Sizing Assumptions

LID Practice	Modelling Assumptions
Soakaway Pit (SP)	• depth of the stones or storage layer thickness was 1500 mm • filled with uniformly-graded, washed 50 mm diameter stones with a 40 % void capacity • occupied a surface area of 2 m² • multiple pits applied to keep the maximum ponded depth lower than 200 mm (8")
Bioretention Cell (BR)	• thicknesses of the surface, soil and storage layers were 0 mm, 95 mm and 300 mm respectively • porosity (volume fraction) of 0.25 for the soil layer • void ratio of 0.75 for the storage layer • drain height of 1000 mm • only treated runoff from parking and driveway areas
Dry Well (DW)	• storage (gravel) depth of 0.91 m • occupied a square area with dimensions of 1.828 m² (6 ft x 6 ft) • storage layer was filled with a uniformly-graded, washed 50 mm diameter stone with a 40 % void capacity • no underdrain • modelled as an "infiltration trench" LID module in SWMM-LID
Rainwater Harvesting (RH)	• for commercial/government/institutional areas, a storage layer height of 2000 mm • for residential areas, a storage layer height of 1300 mm • all of the captured rainwater was directed to a pervious surface • overflows to the storm sewer • modelled as a "rain barrel" LID module in SWMM-LID
Green Roof (GR)	• applied on rooftops greater than 350 m² • the shape of the green roof depends on the roof area • occupied at least 75% of the total roof area • drainage to pervious area
Downspout Disconnection (DD)	• roof runoff directed to the pervious area of the subcatchment • void ratio of 0.99
Porous Pavement (PP)	• height or thickness of storage layer 300 mm • void ratio of 0.4

3.5 Lot-Based Modeling using SWMM

Each typical lot was modeled either with or without LID or LID combinations. Soil characteristics were modified according to the soil type of the modeled region. For the modeling with LID, the parameters modified were: area (ha), width (m), % imperviousness, and number of BMP controls. The parameters of each LID practice were then put into the "BMP Control Editor". BMP control setting parameters for single LID can be found in the Appendix. All the setting assumptions were based on the study by Li *et al.* (2010). To model LID or LID combinations, the procedure is to enter the actual number of LID controls under the "Subcatchment" dialog box and edit the settings, including area of each unit, % initially saturated, % of impervious area treated, and whether to send the outflow to pervious area. The process was repeated until all the simulation of every typical lot with seven types of LID and seventeen LID combinations were finished. A total runoff table, total suspended solids load table, and total phosphorus load table were generated for each region.

3.6 Cost Function

The final step of database development was to create a total cost table of each region to determine the cost-efficiency of implementing LID practices. The cost function was adopted from Low Impact Development Practices Life Cycle Costing Tool published by Toronto and Region Conservation Authority(TRCA) and University of Toronto in 2013. According to TRCA(2013), bioretention cell, dry well, and soakaway pits are some of the least expensice practices when only the practice cost itself is considered. Rainwater harvesting provides additional saving by reducing the cost of potable water supplied. Porous pavement are comparably more expensive than other practices. However, these costs would be offset to some extent by a reduction in the need to pave the drainage area because pavement can serve as both a parking area and stormwater treatment practice. Green roof is the most expensive LID because it is installed in less accessible locations and need to be carefully engineered to protect the integrity of the building envelope. The cost function allows users to optimize proposed designs based on both performance and cost.

The construction cost includes all material, delivery, labour, equipment, hauling and disposal costs. (TRCA, 2013) The RSMeans database (Toronto, 2010) was used as the basis for the costing. RSMeans assumes that there are no general contractor for the construction project. Standard Union labour costs are used, which is 18% higher then Open Shop labour costs. Also, RSMeans does not include sales tax. If data were not available in RSMeans, the other sources, such as suppliers, and experienced construction managers, were used. Some of these costs are Open Shop labour rates and do not include sales tax. For rainwater harvesting, the cost is obtained from a costing tool developed by University of Guelph, TRCA, and Connect the Drops. (STEP, 2011) Because LIDs were assumed to be constructed as part of a new development, mobilization and demonization costs were not included. For all LIDs, the following overhead costs are assumed:

- Construction management (4.5%)
- Design (2.5%), small tools (0.5%)
- Clean up (0.3%)

Establishing maintenance and rehabilitation costs are calculated using the same approach. One difference is the mobilization cost was included because equipment would not already be on site. Also, the design costs are not included because the original LID design is assumed to be used to inform this work. (TRCA, 2013)

Life cycle cost is calculated based on an evaluation period of 50 years. At the end of 50 years, the LID is considered to have no salvage value, and no extra value is attributed to the additional lifespan expected for the LID beyond the 50 year mark. Equation 16 is used to obtain the present value of the future cost. In this case, discount rates of 0%, 3%, and 5% are considered. Inflation was assumed to be 0%.

$$PV = \frac{FC}{(1+r)^n} \tag{16}$$

where PV is present value (Canadian Dollar)

FC is future cost (Canadian Dollar)

r is discount rate

n is year of future cost

Table 20 concludes the cost estimation of each LID practices. Because cost of downspout disconnection is not available in Low Impact Development Practices Life Cycle Costing Tool, the cost was obtain from study by Li and Banting (1999)

LID Practices	Capital Cost ($\$/m^2$)	Present Value including capital, maintenace, and rehabilitation cost ($\$/m^2$)		
		0%	**3%**	**5%**
Soakaway Pits	270.8	306.9	289.1	275.8
Rainwater Harvesting	47.2	84.5	66.1	60.1
Bioretention Cell	245.9	667	456.2	401.4
Green Roof	231.3	706	413.5	341.2
Dry Well	244	279.1	261.7	256.4
Downspout Disconnection	300/house	-	-	-
Porous Pavement	98.3	193	139.6	123.1

3.7 Sensitivity Analysis

All the simulations in the previous section were based on a typical lot method, which means that the average lot depth was used to obtain average lot area and imperviousness.

Although the lot width should generally be fixed, the lot depth could vary from 75 ft to 200ft. Lot area and imperviousness were both quite sensitive to the outputs. An sensitivity analysis must be conducted to ensure the data validation. There were two methods to identify the sensitivity. The first method was modeling all the lot samples with specific width to summarize the linear regression between lot depth and total runoff, TSS loading and TP loading. However, it would require more than ten thousand simulations to evaluate all four regions, and strong linear regression was not guaranteed. Due to time limitation and low time-efficiency, a second method was considered. This method only considered two extreme conditions: an upper limit (largest area and highest percentage imperviousness with specific lot width) and a lower limit(smallest area and lowest percentage imperviousness with specific lot width) to generalize a confidence envelope for the typical values. If the typical values were within range of $\pm$20%, they were considered adequate for the new planning tool.

