Sustainable Stormwater Management using Green Infrastructure for Parking Lot Design in Kitchener and Waterloo Region

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Urbanization growth resulting in increasing the amount of runoff caused by land use change has become a major challenge for water management and water security worldwide. Along with rapid urbanization, climate change has been straining traditional water resources and degrading the environment too. With Canada facing rapid change in climate, the Region of Waterloo and Kitchener is likely to face more rainfall and rise in temperature in the future, hence a more sustainable use of land and water is a necessity. New land development methods and engineering should be proposed to minimize these adverse impacts on the environment and local ecology. Low impact development is considered as such an innovative methodology and engineering system.

This research project takes a commercial parking lot in the Kitchener-Waterloo Region and proposes a cost-effective, sustainable stormwater management redesign to mitigate the problems of climate change through social, economic and aesthetic interventions utilizing low impact development principles. The proposed redesign demonstrates that low impact development interventions can help reduce stormwater runoff in an urban area; be economically affordable relative to 'business as usual' infrastructures; add social benefits; preserve environmental integrity; and enhance ecosystem services. Furthermore, implementing such interventions in that area will help the municipality to achieve sustainable development goals 11, 6, and 13.

Keywords: Low Impact Development, Green Infrastructures, Urban Runoff, Stormwater Management, Sustainable Architecture

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List of Abbreviations

ABC	Active Beautiful Clean
CNT	Center of Neighborhood Technology
CVC	Credit Valley Conservation
EPA	Environmental Protection Agency
GI	Green Infrastructure
GVC	Green Value Calculator
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
ISWMP	Integrated Stormwater Management Plan
KW	Kitchener-Waterloo
LID	Low Impact Development
PUB	Public Utilities Board
PV	Present Value
SDG	Sustainable Development Goal
SW	Stormwater
SWM	Stormwater Management
USEPA	United States Environmental Protection Agency

Chapter 1

Introduction

This thesis focuses on low impact development for improved stormwater management (SWM). It commences from the perspective that urban water security may be improved by retrofitting existing developed urban areas with climate conscious interventions (Valinski and Chandler, 2015). As cities expand, natural ecosystems are altered primarily through the displacement of soft soils and trees with a hardened built environment (Weng, 2012). This results in several forms of water insecurity:

- Increased runoff, decreased infiltration, and increased evaporation leading to, among other things, flash flooding, seasonal water scarcity, urban heat islands, downstream vulnerabilities to both drought and flood.

This thesis engages the challenge of water insecurity through architectural design. It uses a case study of The Boardwalk parking lot – an area straddling the municipal jurisdictions of Kitchener and Waterloo – to showcase several possible interventions in support of sustainable water management through improved stormwater flows.

Stormwater is a natural part of our environment, no different from rivers, ponds, or forests. In both natural and human-altered environments, precipitation will flow as runoff over permeable and semi-permeable surfaces, creating elaborate systems of drainage that include natural areas, such as creeks, lakes, and wetlands (Boller, 2004). Precipitation also will be absorbed by the ground, evaporated from land and water bodies, and transpired by vegetation. Together, this comprises the water-cycle (Keeley, Koburger, Dolowitz, Medearis, & Shuster, 2013). As humans have dramatically altered the landscape through urbanization and suburbanization, so too have they altered the flow of water through the environment (Yang and Yuhong, 2017). The built environment, comprising structures such as houses, businesses, roads, and parking lots, reduces the areas where stormwater can be absorbed into the ground - referred to as permeable or porous areas (Barnes, Morgan, & Roberge, 2001). As cities expand, replacing natural surfaces with hard, non-absorbent, impervious surfaces, the challenges of sustainable water management also expand in significance and difficulty (Kidner and Roesner, 2007). Put differently, there are many things that we can do to improve urban water security, but the longer we wait the more difficult and expensive it will be to retrofit areas designed by conventional means.

An increase in the amount of impervious surface area in urban and peri-urban environments means an increase in the amount (and concentration) of surface run-off and a decrease in the amount of water infiltration (Haris, Chow, Usmen, Sidek, Roseli, & Norlida, 2016). This raises the chances for flooding downstream and in low lying areas as stormwater exceeds channel capacities. Also, by disrupting the natural water cycle through a physical change to the ecosystem, the probability of property damage and human harm increases significantly (Jayasooriya and Ng, 2014). As a result, examining stormwater management practices is significant both in terms of urban planning and human lives. Because impervious surfaces cannot absorb precipitation, this water flows off surfaces which creates stormwater run-off. During runoff events, pollutants may wash into waterways, posing significant health hazards (Getter and Bradley, 2006). Previous studies support the link between urban runoff from impervious surfaces and the reduction of water quality in streams (Novotny and Chesters, 1981). Even 10% of land area covered with impervious surfaces can have a significant effect on stream water quality (Ferguson and Male, 1980). It is also reported that urban runoff can contaminate drinking water supplies (Moran, Hunt, & Smith. 2005). In addition, to the human-made problems, it was seen in this study that capability of government to intervene or change conventional stormwater management systems plays a role in achieving better measures to prevent stormwater runoff and management (Environmental Commissioner of Ontario, 2016). This capability usually includes funding and existing laws. However, with new measures being taken like rebate programs and stormwater management fees in provinces such as Ontario and Alberta these problems are slowly being addressed (Environmental Commissioner of Ontario, 2016).

Climate Change

Climate Change is the biggest challenge of our lives, both in terms of long-term sustainability and of short-term impacts of extreme events such as drought, flood, and heat. For example, the city of Toronto suffered extreme precipitation events in the years 2000, 2005, 2013 and 2018, each of which caused major flooding (Ligaya, 2013; Yousif, 2018). The two-day rain event in July 2013 resulted in insured property damages of CAD 850 million. The City of Toronto is investing an estimated CAD 3.1 billion in stormwater management planning over a ten-year period (Ligaya, 2013; Yousif, 2018).

Similarly, the Regional Muncipality of Waterloo saw significant local flooding in February 2018 caused by a combination of unusually warm weather, snowmelt, and extended rain events. According to the City of Kitchener's (n.d.: no page numbers) corporate climate action plan, Waterloo Region faces the following climate projections:

- Annual average temperature projected to increase by about 2-3 degrees Celsius by the 2050s.

- Warmer winters: The monthly average temperature in February in the 2050s is expected to be 3-5 degrees Celsius higher than it is today, meaning it will hover around 0 degrees Celsius.
- More extreme summer heat: Currently, the region experiences around 10 days per year with extreme heat (daily maximum temperature exceeding 30 degrees Celsius). The number of days with extreme heat is projected to more than triple to 32 days by the 2050s, and then nearly double again to 60 days by the 2080s.
- More intense rain storms: Large-scale rainfalls and wind storms are projected to happen more frequently.
- 40% more freezing rain events by the 2050s in December, January, and February.
- Total annual precipitation is projected to increase by approximately 4-6% by the 2020s and 8-12% in the 2050s.

With change in climate having a vast impact in this region, necessary steps are needed by both municipal and local governments to intervene and prepare for impacts. The following sections will discuss how such measures are being taken in terms of the Sustainable Development Goals (SDGs), and my green design will be a proposal on how the government, civil society, citizens and the private sector can come together to take climate action to effectively address these problems.

Sustainable Development Goals (SDGs)

As the Waterloo Region aims to move toward a more sustainable future, integrating the SDGs into resource use planning is essential for effective water management. The following section highlights how stormwater management systems can help Waterloo Region reach its sustainable development goals.

Goal 11 Sustainable Cities and Communities

SDG 11 aims to make cities safe, resilient and sustainable. More than half of humanity -- 3.5 billion people -- live in cities today and this number will continue to grow. Waterloo Region, comprising the cities of Cambridge, Kitchener and Waterloo, is the second fastest growing region in Canada (Canadian Broadcasting Corporation, 2019).

According to Global Compact Network Canada, SDG11 Target 6 aims to reduce by 2030 the adverse per capita environmental impact of cities, with a focus on air quality and municipal and other waste management. My design will try to highlight sustainable water and waste management practices to meet this goal (Global Compact Network Canada, 2017). Target 11.7 aims to provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities by 2030. My design will highlight aesthetic interventions and improve people's quality of life (Global Compact Network Canada, 2017). Target 11.a of SDG11 aims to create a positive economic, social and environmental development in urban areas by strengthening national and regional development planning. My plan is to showcase an example so that it can be highlighted in other parking areas in Canada (Global Compact Network Canada, 2017).

Target 11.b of SDG 11 focuses on effective hazard risk reduction. Effective storm water management for flood hazard risk reduction is of increasing importance in Waterloo Region (City of Kitchener, n.d.). My project presents a prototype for stormwater management in a densifying urban environment which may be used as an example for large scale intervention elsewhere (Global Compact Network Canada, 2017).

Goal 13 Climate Action

Effective climate action is essential to ensure mitigation and adaptation goals are achieved in urban areas (Global Compact Network Canada, 2017). The following SDG 13 targets are important for my project design. Target 13.3 focuses on improvement of education and awareness by strengthening human and institutional capacity. By implementing my design plans Kitchener-Waterloo municipalities can take green measures to mitigate adverse climate impacts and adapt to changing weather patterns by 2030 (Global Compact Network Canada, 2017).

Although Target 13.b, of SDG 13, focuses on raising awareness and capacity in developing countries, it also reflects on how all countries can promote mechanisms to educate people about climate actions. My project will help highlight such awareness through green practices and overall contributing to the country's climate action plan (Global Compact Network Canada, 2017).

Goal 6 Clean Water and Sanitation

According to the SDG 6 synthesis report of 2018, community participation is essential for developing an effective water management plan. SDG Target 6.1 demands equitable access of safe and clean drinking water, while Target 6.3 focuses on effective treatment of wastewater and safeguarding natural water bodies. In the context of Canada, it is surprising that Canadians surveyed for the 2017 Global Compact Network Canada report did not list SDG 6 among their top 5 concerns. Water is at the heart of all development. Though it has its own SDG, it is clearly a cross-cutting issue (as highlighted in SDG 11 and SDG 13 above). Effective water management will facilitate climate change adaptation. As shown in this study, several low impact development (LID) interventions will facilitate improved water security for people and nature.

Achieving the SDGs through Low Impact Development (LID)

To design a sustainable and economical stormwater management system there are certain aspects that must be considered. There are two types of land development practices being done all over the world. One is known as traditional development and another is known as low Impact development (Fletcher, 2015).

- Low impact development is defined as an *"an innovative land planning and design approach which seeks to maintain a site's pre-development ecological and hydrological function through the protection, enhancement, or mimicry of natural processes"* (United States Environmental Protection Agency, 2016).

- LID aspects of a sustainable stormwater management system include but are not limited to conservation development, minimizing soil compaction, protecting natural water systems, reducing impervious surfaces and stormwater disconnection (EPA, 2016).

For my project, I have chosen to create an effective stormwater management system by developing the Boardwalk shopping area parking lot with the addition of green infrastructures considering effective conservation development which would adhere to both the aesthetic view of the parking lot and effective water management in that area.

To set the context for this design, eight main principles of LID were examined and studied. The Government of Vermont Watershed Management (illustrated in Figure1) came up with eight principles to assess stormwater management. These are as follows: Conservation development, minimizing soil compaction, protecting natural water flows, protecting riparian buffers, protecting sensitive areas, reducing impervious surfaces, stormwater disconnection, and minimizing disturbance (Figure 1). With these principles in mind, I chose the most relevant and effective LIDs for the project site. These are: conservation development, minimizing soil compaction, reducing impervious surfaces, and stormwater disconnection.

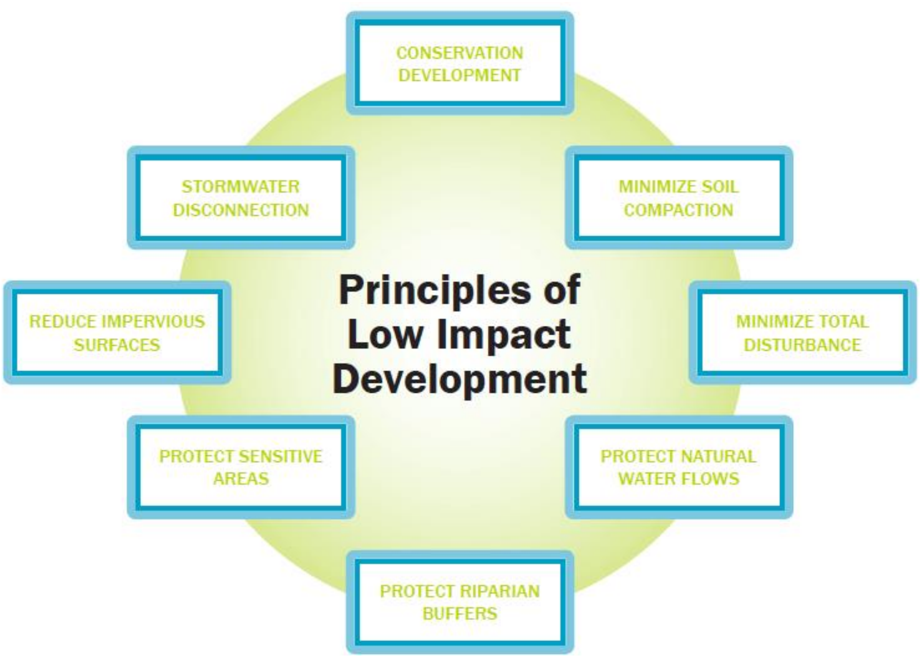

Figure 1: Principles of low impact development

Source: Government of Vermont Watershed Management, 2017

Why were these LID principles chosen?

The Boardwalk parking area of Kitchener-Waterloo Region has several problems. The initial survey of the land presented that the area had a conventional stormwater management system with large impervious surfaces. Runoff is high, and infiltration is low with such a system. The second problem from the survey showed that with the rapid development of commercial complexes in the area surrounding the parking lot, green areas were not preserved and surrounding green areas will decrease further in the future. This, in turn, causes multiple problems. The rich green environment is being lost to land development, which is leading to soil loss and decreased infiltration capacities in the surrounding area. With many commercial complexes in the area, no final planning for external water management was seen other than downspouts connecting to traditional drainage systems. Moreover, the resulting environmental degradation decreases the aesthetic view of the area and the property. It is a known fact that a property having trees or other green infrastructures raises the property value by 5-15% (Eberlin, 2018). Overall, without green infrastructures, the problem of runoff will continue to have negative impacts on the natural water cycle both in the short run (periodic flash flooding; water pollution from parking area runoff) and in the long run (reduction of the water table). In addition, the four principles were chosen based on implementation and monitoring criteria which are best fit for the Boardwalk area. These criteria are explained below:

Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance (through minimizing soil compaction and reducing impervious surfaces):

- Questions and concerns regarding operation and maintenance are largely unanswered, impeding the use of LID systems according to case studies which will be discussed in detail in Chapter 2. As new technologies emerge, development, testing and refinement of operation and maintenance needs to be practiced and updated. Having said that, the most cost-effective LID practices must be picked for interventions (IMAX Parking Lot Retrofit, 2013).

- Performance data collected through the monitoring program for water infiltration, runoff, soil quality, and water quality need to be monitored to evaluate the projects to provide optimum results.

Determine the life cycle costs for LID practices:

- Site inspections are recommended on a biweekly basis in order to collect and maintain an accurate database (IMAX Technical Report, 2015).

- Cost data will support life cycle costing tool development which includs long term operation, maintenance and eventual replacement for low impact development (Keeley et al., 2013). This exercise will define the life cycle maintenance and costs needed in Kitchener-Waterloo. Furthermore, as the maintenance data set grows, an evaluation can be performed on the optimum design and management strategies that reduce maintenance and life cycles costs.

- From several studies, implementing Green Infrastructures through conservation development or implementing water harvesting systems with bioswales are the cheapest retrofit available for stormwater management systems in comparison to protecting natural water flow which needs large project interventions making it costlier and time consuming to monitor and inspect.

Assessing the water quality and quantity performance of LID design

- Local performance data is needed to better understand the impact of LID on stormwater flows and water quality (IMAX Technical Report, 2015; IMAX Parking Lot Retrofit, 2013).
- Long term performance will demonstrate how LID systems perform with respect to water quality and quantity in soils (IMAX Technical Report, 2015).
- Water quality, disconnection, wetland maintenance data are easily accessible and easier to monitor since there is already a stormwater control in the Boardwalk area with two established catchment ponds.

Evaluating how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity (through rain gardens, harvesting systems and green infrastructures):

- With Stormwater controls in place the Boardwalk authorities can monitor water retention and discharge data.
- With data logging in mind to determine short term and long-term cost, such small retrofits or interventions can be easily monitored

Evaluating whether LID SWM systems are providing flood control, erosion control, water quality, recharge, and natural heritage protection as per the design standard:

- The Boardwalk authorities can monitor data when it is collected, and performance will be evaluated for the SWM in the parking lot (IMAX Parking Lot Retrofit, 2013). This is a tool for providing flood control, erosion control, water quality, recharge and natural heritage protection.

- Having pervious surfaces, disconnection rates, water storage and water diversion from the impervious surfaces can be used to monitor water data in the area. With the 4 LID principle chosen such criteria can be met by the private owners and the municipal government.

Although it is explained by experts that all eight combination of principles are necessary to achieve maximum outcome from sustainable stormwater management systems, the other four LID principles could not be used in this project. The 'minimizing disturbance' LID principle focuses on preserving ecological integrity of a project site before SWM systems are built. Since the project investigates an already constructed site this principle cannot be applied. Similarly, LID principle 'protecting natural water flow' is a pre-site development practice that builds a new system around natural water flow of a land. Though this principle is an important part of conservation development, it can only be used as pre-site planning. The other two LID principles – protecting riparian buffers and protecting sensitive areas – are river site specific, investigating appropriate ways of protecting vegetation around river banks and sensitive areas such as floodplains.

With cost, monitoring and maintenance in mind, my project aimed to deconstruct and reconstruct the parking area with minimal soil compaction. It will also include conservation development with pervious surfaces to reduce stormwater disconnection and to ultimately reduce runoff.

