Low Impact Development

Stormwater Management
In The Muskoka Watershed

April 2011

School of Environmental Sciences
University of Guelph
Guelph, Ontario N1G 2W1

LOW IMPACT DEVELOPMENT
STORMWATER MANAGEMENT IN THE MUSKOKA WATERSHED

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April 4th 2011

Low Impact Development Stormwater Management in the Muskoka Region
University of Guelph
Guelph, Ontario, N1G 2W1

April 4, 2011

Isobel Heathcote
Muskoka Watershed Council
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Dear Ms. Isobel Heathcote,

We are pleased to submit this report, assigned as part of the requirements for the ENVS*4011 course at the University of Guelph. We are a group of forth year environmental sciences students with research and project management experience. More specifically, our expertise are in the areas of natural resource management, environmental biology, environmental economics and policy, earth and atmospheric science, ecology, and environmental geography.

Over the past eight months, we have reviewed a significant amount of literature as it pertains to Low Impact Development (LID) stormwater management. From this, we have designed a research investigation that has addressed the problem of a lack of consolidated information on LID as they apply to the Muskoka River watershed, as identified in your request for proposal. In particular, our goal is to identify a strategic plan towards implementing appropriate LID practices in the Muskoka River watershed that address the barriers of specific LID techniques.

To achieve this goal, the first and second objectives identify the benefits and barriers of specific LID practices that are suited to the Muskoka River watershed. The third objective is to explore programs and solutions to overcome the barriers associated with the specific LID practices, as suited to the Muskoka River watershed. Methods used to collect, understand or organize information are comprehensive literature reviews and content analyses. The method used to determine the most common barriers influencing LID implementation is a frequency distribution analyses.

As project deliverables, we have provided you with this report as well as a scientific poster as a communication tool to help publish the findings of our research. We are glad that our report meets the research and project needs that you have identified in your request for proposal. We look forward to discussing our findings with you.

Sincerely,

Evan Bracken   Cassie Kuehni   Effie Kalantzis   Mark MacDougall   Mark Su   Seth Wasylycia

Acknowledgements

We would like to thank Dr. Andrea Bradford, who has acted as a faculty contact. She has provided us with pertinent information on specific LID practices, and a variety of resources that were imperative for the development of this research report. Additionally, we thank the School of Environmental Sciences for providing us with a budget to carry out our research. As well, our course instructor and teaching assistant, Jason Tran and Leilan Baxter, have provided insight regarding the methodological framework and poster compilation.

Executive Summary

Stormwater management in rural and low-density areas is essential for protecting water quality in local lakes and streams as well as for preserving the scenic character of these areas. Increasing concern over water quality in the Muskoka Watershed has led to the evolution of stormwater management and the introduction of Low Impact Development (LID). The purpose of this report is to address the lack of consolidated information available on the most effective LID practices suited to the Muskoka Watershed for use by the Muskoka Watershed Council. To accomplish this, a strategic plan affixed towards implementing appropriate LID practices in the Muskoka Watershed was developed. Five specific LID practices, and their associated barriers and benefits, suited to the Muskoka Watershed were identified through a comprehensive literature review and a content analysis. From the data obtained, a frequency analysis was completed to determine which barriers are most common in influencing LID implementation. Programs and solutions to overcome barriers associated with the five LID practices are discussed. It is recommended that Muskoka Watershed Council form a three-phase strategy to progressively implement LID. In the short term, programs focusing on education and site priority identification are integral to building a framework for LID. Moving forward, the Muskoka Watershed Council must begin the deployment of physical LID systems eliminating point sources of stormwater runoff. The Muskoka Watershed Council must further develop a general reporting system monitoring the effectiveness of LID on stormwater mitigation. Finally it is recommended that the Muskoka Watershed Council incorporate and promote private initiatives, by rewarding landowners for private stormwater mitigation and LID implementation.

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1.0 Introduction

Land use changes associated with development increase the percent of impervious surface within an area, negatively impacting nearby water (Stockwell, 2009). Nature's capacity to absorb storm events through soil, vegetation, micro-organisms and deep infiltration allows for relatively clean water to be returned to local watersheds (Stockwell, 2009). The combined creation of roads, roofs, parking lots and sidewalks disrupts the hydrology in a given watershed by reducing infiltration and evapotranspiration; which in turn increases runoff and erosion, introducing pollutants to water resources (WEF, 1998). As urban development occurs, native soils are compacted and vegetation is removed, preventing infiltration and reducing ecosystem water storage (Abida & Sabourin, 2006). Developed landscapes experience earlier storm peak flows of greater volume and velocity than undisturbed landscapes, given equal levels of precipitation (Mount, 1995). Therefore, the success of a stormwater management program to maintain natural drainage and hydrology relies heavily on an understanding of the impacts of land use change on specific watersheds (Booth et al., 2004; McHarg, 1969).