Porous pavement implementation in the central region was selected as an example to illustrate the sensitivity analysis. Parameters related to the extreme conditions included lot depth, soil type and imperviousness. Table 21 indicates the upper and lower limits used for the analysis. By editing the site characteristics, the SWMM modeling results were used to synthesize Figure 17 and Figure 18. Triangle, diamond, and square points represent typical values, upper limit, and lower limit respectively. Due to lot variance, the runoff reduction with each specific lot width did not show a strong linear relation. That was why typical lot width was selected other than use the trend line equation to calculate LID performance with any lot width. However, Figure 16 and Figure 17 illustrate that the difference between typical values and upper/lower limits range from about 1% to 11%.

The method of typical lots can be accepted in the new tool development.

Table 20: Maximum and Minimum Lot Depth and Imperviousness in Central Region

	22ft	30ft	40ft	50ft	70ft
Maximum Lot Depth (ft)	121	180	120	122	230
Driveway Area(ft^2)	450	535	785	895	1300
% Impervious	57%	58%	59%	58%	38%
Minimum Lot Depth(ft)	100	95	90	90	165
Driveway Area(ft^2)	300	350	420	500	1800
% Impervious	53%	51%	48%	50%	35%
Typical Lot Depth(ft)	110	110	103	115	190
Driveway Area(ft^2)	370	450	770	870	1530
% Impervious	54%	53%	54%	55%	37%

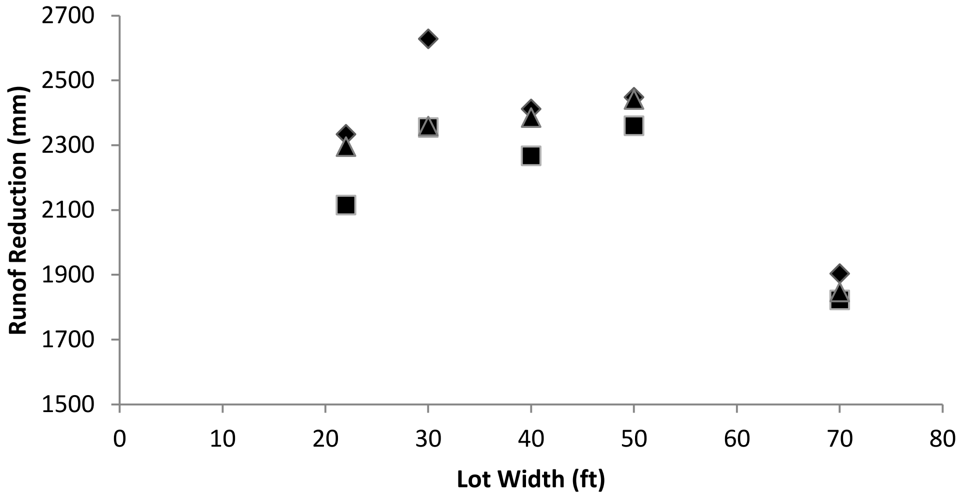


Figure 17: Total Runoff Confidence Envelope with Porous Pavement Implementation in Central Region

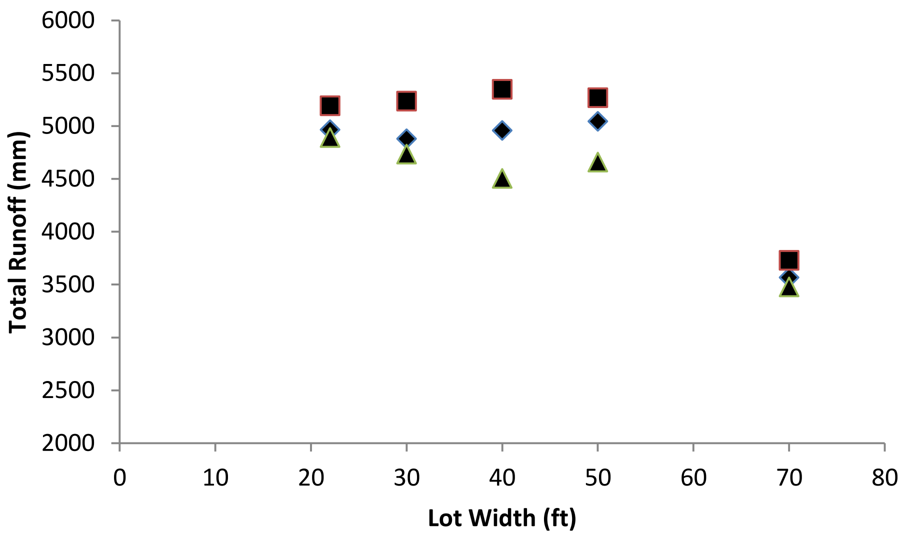


Figure 18: Total Runoff Confidence Envelope without LIDs Implementation in Central Region

CHAPTER FOUR

4 Tool Development

4.1 Introduction

Having developed the database in the previous chapter, the next stage of this study was to develop the tool structure linked to the database. The new planning tool consists of seven worksheets, one summary table and seventeen reference tables. The reference database covered the possible total runoff of LID combinations, TSS loading, TP loading, and total cost for each region. This chapter describes the seven worksheets in detail. Figure 19 shows the steps in applying the new tool to the decision-making process. By several clicks and a few data inputs, the tool canlink all the parameters to the database and generated outputs automatically. An 80% reduction of TSS loading (OMOE, 2003) was used as the pollutant control standard. If all alternative designs meet the standard, a final decision could be made based on the best cost-efficiency.