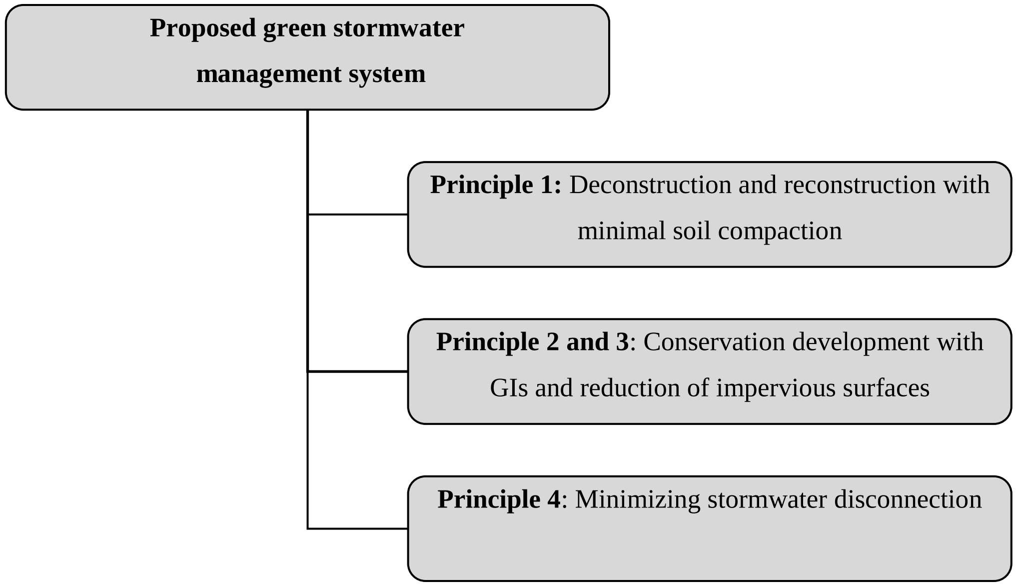

Figure 2: Proposed green stormwater management system

LID Principles

Keeping problems mentioned earlier in mind, as stated above, four of the eight principles as shown in Figure 2 were selected for the design interventions. These are conservation development, protecting water systems, reducing impervious surfaces and stormwater disconnection.

Conservation Development

One of the approaches to planning which protects the natural environment of an area is conservation development. Considering conservation development in design leads to a large number of open spaces which also enhance site features (Arendt, 2012). The site features of conservation development on a large scale include several environmental, recreational, and aesthetic benefits (Valtanen, Sillanpää, & Setälä, 2014). There are several common types of conservation development interventions, also known as green infrastructure:

- Green Swales
- Constructed Wetland(s)
- Rain Gardens

Reduce Impervious Surface

An impervious surface is an area which cannot absorb water. Impervious surfaces such as rooftops, parking lots, and even gravel roads are all the result of human development (Weng, 2012 and Zhou, Qian, Li, & Han, 2014). By reducing the rooftops and pavement, using porous surfacing, protecting natural conditions, and using LID applications, the number of impervious surfaces can be decreased (Hoang and Fenner, 2016).

Stormwater Disconnection

According to the Vermont Green Infrastructure Initiative’s fact sheet, disconnecting stormwater runoff from impervious surfaces and sewer system has many benefits. A design that involves stormwater disconnection can direct the runoff to a landscape where water can be captured and/or filtered while reducing the amount of runoff in the process (Ruiz, Vogel, & Taghvaeian, 2017).

Minimizing Soil Compaction

To minimize erosion of soils during any construction and de-construction process, soil compaction has to be considered for stormwater management designs. Minimizing soil compaction has many benefits, two of the most important ones are increasing the soil infiltration capacity and preserving the green areas from human-made disturbances (Pitt et al., 1999). Using this principle in my design will encourage infiltration, discourage runoff and help preserve the natural greens in the area during the deconstruction process.

Research Overview

The primary question to be asked is why improved stormwater management is essential for the cities of Waterloo Region? First, as highlighted earlier, numerous and costly Canadian flood disasters are happening all over Canada (Doberstein, Fitzgibbons, & Mitchell, 2018). Second, there is evidence to show that with the projected data we will see increased rainfall and snowmelt in the future which will lead to water management challenges across the region (Localized climate projections for Waterloo Region, 2015). Third, business as usual developments will lead to high financial liability for the region's cities in terms of damages which will add to infrastructure costs.

Given the increasing impermeability of growing cities, especially through areas such as parking lots, it is necessary to redesign these environments in line with the principles of low impact development in order to minimize adverse impacts today and to increase urban water security in a climate altered future. The purpose of this study is, therefore, to design an effective urban stormwater system using a case study of the Boardwalk shopping area. The study will use this design to illustrate the ways and means of realizing urban water security through low impact development. There are currently 4000 parking spaces in the Boardwalk area which is mainly constructed with impervious material. Some of these parking spaces can be replaced by LID interventions so that stormwater is discharged, retained and added back to the groundwater table.

Moreover, the current sidewalks (which are not impervious surfaces) are not usable and it brings health and safety issues for consideration.

Problem Statement

Like many other areas, the conurbation of Kitchener-Waterloo (KW) faces continued pressure from rapid urbanization. Rapid population growth and urban development have transformed natural environments into areas of highly engineered infrastructure, creating large areas of impervious surfaces, including parking lots (Carpenter, 2014). This will cause numerous issues such as increased stormwater runoff, rapid decline in underground water resources, poor water quality, and urban vulnerability to drought, flood and heat.

As outlined earlier, the adverse effects of the impervious surfaces need to be further addressed in KW by using green infrastructures. This research project takes a commercial parking lot in the KW region and proposes a cost-effective, sustainable stormwater management green redesign. It is hoped that this case study will serve as a role-model for rethinking and redesigning other built structures at the municipal level.

Research Questions and Objectives

Research questions:

In the time of changing climate and increasing urban water insecurity:

1. What would be the most effective sustainable architectural redesign of impervious surfaces in the Kitchener-Waterloo area?
2. How effective would be a green stormwater management system in terms of cost?

Research objectives:

1. To propose a green stormwater management system redesign for a selected parking lot to assess whether runoff reduction is achievable through LID and GI interventions.
2. To suggest design interventions for a cost-effective stormwater management system in the Kitchener-Waterloo area.

Research Contributions

In the current status quo, the Kitchener master plan states that 25% of the city is covered by urban stormwater management while 75% of the land is not, while in contrast, the Waterloo Strategic Plan of the municipal government is yet to implement any stormwater management plan in the area. Both papers acknowledge the importance of stormwater management systems in the municipalities. The Kitchener project discusses runoff protections while the Waterloo project talks about protecting streams, groundwater and rivers. However, both plans fail to mention the use of interventions, which includes public spaces that affect social, aesthetic and economic values of the cities. Both cities participate in Ontario's utility program known as stormwater management (SWM) fees, which helps municipalities find enough funding for the maintenances or reconstruction of stormwater management projects. This suggests that, if there is political will to engage in LID interventions, then the financial resources may be available. Most recently, it was announced that the Federal Government will provide nearly CAD $50 million to the City of Kitchener for SWM upgrading (see https://www.watercanada.net/stormwater-system-in-kitchener-receives-49-9-million-in-funding/). Early indications suggest that some of this upgrading may be undertaken with LID principles in mind, increasing the likelihood of adoption of designs such as the one shown in this thesis.

My project investigates an effective means to mitigate the problems of climate change through social, economic and aesthetic interventions utilizing LID principles and practices. It designs a framework to better connect the urban water system with the human network of the KW area. The addition of new design features in the Boardwalk parking lot specifically aims to enhance the local social network along managing the stormwater more effectively.

Thesis Structure

This thesis is presented in five chapters:

Chapter One – Introduction: Background information is provided in this chapter.

Chapter Two – Literature Review: Academic literature and previous studies related to the subject of the current research are discussed in this chapter.

Chapter Three – Research Methods: The methodology of this research is described in this chapter.

Chapter Four – Results: This section describes the selected site and presents the results of this research including the final design.

Chapter Five – Discussion, conclusion and future considerations: This part summarizes the steps and findings of the research.

Chapter 2

Literature review

To set the context for this study and understand both the challenges and opportunities of stormwater management for KW region, it was necessary to place the study area into a broader theoretical, conceptual and comparative case study context. To that end, this chapter critically reviews the relevant literature. The chapter proceeds as follows. Section I presents the importance of climate change and SDGs in stormwater management systems, Section II focuses on how costs affect stormwater management systems and Section III presents sustainable urban stormwater management systems. This section includes a description of and critical reflection upon three urban case studies -- Singapore, Mississauga and Kitchener.

Population Growth, SDGs and Importance of Stormwater Management

It has been estimated from recent studies that the annual stormwater runoff volume is greater than the amount of water saved by stormwater management in urban areas (Stormwater Guidelines, 2014). This is unfortunate given the context of increasing variability of available water resources. According to a recent study by the UN, it is estimated that about 53% (3.8 billion people) out of 7.2 billion people are currently living in urban areas and this is projected to increase by 66% by the year 2050. In comparison, the population of Canada will increase to 52.6 million by the year 2060 according to Population Projection Bureau of Canada. Ontario's population will increase by 20 million by the year 2040 (according to the available data) as reported by the Ontario population projections update (2018). This will significantly put pressure on Canada's urban freshwater sources. It should also be pointed out in the context of climate change a significant number of the world's largest cities suffer seasonal flooding of increasing severity and the trend will likely to increase according to the United Nations. Provinces such as Ontario, New Brunswick and Quebec are struggling with rising water levels, evacuations, and maintenance of properties and businesses (Global News, 2019). Officials have already labeled Eastern Canada as experiencing exceptional flood water increases compared to that of 2017 levels. This is an important factor to be recognized because Canada is already facing problems of natural disasters and poorly planned water management in these urban areas.

Climate Change and the Water Environment

Based on weather records and climate projections from IPCC (2008) it has been confirmed that freshwater resources are highly vulnerable to climate change. Increased temperatures and changes to annual rainfall patterns, the timing of the wet seasons and frequency of droughts will adversely affect water availability and quality. The Region of Waterloo (2018) saw significant local flooding in February 2018 caused by a combination of unusually warm weather, snowmelt, and extended rain events. It has been predicted that this scenario shows the projected data to lead to 40% more freezing rain events by the year 2050 and total precipitation is projected to increase by approximately 8-12 % by 2050 (Localized climate projections for Waterloo Region, 2015). If we consider the latest data set, rainfall will increase by 4-6% by the year 2020. Thus, climate change will have significant impacts on the water regime in Ontario which may cause flooding or excess runoff if measures are not taken to control them.

How Implementing Green Stormwater Management System Helps to Achieve SDG 11

Stormwater management in urban centers requires the combination of SDGs 11, 13 and 6. SDG 11 Sustainable Cities and Communities, talks about how to make cities safe, resilient and sustainable in any urban centers. SDG 11 is currently the focus of the Canadian Government because it incorporates both climate actions (SDG 13) through emission reduction and by improving water quality (SDG 6).

As mentioned earlier the cities of Waterloo and Kitchener are home to two International Universities and one college which attract students from the entire world. With the current local population, these areas will see more rapid urbanization and development which will add impacts on freshwater resources and management. To achieve sustainable practices for this SDG, several interventions can be taken by the municipal government to reduce water wastage and at the same time practices can be done to improve stormwater management.

Target 11.6 of SDG 11 is to reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. According to the Government of Canada, wastewater is one of the largest sources of pollution by volume which is threatening surface water in Canada. Researchers describe wastewater flow as the combined flow of industrial wastewater, domestic wastewater, and stormwater runoff (Amoatery and Bani, 2011). The latter one, which is generated from rain or snowmelt from rooftops, parking lots, roads, and other urban surfaces, is going to be managed through the LID principles in this study. Buildings and homes account for 17% of Canada's GHG emissions. In support of Canada's climate action agenda, *Build Smart,* Canada's Buildings Strategy ($182 million over 8 years) aims to make new homes/public spaces more sustainable by emphasizing on green infrastructures (SDG Canada National Review, 2018) The City of Vancouver developed a 100 year sustainability vision to become a 'net-zero' community by 2017, out of which emission reduction claims 30% reduction on land use alone (SDG Canada National

Review, 2018). By incorporating such goals and targets in my project design I hope to help the cities of Waterloo and Kitchener meet their SDGs.

Target 11.7 talks about providing universal access to safe, inclusive and accessible, green and public spaces, for women and children, older persons and persons with disabilities. According to studies, having more green areas in public spaces provides an indirect human health benefit for both the human body and mind (Jiang, Lim, Huang, McCarhy, & Hamilton, 2015). This is achieved by reducing water pollution and improving water quality through GIs such as constructed wetlands or rain gardens.

Target 11.a focuses on creating a positive economic, social and environmental development in urban areas by strengthening national and regional development planning. Ontario is experiencing great changes as its population is growing. Based on Health, Prosperity and Sustainability report published in 2016, the Provincial Government is dealing with the changing of the population by investing in public infrastructure development, especially for stormwater management. Adding such design interventions in the Boardwalk area will help reach this sustainability target for the cities of Kitchener and Waterloo.

Target 11.b focuses on effective disaster risk reduction. Flood water management is one of the emerging hazard risk reduction focal points in plans taken up by cities such as Windsor, Toronto, and Oshawa. In a recent study by INTACT Center of the Waterloo University (Flood Water Protection, 2019) it was found that communities are facing barriers to reduce hazards such as flooding in their designated areas. It was found that among access to resources, the community would prefer a third party to intervene in solving flooding problems in their areas. Having a prototype example of a stormwater management plan can be used as an example for these communities where they can play a part in reducing such hazards.

Problems Associated with Sustainable Stormwater Management in Ontario

In addition to problems associated with climate change and population growth, the major problem highlighted by experts has been that associated with cost and implementation of stormwater management. Several problems were highlighted by the Environmental Commissioner of Ontario (2016):

- The Ontario government identified that 43% of municipalities in Ontario do not have asset management capabilities associated with effective stormwater management.
- While the responsibility for stormwater management resides with municipal governments, inadequate funding in this sector has created a CAD $23 billion deficit for the governments (MOI, 2006).
- At the same time, upgrading conventional systems to current standards will cost an additional CAD $56.6 billion nation-wide (FCM, 2007).
- Finally, it was calculated that it will take 10 years and around CAD $7 billion to close the gap between Ontario's stormwater systems (cost to rehabilitate, replace, upgrade).

These problems are due to multiple factors. One factor identified by the Ontario Commissioner is that property taxes from many residential buildings, schools, churches and government owned land does not pay for runoff. Property taxes also do not create incentives for property owners to reduce stormwater runoff and pollutant discharge and overall these taxes compete with other development sector practices such as road development, transit, and police every budget cycle. It was also identified that Provincial and Federal grants like the Building Canada Fund do not cater to stormwater management projects. It was concluded that such factors cause the municipal government to stay with existing conventional systems. However necessary, upgrading, let alone green infrastructure development, is regarded as a financial impossibility. New measures are being taken in the Kitchener-Waterloo area to solve the problem of deficit. This is done through rebate programs known as *SWM fees* which will be discussed in the Kitchener-Waterloo stormwater management master plan later in this chapter.

Urbanization

Before urbanization soil and vegetation were the primary elements of a balanced ecosystem that effectively managed precipitation. Human population growth followed by uncontrolled expansion in urban areas has resulted in more construction, which affected these natural habitats gradually (Jia, Tang, Lou, Li, & Zhou, 2016). An impervious surface is usually defined as a type of surface material that does not allow water to penetrate through the ground, for example, asphalt roads, highways, sidewalks, parking lots, and most widely-used building rooftops (Weng, 2012). Cities, towns, and suburbs all contribute to more impervious surfaces as we construct buildings, roads, and parking lots.

Increase in the number of impervious surfaces in the cities means an increase in the amount of surface run-off and a decrease in the amount of water infiltration (Göbel, Dierkes, & Coldewey, 2007). These factors increase the chances for flooding downstream and in low lying areas as stormwater exceeds channel capacities (Demuzere et al., 2014). Also, it endangers the vital component of our lives by disrupting the natural water cycle, resulting in the probability of property damage and human harm (Valinski and Chandler, 2015). As a result, examining stormwater management practices is significant both in terms of urban planning and human lives. Stormwater runoff also collects contaminants such as oil, heavy metals, salts, pesticides, and animal wastes. During runoff events, these pollutants may wash into waterways, posing significant health hazards (Getter and Bradley, 2006). Novotny and Chesters (1981) equate the quality of urban runoff water to the quality of treated sewage or even worse. Scientific studies and evidence have supported the link between urban runoff from impervious surfaces and the reduction of water quality in streams (Lewitus et al., 2008). Even 10% of land area covered with impervious surfaces can have a significant effect on stream water quality (Ferguson, 1998). Since the impervious surfaces eliminate the possibility of water soaking into soils and recharging groundwater supplies, it can also contaminate drinking water supplies (Slaney, 2017).

Natural Water Cycle

Population growth, rapid urbanization, and climate change have been straining our traditional water resources and degrading the environment (Minnig, Moeck, Radny, & Schirmer, 2018). According to Watershed Protection (2003), impervious surfaces are also appreciably responsible for disruption in the natural water cycle. The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, waterbodies, and the atmosphere. Precipitation follows different paths when it falls over the land which is shown in Figure 3 (Yang and Yuhong, 2017). Evaporation, transpiration, and infiltration are the three main natural mechanisms, taking the greatest portions of the natural water cycle (Water Cycle, 2018). The rest flows on the surface, traveling to oceans and lakes by means of rivers and streams (Water Cycle, 2018). Impervious surfaces associated with urbanization change the amount of water that naturally takes each route. Consequently, the volume and the quality of water that percolates into the ground dramatically decreases, whereas there is an increase in the volume of surface runoff (Yang and Yuhong, 2017). These hydrological changes have significant implications for the quality and quantity of fresh water which is usable by humans, flora and fauna. Furthermore, an increase in the impervious surfaces will result in the loss of green space, create urban heat islands, and deteriorate the general quality of life (O'Neill and Cairns, 2016).