Stormwater management in rural and low-density development areas such as the Muskoka Watershed is essential to protecting water quality in local lakes and streams as well as preserving the areas scenic character (Thurston et al., 2010). Watershed degradation has been documented in stream channels with total impervious surface coverage less than 10% (Booth et al., 2002; Klein, 1979; Moglen & Kim, 2007). Any increase in the amount of impervious surfaces can adversely impact a watershed, depending on the geology, climate, biology, vegetation, topography and land use (Booth et al., 2004; Brabec et al., 2002; Hershey et al., 2006; WEF, 1998). In rural areas, development impacts on the local watershed are typically characterized by the presence of sediment, organic material, high temperatures, heavy metals, trash and oil (Mount, 1995). These pollutants can adversely impact the biological health of aquatic systems (Mount, 1995; Ward & Trimble, 2004). Therefore, while rural, low-density development typically has limited impervious surfaces, degradation of water resources can still occur.

Conventional stormwater management practices often exacerbate problems caused by urbanization (Stockwell, 2009). As a result, a shift is taking place from blue water management (water runoff into pipes and streams) to green water management (intercepting, infiltrating, detaining and evapotranspiring rainfall) (Ellis, 2008; Novotny & Brown, 2007). This new innovative management method is referred to as Low Impact Development (LID). LID attempts to reduce runoff and mimic the natural hydrology and function of the landscape by preserving open space, native vegetation, canopy cover, soils and wetlands (Hinman, 2005). Bedan & Clausen (2009) affirm that compared to traditional stormwater management, the implementation of LID significantly reduces storm flow and exports of pollutants in stormwater. Therefore, LID has become prominent as many of its benefits surpass those of traditional stormwater management.

2.0 Background

The following report is concerned with the implementation of specific LID practices as they apply to the Muskoka Watershed. LID strategies have been thoroughly studied in the literature since problems of pollution and excess runoff were correlated to conventional stormwater management systems (Dietz, 2007). A comprehensive examination of the literature, as this report provides, aids in the understanding of LID stormwater management.

2.1 The Need for a Solution

Natural ecosystems have the capacity to absorb rainfall events with minimal runoff as plants and micro-organisms absorb precipitation (Schueler, 1994). Water input is utilized by vegetation and can infiltrate deep into the soil, replenishing groundwater reservoirs while simultaneously filtering the water (Kelly & McGinnis, 2002). Consider a case where the forest is removed for urban development. When houses, parking lots, pavement, or various other components of conventional infrastructure are created, a total change of the water infiltration regime occurs due to the loss of vegetation and alteration of the available soil surface (Figure 1). With increasing levels of imperviousness, there is a lack of infiltration and an increase in erosion and pollution caused by elevated runoff (Schueler, 1994). Schueler (1994) further illustrates that streams adjacent to impervious areas are transformed from clean, stable conditions, to one of elevated

Figure 1- The basic flow of runoff after a rainfall. Adapted from City of Wilmington (2009).

water temperature with increased levels of nutrients, metals, and hydrocarbons.

Barnes et al. (2002) classified imperviousness as an important component in determining the effects of stormwater runoff on water quality. For example, an increase in impervious cover from 6% to 95% in one acre of land can create 16 times more stormwater runoff (Barnes et al., 2002). As a consequence of increased impervious cover, it has been demonstrated that levels of phosphorus increase by three times, nitrogen by seven times and zinc is detected at low levels (Schueler, 1994). The measurement of imperviousness is thus directly correlated to stream degradation.

An urban area is expected to contain 55.2% impervious surface, while levels on resort land are estimated to be approximately 22.1% and rural areas are roughly 12.9% (Kelly & McGinnis, 2002). It is important to note that in rural areas with low-density development, such as the Muskoka River watershed, changes in slope and canopy cover are also indicators of potential degradation due to stormwater runoff (Gaffield et al., 2003; WEF, 1998). LID practices have been developed to address the relationship between imperviousness and water quality. To assess the need for improved stormwater management, the impervious nature of locations along with their unique natural attributes should be considered for appropriate stormwater development.

Although there are various stormwater management techniques available, this report focuses on LID. Unlike conventional stormwater design, which creates an area dedicated to treating excessive runoff and pollution, the LID approach is integrated into the landscape (Stockwell, 2009). These designs integrate the preservation of natural conditions, to have minimal impact on soils, vegetation and aquatic systems (Dietz, 2007). Many LID designs reduce the amount of impervious cover by using natural filtration systems through existing soil and biological processes (EPA, 2000). LID is capable of removing nutrients, pathogens and metals from stormwater (EPA, 2000).

Furthermore, environmental benefits are complimented by a series of social and economic benefits, including an aesthetic improvement to the community, increases in property values and possible cost savings (EPA, 2007).