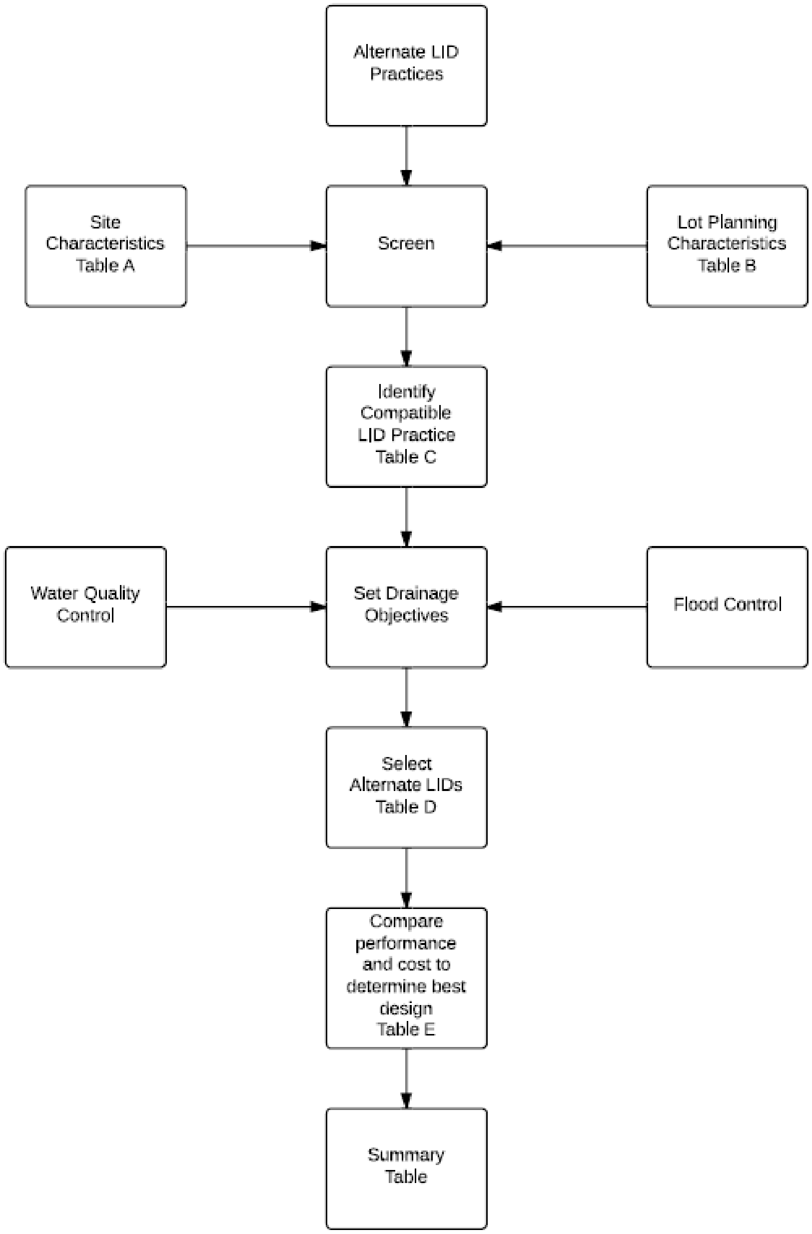


Figure 19: Flow Chart of Application of the New LID Planning Tool

4.2 Table A: Site Characteristics & Table B: Lot Planning Characteristics

The first step of LID planning is to screen alternate LID practices to eliminate any unsuitable practices. All the physical constraints were referred to the Low Impact

Development Stormwater Management Manuel by CVC and TRCA(2010) and the study by Li *et al.* (2010). All the criteria are listed in Table 22.

Table 21: Physical Constraints Imposed on Lots for Each Lot-based LID

Lot- Based LID	Site Criteria
Bioretention Cell	Soil over 2.2m deep to water or bedrock Slopes between 2% and 5% Off trees and roads Beyond Buildings and their buffers Not located within 2 year time-of-travel well head protection areas Not treat pollution hot spot runoff Drainage area : Bioretention Cell range from 5:1 to 15:1
Downspout Disconnection	Slopes between 2% and 5% Off trees and roads Beyond Buildings and their buffers
Dry Well	Slopes below 15% Beyond Buildings and their buffers Off trees and roads Drainage area : Dry Well range from 5:1 to 15:1
Green Roofs	On buildings larger than $500m^2$ in area
Porous Pavement	Soil over 2.2m deep to water or bedrock Slopes between 2% and 5% Off trees and roads On driveways, parking lots, and sideways Not located within 2 year time-of-travel well head protection areas Not treat pollution hot spot runoff Drainage area : Porous Pavement greater than 1.5:1
Rainwater Harvesting	Soil over 2.2m deep to water or bedrock Off trees and roads Beyond Buildings and their buffers
Soakaway Pit	Slopes below 15% Beyond Buildings and their buffers Off trees and roads Drainage area : Soakaway Pit range from 5:1 to 15:1

Table A (Figure 20) and Table B (Figure 21) were developed based on physical constraints. Users can use the check boxes to match the site characteristics. As DSST, any "X" means the LID practice is not suitable for the design lot; the entire row will be highlighted with a red background and given a score of zero. A "O" means that the designer is required to check the comment table to determine whether the practice is valid; the line would be highlighted with a yellow background and given a score of 0.5. All other alternatives would be given a score of 1. A comment table (Figure 22) is provided for users to review the practice suitability.

Table A: Selectipon of alternative LID practices based on site characteristics

Score	LID Practices	Site Characteristics												
		Soil Infiltration	Surface Slope(%)				Climate is vulnerable to cold and snowy winters	Depth of groundwater and bedrock(m)	Within 2 yr time-of-travel wellhead protection area	Pollution Hot Spot	Heavy Traffic Loading	Land Use		
		<15mm/hr	<1.0	>5.0	>10	>15		<2.2				Residential	Commercial/Industrial	ROW
1	Soakaway Pit					X		X	X	X				
1	Bioretention Cell		X	X	X	X		X	X	X				
1	Dry Well					X		X	X	X				
1	Rainwater Havesting						O1	X			O2			
1	Green Roof				X							X		
1	Downspout Disconnection	O3	X	X										
1	Porous Pavement	O4	X	X			O5	X	X	X				

Figure 20: Table A: Site Characteristics

Table B: Selection of alternative LID practices based on lot planning characteristics

Score	LID Practices	Lot Planning					
		Trees and Roads on Site	Drainage Area >0.8ha	Drainage Area/Treated Area >1.2	Drainage Area/Treated Area <5	Drainage Area/Treated Area >20	Flow Path Length(m) <5
1	Soakaway Pit	X			X	X	
1	Bioretention Cell	X	X		X	X	
1	Dry Well	X			X	X	
1	Rainwater Havesting	X					
1	Green Roof						
1	Downspout Disconnection	X					O6
1	Porous Pavement	X		X			

Figure 21: Table B: Lot Planning Characteristics

Table A & Table B Notes

Note #	Note for Table A & Table B
1	The systems can be used through the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternatively, an outdoor system can be used seasonally.
2	Underground cisterns should be placed in areas without vehicular traffic. Tanks under roadways, parking lots, or driveways must be designed for the live loads from heavy trucks, a requirement that could significantly increase construction costs
3	If the infiltration rate of soils in the pervious area is less than 15 mm/hr, they should be tilled to a depth of 300 mm and amended with compost to achieve an organic content in the range of 8 to 15% by weight or 30 to 40% by volume.
4	Systems located in low permeability soils with an infiltration rate of less than 15 mm/hr require incorporation of a perforated pipe underdrain.
5	Sand or other granular materials should not be applied as anti-skid agents during winter operation because they can quickly clog the system. Winter maintenance practices should be limited to plowing, with de-icing salts applied sparingly.
6	Roof downspouts should be directed to another LID practice such as a rainwater harvesting system, soakaway, swale, bioretention area or perforated pipe system.