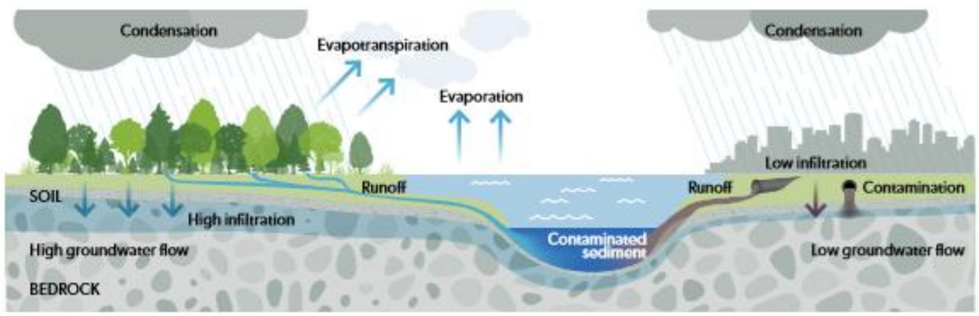

Figure 3: Change in water cycles as a result of urbanization

Retrieved from: New solutions for sustainable stormwater management in Canada, 2016

Urban Stormwater Runoff and Grey Infrastructure

Traditionally, stormwater management has mainly relied on pipes and sewers, also known as grey infrastructure, to transfer stormwater to treatment facilities or into surface waters (Berlanda et al., 2017). There are two main categories of grey infrastructure wastewater collection – combined and separate. Combined sewer systems carry stormwater and wastewater from residential, commercial, and industrial sources in the same piping structure (Semadeni, Hernebring, Avensson, & Gustafsson, 2008). These systems have limited storage capacity and, as a result, they are susceptible to overflowing during storm events wherein a mixture of stormwater and untreated sewage is discharged directly to the surface (Berlanda et al., 2017). On the other hand, separate sewer systems are generally found in suburban areas and recently renovated urban centers. These sewers convey stormwater and sewage in separate conveyance systems (Berlanda et al., 2017).

Clearly, there are numerous downsides to the grey-only approach. Aside from localized issues related to flood, drought and heat-island creation, increased runoff exacerbates the problems downstream: e.g. declining water quality; too much water available at the wrong time. LID aims to mimic or help restore the natural hydrological cycles that are critical to healthy catchment-ecosystem functioning (Bartens, Harris, Dove, & Wynn, 2008). Also, maintenance costs associated with end-of-pipe treatment systems are high and do not consider values of waterways throughout the catchment (Roy et al., 2008). As a result, where improvements to grey infrastructure are too expensive or not effective at mitigating sewer malfunctions due to excessive stormwater runoff, there is an opportunity to decentralize stormwater management practices (Lim and Lu, 2016). In such cases, green infrastructure is a viable solution since it significantly drops the volume of stormwater reaching centralized collection-conveyance systems (Berlanda et al., 2017).

Managing Urban Stormwater for Urban Sustainability

The traditional urban development style and urban control method causes many adverse social, economic and environmental impacts (Wheeler, 2004). The main stressor is the increase in impervious areas. Facing the dilemma of conventional drainage systems under rapid urbanization, new land development methods and engineering should be proposed to minimize these adverse impacts on the environment and local ecology (Dhakal and Chevalier, 2017). Low impact development is considered as such an innovative methodology and engineering system (Zevenbergen et al., 2018). This concept/technology is recognized widely and is known with different names in different part of the world. In US and Canada, it is known as “Low Impact Development (LID)” In Australia it is known as “Water Sensitive Urban Design (WSUD)”, in the United Kingdom this practice is known as “Sustainable Urban Drainage System (SUDS)” and in New Zealand this is known as “Low Impact Urban Development (LIUD)” (Marsalek and Chocat, 2002). Although it has different names in different regions, the general concept behind these practices is to conserve stormwater runoff in urban areas.

Green Infrastructure for Urban Stormwater Management

Odefey-Raviprakash et al. (2012) explained green infrastructure as a promising cost-effective approach for sustainable stormwater management. Despite the economic, environmental, and social benefits of green infrastructure, cities have been slow to implement green infrastructure for stormwater management. In the last decade, however, implementation has increased, and cities are beginning to devote more resources to GI programs. It is clarified that the cost of GI materials is more expensive than most conventional stormwater management systems. However, when comparing the long-term cost, the conventional system has more annual maintenance costs with few benefits which makes it unsustainable. For GI materials, the implementation cost is higher than conventional stormwater management systems but in the long run, with fewer maintenance cost and added benefits, it is more socially, environmentally and economically cost-effective than conventional systems (Keeley, et.al., 2013). GI was introduced as an effective runoff management strategy which considerably reduces overall pressure on the current overstressed sewer systems. It also promotes energy efficiency and a healthier environment. As shown in Figure 2, the LIDs selected for this project looked into manage deconstruction and reconstruction of the parking lot to improve the stormwater management of the area. These LIDs are described in the following section.

Conservation Development

It has been well noted in the past 20 years (Jacob and Lopez, 2009; Berland, A et al., 2017) that urban impervious surfaces convert precipitation to stormwater runoff, which causes water quality and quantity problems. It has been the norm that traditional stormwater management has relied on grey infrastructure such as piped conveyances to collect and convey stormwater to wastewater treatment facilities or into surface waters (Hammitt, 2010). Cities are exploring green infrastructure to manage stormwater at its source; however, converting an already urbanized area with the means of preserving the green areas has been a challenge (Berland, et al., 2017). Decentralized green infrastructure leverages the capabilities of soil and vegetation to infiltrate, redistribute, and otherwise store stormwater volume, with the potential to realize additional environmental, social, and economic benefits (Sheri, William, Ahjond, Haynes, Dustin, & Matthew, 2017). To date, green infrastructure science and practice have largely focused on infiltration-based technologies that include rain gardens, bioswales, and permeable pavements (Sheri, et al., 2017). However, my intervention will investigate not only infiltration practices but also blue and grey water conservation options – preserving trees, introducing bioswales, preserving or creating wetlands, softening existing stormwater conveyance channels, all of which will improve stormwater management in the interests of long-term urban water security.

Conservation development is an approach to land use planning recommended by Jacob and Lopez (2009), Berland, et al. (2017) among others whose work shows that stormwater runoff can be effectively managed through integrated systems mimicking natural processes. Two methods are always considered when looking into interventions or pre-site design. These are population density of the area surrounding the planned intervention and the extent to which the intervention will impact the surrounding land.

My project area is located at the Western edge of the built boundary of the cities of Kitchener and Waterloo (see Google Earth image below). The land area may be classified as the 'rural-urban fringe', with suburban sprawl moving into formerly rural land (Pryor, 1968; Bryant et al., 1982). The area to the west of the Boardwalk is constituted by farmland, water bodies, and natural greens, and has sparse population in relation to the residential areas to the east of the Boardwalk (the 2011 Census states that Waterloo-Kitchener-Cambridge has a population density of 576.7 people/km^2; see https://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-cma-eng.cfm?LANG=Eng&GK=CMA&GC=541).

Having these two factors – population density and existing green space – in mind, I investigated how best I can preserve and plan in the area accordingly. Considering conservation development in design and planning leads to preserving open space which can provide environmental, recreational, and aesthetic benefits (Government of Vermont Watershed Management, 2019). A recent study by Jacob et al. (2009) showed that having multiple green interventions in any stormwater management system will help water retention and water runoff, especially polluted runoff or grey water runoff.

Green infrastructures (GI) are broadly defined as *“a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings”* (Schiappacasse and Müller, 2015). According to the United States Environmental Protection Agency (U.S. EPA), there are eleven types of green infrastructure practices: downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green streets and alleys, green parking, green roofs, urban tree canopy, and land conservation. Rain gardens, rainwater harvesting, bioswales, and constructed wetlands, are widely used as GI in urban areas and can influence the stormwater runoff without heavy structural installation (U.S. EPA, 2000).

Rainwater harvesting is an effective way of collecting and reusing of rainwater for washing, cleaning, and flushing (Hinman, 2013). The Federal Government of Canada (2017) has described rain water harvesting systems as the essential and necessary intervention in urban areas with high rainfall and commercial buildings (Canada Water Act, 2017). Such intervention can help conserve water and can be used to reduce runoff in areas with high percentages of impervious surfaces. Rain gardens are described as a functional landscape area which is constructed to collect, absorb and filter stormwater runoff from driveways, roof tops and other hard surfaces (Hinman, 2013). On the outside, rain gardens seem like typical gardens; nevertheless, their role is more considerable than a normal garden (Eckart, Mcphee, & Bolisetti, 2017). Rain gardens play an important role in my design as they help to mitigate the runoff from the parking area and the roads attached to it.

Simple bioswales, generally known as ditches, are widespread in many parking lots (Xiao and McPherson, 2009). They are also used in city parks and other public green spaces because of their simple and low-cost maintenance requirements. Moreover, swales can lessen impervious cover, highlight the natural landscape, and provide aesthetic advantages. Bioswales are close to enhanced grassed swales in terms of the design of their surface geometry, slope, and optional use of check dams. They also incorporate elements of bioretention features like bioretention soil media, a gravel storage layer, and optional underdrain components. In comparison to curb-and-gutter or ditch conveyance systems, bioswales can remarkably increase neighborhood aesthetics and they are proper candidates for low-to-medium density residential development (Nemeth et al., 2011).

In addition to blue water management through the above-mentioned green infrastructures, constructed wetlands in the parking lot will help filter out the grey water from the commercial buildings as an addition to this project (Vymazal, 2007). Constructed wetlands follow two basic principles. They investigate how wastewater can be treated so that the nutrients can be added to the surroundings through infiltration. Secondly, they adhere to the water flow regime in the area (Vymazal, 2007). Since the design investigates runoff and maintains blue water flow in the area, the grey water flow will help the surrounding greens and soil structures in the nitrification process. This will further help the soil maintain moisture and prevent erosion (Vymazal, 2007). In addition to grey water, commercial buildings can be used to hold blue water. Rainwater harvesting systems are convenient and cost-effective methods to store water in areas with high rainfall. The harvesting system can also be used for commercial uses in that area such as kitchen use or toilet flushing. As part of the green infrastructure project, roof tops are perfect areas to install rainwater harvesting systems; however, other approaches to install rainwater harvesting systems are also used e.g. rainwater harvesting systems inside buildings. The proposed intervention will help the people store water during high rainfall days and at the same recharge ground water when necessary (Vymazal, 2007).

Conservation development is a step-wise planning process that begins with general mapping and a survey of natural or undisturbed conditions. Details such as wetlands, floodplains, steep slopes, soil type, woodlands, drainage features, large trees, meadows and other features that contribute to the character of the site are all included (Government of Vermont Watershed Management, 2019). Once this base information is collected and mapped, landowners and their consultants schedule an on-site visit with municipal and/or state officials (Credit Valley Conservation, 2010). This provides the municipal officials with a better understanding of the site and its features. This is followed by a concept plan that shows areas of the proposed development and proposed conservation (Dietz, 2007). Feedback from municipal officials and other stakeholders is crucial at this point in the process and can save a great deal of design and engineering cost in the long run (Government of Vermont Watershed Management, 2019).

Every design has a sequence for achieving conservation development. It is generally agreed that this is done in sequential order as outlined below (Credit Valley Conservation, 2010):

- Designate open space, primary and secondary conservation areas
- Locate building sites
- Layout streets, trails, or other transportation routes
- Delineate lot lines as necessary

Whether done in a residential, commercial, or industrial setting, the resulting design is one that provides a multitude of benefits with little impact on the surrounding landscape (Dietz, 2007).

Minimize Soil Compaction

Minimizing Soil compaction is a LID principle designed to limit erosion of soils and protect soils from damages during the construction process (Government of Vermont Watershed Management, 2019). Cleaning the area and introducing construction materials in the construction processes also affects the blue water infiltration in that area (Pitt et al. 2008).

Having the soils compacted by heavy equipment will reduce the ability of the soil to absorb water. Studies have shown that soil compaction, which is a common thing in construction phases, significantly decreases infiltration capacity (Pitt et al., 1999). According to Gregory, Dukes, Jones, & Miller (2006) and Pitt et al. (2008), an increase in frequency, volume, and peak flow of runoff from impervious surfaces are followed by the infiltration capacity reduction. This is particularly important in low impact development strategies when infiltration plays an important role in the stormwater system rather than flow through a traditional stormwater network (Gregory et al., 2006).

To prevent unnecessary damages to the site's existing soils during the construction process, setting a minimum of disturbance during the design phase also has to be considered (Schueler, 2000). Having that in mind, minimum soil compaction and site disturbance was considered during the re-construction process in my project.

In traditional practices, an area with the environmental or ecological system is conserved before construction is done in that area (Dietz, 2007). This process also can be used in an already constructed area as well. Through conservation development, green infrastructures will be added to the already existing parking lot. To maximize infiltration and minimize disturbance of the soil after the deconstruction of the parking lot, this LID principle will be practiced in this area. Such problems can be reduced by protecting natural healthy soils in the parking lot where bioswales and wetlands will be constructed (Credit Valley Conservation, 2010). It is important to preserve such artificial green infrastructures from future disturbances. One of the practices that have been learned in recent studies is the prevention of interference from external forces in those areas (IMAX Parking Lot Retrofit, 2013). In the IMAX parking lot in Mississauga, after construction barriers were put into place to minimize disturbances, the soil was remediated in that area. Another way to reduce disturbances is by minimizing traffic flow in that area (IMAX Parking Lot Retrofit, 2013). Problems cannot always be mitigated in any construction site. To prevent future problems which can lead to soil erosion, a sedimentation method could be used to reduce soil disturbance in that area (Woletmadel, 2010).

In recent studies, it has been proven that there are multiple advantages that result from minimizing soil compactions. These include minimizing the cost of building the stormwater management system, providing an ideal environment for vegetation and adding to the water quality of that area. Studies show that sites which have had minimal soil compaction effectively require less maintenance than the sites that had significant compaction (Government of Vermont Watershed Management, 2019). The healthier vegetation in these sites also adds more aesthetic value to the parking lot.

Stormwater Disconnection

Stormwater disconnection is a LID principle developed to highlight water loss due to pipes or conveyance systems directly linking to an impervious area that does not allow water to follow the natural hydraulic gradient; rather, it encourages flow into the established sewer systems which are often overwhelmed by runoff from impervious surfaces. Stormwater disconnection helps break these connections between impervious areas and water distribution systems (Government of Vermont Watershed Management, 2019). In any water management system where water is added back to the hydrological cycle or watershed, the blue or grey water needs to be added back through evapotranspiration and/or infiltration (Credit Valley Conservation, 2010). This is highly applicable in areas with high rainfall or high pipes and conveyance systems. Stormwater disconnections can occur from rooftops to the ground or in areas where the water drainage systems such as manhole covers are far away. This is important for a large area such as a parking lot with multiple water access and exit points or areas with high commercial and residential buildings (Siekar, Bandermann, Becker, & Raasch, 2006).

In LID practices, disconnection is associated with rooftop runoff but can also be used as a mechanism for managing runoff from other impervious surfaces such as roads, driveways, and parking lots (Siekar, et al., 2006). In urban stormwater management in Emscher Region of Germany (Siekar, et al., 2006), runoff is directed to an appropriate best management practice, e.g. constructed wetland, or simply to soils with good to high infiltrative capacity. This experiment was done through a pilot project to measure and direct stormwater runoff from residential and industrial buildings. The project successfully directed stormwater from roads and houses to enhance disconnection in the area and thereby increase infiltration and increase groundwater recharge. A similar project was implemented in Ontario's Highland Creek of Lake Ontario. Through effective measures in the form of municipal legislation supporting disconnection practices, downspout disconnection, stormwater infiltration and water quality control practices were utilized to manage stormwater disconnection in the area (SWPP Ontario, 2013).

There are multiple advantages of using stormwater disconnection in any area with a high amount of stormwater runoff, these include:

- Directing runoff to vegetated areas reduces peak discharge and stormwater volume. This increases the water to be infiltrated into the ground and helps the evapotranspiration process of blue or grey water (Marssalek and Schreier, 2009)
- Infiltrated stormwater can add to soil water quality adding to nitrification and reducing soil compaction (Marssalek and Schreier, 2009).
- Capturing water from rainwater harvesting through downspouts into barrels and running it through constructed wetlands have two kinds of benefits. The stored water can be used to water outdoor plants, and/or it can be used for toilet flushing or other household uses (Marssalek and Schreier, 2009).
- Disconnection practices are inexpensive and are easily maintained and installed (Marssalek and Schreier, 2009).

Reducing Impervious Surfaces

An impervious surface is an area on the earth that impedes or prevents the flow of water into the soil (Government of Vermont Watershed Management, 2019). Impervious surfaces increase runoff volume, velocity, temperature, and pollutant loads (Berland, A et al., 2017). Although some impervious surfaces occur naturally such as clays and bedrock, most impervious surfaces in urban areas result directly from human development in the form of rooftops, parking lots, severely compacted soils, and roads (Berland, A et al., 2017). This results in problems in the watershed and studies have suggested that noticeable degradation to water bodies begins when watersheds reach just 10% imperviousness. Reducing impervious surfaces involves the minimization of rooftops and pavements, the use of permeable surfacing, the protection of natural conditions, the use of disconnection practices and the application of LID principles (Government of Vermont Watershed Management, 2019; Zevenbergen et al., 2018). This can be achieved through practice-oriented soil compactions and conservation development as mentioned earlier with addition to creating permeable surfaces to minimize runoff and increase infiltrations.

Recent studies indicate that amongst several negative factors that contribute to poor urbanization planning, recharge of groundwater and flash flooding are a direct result of using poor impervious surfaces in an urban area (Arnold and Gibbons, 1996). Poor/unplanned urbanization planning for stormwater management systems was defined as urban areas with high impervious surfaces or low water management plan (Arnold and Gibbons, 1996). Introducing permeable surfaces in such areas with addition to green infrastructures can significantly improve water retention in that area and ultimately contribute to watershed health and urban water security (Arnold and Gibbons, 1996).

The pervious surfaces can be implemented in many ways and these were tested out in different stormwater management situations. These are as follows:

- **Cluster development using conservation design principle**s: Through conservation development LID principles green areas surrounding the stormwater management site can be preserved to capture water or artificial greeneries can be implemented by means of bioswales or constructed wetlands to capture stormwater runoff.
- **Roads and pathways design:** Using wavy designs on roads and trails to promote sheet flow of runoff with reduced width of the roads in the project site can reduce stormwater runoff and increase infiltration (Virginia Cooperative Extension, 2013).
- **Using green infrastructures:** Introducing bioswales, green roofs or constructed wetlands/vegetation for water infiltration can improve water disconnection.
- **Using permeable materials:** Replacing solid concrete and asphalt driveways with pavers, cobblestones, brick and turf stone, all of which will slow down the flow of water and allow it to settle into the ground. Solid concrete can also be divided with decorative and functional paver inlays adding to the aesthetic view of an area.