2.2 The Muskoka River Watershed

The Muskoka River watershed encompasses vast amounts of natural, pristine and valued lands in Ontario (DMM, 2007). This includes hundreds of freshwater lakes, streams, rivers and wetlands (DMM, 2007). The Muskoka River watershed, part of the southern Lake Huron drainage basin, is located on a section of the Precambrian Shield of central Ontario (MNR, 2003; O'Connor et al., 2009). The watershed encompasses an area of 5,100 km^2 and includes approximately 780 km^2 of lakes (MNR, 2003). Two headwater branches of the Muskoka River arise in the western portion of Algonquin Provincial Park, flowing in a south-westerly direction (MNR, 2003). Converging near the town of Bracebridge, the Muskoka River continues through Lake Muskoka and other interconnected water bodies to Georgian Bay (MNR, 2003). The watershed is divided into three secondary sub-watersheds: the North and South Branches and the Lower Muskoka sub-watershed (DMM, 2004). Within the watershed, 48% of the land is privately owned, approximately 50% is Crown land and the remaining falls under First Nations or other federal lands (2%) (Tran, 2007). Furthermore, Tran (2007) notes that approximately 68% of the watershed is covered in forest and natural vegetation, 11% consists of wetlands, 18% is lakes and ponds, and just over 2% are rock barrens and outcrops (Table 1). The entire watershed is part of the Great Lakes-St. Lawrence Forest Region (Acres International Limited, 2006).

Table 1-The regional demographic and physical characteristics of the Muskoka River watershed. Adopted from MWC (2010a).

Characteristic	Value
Approximate Permanent Population	59,000
Approximate Seasonal Population	100,000
Towns	3 (Bracebridge, Gravenhurst, Huntsville)
Villages	11
Number of Sub-watersheds	20
Number of Lakes	Over 500

Rocky knolls and ridges through much of the area define the topography of the watershed (MNR, 2003). Soils are shallow and generally sandy with underlying bedrock generating low permeability, which restricts the infiltration of precipitation (MWC, 2010b). Within valleys of the central portion of the watershed, deeper deposits of sand, silt and clay soils can be found (MWC, 2010b). The climate of the watershed is characterized by cool to moderate temperatures (MNR, 2003). The Muskoka River watershed is one of the wetter areas in the province, receiving one third of its total precipitation as snowfall (MWC, 2010b), which results in high levels of runoff during the spring melt. Specifically, the average annual liquid precipitation reaches nearly 1000 mm, of which 300 mm is snowfall (MWC, 2010b).

According to the Muskoka Watershed Council (2010b), the population of the watershed is approximately 150,000, with almost 65% comprising of seasonal residents. The larger permanent population centers within the watershed include Huntsville (pop. 17,338), Bracebridge (pop. 13,751) and Gravenhurst (pop. 10,899) (MWC, 2010b). The Muskoka River and its associated lakes are prominent attractions for the recreational and tourism based economy (MNR, 2003). From 2001 to 2006, Statistics Canada (2006) indicated a population increase of 5.1%. Although this is indicative of the increasing popularity of the Muskoka River watershed, it is also significant from a developmental standpoint, as this correlates to an increase in urban development and a decrease in surface permeability. Thus there is need for the development of sustainable practices with regards to the management of stormwater in the Muskoka River watershed.

A recent report card of the Muskoka River watershed indicates that the health of the watershed is above standard; however, also noted is that enhancement is needed in the higher developed central region of the Muskoka River watershed (MWC, 2010a). Increasing concern over water quality in local lakes and streams as well as protecting the scenic charm of these areas has led to the evaluation of LID stormwater management in the Muskoka River watershed (Aquafor Beech Limited, 2008; MWC, 2010b). LID is viewed as an integrative solution, which can help maintain aesthetic value within the Muskoka River watershed as well as address the increasing issues regarding imperviousness from development.

3.0 Goal and Objectives

This section outlines the overall goal of this report as well as the objectives, which have been completed to fulfill the goal. This report identifies the problem of the lack of consolidated information available on the most effective LID practices suited to the Muskoka River watershed for the Muskoka Watershed Council.

3.1 Goal

Our goal is to identify a strategic plan towards implementing appropriate LID practices in the Muskoka River watershed, which address the barriers of the selected LID practices.

3.2 Objectives

To achieve our goal, the following objectives have been completed:

1) Identify the benefits of *five specific LID practices suited to the Muskoka River watershed.
2) Identify the barriers associated with *five specific LID practices suited to the Muskoka River watershed.
3) Explore programs and solutions to overcome the barriers associated to *LID implementation in the Muskoka River watershed.

*See Section 4.3 for the methods to determine the specific LID practices.

4.0 Methods

To achieve our goal and objectives, our research framework presented in Figure 2 was followed.