Figure 22: Table A& B Notes

4.3 Table C: Identification of Compatible LID Practices

Table C is used to identify compatible LID practices. It summarizes the scores obtained from Table A and B. Features that end up with a final score of one are fully compatible with the designed site. Features with a final score of 0.5 or 0.25 are potentially compatible with either or both site characteristics and lot planning characteristics.

Table C: Identification of Compatible LID Practices

LID Practices	Scores (refer to table A & B)		
	Site Characteristics	Lot Planning	Overall Score
Soakaway Pit	1	1	1
Bioretention Cell	1	1	1
Dry Well	1	1	1
Rainwater Havesting	1	1	1
Green Roof	1	1	1
Downspout Disconnection	1	1	1
Porous Pavement	1	1	1

Figure 23: Table C: Identification of Compatible LID Practices

4.4 Table D: Selection of LID Practices

Table D is used to select appropriate LID or LID combinations based on the overall score from Table C. Users can choose up to three scenarios to compare their performance. Each scenario is related to a Table E.

Table D: Selection of LID Practices

Scen 1	Scen2	Scen 3	LID Practices	Overall Score
☐	☐	☑	Soakaway Pit	1
☑	☐	☐	Bioretention Cell	1
☐	☐	☐	Dry Well	1
☐	☑	☐	Rainwater Harvesting	1
☐	☐	☐	Green Roof	1
☐	☐	☐	Downspout Disconnection	1
☑	☑	☑	Porous Pavement	1

Figure 24: Table D: Selection of LID Practices

4.5 Table E: Comparison of Different LID Combination

In order to compare different scenarios from Table D, there are three Table Es to evaluate different LID combinations at the same time. Green colored cells are data input and yellow colored cells are outputs. Users can choose the study region from a drop-down list first, then the lot width can be selected from another drop-down list. There are five tables to estimate up to five different lot types. Figure 25 only shows two of them. The only number required for the whole tool is the total number of lots because the database is based on single lot simulation. All the results will be illustrated in a summary table to decide the best alternative.

Table E: Comparison of Different LID conbination - Scenario 1

Region							
Lot Size(ft)		# of Lots					
Lot Area(ft^2)		Total Runoff(mm)	0	TSS(kg)	0	TP(kg)	0
		Total Runoff(m^3)	0				

Selected LID	# of Units	Runoff (mm)	Runoff Reduction(m^3)	TSS(kg)	TSS Reduction(kg)	TP(kg)	TP Redution(kg)	Cost
Bioretention Cell	1	0	0	0	0	0	0	0
Porous Pavement	1	0	0	0	0	0	0	0
BR+PP	1	0	0	0	0	0	0	
Total			0		0		0	0

Lot Size(ft)		# of Lots					
Lot Area(ft^2)		Total Runoff(mm)	0	TSS(kg)	0	TP(kg)	0
		Total Runoff(m^3)	0				

Selected LID	# of Units	Runoff (mm)	Runoff Reduction(m^3)	TSS(kg)	TSS Reduction	TP(kg)	TP Redution(kg)	Cost
Bioretention Cell	1	0	0	0	0	0	0	0
Porous Pavement	1	0	0	0	0	0	0	0

Total Cost	0
Total Runoff Without LIDs(m3)	0
Total TSS Without LIDs	0
Total TP Without LIDs	0
Total Runoff Reduction(m3)	0
Total TSS Reduction	0
Total TP Reduction	0
Cost Efficiency($/m3 removal)	#DIV/0!
Meet MOE Standard	#DIV/0!

Figure 25: Table E: Comparison of Different LID Combinations

5 Case Study: Bayview Wellington Center in the Town of Aurora

5.1 Case Study Background

The Bayview Wellington Center is located in the Town of Aurora, on the north-west corner of Bayview Avenue and Wellington Street (Figure 26). The subject area is within the Aurora East Industrial Area. The 79-hectare study area consists of the former Bayview Business Park and the Don Schmidt Land. In March 1994, the Bayview Wellington Centre Secondary Plan was proposed to revise the land use from industrial to residential and commercial (Cosburn Patterson Wardman Limited, 1994). In 2008, the town of Aurora released Bayview Wellington Center Secondary Plan Official Plan Amendment #6 to promote a multi-use urban centre providing a range of housing, shopping, and employment and recreation opportunities. The amendment aimed to redesign the study area.

From:

- Prestige Industrial;
- General Industrial Official Commercial;
- Service Commercial;
- Commercial; and
- Major Open Space Specific.

To:

- Community Commercial Center;
- Campus Commercial Center;

- Office Commercial;
- Neighborhood Commercial;
- Urban Residential (low-medium density, medium density, medium-high density, high density and high density mixed used residential and commercial);
- Institutional; and
- Public Open Space.

There are two drainage area at the studied site, as shown in Figure 26. The majority of the site (yellow highlighted area) sheet drained from east to west to the Holland River. A smaller area (green highlighted area) drains to a tributary at the Bayview Avenue and Wellington Street intersection. The tributary flows into the Holland River on the South side of Wellington, approximately 750m west of Bayview Avenue. (Town of Aurora, 1994) The case study only focuses on residential area, so only the red highlighted area was studied.