Sustainable Architecture

Sustainable architecture is a mixture of traditional architecture practices and sustainability practices. It is an architecture which reduces the negative environmental impacts by using green-materials, development spaces and environmentally friendly materials in the design process. By following LID principles and green infrastructures is a contemporary way of achieving sustainability in any architectural design (Chansomsak and Vale, 2008).

For such architecture, it is encouraged to use living materials in the design process. Two living materials were introduced in my design to address the requirements needed to achieve sustainable design goals. The first material was water and the second one was vegetation (Bean and Yang, 2009). In the study, water was recognized as a system rather than as a substance. Impervious surfaces were identified as the key elements that usually increases surface runoffs. One way of reducing runoff is by using containers under or above ground and water harvesting infrastructures to collect stormwater. Vegetation was suggested as the second living material towards sustainable landscape architecture (Bean and Yang, 2009). Vegetation plays a part in capturing water flow and helps the soil in retaining its shape (Bean and Yang, 2009).

Ragheb, El-Shimy, and Ragheb (2011) investigated the principles of green architecture and concluded that water, passive *solar design*, *green building material, and living architecture* are primary elements of sustainable architecture. They added that every building has the potential to be architecturally designed by using low carbon dioxide materials. However, for my design, I will be only considering stormwater runoff management. The results of the study by Ragheb et al. (2011) demonstrated that sustainable architecture produces economic, social, and environmental benefits. Economically, it reduces the net expenses of the building operation by implementing energy management policies (Ragheb et al., 2011). Socially, it improves the aesthetics of the local neighborhood (Ragheb et al., 2011). Environmentally, it helps nature by retaining natural water table and quality and by providing natural habitats for local species (Ragheb et al., 2011).

International Green Infrastructure Programs and Case Studies

Singapore's ABC Water Program

Lim and Lu (2016) investigated successful sustainable urban stormwater management practices in Singapore. Their project looked into how to effectively manage water resources in Singapore. The city receives a high amount of rainfall but is considered water scarce due to poor management of water resources. A program called the Active Beautiful Clean (ABC) Waters Program was implemented in 2006 as part of Singapore's stormwater management strategy. Alongside ABC, other ideas suggested minimizing impervious areas to modify drainage to increase infiltration, reduce water loss and improve water quality through proper sedimentation, filtration, and adsorption. Their main goal was to manage urban stormwater and prevent flooding using LID practices in the project area. The project evaluated existing green infrastructure elements such as rain gardens, green roofs, and canal restoration projects to come up with a solution for better water management. What was unique about this case study was that it was the first of its kind with comprehensive green infrastructure planning that considered the positives of urban stormwater management and the challenges and issues associated with it. This design was further replicated in other cities due to its success.

Project Background

The Active Beautiful Clean (ABC) Waters Program was launched in April 2006 by Singapore's water agency, Public Utilities Board (PUB). The main goal of the program was to manage stormwater management and flood control using LID practices in the replication of designs done in Europe and USA. Singapore has created 60 projects and will complete over 100 by the year 2030.

Urban stormwater runoff and low impact development (LID)

Through LID and recognizing urban runoff the authors described how urban centers are moving away from traditional storm water management which only considers runoff through the drainage system. In the current status quo, this runoff is considered a valuable resource. Nowadays, cities are increasingly designing ways to retain stormwater runoff to augment water supply and add to the aesthetic and recreational aspects of the urban centers (Zevenbergen et al, 2018). This new approach adopts whole systems, catchment-based design planning to restore the pre-development flow regime by bringing back natural hydrological characteristics in the urban center. This has become increasingly part of the water saving philosophy where water is seen as a resource (Keeley, 2007; Keeley et al., 2013).

Stormwater Management Practices

The project investigated how hydrology can be integrated into the design or urban runoff framework. This is achieved through several micro-scale projects distributed throughout the project area or from where runoff is managed. It tried to manage and control stormwater at its source to maximize disconnection and to obtain the maximum outcome. To reduce cost, simple technologies will help maintain water quality through bioretention. To cover the aesthetical aspect of the design, conservation development helped create multifunctional landscapes and infrastructure designs which not only help manage water runoff but also at the same time put the water into best practice in terms of recreation for the public or through rain gardens.

Project Outcomes

The project was divided into several different outcomes or goals which included installing, monitoring and managing problems for the best outcome:

1. Objectives and framework of the ABC Waters Program: The objective of the ABC framework looked into best practices, problems and best solutions depending on the resources available in the project areas. It was however made mandatory for all interventions to have aesthetically pleasing design and to have clean water throughout the project.
2. Regulatory and administration reform: The reform made it mandatory for the municipal government to introduce ABC practices in their water management plans for the cities.
3. Technical development and implementation: Creation of partnership between local government and research firms to come up with best practices for the water management systems to be implemented in those areas.
4. Building Capacity: PUB builds technical expertise through its training and certification programs; ABC Certification (2010), ABC Professionals Program (2011) and the ABC Professionals Registry (2013). The curriculum of local academic institutions has ABC practices in their curricula.

5. Building Social Capital: One important component of the ABC goal was to develop environmental stewardships between citizens and implementers. This was done through public PSAs, reports and open access information for the public.

Using ABC principles in my design framework

Using the ABC approach in Singapore helped establish a three-way connection between best practices, project design, and policies in Singapore's urban stormwater management systems. The project goals help regulate new methods in monitoring stormwater runoff and at the same time makes it mandatory for the local government to monitor and maintain those interventions through public participation. My design will try to replicate such best practices through LID principles and green infrastructure design so that the K-W municipality can replicate stormwater best practices in the future and help achieve SDGs as mentioned earlier in the paper.

IMAX Parking Lot Retrofit – Green Infrastructure Design

The IMAX project is one of the first commercial LID Parking lot retrofits in Ontario. It was a joint partnership with Credit Valley Conservation (CVC), the city of Mississauga, and product suppliers, completed in 2012. This project is about parking lot expansion by LID practices which included bioretention cells, permeable pavement, and enhanced water filtration systems. It provides a more functional parking lot with direct benefits to the local water systems along with enhanced aesthetic values. The 7570 m^2 parking lot was accomplished as part of the Ontario Ministry of the Environment's Showcasing Water Innovation (SWI) program, which helps to meet municipal sustainability planning provisions. This classified the IMAX as an environmentally sustainable company. The actual cost for construction of the LID practices for this project was CAD $776,000 which is below the total budget that was estimated at CAD $797,000. It was also mentioned in the report that the operation and maintenance costs of permeable pavements are less than asphalt surfaces, for example, by using fewer de-icers in winter conditions. This parking lot absorbed pollutants from stormwater runoff that previously drained directly into Sheridan Creek through the municipal sewer network. There was no opportunity for pre-treatment before entering the Sheridan Creek Watershed. The main goal of the IMAX project was to upgrade the parking lot surfaces with LID techniques to control stormwater quality and quantity. Planners assessed, monitored, and evaluated multiple LID practices implemented in the parking lot. Also, the behavior of LID technologies was evaluated as an individual practice and as a collective system against a benchmark of a traditional asphalt-to-catch basin system. The cumulative total annual runoff volume was reduced by 84 % for all events (based on 54 events between April 2013 and mid-December 2013) by using permeable pavement and bio-retention. This case provides clear evidence that municipalities can better manage stormwater by incorporating LID practices into existing and new urban development.

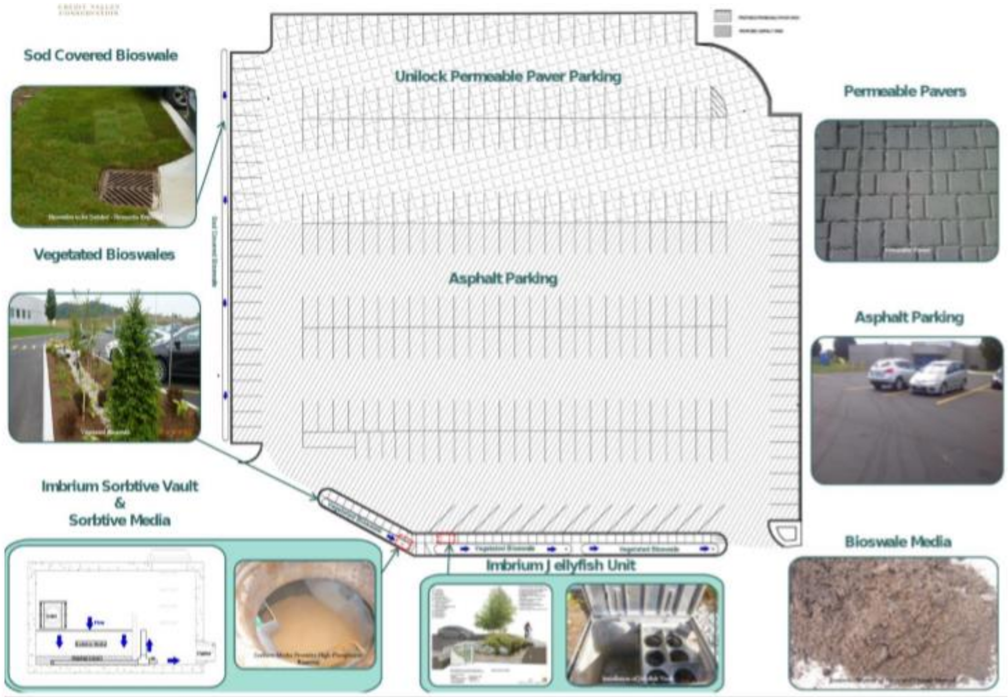

Figure 4: IMAX retrofit design concept

As it is shown in Figure 4, the north one-third of the parking lot is covered with permeable pavement and the rest is traditional asphalt.

Project Outcome

The Project developed a comprehensive data management and analysis program for LID monitoring sites which can be replicated in the parking lot design in the K-W area. The IMAX project investigated flow rate, rainfall depth and intensity, water quality, ground water level and moisture level in the project area as a form of effective monitoring tool. Additionally, several hydrological factors were used to monitor water flow in that area. For example, to monitor the flow rate and to determine opportunities for disconnection, *flow logger*[1] was used by the municipal government to monitor water flow to established systems (i.e. manholes) across permeable surfaces. This is an important factor as mentioned in chapter one where monitoring and implementation criteria helps determine the viability of LID practices. Such intervention can be used in the parking lot in the K-W area to monitor storm water disconnection and water flow. Similarly, Standard Automatic Sampler[2] was used to monitor water quality in the runoff area. The municipal government of K-W can utilize these tools to monitor water quality in the constructed wetlands which will be implemented through my design.

Kitchener-Waterloo Stormwater Management Plans

The City of Kitchener's Integrated Stormwater Management Master Plan was formulated in the year 2016 (City of Kitchener, 2016). Urban flooding in the time of climate change is regarded as a key factor motivating for movement away from the conventional stormwater management system. The Master Plan provides an integrated design solution combining upgrades of existing systems with green stormwater management innovations. It is interesting to note that this 'integrated' plan does not extend beyond the jurisdictional boundary of the City of Kitchener, so complicating management practices in border regions such as those shared with the City of Waterloo.

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[1] Flow Logger: *The Hydro-Logic™ Flow Logger is a precision flow meter that delivers spot or continuous flow monitoring of rivers, streams, sewers and other bodies of moving water, helping engineers to understand water flow in natural and built environments and make better design, upgrade, asset management and planning decisions.* Retrieved from: 2019 Hydro International UK Ltd.

[2] Standard Automatic Sampler: A portable device water sampling device that helps detect water standards such Ph, turbidity, Dissolved Oxygen etc. Retrieved from: Global Water Xylem Brand 2011

The implementation plan (City of Kitchener, 2016: i) has six stormwater management program elements:

- Municipal pollution prevention, operations and maintenance practices;
- Market based strategies for private property (source controls);
- Stormwater for the capital roads program (conveyance controls);
- Stormwater management facilities;
- Watercourse and erosion restoration;
- Urban flood management and stormwater infrastructure.

The plan highlights numerous key facts, some of which are as follows:

- Only 25% of the KW area has stormwater management plans (Kitchener ISWMP, 2016)
- The proposed interventions are only for sidewalks, roads, and grassed areas; the document does not talk about parking lots (Kitchener ISWMP, 2016).
- The proposed Master Plan presents green infrastructures such as permeable pavements, rainwater cisterns, and conservation development as cost-effective options (Kitchener ISWMP, 2016).
- The Master Plan does not include cost-benefit for each of the projects highlighted.
- The project only plans to change the current 25% of the stormwater management systems.

The Master Plan focuses mainly on improving the 25% of the KW area with stormwater management systems to make them more viable for the long run. Remembering that there is an estimated Province-wide stormwater infrastructure funding deficit of about CAD $23 billion (IMAX Technical Report, 2015), innovations and updates have been difficult to realize. There may also be additional costs to upgrade or replace existing stormwater infrastructure to deal with changes in precipitation, and thus runoff, due to climate change. To address stormwater infrastructure costs, some of Ontario municipalities have been using a stormwater utility rebate program. Kitchener and Waterloo utilize one known as the *Stormwater Management fees or SWM fees* (IMAX Technical Report, 2015). The stormwater rate is based on measured impervious area (driveway and parking areas, rooftop areas, patio, sidewalks, roads, etc.) covered by the properties. Properties are eligible for a rebate if they undertake green infrastructure upgrades. The plan describes criteria that qualify commercial or residential areas with impervious surfaces for the SWM fees rebate. Amongst those criteria, flood prevention or pollution control measurement is seen as one of the municipal government assessments.

The Boardwalk area which is chosen for this project has approved flood prevention (quantity) and pollution reduction (quality) controls, which makes the area eligible to have the 45% credit on the stormwater portion of their regular utility bill which is paid to the city by their private owner (Gollan, 2012). The monthly SWM fee, before applying 45 % credit for the area, is shown in Table 1.

Table 1: Monthly stormwater management (SWM) fees (Kitchener- Waterloo)

Non-Residential Large	16,325 - 39,034 m^2 of impervious area	$1,302.15 per month

It can be concluded that Kitchener's current plan is seeking green infrastructure interventions through private, small scale projects. However, as time progresses the problems associated with ineffective stormwater management will increase as will the costs associated with their amelioration. Though the current plan is adequate for the short run, long run projects need more stringent approaches and must reach beyond 25% of the areas to reduce problems associated with runoff.

Canada's population is projected to increase to 52.6 million by the year 2060 which will increase urbanization and more impervious surface (Ontario Population Projections Update, 2018). Climate Change will increase freezing rainfall by 40% (Climate Adaptation Plan, 2018) which will raise the impacts of flooding (ICLEI Canada, 2018). Additionally, climate change and increased urbanization will affect the water regime and living conditions in many areas.

Stormwater Management plays a key role in the fight against these adverse effects. Effective Stormwater management can reduce runoff, increase soil retention and infiltration, improve water quality and have positive impacts on watersheds and groundwater. These combinations of interventions can help improve Canada's SDGs performance. With improved water quality SDG 6 can be achieved. With improved sustainable urbanization practices SDG 11 can be achieved and under the umbrella of SDG 13, effective climate action can be realized through effective stormwater systems. A green stormwater management plan can be achieved through the combination of LID principles and green infrastructures.

To review, amongst eight LID principles used by planners and practitioners around the world, 4 principles were chosen for my design. These are conservation development, minimizing soil compaction, reducing impervious surfaces and stormwater disconnection. With the new design, soil quality and erosion can be reduced through minimized soil compaction. This, in turn, will help with water retention and limit runoff. With conservation development, projects such as rain gardens and planting trees will help reduce and conserve water discharge in the area. With impervious surfaces playing a significant part in the runoff, replacing such surfaces is the main goal of any stormwater management system. Furthermore, in project sites, it is essential to have water flow with minimum water loss, hence stormwater disconnection practices are vital for this project. These interventions are a combination of mainstream and green architectures.

As illustrated in the Singapore case study, in addition to implementation, monitoring is essential for the stormwater management system to be successful. The pilot project from Mississauga showed that sustainable practices can replace conventional stormwater management systems in Canada with the right LID and GI approaches. However, it was seen through the current planning of the KW stormwater management plan that small steps are being taken to replace old systems mainly due to the budget constraint in the Ontario region. However, moving forward these small-scale projects need to be converted to large scale projects to enhance urban water security at various scales, from the city, to the watershed, to the region.

Chapter 3

Research Methods

Introduction to Methods

With the objective of the study being to improve the stormwater management of parking lots in the KW area using green infrastructure, qualitative and quantitative approaches were used in this project. The study proceeded in four phases. At the first phase of this study, a qualitative approach grounded in the literature review is used to investigate the best sustainable practices for stormwater management in parking lots. Multiple case studies were considered which assisted in developing a redesign for the selected parking lot by using green infrastructure. The second phase involved a transect walk of the property where notes, photographs, and measures were taken to assist with visualization of a viable redesign. The third phase of the study investigated the cost and benefit analysis of LID practices to answer whether such practices will be feasible moving forward. These calculations were done through existing construction database known as RSMeans and Green Value Calculator established by the Center of Neighborhood Technology (CNT) based in the USA. In the fourth phase, the study evaluated alternative design concepts, which were modeled in AutoCAD and 3Dmax as a proposed solution. The overall intent of these combined methods is to use insights gained from secondary literature, estimations of financial costs, and sustainable designs to highlight options for sustainable stormwater management not only in the K-W area, but for urban settings broadly defined.

Selection Criteria

The study area was selected based on multiple evidence-based sources for stormwater management in the KW region. The selection was based on three criteria. These were social, environmental and hydrological aspects for the stormwater management system implementation. In my initial evaluation, I looked for a place with limited stormwater management practices that affected social and environmental aspects of the area. The site selected for this project was the Boardwalk parking lot which straddles Kitchener and Waterloo municipal jurisdictions. The site was chosen for two reasons. The Boardwalk parking area of the KW region is a commercial and public space with 22, 292 m^2 of impervious surface with conventional stormwater management system. It is a typical large-scale parking lot commonly seen across North American urban and peri-urban landscapes. It is located at the rural-urban fringe (Bryant et al., 1982; Pryor, 1968). In comparison, the IMAX parking lot in Mississauga described in Chapter 2 has an area of 7,570 m^2 – roughly one-third of the size of the Boardwalk lot – and is located in a highly developed, urbanized area. The Boardwalk area attracts thousands of residents daily due to the presence of numerous commercial buildings. This makes it a high motorized vehicle traffic, high pollution area. In comparison, IMAX is a limited use commercial space. Planners for the IMAX parking lot stated that population growth in that area played a significant part in changing the old design to accommodate anticipated increases in vehicle traffic. Additionally, the IMAX redesign project aimed to lower operating costs of the conventional stormwater management system which has issues such as occasional flooding and recurrent, high maintenance costs. Importantly, attending to these issues enhances economic sustainability – a key determinant for any business. All these factors play a part in the Boardwalk redesign.