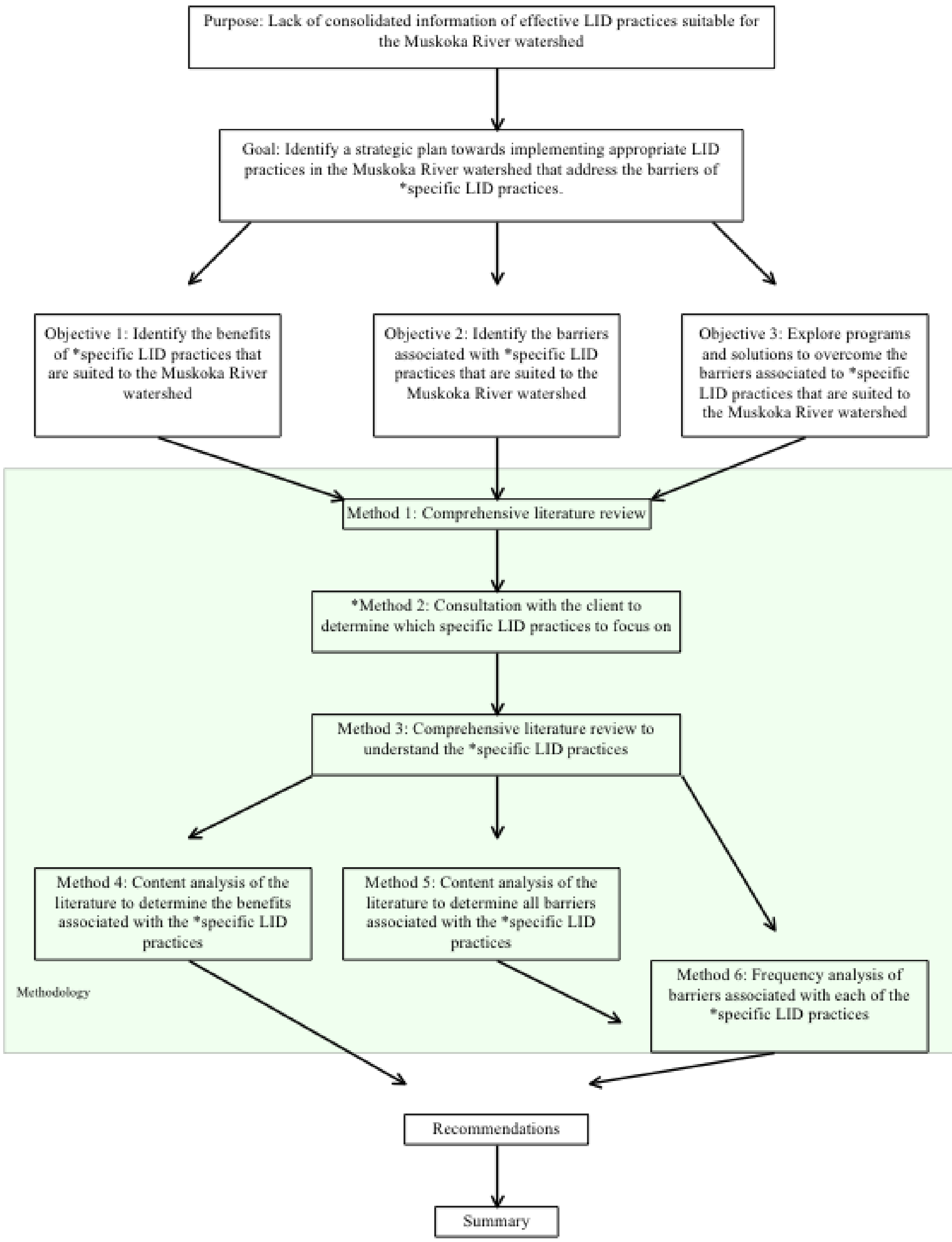

Figure 2 – An overview of the research framework

4.1 Comprehensive Literature Review

A comprehensive literature review of general LID was first completed. From this, after consultation with the client to determine suitable LID for the Muskoka River watershed (as seen in section 4.2), a second comprehensive literature review was completed to evaluate the five selected LID practices.

4.2 Consultation with Client

After the first comprehensive literature review, the client was consulted to determine which specific LID practices to focus on, as suited to the Muskoka River watershed. This was completed through e-mail correspondence with Isobel Heathcote and Judith Brouse.

4.3 Content Analysis

Next, a content analysis of the literature was completed to determine both the benefits and barriers associated with the selected LID practices. Stemler (2001) notes, a content analysis is a systematic, replicable technique for compressing large amounts of text into fewer categories by using code words to sort through data. Stemler (2001) affirms that this method enables researchers to sift through large volumes of data and is useful in allowing one to discover and describe information. The content analysis, through coded keywords (e.g. the selected LID practices), filtered and narrowed the volume of data retrieved from the literature review. For each LID practice, the benefits and barriers associated with each code word was established.