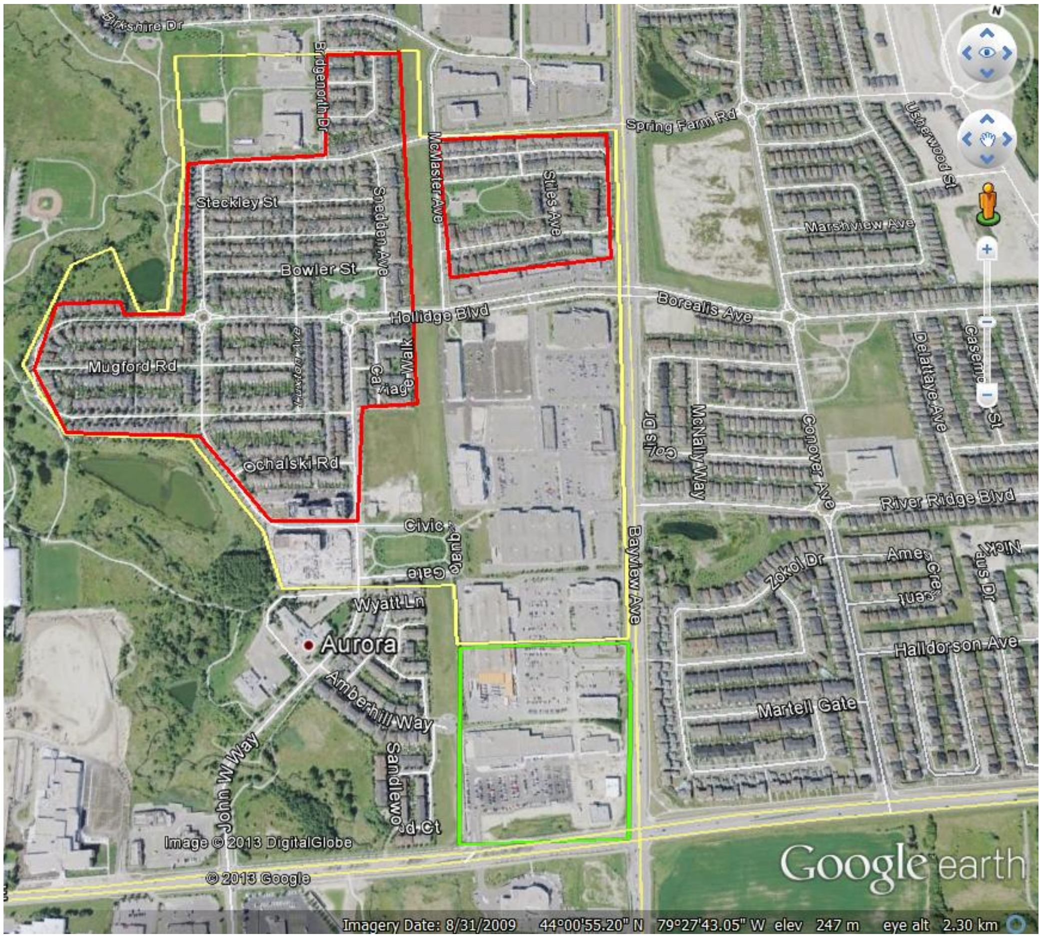


Figure 26: Site Location of Bayview Wellington Center (Google Inc, 2013)

5.2 Objective and Scope of Case Study

To illustrate the use and benefits of the new planning tool developed in this thesis, Bayview Wellington Center was examined as a case study. The objective was of conducting the case study was to determine performance, adaptability and stability of the new tool, and reveal the convenience of using the new tool at the planning level. The goal of this case study was to obtain information for further modifications.

After gathering the site characteristics, the new planning tool could be applied to the study area. It should be emphasized that only a single-family residential housing area was simulated in this case study. The total runoff and total pollutant loading cannot represent the whole subdivision because the residential area comprises about 60% of the total area (Cosburn Patterson Wardman Limited, 1994). Single-family housing is only about 50% of the residential area (21 ha) according to Google Earth Pro estimation. There is a shopping mall with large parking lot in this area. Roads, sidewalks, and open space were also not included in previous studies. In order to approximate total runoff and pollutant loading of the whole subdivision, further simulations of commercial, institutional, and industrial land use are strongly recommended. The other two available LID planning tools, which were New York State Green Infrastructure Worksheets and Phosphorus Budget Tool for the Lake Simcoe Watershed, were also applied to the study area under the same settings. The outputs of these three tools are compared and discussed at the end of the chapter.

5.3 Data Collection

According to Cosburn Patterson Wardman Limited (1994), the physical constraints of the study area could be concluded as:

- Climate is vulnerable to cold and snowy winters
- Soil infiltration is smaller than 15mm/hr (Soil infiltration rate of loam is 3.4mm/hr)
- Drainage area is larger than 0.8ha
- Drainage area/treated area is smaller than 5

Because soil type, rainfall, imperviousness and single lot area have been defaulted in the database, only data on the type of lot and total number of each type had to be collected. And, as lot information was not available for public access, Google Earth Pro was used to estimate the lot width and number of lots. The information is shown in Table 23 below.

Table 22: Bayview Wellington Center Single-family Housing Survey

Lot Width	30	40	50
# of Lots	202	349	37

The other two planning tools require precipitation, soil, and imperviousness inputs. The typical values would be applied to make sure consistency of the analysis. New York State Green Infrastructure Worksheets use United States customary units. Unit conversion was necessary. Typical values and unit conversion is shown in Table 24 below.

Table 23: Typical Precipitation, Soil Type, and Imperviousness

Precipitation (mm)	531.4
Precipitation (in)	20.9
Soil Type	Loam
Soil Group	B
% Impervious (30ft)	53%
% Impervious (40ft)	54%
% Impervious (50ft)	55%

5.4 New Tool Application Procedure

By applying physical constraints to Table A (Figure 27) and Table B (Figure 28), Soakaway Pit, Bioretention Cell, and Dry Well were not feasible for the designed lots. Also, Rainwater Harvesting, Downspout Disconnection, and Porous Pavement were considered potentially incompatible with the study area. The following comments from the comment table were considered:

- Comment 1 - Rainwater Harvesting System can be used through the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternatively, an outdoor system can be used seasonally.
- Comment 3 - If the infiltration rate of soils in the previous area is less than 15 mm/hr, Downspout Disconnection should be tilled to a depth of 300 mm and amended with compost to achieve an organic content in the range of 8 to 15% by weight or 30 to 40% by volume.
- Comment 4 - Porous Pavement located in low permeability soils with an infiltration rate of less than 15 mm/hr require incorporation of a perforated pipe underdrain.
- Comment 5 - Sand or other granular materials should not be applied as anti-skid agents during winter operation because they can quickly clog the system. Winter maintenance practices should be limited to plowing, with de-icing salts applied sparingly.

Table A: Selectipon of alternative LID practices based on site characteristics

Score	LID Practices	Site Characteristics												
		Soil Infiltration	Surface Slope(%)				Climate is vulnerable to cold and snowy winters	Depth of groundwater and bedrock(m)	Within 2 yr time-of-travel wellhead protection area	Pollution Hot Spot	Heavy Traffic Loading	Land Use		
		<15mm/hr	<1.0	>5.0	>10	>15		<2.2				Residential	Commercial/Industrial	ROW
		☑	☐	☐	☐	☐	☑	☐	☐	☐	☐	☑	☐	☐
1	**Soakaway Pit**					X		X	X	X				
1	**Bioretention Cell**		X	X	X	X		X	X	X				
1	**Dry Well**					X		X	X	X				
0.5	Rainwater Havesting						O1	X			O2			
1	Green Roof				X							X		
0.5	Downspout Disconnection	O3	X	X										
0.5	Porous Pavement	O4	X	X			O5	X	X	X				

Figure 27: Table A Site Characteristics (Bayview Wellington Center)

Table B: Selection of alternative LID practices based on lot planning characteristics

Score	LID Practices	Lot Planning					
		Trees and Roads on Site	Drainage Area	Drainage Area/Treated Area			Flow Path Length(m)
			>0.8ha	>1.2	<5	>20	<5
		☐	☑	☐	☑	☐	☐
0	Soakaway Pit	X			X	X	
0	Bioretention Cell	X	X		X	X	
0	Dry Well	X			X	X	
1	Rainwater Havesting	X					
1	Green Roof						
1	Downspout Disconnection	X					O6
1	Porous Pavement	X		X			