Assessment Criteria

In summary, the assessment of the design included the following:

- Structured review of 40 + journal articles and grey literature from scientists, academics, planners, and engineers;
- LID principles selected based on their perceived effectiveness for the KW region and the project site;
- Sustainability was assessed through financial evaluation of constructions, maintenance and rehabilitation cost of such designs;
- Existing projects and case studies were assessed to produce the best results for the design outcomes.

Discussion and Considerations

As stated in Chapter 1, the goal of this project is to apply the best stormwater management practices such as low impact development (LID) for parking lots to reduce surface runoffs, secure underground water supplies, and improve people's quality of life. Towards sustainable landscape architecture design, this project needs to be real-world, practice-oriented and problem-centered in nature to successfully implement green infrastructure concepts into the KW community (Creswell, 2014). Moreover, the transdisciplinary nature of this project will require different stakeholders and private sector owners to be epistemologically involved. Beyond my design, and to be realized in fact, meaningful collaboration among all stakeholders throughout the project will be necessary to attain optimum solutions for sustainable stormwater management.

Limitations and Boundaries of Methods

Beyond some of the above challenges of relying on quantitative research, there are some specific limitations for this study that should be considered.

- Municipal borders between Kitchener and Waterloo have different jurisdictions and criteria in managing stormwater. These were not specifically considered in the design, though it is clear that to be able to move forward with the project, a desk study related to competing, complementary and/or overlapping laws, policies and procedures would have to be conducted.
- Data are relatively recent and past data sets are not well documented.
- Monitoring and maintenance of LID practices are as important as the design and planning processes. As this is a design-oriented project, monitoring and maintenance factors were not considered in any detail.

Chapter 4

Results

According to the United Nations (1997), urbanization may be defined as an increase in the proportion of a population living in urban areas, and the process by which a large number of people become permanently concentrated in relatively small areas, forming cities. As reported by UN Habitat (2016: 6), the global urban population increased by roughly 2 billion people between 1990 and 2015. An estimated 54% of the world's population lived in cities in 2015. While not evenly spread out across the world, these figures indicate the sort of population pressure being placed on urban services and the resources, such as watersheds, required to sustain these populations. A New York University (Angel et al., 2015) study showed that across a sample of 120 cities, whereas population grew at a rate of 17% on average, the built-environment increased by 28% (Angel et al., 2015). As people continue to flock to cities, the imbalance between urban water demand and supply is also increasing. With more than half of humanity urbanized, an integrated and holistic view to ensuring urban water security must be obtained as early as possible.

As described in Chapter 2, the Waterloo Region will face a number of water-related challenges under different climate change scenarios. Therefore, effectively managing the water you have, when it falls where and how is a key element of ensuring urban water security (Falkenmark and Rockstrom, 2005). My redesign of the Boardwalk parking lot shows that improved stormwater management in large-scale, typical built environments is possible and therefore can make a valuable contribution to urban water security.

Alternative Water Supply Options

To overcome the excess water waste in the parking area a very simple strategy was followed in my design principle. These principles consisted of the 3R options: Reduce, Reuse and Recycle. Sustainability of integrated urban water management system is largely dependent on how well the water in the parking lot system is utilized; hence my water management system is using the reuse and recycle principles for blue and grey water in that area.

Figure 5: Urban water management system

Site Description

The Boardwalk is the largest commercial center in the border of Kitchener and Waterloo on Ira Needles Boulevard near a large landfill site (MacDonald, 2008). The site consists of a mega-mall that covers an area of 1 million square feet (i.e. 92,903 m^2), about half of which is in Kitchener and half in Waterloo on the west end as it is shown in Figure 6.

Figure 6: The Boardwalk map

This area includes about 30 buildings at least 220,000 square feet of office uses, two large retail anchors, mid-size retail businesses, entertainment and fitness centers, service and restaurant facilities, medical clinics, banks, and a movie theatre (Figure 7 and 8). It is surrounded by environmentally sensitive land. It was regarded as 'one of its kind' at the time that the development started. Originally, it was proposed as a mixed-use development, not purely retail.

Figure 7: Boardwalk as viewed in Google Earth with region of focus in red

Figure 8: Bird view of the site

The project site is designed in a grid pattern, with a central street connecting the various areas and three entrances from Ira Needles Boulevard. The place is not only servicing the twin cities, people also come in from neighbouring towns of Heidelberg, Wellesley, Baden. St. Agatha and so on. As shown in Figure 9, the stores are arranged in a modified rectangular shape facing onto shared parking space. The transect walk reveals that the design privileges automobile traffic and is not pedestrian friendly. It includes three roundabouts and 4,000 parking spaces. The mall is adjacent to the regional landfill, which brought up many health and environment concerns at the time. As the prevailing winds are blow in from the west, any person in that area is exposed to the noxious smells emanating from the landfill. The Boardwalk covers a total of 35.8 hectares (88.5 acres) and straddles the cities of Waterloo and Kitchener. It is the Waterloo Region's biggest retail and office development (Monteiro, 2009). Importantly, it abuts rural area that one day will no doubt come in for urban development. It is therefore important to demonstrate the possibilities for better water management at the built boundary now before more rural land is covered over with impervious surface.

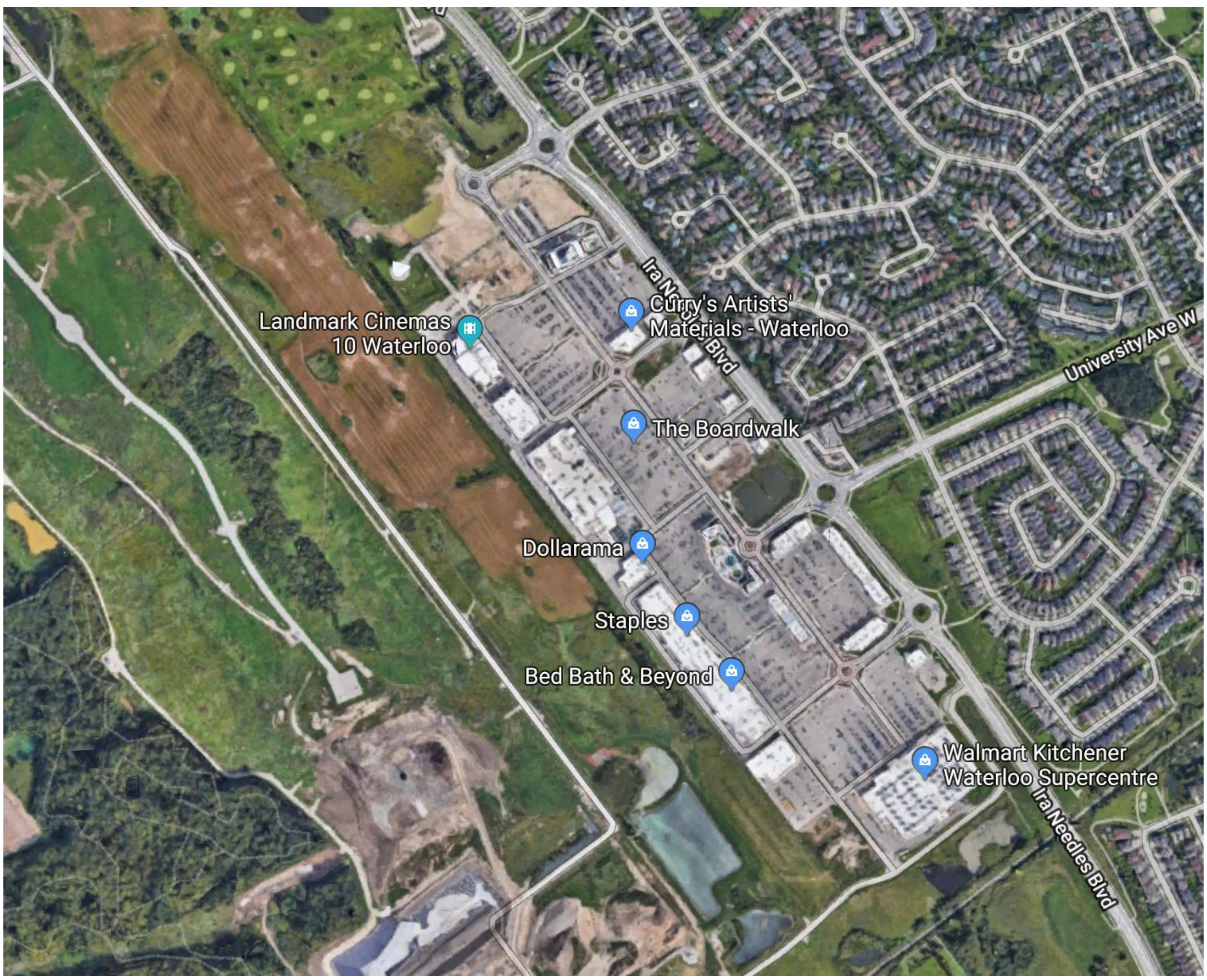

Figure 9: Google earth view of the selected site

The Boardwalk is a largely developed space, with an onsite network of storm sewers and drains which exit to the end-of-pipe stormwater treatment system. There are approximately 50 stores in the area, covering almost half of the whole area (Figure 10).

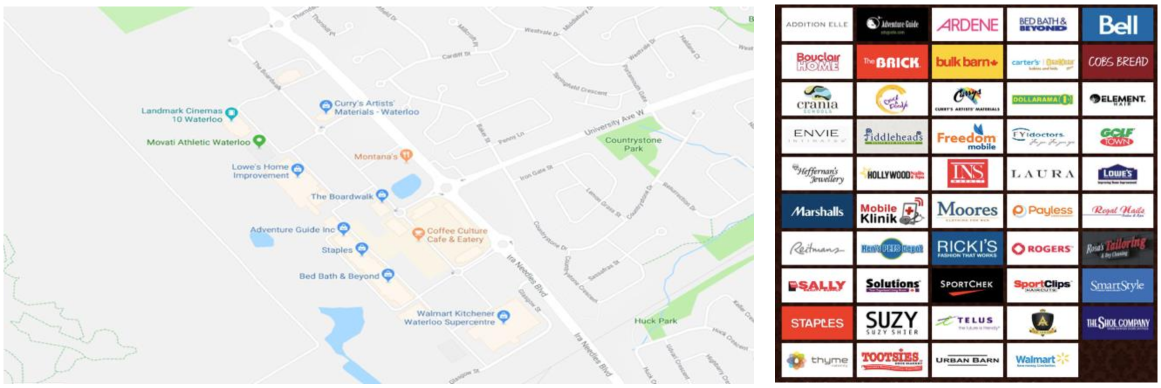

Figure 10: Commercial areas

The following challenges were identified at the site:

- High volume of stormwater runoff due to large impermeable parking lot area (Figure 12).

- Increases in frequency and intensity of storms due to climate change (Figure 11).

Figure 11: The current situation in winter

These challenges require a stormwater management design which addresses the problems by using low impact development practices. The implementation of LID practices not only improves water quality and the regional water balance, but also provides social, environmental, and economic benefits.

Figure 12: The current situation plan

Proposed Solution

My design follows LID principles using sustainable practices and mobilizing the blue and grey water in the area. It should be noted that LID practices increase retention within a water management site by capturing stormwater runoff at the source. The retention processes capture and store water until it is either recharged in the ground, evaporated from the surface from the top-soil, or taken up by plants and reintroduced into the environment through transpiration. In detention, runoff is stored onsite near the parking lot and eventually released back or recharged. This controlled stormwater discharge is conveyed through human-made systems such as man-hole covers, drains, storm sewers, bioswales, and pipes. Rainfall can enter a LID feature as runoff from the parking lot's impervious surfaces. Water treatment features utilize the following treatment processes to improve water quality: infiltration, sedimentation, filtration, soil adsorption, and plant uptake. Treatment can be achieved through both retention and detention processes. When stormwater is detained by this design, the concentration of contaminants is reduced due to physical and biological treatment processes, which occur as the stormwater passes through the parking lot system.

Figure 13: Final design plan

Table 2: Total area use after implementation of the new design

Total area of parking lot	22,922.9 square meters
Total impervious area after design	8,372.9 square meters
Total area covered by green infrastructures	14,550 square meters
Catchment area size	390 square meters
Grey water recycling	Yes
Blue water retention	Yes

Design Criteria and Constraints

Table 3 summarizes the hydrological, social, and economic objectives of the proposed design for the Boardwalk area.

Table 3: Design Criteria and Constraints

Hydrological Objectives	
Water Quality	Maximize the capture, detention and reintroduction through natural infiltration
Water Balance	Maximize onsite retention
Social Objectives	
Value for public	Design to maximize aesthetic appeal Design more pathways for pedestrians Design spaces to serve the community Visual aesthetics, recreational opportunities, cultural/heritage resources, and health and safety
Value for Environment	Improve air quality Decrease urban heat island
Economic Objectives	
Economic Cost Analysis	Design in a way to minimize the cost of installation and maintenance

Stormwater Management System Design

My stormwater management system in the parking lot will capture, store and use rainwater and runoff. It does this through the introduction of rain gardens and constructed wetlands. Essentially, these particular stormwater systems use the principle of conserving rainwater 'where it falls' (Falkenmark and Rockstrom, 2005) in the process recharging groundwater. Rainwater harvesting systems will be introduced to the on-site commercial buildings on rooftops, and on paved and unpaved areas not open to the public. In addition, the constructed wetlands will be used to collect and filter grey water from the kitchens in the buildings before reintroducing it to the natural system through infiltration.

Design elements

Elements for Blue Water Recharge and Storage:

1. The catchment area where rain falls (commercial buildings, pervious surfaces, rain gardens)

2. The conveyance or conduit system that channels the flow of water in a given direction (pipes from kitchens and pipes to the main sewer system. Pipes will also be attached to the catchment as overflow backup or for the wetland)

4. The filter system (constructed wetland)

5. The storage area, consisting of tanks/receptacles located on commercial building rooftops

6. The recharge area through rain gardens and constructed wetlands

Catchment: The trees planted around the parking lot with the rain gardens and constructed wetland will catch the runoff from the rain through the paved and unpaved surfaces around the parking area. The roof catchments will be installed above the commercial buildings while the two ponds will act as a backup.

Conveyance systems: Conveyance or conduit systems direct water flow from the catchment area to the storage area. A carefully designed and constructed conveyance system can divert more than 90 percent of all the water that falls on the roof.

Flat Roof Conveyance**:** Flat roofs have rain outlets from which pipes lead out to stormwater drains and sewers, or simply terminate at the ground level. The downspouts (i.e. roof drain pipes) can be connected to rainwater storage cisterns or to recharge systems. Downspouts can be concealed or attached to the walls of buildings.

Storage: The water will be stored in tanks above/inside the commercial buildings, rain gardens in the roundabouts and at the ponds.

Discharge: Water not caught will be discharged through the pervious surfaces through the pavements and the concrete for the parking space. The grey water will be filtered and discharged into the ground.

Elements for Grey Water Recharge: Constructed Wetland

The constructed wetland is a grey water bio-filtration system, which is often built to reduce pollution from grey water prior to its return flow into the blue water system. A constructed wetland system offers a satisfying, aesthetic, alternative on-site wastewater management facility where physical conditions prevent the use of standard septic systems.

A constructed wetland system generally mimics the natural wetland process as a means of improving wastewater quality. Grey water flowing from the commercial building will pass slowly through the gravel level of the treatment wetland and treated water exits the system at the same level as it entered. A hose or pipe which is illustrated in Figure 14 is used to lower the water table and preferably clean water discharges to surface water with gravity through a vegetated pathway.

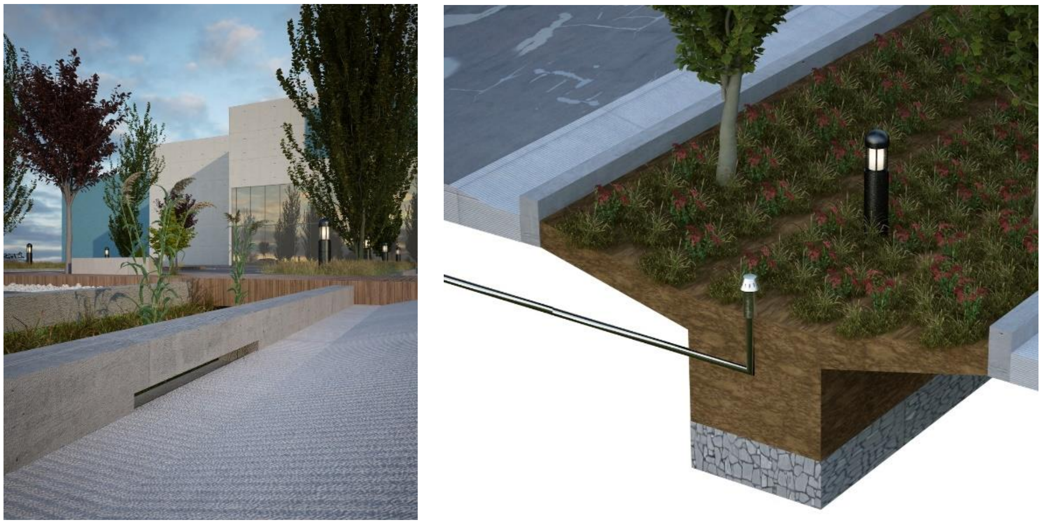

Figure 14: Constructed wetland design

There are several ways water will flow through the parking lot. This is described below:

- Blue water flow: Rainfall in the roofs, rainfall into the pavement, rainfall into the harvesting systems, water through bioswales, water to the catchment.
- Grey water flow: Through the kitchens connected to the constructed wetland

When it rains, some part of the water absorbs through the soils and the excess would become the runoff which will be managed in a sustainable manner through my design. The roof runoff is stored in a rainwater harvesting system in high rain-days and it combines with the water stored in the bioswales and constructed wetlands after filtering through the vegetation. The surplus of this water will be stored in the existing pond in the area. The water which goes into the roads and parking areas (all impervious surfaces) will be led with the surface slopes and curb designs to the green areas so that the total amount of runoff would be reduced. Additionally, the excess runoff can be either stored in the catchment area or in water tanks above the commercial buildings. The LID principles and GI practices in the conceptual phase of the design can be seen in figure 15.