4.4 Frequency Distribution Analysis

To determine which barriers are the most common factors influencing LID implementation, a frequency distribution analysis on the content analysis data for the LID barriers was completed.

According to Gravetter & Wallnau (2008), a frequency distribution analysis is effective for organizing data according to the frequency (the number of times a code word is found), establishing common factors. Recommendations were made for the Muskoka Watershed Council from review of the content and frequency analyses, as well as focusing on relevant case studies regarding the overcoming of barriers.

5.0 LID Practices

Although there is a plethora of potential LID practices available, because of time and resource constraints, this report will focus on the five most applicable practices to the Muskoka River watershed. These include: bioswales, permeable pavement, bioretention gardens, green roofs and rain barrels. There are many case specific factors such as performance, capacity, space and cost, which must be taken into consideration when deciding the best stormwater system for a given area. Therefore, depending on location, specific use and effectiveness of specific LID, a combination of LID practices may be required to successfully manage for stormwater.

5.1 Bioswales

The use of bioswales, also commonly referred to as grassy swales, is an LID approach which mitigates onsite runoff (Storey et al., 2009). Bioswales are typically wide, shallow drainage ditches with vegetated sides and bottoms, used to reduce standing water and remove pollutants through filtration, settling, and infiltration into the subsoil (Figure 3) (Barrett, 1998; Kirby et al., 2005). These systems can be applied to parking lots, residential roadsides, highway medians, and landscape buffs (University of Florida, 2008). Bioswales are generally at least 30 meters long, 0.6 meters wide, ranging in longitudinal slope from 0.5% to 6%, and located in series with detention ponds, which store runoff and reduce peak discharges (Mazer et al., 2001). Bioswales provide a depressed area where excess stormwater can enter and slowly infiltrate into the soil. Vegetation in bioswales allows not only for the uptake of water but also provides resistance against the flow of water, allowing additional time and dispersed infiltration of water into the soil (Mazer et al., 2001). Bioswales have slight inclines such that excess water which does not infiltrate can eventually flow into wetland areas or reservoirs (Elfering, 2002).

Figure 3- Stormwater runoff from surrounding area draining into bioswale. Adapted from Guillette (2010).

5.2 Permeable Pavement

To manage excess stormwater runoff on roads and parking lots, permeable pavement can be implemented in place of traditional asphalt, which directly increases infiltration (Brabec et al., 2002; Dietz, 2007). Permeable pavement was developed to decrease impervious surfaces to reduce runoff during peak flow hours and diminish overall pollutant contamination in surrounding landscapes. There are a number of permeable pavement solutions, which can be implemented:

- Concrete blocks can be inserted in various areas, such as intersections, and walkways to eliminate areas of continuous impermeability, as well as improve aesthetics
- Pervious concrete and asphalt can also increase the permeability of roads and walkways, which is achieved by altering the mixture used to make the concrete or asphalt

Regardless of the method, the purpose of permeable pavement is to give standing water, which normally runs off or pools, a destination. This occurs by allowing stormwater to infiltrate through the sub-base, where it is filtered and either retained within the sub-base soil or released, supporting groundwater recharge (Figure 4) (Tota-Maharaj & Scholz, 2010). By allowing water to infiltrate into the soil or other reservoirs directly under the road or walkway, permeable pavements greatly reduce water accumulation on impervious surfaces (Dietz, 2007; Legret & Colandini, 1999).

Figure 4-Water infiltrating through permeable pavements into the soil below. Adapted from Dierkes et al. (2002).

5.3 Bioretention Gardens

Bioretention gardens replace impermeable surfaces and create naturally vegetated areas (Rushton, 2001). There are many forms of bioretention gardens; however all are designed to increase the amount of permeable area available for water to infiltrate (ESD, 2007). Bioretention gardens are areas of depressed soil, found within or adjacent to impermeable surfaces where water can freely infiltrate (Figure 5) (Dietz, 2007). Typically, to increase the detention capacity of these gardens, hydrophytic trees and shrubs (which grow partially or wholly in water) are planted which allow for improved water uptake (Dietz, 2007). Bioretention gardens can be a variety of different sizes, but are most effective at reducing stormwater runoff if they fragment impervious surfaces (Rushton, 2001). This allows for the infiltration of runoff without risking oversaturation of the garden.

Figure 5-Typical bioretention garden in which runoff infiltrates into the soil. Adapted from Griffin (2008).