Figure 28: Table B Lot Planning Characteristics

Table C (Figure 29) calculated the overall score of each LID practice. According to the overall score, three LID combinations were selected in Table D (Figure 30). Comment 1, Comment 4 and Comment 5 were assumed to apply. The three combinations were:

- Downspout Disconnection + Porous Pavement (DD+PP)
- Rainwater Harvesting + Porous Pavement (RH+PP)
- Downspout Disconnection + Rainwater Harvesting (RH+DD)

Table C: Identification of Compatible LID Practices			
LID Practices	Scores (refer to table A & B)		
	Site Characteristics	Lot Planning	Overall Score
Soakaway Pit	1	0	0
Bioretention Cell	1	0	0
Dry Well	1	0	0
Rainwater Havesting	0.5	1	0.5
Green Roof	0	1	0
Downspout Disconnection	0.5	1	0.5
Porous Pavement	0.5	1	0.5

Figure 29: Table C Identification of Compatible LID Practices (Bayview Wellington Center)

Table D: Selection of LID Practices				
Scen 1	Scen2	Scen 3	LID Practices	Overall Score
☐	☐	☐	Soakaway Pit	0
☐	☐	☐	Bioretention Cell	0
☐	☐	☐	Dry Well	0
☐	☑	☑	Rainwater Harvesting	0.5
☐	☐	☐	Green Roof	0
☑	☐	☑	Downspout Disconnection	0.5
☑	☑	☐	Porous Pavement	0.5

Figure 30 Table D Selection of LID practices (Bayview Wellington Center)

Table E: Comparison of Different LID conbination - Scenario 1

Region	Central						
Lot Size(ft)	30	# of Lots	202				
Lot Area(ft^2)	3300	Total Runoff(mm)	243.98	TSS(kg)	3920.07	TP(kg)	6.04
		Total Runoff(m^3)	15125.03				

Selected LID	# of Units	Runoff (mm)	Runoff Reduction(m^3)	TSS(kg)	TSS Reduction(kg)	TP(kg)	TP Redution(kg)	Cost
Downspout Disconnectio	2	166.71	4790.20	2680.54	1239.53	4.13	1.91	181800.00
Porous Pavement	1	167.95	4713.26	1877.44	2042.63	2.90	3.14	1878357.60
GR+PP+DD	1	102.82	8750.73	862.04	3058.04	1.33	4.71	
Total			8750.73		3058.04		4.71	2060157.60

Total Cost	7010685.00
Total Runoff Without LIDs(m3)	52300.45
Total TSS Without LIDs (kg)	13887.34
Total TP Without LIDs (kg)	21.93
Total Runoff Reduction(m3)	30361.92
Total TSS Reduction (kg)	10752.92
Total TP Reduction (kg)	17.09
Cost Efficiency($/m3 removal)	230.90
Meet MOE Standard	No

Figure 31: Table E Comparison of Different LID Combinations (PP+DD)

Lot Size(ft)	40	# of Lots	349					
Lot Area(ft^2)	4000	Total Runoff(mm)	247.91	TSS(kg)	8851.08	TP(kg)	14.17	
		Total Runoff(m^3)	32185.08					
Selected LID	**# of Units**	**Runoff (mm)**	**Runoff Reduction(m^3)**	**TSS(kg)**	**TSS Reduction**	**TP(kg)**	**TP Redution(kg)**	**Cost**
Downspout Disconnectio	2	169.56	10172.02	6305.21	2545.87	9.72	4.45	314100.00
Porous Pavement	1	169.27	10209.54	4397.21	4453.87	6.77	7.40	4095235.80
GR+PP+DD	1	103.7985	18709.1236	2023.1879	6827.88835	3.12355	11.04585	
Total			18709.1236		6827.88835		11.04585	4409335.8
Lot Size(ft)	50	# of Lots	37					
Lot Area(ft^2)	5750	Total Runoff(mm)	252.219	TSS(kg)	1116.19195	TP(kg)	1.7205	
		Total Runoff(m^3)	4990.342079					
Selected LID	**# of Units**	**Runoff (mm)**	**Runoff Reduction(m^3)**	**TSS(kg)**	**TSS Reduction**	**TP(kg)**	**TP Redution(kg)**	**Cost**
Downspout Disconnectio	2	172.9735	1567.931652	767.9942	348.19775	1.184	0.5365	33300
Porous Pavement	1	172.052	1586.16422	537.6914	578.50055	0.8288	0.8917	507891.6
GR+PP+DD	1	105.5445	2902.064988	249.19685	866.9951	0.3848	1.3357	
Total			2902.064988		866.9951		1.3357	541191.6

Figure 32: Table E Comparison of Different LID Combinations (PP+DD) (Continued)

The results of the analysis of LIDs are summarized in Figure 33. The table illustrates that only one combination (RH+PP) met the MOE standard of 80 percent TSS loading reduction. Scenario 3. This combination could be selected as the best combination. The recommended combination is highlighted with a green background. If more than one combination meet MOE standard, the tool will choose the one with lowest cost.

Comparison Summary Table			
	Scenario 1	Scenario 2	Scenario 3
Total Runoff (m^3)	52300.45	52300.45	52300.45
Total Runoff Reduction (m3)	30361.92	34264.64	38028.75
Total Runoff Reduction (%)	58%	66%	73%
Total TSS (kg)	13887.34	13887.34	13887.34
Total TSS Reduction (kg)	10752.92	11834.06	9669.30
Total TSS Reduction (%)	77%	85%	70%
Total TP (kg)	21.93	21.93	21.93
Total TP Reduction (kg)	17.09	18.77	15.95
Total TP Reduction (%)	78%	86%	73%
Total Cost (Canadian Dollar)	7010685.00	8587368.00	2635083.00
Cost Effiency ($\$/m^3$)	230.90	250.62	69.29
Meet MOE Standard	No	Yes	No

Figure 33: Summary Table (Bayview Wellington Center)

5.5 Phosphorus Budget Tool for the Lake Simcoe Watershed Application

The first step to use this tool was to create a new development. The study area is located in East Holland Subwatershed. Only pre-development and post-development modules were reviewed because the new tool cannot provide a construction phase estimation. The next step was choosing land use and entering the land use area. A twenty-one hectare high intensity-residential area was simulated. Then the Post-Development Module was used to calculateTP reduction. This tool can only simulate one BMP at a time. In addition, only one soakaway pit among the four LID practices used in previous sections is available. The results are shown in Figure 35.