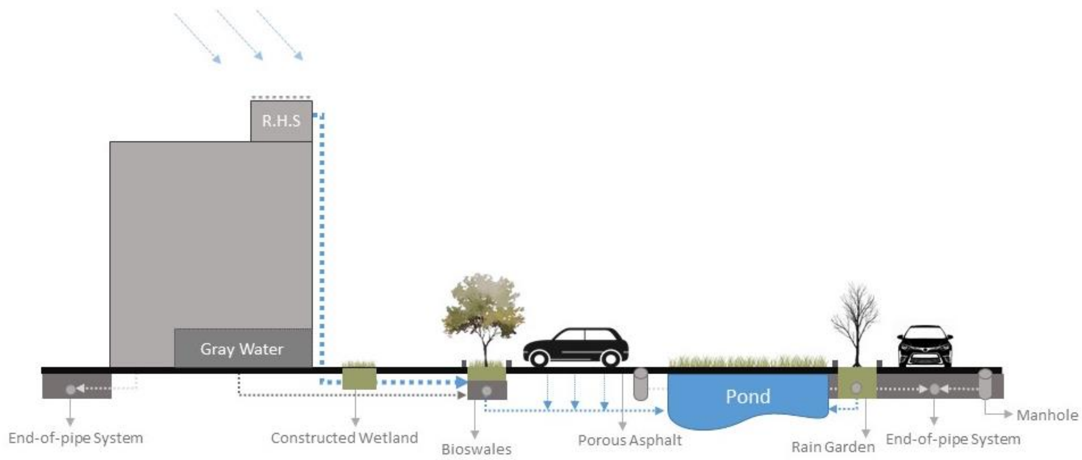

Figure 15: Proposed design diagram

As described in Chapter 2, the proposed design investigates 4 LID principles. The first one is Conservation Development which features the trees used in the area for water retention and discharge. This also adds to the aesthetics of the area. The constructed wetlands, bioswales and rain gardens enhance biodiversity so supporting the ecosystem within which the Boardwalk is located. The current parking lot has impervious surfaces which increase the local and broader system-wide negative effects of runoff. With the help of porous asphalts and by using effective conveyance systems the water will be directed towards the ground for effective discharge and ground water recharge.

Soil compaction process in my design will look into high permeable soil in any area to look for water retention capability of the soil where the construction is taking place. This process will be used in the parking lot during the design phase. This will also be used during the construction of the wetland and the roads around the parking lot.

Stormwater disconnection will be used around the water catchment to reduce water runoff around the area through the design. The water conveyance will make sure that the water is distributed with a minimum loss around the system.

Final Design

The proposed final design tried to focus on retrofitting Boardwalk area with LID practices to reduce runoff and pollutant loading and to recharge the groundwater level while enhancing the aesthetics of the built environment. It is important to note that the minimum soil compaction has to be taken into consideration before the deconstruction process.

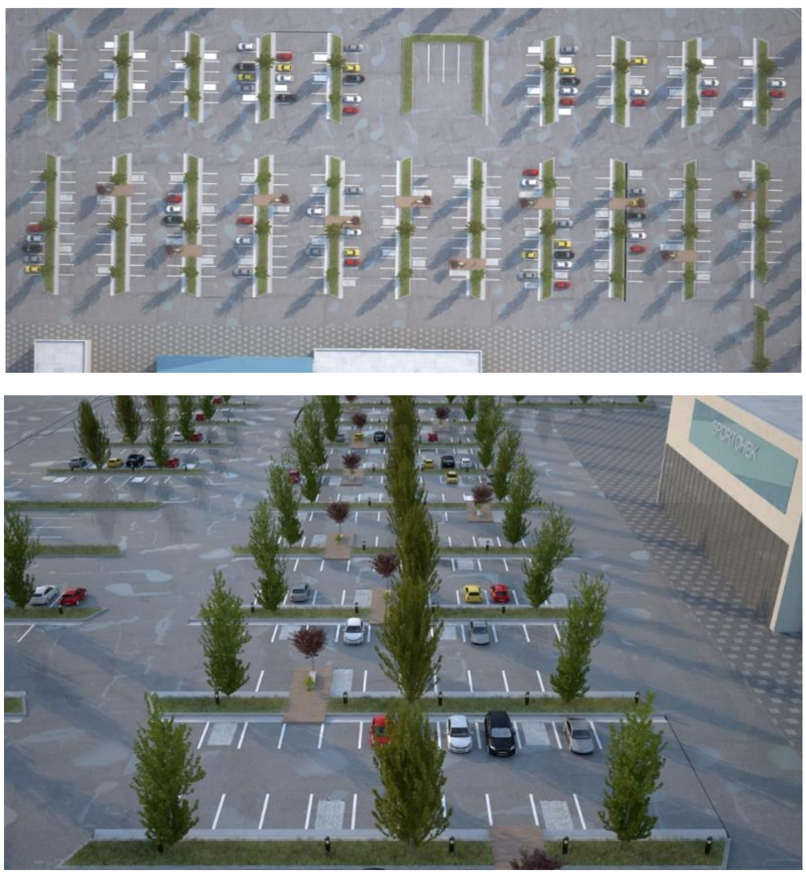

Figure 16: Final design layout

Location and Layout

The surface parking spaces in my design are located behind and beside the buildings, away from primary streets. Also, the larger existing parking areas (both visually and functionally) were broken into smaller parking spaces. For this project, the parking spaces and rows are organized in a way that the parking areas are combined with the landscape which is an opportunity for on-site stormwater management.

Figure 17: Parking design layout

The parking spaces are arranged perpendicular to the main building entrances for safe pedestrian movements toward buildings. In my design, the maximum length of each parking row is 60m (20-23 contiguous spaces) and the longer rows are broken with landscapes such as islands to maximize green space usage.

Surface Materials

The proposed parking lot surfaces are a combination of porous pavement and traditional asphalt. The ratio for porous pavement is one-third of the whole parking surfaces which is around 7,430 m^2. The permeable pavement design will allow runoff to infiltrate through the permeable pavement (gravel, mulch as shown in the design) to reduce surface stormwater flows. The stormwater runoff that infiltrated through the surface of the permeable pavement was designed to carry the water to the catchment and constructed wetlands where it can filter and evaporate prior to discharging to the municipal storm sewer.

As it is illustrated in the following pictures, inlets A and C are designed in order to guide the water to the swales, catchment, and the sewer system. Inlet designs are inserted in every sidewalk and in the joint areas of parking surfaces to the greeneries. Diagram B and D show the cross-sectional cut out of the inlets under the ground which will transfer the water to their designated areas. The inlets are designed in such a manner to reduce the cost of installation and are part of the surface rather than conventional inlets which are built separately.

Figure 18: Inlet designs

Landscaping

Native and non-native species which are resistant to the compacted soils and weather exposure are selected according to the Design Guidelines for 'Greening' Surface parking lots for city of Toronto. A seasonal variety with shade trees and suitable to the growing environment of the parking lot is chosen. (A complete list can be found in Appendix A). The purpose of this design is to conserve greeneries in the area which add to the aesthetic view of the property. The purpose of the plants is to reduce carbon footprint and air pollution from the cars coming into this area, and to help intercept and slow rainfall as it makes its way to the ground (so encouraging infiltration and discouraging rapid runoff and flash flooding). The plants and trees in the design will also help reduce the urban heat island effect from the surrounding buildings. This design concept is mainly introduced in the public spaces and the sidewalk areas. Such designs will improve the recreational aspect of the parking lot thus adding to the overall quality of life of the people in the area. It is hoped that at some point, if adopted, the enhanced aesthetics will encourage future sidewalk café and other mixed-use development, so enlivening an otherwise dispiriting 'concrete jungle'.

Figure 19: Public space design

Having greened the landscape throughout the design creates pleasant pedestrian conditions and maximizes stormwater benefits for the area. Designated areas for pedestrians as part of the landscape design will create a safe walking environment around the parking lot, with addition to trees and vegetations added as part of conservation development; the trees will provide shade and reinforce water circulation routes in the project area.

Figure 20: Sidewalk design

The bioswales are intended to treat stormwater runoff from the expanded asphalt surfaces. In addition to stormwater and grey water treatment, the bioswales play a part in snow storage. The design was done in such a manner (22.6m x 1.5m) to accommodate snow piling from a typical plough blade. Bioswales can also act as areas where snow can be stored away from the public. This design includes plants specifically chosen for the swales, as mentioned earlier, which help filter snow melt or help in snow storage. The swales also act as drainage systems for high-snow days if the hard surfaces surrounding it overflow.

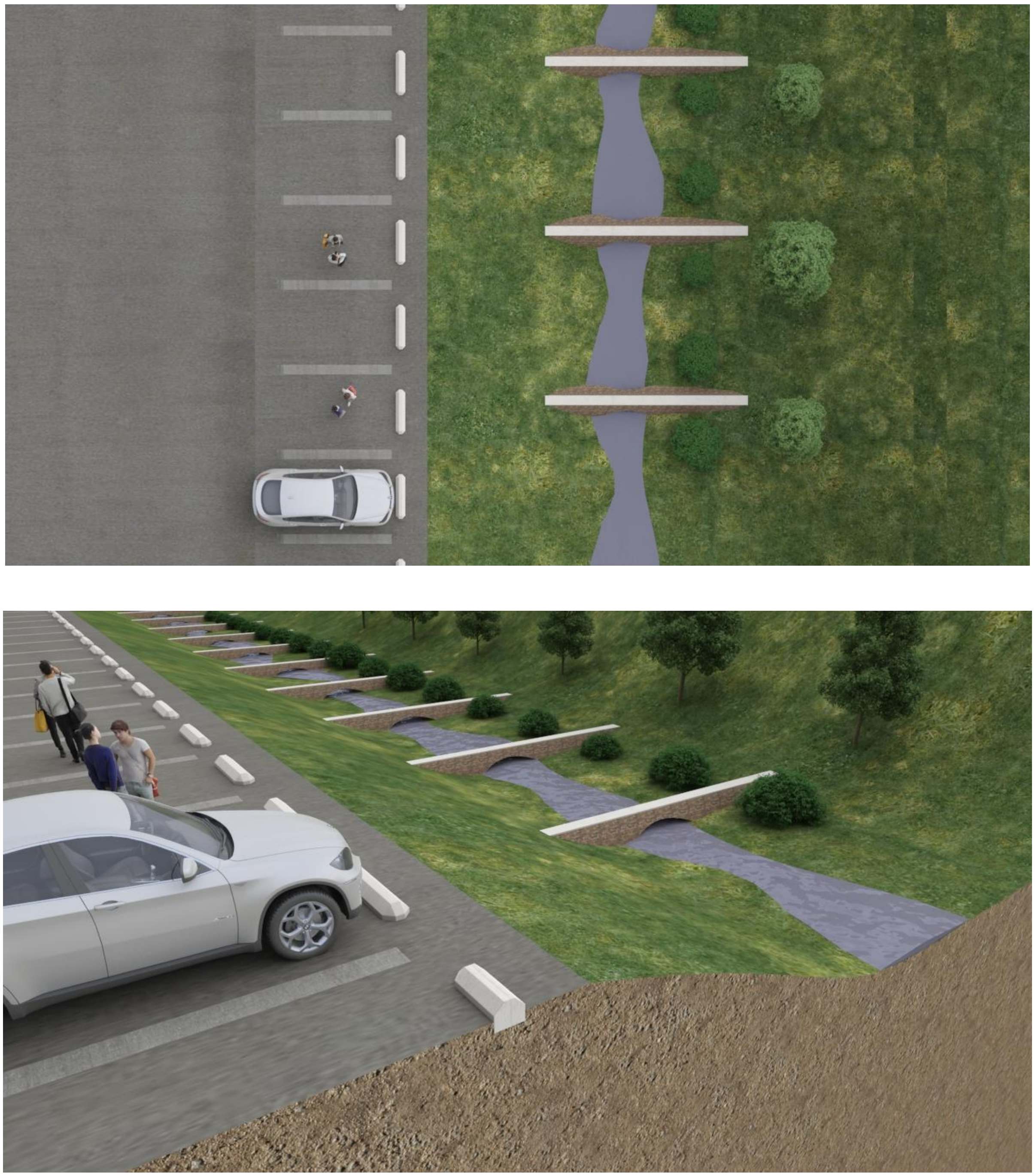

Figure 21: Bioswales design

Figure 22: Perspective views of final design

Figure 23: Bird views of the new design of Board walk area

Main Findings

The Value of Low Impact Development and Green Infrastructure Design Principles

As discussed in the literature review, several studies showed that LID and GI interventions can have multiple positive effects on the project site. However, through my research findings, such interventions depend on several factors.

- Conservation development
    - Conservation development was introduced because of its environmental, social and economic benefits. Conservation development is done by introducing green infrastructures. According to several authors conservation development is necessary for preserving trees, bioswales, and wetlands.
    - According to Chapter 3, in my design bioswales were used for first decreasing the impervious cover and second for highlighting the natural landscape which provides aesthetic advantages. Moreover, they can be used to improve the water quality by infiltrating the first flush of stormwater runoff. Also, rain gardens are used as a functional landscape which collects, absorbs and filters the stormwater runoff from the hard surfaces.
    - Additionally, the constructed wetland is an intervention to reduce pollution from the surrounding commercial buildings and is designed in such a manner whereby water will be reintroduced through bio mimicry to the flow regime of the area.
    - In line with evidence presented in the case studies (Chapter 2), green infrastructures such as rain gardens, bioswales and constructed wetlands help both

the immediate environment and the Waterloo Region to move away from conventional stormwater management systems. The project also serves as an aesthetic intervention in addition to managing stormwater. However, the Singapore and IMAX studies show that although such programs can be successful, effective monitoring, and appropriate bylaws are necessary to encourage and maintain green infrastructures in the city.

  - In the IMAX case study, it was found that a comprehensive data management and analysis system was developed from a monitoring tool which highlighted why maintenance and monitoring are needed for an effective stormwater management system. This furthers gives proof that, as with the Singapore case study, post-construction maintenance is necessary for effective and sustainable stormwater management systems.
  - In addition to monitoring systems, it was also found that effective implementation of such systems depends on municipal bylaws, rules, and regulations, which sometimes may hinder conservation development for such systems.

- Soil compaction
  - As discussed in Chapter 2, it is important to have minimum disturbance during the design phase to prevent unnecessary damage to the site's existing situation. Accordingly, conserving the parking lot area, minimum soil compaction, and site disturbance before deconstruction was considered in the design process in my project.

- Stormwater disconnection
  - Based on the previous studies, stormwater disconnection is identified by experts as a potential source of supplementary water that is otherwise lost in both conventional and green stormwater management systems.
  - As shown in the literature review, Germany and Ontario's Highland Creek of Lake Ontario demonstrated that traditional stormwater systems reduce stormwater infiltration. To avoid such problems my design uses the conveyance systems which are linked to the green areas.
- Reduce impervious surfaces
  - According to the literature review, path-dependent, orthodox urban developments – i.e. planning based on past practice – generally involve creation of impervious surfaces resulting in the numerous problems described above. LID processes which, at minimum, replace some part of the parking lot with porous pavements and related green infrastructure improves water retention. This is clearly shown in my design.

Projected Costs of the Redesign

It is not enough to design an ideal-type of LID/GI project and expect it to be implemented. Municipalities are challenged by escalating costs related to services and the operation and maintenance of existing infrastructure. In many cases, it is easier for a municipal government to pursue 'business as usual' through path-dependent planning, because it is readily understandable, costed and integrated into existing plans. Shifting to something new and different will be made more difficult if it is thought to be too expensive. To determine potential costs of my project, I compared the cost of an established green calculator from the USA with a peer review journal article in Canada. This method was chosen to determine the accuracy of the estimated cost and benefits for the proposed designs. It should be noted that due to the lack of green calculators in Canada such method was chosen. The cost and benefit analysis were done as follows:

1. This project evaluates the capital and life-cycle costs of Low Impact Development (LID) practices over a 10-year time horizon based on a detailed assessment of local input costs, maintenance requirements, rehabilitation costs and design scenarios relevant to Canadian climates.
2. A replicable methodology was used to compile capital and life-cycle costs for the LID practices evaluated in my design. The current model designs for Canada were developed in 2013 for 3 typical variations of each LID practice assuming a 2,000 m^2 paved and/or roof drainage area. An RSMeans database, widely used for construction and maintenance cost estimation, was used as the basis for most of the costing. Where RSMeans cost data were not available, costs were derived from other sources (e.g. supplier quotes, experienced construction managers). Maintenance and rehabilitation schedules for each practice were assessed based on local guidance manuals and literature sources. The Canadian database used 3 scenarios where LIDs were divided into three separate scenarios that depicted data where water infiltrated the surface, where water did not infiltrate the surface and a scenario where water partially infiltrated the surface. For each of these scenarios, the consecutive cost and benefits were also assessed by the authors.

3. The Green Value Calculator is an American based LID cost calculator that uses hydrological and financial data to estimate the cost of GIs. This calculator was chosen because it also used the RSMeans dataset.

The calculation equation used for the Canadian estimation was calculated through *present value* market standards, average maintenance cost and cost for reconstructions to get the total value (Uda, Van Seters, Graham & Rocha, 2013). The following cost is in Canadian Dollar.

PV= design and construction cost + PV of maintenance + PV of rehabilitation

Bioretention: For each 2,000 m^2 parking area, 130 m^2 bioretention swale was considered in the design phase, where the standards mentioned indicated average LID practices in Canada (Uda et al., 2013). For 2,000 m^2 drainage area the total cost for planning and site preparation, excavation and material needed for installation cost around $31,973. For my project, the total area of 3,640 m^2 was used for the GI retrofitting and interventions. The total cost calculated for my project under this estimation is approximately $895,244.

Rain Gardens: For each 2,000 m^2 parking area, 200 m^2 rain gardens were designed in the control, the total cost of which was $18,233 (Uda et al., 2013). However, for my project, the total rain garden area is one-tenth of the drainage area. The total cost for that intervention is $437,592.