5.4 Green Roofs

Green roofs have been widely used for a number of years in Europe however remain a novelty in much of North America (Dietz, 2007). There are typically two types of green roofs: extensive and intensive. Extensive green roofs mimic nature and require very little external input for either maintenance or propagation (KWL, 2009). Conversely, intensive green roofs are usually constructed where public access and recreational use are a primary function (KWL, 2009). These roofs have a deeper growing material than extensive roofs, containing a higher organic content, and can support lawns, large plants, trees as well as outdoor furnishings (KWL, 2009). Typically a green roof is comprised of a thick layer (5 cm-15 cm) of soil, with grasses, shrubs and in some cases trees. The effectiveness of the green roof is directly related to the thickness of the soil layer, but on average green roofs can retain approximately 63% of precipitation (Bengtsson et al., 2005; Dietz, 2007; Moran et al., 2004). Green roofs require relatively flat, reinforced surfaces; therefore they tend to be limited to commercial or industrial buildings (Carter & Jackson, 2007). By providing a permeable layer of vegetation, water that would typically be concentrated by downspouts, can infiltrate and be taken up by the vegetation (Figure 6). Drought tolerant plants are usually grown to limit plant mortality during long periods of drought due to the isolation and limited detention ability of green roofs (Dietz, 2007).

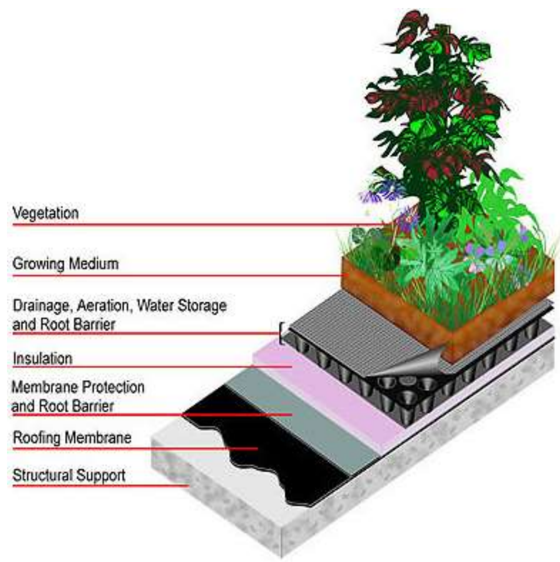

Figure 6- Layers found in a green roof system, which allows for precipitation to infiltrate. Adapted from Roof Helper (2011).

5.5 Rain Barrels

Unlike commercial buildings, private residences typically do not have the proper structural elements to allow for the use of a green roof to reduce runoff (Carter & Jackson, 2007). As a result, houses and other small buildings remain a significant point source for runoff, as eavestroughs concentrate stormwater runoff from roofs. Rain barrels are large storage devises which act as holding tanks, in which water caught can be released at a later time (Figure 7) (Hager, 2003; Thurston et al., 2010). These can play an important role in areas which have restrictions on water use or that charge for water consumption, as rain barrels provide a free source of clean water (Hager, 2003).

Figure 7- Stormwater flows from roofs of adjacent building and then retained in the rain barrel. Adapted from WATER (2011).

6.0 Benefits of LID Practices

This section outlines the benefits of each of the five LID practices. There are a number of significant benefits associated with the implementation of each LID practice. Typical environment benefits generally include increased management of water quality, decreased runoff during peak flow as a result of increased rain capture, decreased pollution contamination through filtration and groundwater recharge through infiltration (Barrett, 1998; Kirby et al., 2005; Mazer, 2001). Similarly, there are significant practical benefits as a result of LID such as a habitat protection and increases in community value through improved aesthetic and land value (Peck et al., 1999). Overall, the five LID practices have many benefits associated with their implementation; each practice will be outlined illustrating their individual benefits.

6.1 Bioswales

Bioswales offer many economic, environmental and social benefits. They filter stormwater via the processes illustrated in Figure 8:

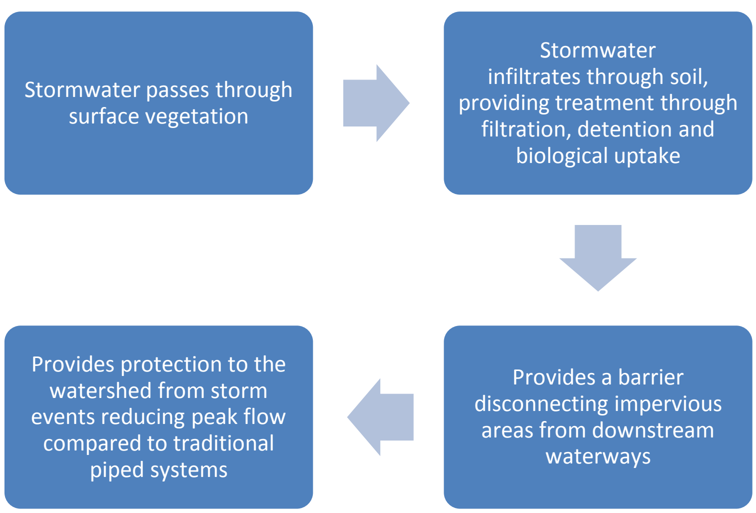

Figure 8- Illustration of how Bioswales promote the mitigation of stormwater runoff and filtration of pollutants (University of Florida, 2008)