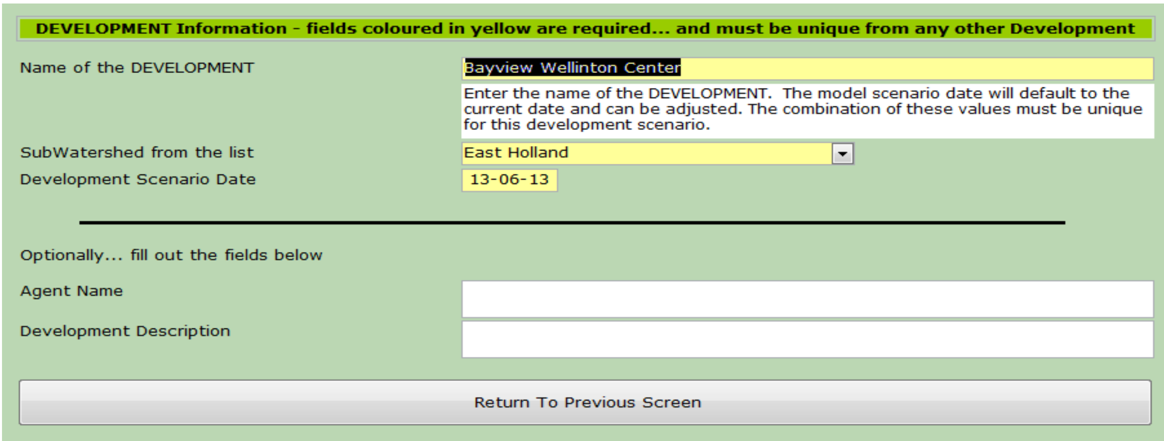
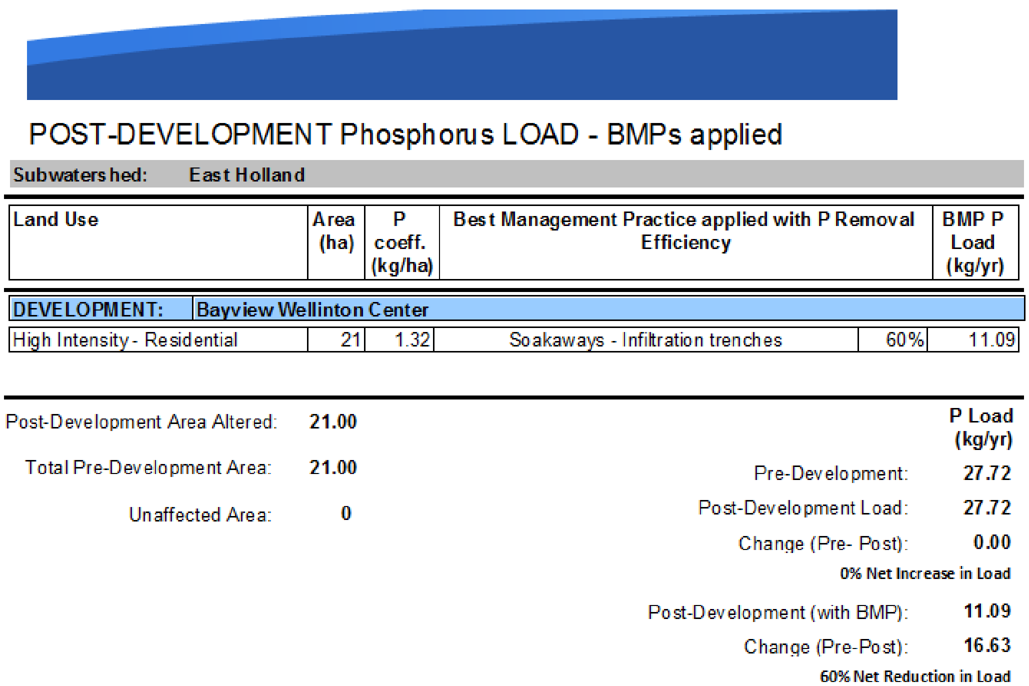


Figure 34: New Development Creation



POST-DEVELOPMENT Phosphorus LOAD - BMPs applied

Subwatershed: East Holland

Land Use	Area (ha)	P coeff. (kg/ha)	Best Management Practice applied with P Removal Efficiency		BMP P Load (kg/yr)
DEVELOPMENT:	Bayview Wellinton Center				
High Intensity - Residential	21	1.32	Soakaways - Infiltration trenches	60%	11.09

Post-Development Area Altered:	21.00		P Load (kg/yr)
Total Pre-Development Area:	21.00	Pre-Development:	27.72
Unaffected Area:	0	Post-Development Load:	27.72
		Change (Pre- Post):	0.00
			0% Net Increase in Load
		Post-Development (with BMP):	11.09
		Change (Pre-Post):	16.63
			60% Net Reduction in Load

Figure 35: Post-development Phosphorus Load - Soakaway Pit Applied

5.6 New York State Green Infrastructure Worksheets

The first step to use the New York State Green Infrastructure Worksheets was to enter precipitation, and subcatchment information. Only one LID can apply to each subcatchment. In order to simulate the combinations, the driveway area was isolated as a subcatchment. Figure 36 shows the total runoff calculation table.

A	B	C	D	E	F	G	H	
P=	20.9	*inch*						
Breakdown of Subcatchments								
Catchment	Total Area *(Acres)*	Impervious Cover *(Acres)*	Percent Impervious *%*	Runoff Coefficient *Rv*	WQv *(ft³)*	Description		
1	43	20	47%	0.47	1528720	Bioretention		
2	8	8	100%	0.95	576589	Porous Pavement		
3					0			
4					0			
5					0			
6					0			
7					0			
8					0			
9					0			
10					0			
Total	51.00	28.00	55%	0.54	2,105,309	Initial WQv	48.33	af
Identify Runoff Reduction Techniques By Area								

Figure 36: Total Runoff Calculation of New York State Green Infrastructure Worksheets

The next step was entering BMP settings. BR+PP combination would be used as a sample approach. All the settings were based on the BMP sizing assumption in Chapter 3. Parameters required for Bioretention simulation include soil type, soil infiltration rate, underdrain usage, depth of soil media, hydraulic conductivity, filter time, filter width, and filter length. Parameters required for Porous Pavement simulation include soil infiltration, underdrain usage, porosity of gravel bed, gravel bed depth, and surface area provided. Figure 37 illustrates the runoff reduction estimation. The same procedure is repeated for simulation of RH+PP and SP+PP combinations.