Rainwater Harvesting: For rainwater harvesting systems the total tank size used in the control project was 230,000 liters. For this project plastic water tank was considered. For plastic tanks, the cost of one tank was $ 40,637 (Uda et al., 2013). For my project, 15 tanks were used which will be installed in the commercial buildings in the parking lot. The total cost for 15 rainwater harvesting systems is approximately $609,555.

Permeable pavement: For permeable pavement, the authors took half of the total area for the cost calculation. For 1,000 m^2 control project the cost is estimated to be $98,313 (Uda et al., 2013). The total area used for permeable pavement in my project was 27,654 m^2. The total cost of installing and maintaining such interventions would be $2,752,764. If only one-tenth of the lot is retrofitted with permeable pavement – i.e. 2,765 m^2 – the cost would reduce to $271,835. To give a cost comparison of installing permeable pavement in such a big area I further broke down the cost as follows:

Table 4: Permeable pavement costs

LID practices	With half permeable area	With some permeable are (one-tenth)
Permeable pavement	$2,752,764	$271,835

From the above-mentioned table, it was shown how the cost of installing permeable pavement increases the cost of LID in the parking lot. It was deduced that 1/10th of permeable pavement will be a feasible but not optimal option.

The costs based on the report are shown in the following tables.

Table 5: Capital cost for LID practices

LID practices	Capital cost (Project Control for Canada)	Capital Cost (Boardwalk parking lot)
Bioretention (130 $m^{2)}$	$31,973	$895,244
Permeable pavement (1,000 m^2)	$98,313	$271,835
Rain gardens (200 m^2)	$18,233	$437,592
Rainwater harvesting (23,000 L)	$40,637	$609,555
Total Cost	**$189,156**	**$2,213,361**

Table 6: Life cycle costs for LID practices

LID Practices	Life cycle cost for 50 years	Life cycle cost for 25 years	Life cycle cost for 10 years
Bioretention (130 $m^{2)}$	$86,716	$56,266	$41423[3]
Permeable pavement (1,000 m^2)	$192,970	$109,146	$10,264
Rain gardens (200 m^2)	$43,333	$32,011	$23,582
Rainwater harvesting (23,000 L)	$83,821	$59,244	$48,077
Total			**$123,346**

Green Calculator

Although the calculator is based on Chicago weather patterns, it can be used to get a general sense of how green infrastructure might work in other areas. The following costs are in USD.

Hydrologic Results

The green calculator compares the discharge of conventional and green stormwater management systems. Before interventions, the runoff from the parking lot came as 3972 m^3/s and after the green design, the runoff came as 2953 m^3/s (refer to Table 7). Green interventions reduce hydrological discharge by 25.7%. The annual discharge will reduce the annual runoff from 3% to 26% if such interventions are implemented in the parking lot.[4] There were several results from the Green Value Calculator. The detailed hydrological results can be seen in Table 8.

[3] See Appendix for Calculation

[4] The result table from GVC can be seen in the Appendix

Table 7: Hydrologic results

Total Site Improvements:	**Conventional**	**Green**	**Reduction**
Total Peak Discharge (m^3/s)	3972	2953	25.7 %
Detention Size Improvements:	**Conventional**	**Green**	**Reduction**
Total Detention Required (m^3)	21795	16143	26%

Costs

For the green calculator, the total costs consist of construction, maintenance, and improvement. The cost of this particular life cycle was done in 100 years. The total cost of the conventional stormwater system would be reduced by $368,650 if the green interventions were added to the parking lot.

Table 8: Conventional and green stormwater system costs

Present Value Over 100 Year Life Cycle:	**Conventional**	**Green**	**Reduction**
Per Lot Life Cycle Costs	$89,171	$76,092	**$13,079**
Total Life Cycle Costs	$7,133,706	$6,087,390	**$1,046,316**
First Year Site Construction and Maintenance Costs:	**Conventional**	**Green**	**Reduction**
Per Lot Costs	$24,001	$19,393	**$4,608**
Total Costs	$1,920,065	$1,551,415	**$368,650**
Detention Size Improvements:	**Conventional**	**Green**	**Reduction**
Per Lot Life Benefits	$0	$4,140	**$4,140**
Total Life Benefits	$0	$331,165	**$331,165**

Costs and Benefit Breakout over 100-year life cycle

Giving more benefits back to the community is one of the main goals of this study. As it is shown in the next table, there is a noticeable amount of public benefits which includes air pollution reduction, Carbon dioxide sequestration and groundwater replenishment after the design.

Table 9: Costs and benefits breakout over 100-year life cycle

Developer's Construction and Maintenance Costs:	**Conventional**	**Green**	**Reduction**
Per Lot Life Costs	$24,001	$19,393	**$4,608**
Total Costs	$1,920,065	$1,551,415	**$368,650**
Present Value Over 100 Year Life Cycle Public Costs (public costs include: curbs, detention basins, sewer pipes, street)**:**	**Conventional**	**Green**	**Reduction**
Per Lot Life Cycle Cost	$6,707	$4,779	**$1,929**
Total Life Cycle Cost	$536,598	$382,299	**$154,299**
Present Value Over 100 Year Life Cycle Public Benefits (public benefits include: reduces air pollution, carbon dioxide sequestration, groundwater replenishment, reduced treatment benefits):	**Conventional**	**Green**	**Reduction**
Per Lot Life Cycle Benefits	$0	$316	**$316**
Total Life Cycle Benefits	$0	$25,253	**$25,253**

Comparison of Canadian Report and Green Value Calculator

As mentioned in the methodology, the total cost in CAD for the intervention is estimated to be **$2,213,361 dollars**. The total cost from the US Green calculator after conversion of **$1,551,415 USD (i.e. $2,081,455 CAD)**; which gave the difference of **$131,906**. However, I would like to mention that due to some limitation with the Green Value calculator the following factors were considered:

1. The cost for permeable pavement was taken from the Canadian reports.
2. The cost for the total permeable pavement was not calculated in the green calculator due to the calculator's limitation.
3. Other factors can be concluded from this cost break down:
   - It can be concluded that with the consideration of $1/10^{th}$ of the permeable pavement the total cost for installing and maintaining LID would be $2,213,361.
   - Without the permeable pavement, the total cost would come around $2,081,455.
   - The total runoff that would be saved from peak discharge will be 23%
   - The design project with the permeable pavement as mentioned in Table 4, shows that implementing permeable pavement with the other LIDs for the whole area will make the project costlier.
   - The total benefit (public and private owners) from the amount of money saved in the construction and from maintenance after 10 years is $88,430,416.

If the permeable pavement is considered the annual runoff saved would be 57% from this area but will come at a double the cost.

Having shown both the technological and economic viability of my proposed redesign, the paper now turns to a reflection on these findings for sustainable stormwater management and urban water security in light of both climate change and the SDGs.

Chapter 5

Conclusion and Discussions

The purpose of this research was to identify and propose an effective stormwater management system in the Boardwalk parking lot to reduce stormwater runoff in that area. The factors influencing effective stormwater management systems were discussed in the literature review and sustainable design practices were shown in the results chapter. Additionally, previous studies and implemented projects along with costs and benefits were also highlighted in this paper.

Discussions

As shown in Chapter 2, climate change is increasing adverse effects of climate impacts in the Waterloo Region: increasing flood risks, temperature increase, shorter and milder winters and faster snowmelt is causing problems not only locally but across North America. It was evident from these findings that cities in Canada are not well-prepared for increasing rainfall and flood impacts and moreover the old systems are not well-equipped to handle such changes. In addition to hydrological systems, environmental and social systems are also being affected. As discussed earlier, poorly planned urbanization based on business as usual will exacerbate rather than alleviate these problems. With increase in population in the KW area, the region is going through rapid development which needs to adhere to the current environmental and climate mandates. In Chapters 1 and 2, I discussed the ways in which an SDGs-focused approach to LID/GI stormwater management for urban water security can help resolve abiding urban social, economic and environmental issues. As shown in the Singapore case study in Chapter 2, the implementation of the ABC Waters design features within developments would improve the quality of stormwater surface runoff while beautifying urban environments. Below are key lessons learned from this program:

- New recreational and community spaces creation can bring people closer to water.
- Best practices and solutions for having aesthetically pleasing design are achievable depending on the resources available in the site area.
- Environmental stewardship between citizens and implementers can be developed through reports and open access information for public.
- Water quality improvements through holistic management of the water resources and public education is possible by fostering better people-water relationships.
- Partnership between local government, private sector actors, research firms, and academia is able to develop best practices for water management systems in urban areas.

In Chapter 4, the technical and economic feasibility of a parking lot redesign was demonstrated. This redesign illustrated the numerous benefits to be derived from LID principles and practices. From the evidence put forward in this paper, it is clear that LID/GI interventions can help reduce stormwater runoff in an urban area; be economically affordable relative to ‘business as usual’ infrastructures; add social benefits; preserve environmental integrity; and enhance ecosystem services. However, it also is clear that there are important barriers to change. The following section reflects on the barriers associated with LID practices and draws several conclusions in accordance with my findings.

Resource Barriers

One of the most cited barriers in previous studies as shown in chapter 2 is the lack of financial resources (e.g., Ontario Environmental Commissioner 2016, Keeley et al., 2013). Given its cost-effectiveness and other general benefits, the GI approach should not have been financially problematic, at least in comparison to the grey approach. However, a problem exists for two reasons. First, legal restrictions such as property tax and lack of funding for stormwater management restricts creativity. Such legal restrictions generally discourage investing these public funds on private properties (Keeley et al., 2013). Second, it is the absence of a market for most ecosystem services which forces the government to regard economic development as separate from environmental health. This generally leads to an either infrastructure development or environmental preservation approach. As a result, the financial benefit of GI is undervalued. This causes the payback period for GI projects to be longer which hinders private investors (Valderrama et al., 2013) from investing in such projects. What is missing from the valuation, of course, is the fact that a healthy natural environment is the foundation upon which sustainable economic growth and development are possible.

An important but perhaps overlooked barrier to GI uptake is a lack of data on cost and performance. In the absence of a robust number of studies upon which to conduct benefit-cost analyses, the adoption of GI appears risky to the municipal staff, policy makers, and public, discouraging them from embracing the technology, especially in Canada. This is evident for my study where lack of information regarding LID practices created a problem in the cost calculation.

Funding Mechanism

As shown in Chapter 2, previous studies show that, in general and over time, GI costs less than grey infrastructure. However, the approach requires investments not only for installation and maintenance but also on multiple other fronts including education, outreach, research, new governance structures, rebates, and rewards. Based on the findings of this study, it is clear that LID interventions are hampered by (i) the ability of the Government to fund LID projects; and/or (ii) the cost of individual LIDs.

In terms of (i): the Province of Ontario currently faces a significant stormwater management funding deficit. This is causing the government to back-track on stormwater management projects. It was evident from the numerous literatures that LID is a viable method; however, due to lack of funding and existing backlogs, new projects are viewed as a liability by governments. As shown in the Kitchener ISWMP, at best municipalities are willing to encourage property owners to undertake their own initiatives through tax and rebate programs. Yet, as shown in the IMAX case study, a partnership with private sector actors coupled with incentives such as SWM fee rebates suggest that long term costs can be recovered after green designs are implemented.

In terms of (ii) perceived project costs create a dilemma: to choose interventions to either prepare urban areas for the problems of climate change (such as flooding) or to develop city infrastructure. Implementing green stormwater management systems with long term maintenance costs are a perceived additional burden.

Possible Ways Forward

In relation to the Boardwalk parking lot case study, two options were proposed:

1. Some combination of (municipal/provincial/federal) government and/or the private landowner/private sector can either invest in expensive infrastructure with all the LIDs

mentioned in the paper that reduces runoff significantly (57%) with 100% permeable[5] pavements and other LIDs; or

2. Some combination of (municipal/provincial/federal) government and/or the private landowner/private sector can have a combination of specific LIDs with reasonable amount of runoff (26%) with SWM fee rebates used to cover the cost after 10 years; 1/10th of permeable pavement with combination of other LIDs.

Each of these options was shown to be economically viable over time. Given the legal, social and environmental complexity attached to this single parking lot redesign it seems clear to me that some form of decision-making forum guided by government (possibly including citizens) is essential if meaningful action is to be taken. At the same time, perhaps the Boardwalk could serve as a pilot project, similar to the IMAX case, to illustrate the potential not only of LID/GI design but of collective resource use decision making. Perhaps the University of Waterloo could act as the research entity in support of LID/GI redesign.

The results of this project suggest that a dynamic partnership among private sector actors (in this case Boardwalk REIT), local government (i.e. the cities of Kitchener and Waterloo as well as Waterloo Regional Municipality), civil society organizations (e.g. Grand River Conservation Authority), provincial and federal government, and ordinary citizens should be developed to devise the ways and means of improving stormwater management. Such an organization would have benefits for each of the partners. Besides improving the water quality and protecting natural

[5] It should be noted that the cost of permeable pavement was the most expensive of the LIDs as mentioned in the findings.

water bodies - Grand River - both residents and their properties are going to be protected during major climate events in the future. In the short to medium term, upgraded stormwater management systems will improve protection for residents and owners against flooding. While large, impervious surfaces are location-specific, given that water is part of a large, ecological system, the benefits to be derived from location-specific action will be felt far beyond the point of intervention. Improved stormwater management will also minimize the economic costs accruing to property owners and cities from events such as flash floods and summer-time water use restrictions. Private owners can also benefit by adding LID practices to the current stormwater systems. For example, as shown in Chapter 4, reduced runoff through LID interventions will result in immediate cost savings through reduced stormwater utility fees. LID interventions will also result in a more healthy, vibrant and aesthetically pleasing public area to attract people. Evidence shows that increased green areas improve people's quality of life (Bergen Jensen et al., 2000).

In any event, and in light of the pressures of a changing climate, I recommend the following for serious consideration:

- The province should require municipalities to recover the full costs of stormwater management in a more effective manner.
- The Ministry of Infrastructure should require municipalities to prepare asset management plans for their grey and green stormwater infrastructure.
- The Ministry of Municipal Affairs, in collaboration with the Ministry of the Environment and Climate Change, should support municipalities in implementing stormwater fees.

- The Ministry of the Environment and Climate Change should follow through on its outstanding policy initiatives related to stormwater management.
- The Cities of Kitchener and Waterloo should establish a Stormwater Management Forum bringing together private sector actors, government officials, civil society organizations and interested citizens who will meet regularly to discuss the ways and means of increasing LID and green infrastructure development across the two cities.

The City of Kitchener is a good example of successful implementation of stormwater utilities in the Canadian urban context. However, this area is facing a problem of having only 25% of the existing urban areas covered by stormwater facilities. The City of Kitchener borders the City of Waterloo in a way that the boundary between these two cities can easily be missed. Although the Waterloo Region has been developing and working on a more integrated stormwater management plan over the past decades, there is an abiding need to focus on the numerous impervious public spaces in this area. In my view, the Boardwalk parking lot provides an opportunity for the Region of Waterloo to collectively consider its mutual vulnerability to the short- and long-term impacts of climate change.

Without doubt, there is still room for greater integration of the water supply, stormwater, and wastewater components of the urban water cycle, improved dissemination of knowledge, enhancement of skills in both public and private organizations, and monitoring of the performance of systems and technologies in these neighboring cities.

Bibliography

Alam, M. Z., Anwar, A. F., Heitz, A., & Sarker, D. C. (2018). Improving stormwater quality at source using catch basin inserts. Journal of environmental management, 228, 393-404.

Amoatey, P., & Bani, R. (2011). *Wastewater management.* INTECH Open Access Publisher.

Arendt, R. G. (2012). Conservation design for subdivisions: A practical guide to creating open space networks. Island Press.

Arnold Jr, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American planning Association, 62(2), 243-258.

Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices (2013, April). *Toronto and Region Conservation Authority*. Retrieved May 10, 2017 from: https://sustainabletechnologies.ca/app/uploads/2013/06/LID-LCC-final-2013.pdf

Barnes, K. B., Morgan, J., & Roberge, M. (2001). Impervious surfaces and the quality of natural and built environments. *Baltimore: Department of Geography and Environmental Planning, Towson University.*

Bartens, J., Day, S. D., Harris, J. R., Dove, J. E., & Wynn, T. M. (2008). Can urban tree roots improve infiltration through compacted subsoils for stormwater management? *Journal of Environmental Quality*, 37(6), 2048-2057.

Bean, C., & Yang, C., (2009). Standards in sustainable landscape architecture. UTSoA - Seminar in Sustainable Architecture.

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning*, 162, 167-177.

Boller, M. (2004). Towards sustainable urban stormwater management. *Water Science and Technology: Water Supply*, 4(1), 55-65.

Brubaker, E. (2007). Water and wastewater treatment in Canada: tapping into private-sector capital, expertise, and efficiencies. Fraser Institute.

Bryant, C. R., Russwurm, L. J., & McLellan, A. G. (1982). *The city's countryside. Land and its management in the rural-urban fringe*. Longman.

Canada Water Act, (2017, June). Retrieved May 10, 2018 from Ontario Federal Government: http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=E05A7F81-1&pedisable=false

Chan, N. W., Mahamud, K. R. K., Karim, M. Z., Lee, L. K., & Joo, C. H. Hydrological cycle and cities. *sustainable urban development textbook*, 95.

Chini, C., Canning, J., Schreiber, K., Peschel, J., & Stillwell, A. (2017). The green experiment: Cities, green stormwater infrastructure, and sustainability. *Sustainability*, 9(1), 105.

Cirillo, C., & Podolsky, L. (2012). *Health, Prosperity and Sustainability: The Case for Green Infrastructure in Ontario.* Green Infrastructure Ontario Coalition.

City of Kitchener, (2015), Public Open House on Stormwater Master Plan Update; Retrieved Jun 10, 2017, from:(http://www.kitchener.ca/en/livinginkitchener/resources/SWM_Images/INS_SWM_MP_-_Public_Open_House_1_boards_June_24_2015.pdf

City of Kitchener, (n.d). Kitchener, Changing for Good: Our corporate climate action plan for sustainability. Retrieved May 19, 2019 from: https://www.kitchener.ca/en/resourcesGeneral/Documents/Kitcheners-Corporate-Climate-Action-Plan.pdf

Corbett, D. (2012). Linking Urban Planning and Water Planning to Achieve Sustainable Development and Liveability Outcomes in the New Growth Areas of Melbourne, Australia. *Int J Soc Behav Educ Econ Manag Eng*, 6, 220-228.