The efficiency and performance of bioswales are often site-specific, however, runoff reduction and pollutant removal have been observed across a wide variety of bioswale sites. The EPA (1999) reported that a functioning bioswale was able to remove 81%, 51%, 67%, 71% and 9% of total suspended solids, copper, lead, zinc, and phosphors respectively. The expected pollutant removal for total suspended solids, various trace metals, total phosphorus, and total nitrogen for well-designed and well maintained bioswales is estimated to be 70%, 50-90%, 30%, and 25% (Schueler et al., 1992). Additionally, bioswales have been shown to recharge groundwater through infiltration of stormwater (Vlotman et al*.,* 2007). Consequently, bioswales improve water quality and reduce runoff volume, providing additional protection to natural wetlands and ecosystems (Vlotman *et al.,* 2007).

Although bioswales provide environmentally important services through reducing runoff and pollutants, they have also have been identified as the least costly method for controlling highway runoff (Maestri & Lord, 1987). Bioswale construction is much less costly than traditional curb and gutter conveyances, which range from $5-$15 per linear foot (Barrett et al, 1995). Conversely, a study by the University of Florida (2008) suggests that the cost of bioswales is approximately $0.50 per square foot. Therefore, the use of bioswales allows for the elimination of a costly, high maintenance, less efficient gutter system. Additionally, bioswales require minimal maintenance, such as seasonal practices of clearing trash, debris and heavy sediment deposits (Barrett et al., 1995).

6.2 Permeable Pavement

Permeable pavement decreases surface water runoff through infiltration (Dietz, 2007). Research conducted by Booth and Leavitt (1999) reports minimal surface runoff from a permeable pavement parking lot located in Washington. Similar findings were observed in a study conducted by the Toronto and Region Conservation Authority in King City, suggesting that permeable pavement runoff is less than 10% of that produced by traditional pavements for a rainfall event lasting 5.5 hours and producing 72 mm of rain (TRCA, 2008). Collins et al. (2008) conducted studies of four permeable pavement parking lots, finding decreased runoff by 98.2-99.9% compared to traditional pavement parking spaces. Furthermore, it was observed at a test site in France that almost 97% of precipitation infiltrated into the soil below the impermeable asphalt (Legret & Colandini, 1999). Fassman and Blackbourn (2010) reports large reductions in average peak flow for permeable pavement over 44 storms which ranged between 0.15-1.17 liters per second (L/s), whereas average peak flow for traditional asphalt was found to range between 0.82-2.05 L/s (Table 2). As a result of increasing the infiltration of precipitation through permeable pavement, runoff volume as well as peak flow is greatly decreased, reducing rapid surface inputs into the local catchment basin (Fassman & Blackbourn, 2010). This decreases the potential for flash flooding, reducing the threat of property damage and personal risk due to high water levels.

Permeable pavement's ability to filter stormwater allows for the removal of pollutants and, as a result, has significantly improved overall water quality in local waterways. Research conducted by Tota-Maharaj and Scholz (2010) reveals that permeable pavement has a removal efficiency of 98% for microbial pollutants including coliforms, E. coli and fecal streptococci. Other nutrient related pollutants such as total suspended solids (TSS) and chemical oxygen demand (COD) were significantly reduced in permeable pavement systems compared to traditional pavement systems (Dietz, 2007; Swisher, 2002). Additionally, Rushton (2001) notes that permeable pavement is responsible for more than a 75% reduction of a number of metals (copper, iron, lead, manganese and zinc) found in runoff generated by a parking lot. This is reiterated by permeable pavement's ability to remove hydrocarbons (such as gasoline or motor oil), which was undetectable in samples collected from permeable pavement systems (Brattebo & Booth, 2003). These findings are outlined in Table 2. This filtration feature is important, as automobiles release metals and hydrocarbons onto the roadway. Without a filter feature such as permeable pavements, these pollutants would end up in surface waters such as rivers and lakes, posing a potential hazard to the environment and contamination to local groundwater (Swisher, 2002).

Table 2-Percent improvement in stormwater quality and quantity using permeable pavement compared to traditional pavement systems. Adapted from (Brattebo & Booth 2003; Collins et al., 2008; Fassman & Blackbourn, 2010; Rushton, 2001; Tota-Maharaj & Scholz, 2010).