	Runoff Reduction Techiques/Standard SMPs		Total Contributing Area	Total Contributing Impervious Area	WQv Reduced (RRv)	WQv Treated
			(acres)	(acres)	cf	cf
Area Reduction	Conservation of Natural Areas	RR-1	0.00	0.00		
	Sheetflow to Riparian Buffers/Filter Strips	RR-2	0.00	0.00		
	Tree Planting/Tree Pit	RR-3	0.00	0.00		
	Disconnection of Rooftop Runoff	RR-4		0.00		
Volume Reduction	Vegetated Swale	RR-5	0	0.00	0	
	Rain Garden	RR-6	0	0.00	0	
	Stormwater Planter	RR-7	0	0.00	0	
	Rain Barrel/Cistern	RR-8	0	0.00	0	
	Porous Pavement	RR-9	8	8.00	576589	
	Green Roof (Intensive & Extensive)	RR-10	0	0.00	0	
Standard SMPs w/RRv Capacity	Infiltration Trench	I-1	0	0.00	0	0
	Infiltration Basin	I-2	0	0.00	0	0
	Dry Well	I-3	0	0.00	0	0
	Underground Infiltration System	I-4	0			
	Bioretention & Infiltration Bioretention	F-5	43	20.00	1528720	43
	Dry swale	O-1	0	0.00	0	0

Figure 37: Summary Table of New York State Green Infrastructure Worksheets

5.7 Results and Discussion

5.7.1 Runoff Comparison

Results of New York State Green Infrastructure Worksheets were concluded in SI units in Table 25. Compared to the new tool, the difference of total runoff was about 13%, which was considered within a reasonable range. However, the difference between runoff reductions after LID implementation varies significantly from 30% to 40%. The difference between runoff reductions was caused by different removal efficiency assumptions. New York State Green Infrastructure Worksheets assumed that Porous Pavement and Rainwater Harvesting achieve 100% runoff compared with 80% and 50% for the new tool.

Table 24: Outputs of New York State Green Infrastructure Worksheets

LID Combination	Runoff(m3)	Runoff Reduction(m3)	Runoff Reduction(m3) from the new tool	% Difference
Without LID	59614	-	52300	14%
BR + PP	9366	50248	38652	30%
RH + PP	13356	46258	34265	35%
SP + PP	9737	49877	36315	37%

5.7.2 Total Phosphorus Comparison

The new planning tool gave an estimated TP loading of 20.93 kg/yr compared to 27.72kg/yr obtained from Phosphorus Budget Tool for the Lake Simcoe Watershed. The difference is due to the phosphorus export coefficients using in Phosphorus Budget Tool for the Lake Simcoe Watershed. When deriving these coefficients, groundwater, tile drainage and stream bank erosion were also taken into consideration. The new tool does not have any of this information.

Phosphorus Budget Tool for the Lake Simcoe Watershed can only simulate one LID practice at a time, and only a Soakaway Pit was simulated. The new tool was run again to obtain Soakaway Pit TP reduction. The results of 53% and 60% removal were quite close. It illustrated that the new planning tool can provide a good prediction of total phosphorus loading reduction.

CHAPTER SIX

6 Conclusions and Recommendations

6.1 Conclusions

Urban sprawl is causing significant environmental impacts including losing green space, farmland, and important ecosystems. As the urban areas grow, environmental problems grow exponentially. More flooding, higher level of contaminants in receiving water, serious erosion, and reduction in groundwater recharge has been observed. The water resources degradation demands more cost-effective solutions like low impact development practices for controlling urban runoff. Despite the benefits of LID implementation, absence of an effective LID planning tool has been identified.

This thesis aimed to assist closing the gaps between LID planning and technical support. Two major tasks were conducted to achieve the research goals. The first task was to develop a new LID planning tool. By comparing available LID planning models, only one tool (DSST) can predict both runoff reduction and total cost for an Ontario perspective. However, DSST was designed more for traditional drainage features other than LID. A need of developing a new LID planning tool was identified. According to the literature review, successful keys of an ideal LID planning tool can be concluded as workable, timely, defensible, and adaptable.

The planning tool was based on several assumptions including soil, typical single-family lot size, rainfall, evapotranspiration rate, and LID sizing. One typical soil type was selected for each area based on Ontario Soil Maps. Due to data unavailability, evapotranspiration rates of the other three regions were assumed the same as Central

Ontario. 20-year rainfall data was analyzed other than choose a typical year to reduce the uncertainty. A housing survey was conducted to conclude typical lot of each region. However, the accuracy of typical lot assumption cannot guarantee. An sensitivity study was conducted to warrant the accuracy within an acceptable range. The results showed that the sensitivities were all located with ±20%, and the outputs of the new tool were accurate enough at the planning level.

The second task was to apply the new planning tool to a case study of Bayview Wellington Center located in the town of Aurora. The objective of this case study was to demonstrate the effectiveness and accuracy of the new planning tool. Two other models, the New York State Green Infrastructure Worksheets, and the Phosphorus Budget Tool for the Lake Simcoe Watershed Application, were also applied to the case study area. A comparison of the results shows that the new tool could offer a decent estimation for single-family housing at the planning level. The estimation difference between total runoff of the new tool and New York State Green Infrastructure Worksheets was 13%. However, the differences between runoff reductions with LID implementation ranged from 30% to 40%. New York State Green Infrastructure Worksheets have removal assumptions of 100% for the Porous Pavement and Rainwater Harvesting. According to the SWMM simulations, the numbers of 80% and 50% are more practicable. The new tool estimates TP loading effectively by comparing the results with Phosphorus Budget Tool for the Lake Simcoe Watershed. However, the new tool does not build in a background phosphorus estimation as Phosphorus Budget Tool.

6.2 Recommendations

Upon completion of this thesis, a series of recommendations can be made to improve the new LID planning tool in the future, as well as suggest additional fields of research.

1. The new tool can only simulate single-family housing. Other landuse type simulations are strongly recommended. Further analysis should also be conducted to cover other residential types such as townhouses, high-rise condominiums, as well as commercial, industrial, and institutional types.
2. The new tool focused solely on seven lot-based LID practices. The list of LID practices can be further expanded. Once more LID practices have been added to the tool, examinations will be required to assess the feasibility of different LID combinations.
3. Because this tool adapted typical lot method, more housing samples should be collected and classified, particularly from Northern Ontario. More samples will generate better coverage and conclude typical lots that are more representative.
4. Uncertainty analysis should be further developed to confirm the data reliability and the parameter values. To achieve more accurate assessments, several lot depths with specific lot widths can be analyzed.
5. More representation precipitation stations should be selected in the future, especially in Central Ontario. In Southern Ontario, human activities influence environment significantly. The precipitation varies largely from town to town.
6. Only one dominant soil type was selected in this thesis according to the Ontario Soil Maps for each region. More soil types can be added to provide more accurate outputs.

7. Linkages to the database use Microsoft Excel formulas. It is recommended to create a Microsoft Excel macro by using the Visual Basic for Applications (VBA) programming language. The macro can be used to perform repeated tasks automatically, which will save developers' time.
8. Due to data unavailability, evapotranspiration rates were assumed the same as Barrie subwatershed. Further research is recommended to obtain evapotranspiration rates for each region.
9. Only the rainy season from April to November was modeled in this thesis. Snow accumulation and snowmelt can be taken into consideration in future research.

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