Credit valley conservation (2010). Low impact development stormwater management planning and design. Retrieved June 10, 2018, from: https://cvc.ca/wp-content/uploads/2014/04/LID-SWM-Guide-v1.0_2010_1_no-appendices.pdf

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., ... & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of environmental management*, 146, 107-115.

Design guidelines for ‘greening’ surface parking lots (2013). Retrieved May 11, 2017 from: https://web.toronto.ca/wp-content/uploads/2017/08/9642-Design-Guidelines-for-Greening-Surface-Parking-Lots.pdf

Dhakal, K. P., & Chevalier, L. R. (2017). Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. *Journal of environmental management*, 203, 171-181.

Dietz, M. E. (2007). Low impact development practices: A review of current research and recommendations for future directions. *Water, air, and soil pollution*, 186(1-4), 351-363.

Doberstein, B., Fitzgibbons, J., & Mitchell, C. (2018). Protect, accommodate, retreat or avoid (PARA): Canadian community options for flood disaster risk reduction and flood resilience. *Natural Hazards*, 1-20.

Echols, S. (2008). Split-flow theory: Stormwater design to emulate natural landscapes. *Landscape and Urban Planning*, 85(3-4), 205-214.

Eckart, K., McPhee, Z., & Bolisetti, T. (2017). Performance and implementation of low impact development–a review. *Science of the Total Environment*, 607, 413-432.

EPA, U. (2000). Low Impact Development (LID): A Literature Review, Wash. *DC US Environ. Prot. Agency Off. Water Low Impact Dev*. Cent.

Falkenmark, M., Rockstrom, J., & Rockström, J. (2004). *Balancing water for humans and nature: the new approach in ecohydrology*. Earthscan.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., ... & Mikkelsen, P. S. (2015). SUDS, LID, BMPs, WSUD and more–The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525-542.

Georgakakos, A., Fleming, P., Dettinger, M., Peters-Lidard, C., Richmond, T. C., Reckhow, K., ... & Yates, D. (2013). Chapter 3: water resources. *National Climate Assessment*, 107-164.

Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. HortScience, 41(5), 1276-1285.

Global Compact Network Canada. (2017). SDG Survey 2017. Retrieved December 11, 2017 from the Global Compact Network Canada https://globalcompact.ca/wp-content/uploads/2017/06/SDG-Survey-2017-Report.pdf

Gollan, N. (2016). Stormwater Management Master Plan Final Report. Retrieved July 10, 2017 form: https://www.kitchener.ca/en/resourcesGeneral/Documents/DSD_ENG_StormwaterMasterPlan_Final-Report.pdf

Gregory, J. H., Dukes, M. D., Jones, P. H., & Miller, G. L. (2006). Effect of urban soil compaction on infiltration rate. *Journal of soil and water conservation*, 61(3), 117-124.

Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

Haris, H., Chow, M. F., Usman, F., Sidek, L. M., Roseli, Z. A., & Norlida, M. D. (2016, March). Urban stormwater management model and tools for designing stormwater management of green infrastructure practices. *IOP conference series: earth and environmental science* (Vol. 32, No. 1, p. 012022). IOP Publishing.

Heisler, J., Glibert, P. M., Burkholder, J. M., Anderson, D. M., Cochlan, W., Dennison, W. C., ... & Lewitus, A. (2008). Eutrophication and harmful algal blooms: a scientific consensus. Harmful algae, 8(1), 3-13.

Hinman, C., (2013). Rain garden handbook for Western Washington. Retrieved February 25, 2017 from https://fortress.wa.gov/ecy/publications/documents/1310027.pdf

Hoang, L., & Fenner, R. A. (2016). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal*, 13(7), 739-758.

IMAX Low Impact Development Infrastructure Performance and Risk Assessment (2015 July). Credit valley conservation. Retrieved May 05, 2017 form: https://cvc.ca/wp-content/uploads/2016/01/IMAX-Technical-Report.pdf

IMAX Parking Lot Retrofit (2014). Credit Valley Conservation. Retrieved May 06, 2017 from : https://cvc.ca/wp-content/uploads/2014/02/IMAX_Case_Study_Final_21Feb.pdf

IPCC. (2007). Climate change 2007: The physical science basis. Summary for policymakers. Geneva: IPCC.

Jacob, J. S., & Lopez, R. (2009). Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater‐Quality Best Management Practice 1. *JAWRA Journal of the American Water Resources Association*, 45(3), 687-701.

Jayasooriya, V. M., & Ng, A. W. M. (2014). Tools for modeling of stormwater management and economics of green infrastructure practices: a review. *Water, Air, & Soil* Pollution, 225(8), 2055.

Jensen, M. B., Persson, B., Guldager, S., Reeh, U., & Nilsson, K. (2000). Green structure and sustainability—developing a tool for local planning. Landscape and urban planning, 52(2-3), 117-133.

Jia, Z., Tang, S., Luo, W., Li, S., & Zhou, M. (2016). Small scale green infrastructure design to meet different urban hydrological criteria. *Journal of environmental management*, 171, 92-100.

Jiang, S. C., Lim, K. Y., Huang, X., McCarthy, D., & Hamilton, A. J. (2015). Human and environmental health risks and benefits associated with use of urban stormwater. *Wiley Interdisciplinary Reviews: Water*, 2(6), 683-699.

Keeley, M. (2007). Using individual parcel assessments to improve stormwater management. *Journal of the American Planning Association*, 73(2), 149-160.
Keeley, M., Koburger, A., Dolowitz, D. P., Medearis, D., Nickel, D., & Shuster, W. (2013). Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. *Environmental management*, 51(6), 1093-1108.

Kidner, E. M., & Roesner, L. (2007). Guidance for Improving Monitoring and Analysis Methods for Stormwater-Borne Solids. NOVATECH 2007.

Ladson, A. R., Walsh, C. J., & Fletcher, T. D. (2006). Improving stream health in urban areas by reducing runoff frequency from impervious surfaces. *Australasian Journal of Water Resources,* 10(1), 23-33.

Lerner, D. N., & Harris, B. (2009). The relationship between land use and groundwater resources and quality. *Land use policy*, 26, S265-S273.

Ligaya, A. (2013). Toronto storm the costliest natural disaster in Ontario history for insurers. Financial post

Lim, H., & Lu, X. (2016). Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program. *Journal of Hydrology*, 538, 842–862.

Localized Climate Projections for Waterloo Region (2015, December). *University of Waterloo*. Retrieved April 8, 2017 from: https://uwaterloo.ca/climate-centre/sites/ca.climate-centre/files/uploads/files/waterloo_region_climate_projections_final_full_report_dec2015.pdf

MacDonald, G. (2008). Area's largest retail site coming to Ira Needles Boulevard near landfill. WaterlooChronicle. Retrieved July 15, 2017 from: http://www.the-boardwalk.ca/wp-content/uploads/2008/09/Waterloo-Chronicle-sept-23-2008.pdf

Marsalek, J., & Schreier, H. (2009). Innovation in stormwater management in Canada: The way forward. *Water Quality Research Journal*, 44(1), v-x.

Minnig, M., Moeck, C., Radny, D., & Schirmer, M. (2018). Impact of urbanization on groundwater recharge rates in Dübendorf, Switzerland. *Journal of hydrology*, 563, 1135-1146.

Monteiro, L. (2009). West-side residents thrilled at proposal for nearby mall. The Record. Retrieved May 13, 2017 from: http://www.the-boardwalk.ca/wp-content/uploads/2009/06/The-K-W-The-Record-jun-8-2009.pdf

Moran, A., Hunt, B., & Smith, J. (2005, May). Hydrologic and water quality performance from green roofs in Goldsboro and Raleigh, North Carolina. In *Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show* (pp. 4-6).

Nemet, J., Labrecque, D., Szczepanski, S., Wickens, A., Ahmad, M., Polo, I., Stewart, M., … (2011). Low Impact Development public lands retrofits: optimizing parks, public buildings, schools and places of worship through Low Impact Development. Credit Valley Conservation.

Nickel, D., Schoenfelder, W., Medearis, D., Dolowitz, D. P., Keeley, M., & Shuster, W. (2014). German experience in managing stormwater with green infrastructure. *Journal of environmental planning and management*, 57(3), 403-423.

Novotny, V., & Chesters, G. (1981). *Handbook of nonpoint pollution*. Van Nostrand Reinhold Company.

O'Neill, S. J., & Cairns, S. (2016). New Solutions for Sustainable Stormwater Management in Canada. Report published by Sustainable Prosperity. Retrieved Jun 14, 2017 from http://institute. smartprosperity. Ca/sites/default/files/stormwaterreport.pdf.

Oberts, G. L. (1994). Influence of snowmelt dynamics on stormwater runoff quality. *Watershed protection techniques*, 1(2), 16.

Buckley, M., Souchlas, T., Odefey, J., Detwiler, S., Rousseau, K., Trice, A., ... & Raviprakash, P. (2012). Banking on Green: A look at How Green Infrastructure Can Save Municipalities Money and Provide Economic Benefits Community-wide.".

Olmstead, S. M. (2014). Climate change adaptation and water resource management: A review of the literature. Energy Economics, 46, 500-509.

Ontario Ministry of Infrastructure. (2006). ReNew Ontario: Progress report. Retrieved May 02, 2017 from: http://www.moi.gov.on.ca/pdf/en/renew2006/ReNewOntarioSummary.pdf

Ontario population projections update (2018). Ministry of Finance. Retrieved May 10, 2018 form: https://www.fin.gov.on.ca/en/economy/demographics/projections/projections2017-2041.pdf

Pejchar, L., Morgan, P. M., Caldwell, M. R., Palmer, C., & Daily, G. C. (2007). Evaluating the potential for conservation development: biophysical, economic, and institutional perspectives. *Conservation Biology*, 21(1), 69-78.

Pryor, R. J. (1968). Defining the rural-urban fringe. *Social Forces*, 47(2), 202-215.

Qin, X., Wu, X., Chiew, Y. M., & Li, Y. (2012). A green roof test bed for stormwater management and reduction of urban heat island effect in Singapore. *International Journal of Environment and Climate Change,* 410-420.

Ragheb, A., El-Shimy, H., Ragheb, G. (2016). Green architecture: A concept of sustainability. *Social and behavioral sciences*. 216, 778 – 787.

Richards, L. (2006). Water and the density debate. *PLANNING-CHICAGO-*, 72(6), 30.

Robert Pitt, P. E., Engineer, D. E., Lantrip, J., Harrison, R., Henry, C. L., Xue, D., ... & Supply, W. (1999). Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity.

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., ... & Brown, R. R. (2008). Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. *Environmental management,* 42(2), 344-359.

Ruiz, N. J., Vogel, J. R., & Taghvaeian, S. (2017). Minimizing Stormwater Runoff by Disconnecting Residential Downspouts.

Sample, D., & Doumar, L. (2013). Best Management Practice, Fact Sheet 2. Sheet Flow to Open Space. *Virginia Tech/Virginia State University*. Retrieved May 19, 2019 from: https://vtechworks.lib.vt.edu/bitstream/handle/10919/50225/426-121.pdf

Schiappacasse, P., & Müller, B. (2015). Planning Green Infrastructure as a Source of Urban and Regional Resilience–Towards Institutional Challenges. *Urbani izziv,* 26, S13-S24.

Schueler, T. R., & Holland, H. K. (2000). The compaction of urban soils. *The practice of watershed protection,* 12-16.

SDG Canada National Review, (2018). Government of Canada. Retrieved May 21, 2019, from: https://sustainabledevelopment.un.org/.../20033CanadasVoluntaryNationalReviewENv6...

Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology,* 350(1-2), 100-113.

Sheri, A., William, D., Ahjond, S., Haynes, C., Dustin, L., & Matthew, E. (2017). role of trees in urban stormwater management. Landscape and Urban Planning.

Sieker, H., Bandermann, S., Becker, M., & Raasch, U. (2006, January). Urban stormwater management demonstration projects in the Emscher Region. In *First SWITCH Scientific Meeting; The SWITCH Consortium: Birmingham*, UK (pp. 1-8).

United, N. (1997). Glossary of environment statistics, studies in methods. United Nations New York, NY. Retrived May 20, 2019 from: https://stats.oecd.org/glossary/detail.asp?ID=2819

Urban Stormwater Fees: How to Pay for What We Need November (2016). Retrieved June 14, 2017 from: https://media.assets.eco.on.ca/web/2016/11/Urban-Stormwater-Fees.pdf

USEPA (U.S. Environmental Protection Agency), 2000. Low Impact Development (LID) A Literature Review EPA-841-B-00-005.

Valinski, N. A., & Chandler, D. G. (2015). Infiltration performance of engineered surfaces commonly used for distributed stormwater management. *Journal of environmental management*, 160, 297-305.

Valtanen, M., Sillanpää, N., & Setälä, H. (2014). Effects of land use intensity on stormwater runoff and its temporal occurrence in cold climates. *Hydrological Processes*, 28(4), 2639-2650.

Vermont Green Infrastructure Initiative (2017). Government of Vermont Watershed Management. Retrieved May 20, 2019 from: https://dec.vermont.gov/watershed/cwi/green-infrastructure

Virginia Cooperative Extension, (2013). Best Management Practice Fact Sheet 2: Sheet Flow to Open Space. Virginia Tech/Virginia State Universities. Retrieved May 19, 2019 from: https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/426/426-121/426-121_pdf.pdf

Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. Science of the total environment, 380(1-3), 48-65.

Wang, L., & Zhou, Y. W. (2012). Comparative Study on Chinese and Foreign Urban Drainage Design Codes. *China Water & Wastewater*, 28(8), 23-27.

Water cycle (2018, July). Nasa Science. Retrieved July 12, 2018, from: https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle/

Waterloo Region community climate Adaptation plan Waterloo risk assessment report (2018). Region of Waterloo. Retrieved April 8, 2017 from:

https://www.regionofwaterloo.ca/en/resources/Strategic_Framework_for_Community_Climate_Adaptation_Planning.pdf

Wheeler, S. M. (2013). Planning for sustainability: creating livable, equitable and ecological communities. Routledge.

Woltemade, C. J. (2010). Impact of Residential Soil Disturbance on Infiltration Rate and Stormwater Runoff 1. JAWRA Journal of the American Water Resources Association, 46(4), 700-711.

Xiao, Q., & McPherson, E. G. (2009). *Testing a bioswale to treat and reduce parking lot runoff. University of California.*

Yousif, N. (2018, August). Flash floods reignite debate over Toronto's sewer system. The Globe and Mail (Toronto). Retrieved May 19, 2019 from: https://www.theglobeandmail.com/canada/toronto/article-flash-floods-reignite-debate-over-torontos-sewer-system/

Appendix A: The results table from Green Value Calculator

RESULTS

The difference between the conventional system and the green intervention(s) you chose decreases the total 10 year life cycle costs and increases benefits by $88,430,416! This strategy reduces peak discharge by 26%.

Permanent link for this configuration

Hydrologic | Financial | Financial Detail | Scenario Detail

Hydrologic Results

Lot Level Improvements:	Conventional	Green	Reduction
Lot Discharge (cf)	-212	-212	**-0.0%**
Lot Peak Discharge (cfs)	-0.08	-0.07	**4.5%**
Total Site Improvements:	**Conventional**	**Green**	**Reduction**
Total Peak Discharge (cfs)	140,285.35	104,287.74	**25.7%**
Detention Size Improvements:	**Conventional**	**Green**	**Reduction**
Total Detention Required (ft^3)	769,701,656	570,099,404	**26%**
Annual Discharge Improvements:	**Conventional:**	**Green:**	**Average Annual Ground Water Recharge Increase:**
Average Annual Discharge (acre ft)	80,667.13	59,967.72	**12,937.13**

Appendix B: Native Trees for Ontario

Native Trees							Parking Lot Features*				
Common Name	Species	Attributes	Light	Soil	Moisture	Height	Street Perimeter	Non-street Perimeter	Island	Median	Bio-retention Area
Red Maple	*Acer rubrum*	orange to bright red fall colour	☼ ◐	sand, loam	moist-wet	25m	✓	✓			✓
Silver Maple	*Acer saccharinum*	fast growing, tolerant	☼ ◐	sand, loam, clay	moist-wet	35m	✓	✓			✓
Blue Beech	*Carpinus caroliniana*	Interesting thin, smooth, slate grey bark	◐ ●	loam, sandy-loam	moist	8m		✓		✓	✓
Bitternut Hickory	*Carya cordiformis*	fast growing	☼ ◐	sand, loam	moist	20m		✓		✓	✓
Hackberry	*Celtis occidentalis*	fast growing, tolerant	☼ ◐	loam, clay	dry-wet	15m	✓	✓	✓	✓	✓
Red Cedar	*Juniperus virginiana*	provides food & shelter for wildlife, tolerant	☼	sand, loam	dry-moist	4m		✓			✓
Tulip Tree	*Liriodendron tulipifera*	Golden yellow fall colour	☼	loam	moist	25m		✓			
Black Tupelo	*Nyssa sylvatica*	Salt tolerance, dark red fall colour	☼	loam	dry-wet	15m	✓	✓		✓	✓
White Spruce	*Picea glauca*	provides wildlife habitat, salt tolerance, year-round screening	☼ ◐	sand, loam, clay	moist	25m		✓			
Sycamore	*Platanus occidentalis*	interesting, peeling bark	☼ ◐	sand, loam, clay	moist-wet	30m					✓
Trembling Aspen	*Populus tremuloides*	leaves flutter in wind, fast growing, tolerant	☼	sand, loam, clay	moist	25m					✓
Bur Oak	*Quercus macrocarpa*	provides food & shelter for wildlife	☼ ◐	loam, clay	dry-wet	15m	✓	✓	✓	✓	✓
Red Oak	*Quercus rubra*	fast growing, wildlife value	☼ ◐	sand to loamy-clay	dry-moist	25m	✓	✓		✓	✓
White Cedar	*Thuja occidentalis*	provides wildlife habitat	☼ ◐	sand, loam, clay	dry-wet	15m					✓

Appendix C: life Cycle Calculation Cost

Life Cycle Calculation = Area x Cost = New Cost

3640*86714=315,464

27,6*192,470= 5,325

24*29,222= 701,323

15*83,821=1,257,315

Total = 2,279,614