Parameter	Volume	Peak Flow	Biological Pathogens	TSS	COD	Cu, Fe, Pb, Mn, Zn	Hydrocarbons
Percent Improvement	*90.0 -99.9*	*43.9-81.7*	*78.0*	*91.0*	*24.2*	*>75.0*	*~100*

Additional benefits are less intuitive, but equally as important. Dietz (2007) suggests that permeable pavement significantly reduces road noise for travelling automobiles. Furthermore, Fitts (2002) notes that permeable pavement decreases tire spray. As a result, permeable asphalt is frequently used for airport runways to reduce the potential for hydroplaning in landing aircrafts (Dietz, 2007). Consequently, permeable pavement has been shown to have a wide range of practical safety features, which may reduce the risk of traffic accidents (Dietz, 2007) . This feature can be combined with permeable pavement's ability to rapidly infiltrate melted snow and ice (Drake et al., 2010). Permeable pavement has the potential of lowering the cost of snow removal, decreasing the need for salting on roads and reducing spring-thaw runoff volumes (Drake et al., 2010). This will subsequently reduce the amount of ice and salt that can build up on roadways, making winter driving safer for all drivers. Overall, there are many benefits that the Muskoka River watershed would profit from permeable pavement implementation.

6.3 Bioretention Gardens

Bioretention gardens reduce runoff volume and help to decrease pollutants in water (Dietz, 2007). These gardens strongly rely on the biological processes of plants, microbes and soils for the retention of water and removal of pollutants (ESD, 2007). Khan et al. (2010) report a total volume capture rate for bioretention gardens to average 96.31%. Similarly, Roy-Poirier et al. (2010) observe peak flow reductions of 49-58% for various rainfall events. Khan et al. (2010) also note pollution reductions of an average removal of 99.3% of total suspended solids. In addition, total phosphorus removal, which has been found to be deficient in other LID systems, is suggested to range anywhere from 70-85% (Khan et al., 2010).

The removal of metals from stormwater is extremely important as metals can lead to the contamination of groundwater and harmfully affect the ecosystem (Roy-Poirier et al., 2010). Bioretention gardens have shown to have a capacity to remove 43% of copper, 70% of lead and 64% of zinc inputs (Roy-Poirier et al., 2010).

Another noted benefit of bioretention gardens is that they can effectively infiltrate under cyclical freeze-thaw soil conditions, which is of particular attention to the Muskoka River watershed (Roy-Poirier et al., 2010). Similar findings in cold climate conditions reveals that metal removal from snow runoff is found to average 81-99% for zinc, copper lead and cadmium (Roy-Poirier et al., 2010). In relation to the removal of stormwater pathogens, Roy-Poirier et al. (2010) illustrate that bioretention gardens perform extremely well, removing on average 91.6% for fecal coliform and 71% for E coli. This is an important feature as bacterial contamination has shown to be a threat to human health (Roy-Poirier et al., 2010). Finally, a significant reduction (92-96%) of motor oil was also discovered as a result of street-side bioretention gardens in urban areas (Chapman & Horner, 2010).

Another benefit of bioretention gardens is the reduced construction costs compared to conventional techniques (Green et al., 1993). Green et al. (1993) note that construction costs are roughly one third the cost conventional methods such as oil and grit separators. As a result, bioswales have many environmental and economic benefits.

6.4 Green Roofs

Green roofs contribute to many economic, environmental, community and social benefits. Peck et al. (1999) suggest that building owners reap economic benefits such as energy cost savings due to increased insulation, improved protection of the roof membrane which extends its life span, and sound insulation. For example, Liu and Baskaran (2003) observe that an extensive green roof in Ottawa with grass planted on a 150 mm growing medium, reduces the heat flow through the roof by over 75% in the spring and summer (KWL, 2009). In relation to roof life span, Bass (2001) illustrates that a green roof doubles the life span of a conventional roof by protecting the membrane from extreme temperature fluctuations, ultraviolet radiation and mechanical damage (KWL, 2009). Accessible green roofs also improve property values (Peck et al., 1999). Within the community, cost saving opportunities involving increased worker health, productivity and creativity as well as cost savings on infrastructure related to stormwater management are realized (Peck et al., 1999). Furthermore, Peck et al. (1999) state that new employment opportunities will arise for a wide range of professionals including suppliers and manufacturers of roofing membranes and related products, design and engineering professionals.

Significant environmental and related economical benefits from green roofs can be gained as they can contribute to the reduction of impervious surfaces in rural and urban areas, decreasing the volume of stormwater runoff (Nicholson et al., 2010). The quality of stormwater runoff increases due to reduced volume and the natural filtration of materials (Peck et al., 1999). Kohler

(2004) reveals that stormwater runoff reduction of a green roof, which contains a growing medium of 75-150 mm in depth, varies from 21% to 75%. Green roofs in Vancouver are found to retain 29% of total rainfall (Roehr & Kong, 2010). Green roofs have the potential to greatly reduce stormwater runoff in urban settings as impermeable flat roofs account for approximately 40-50% of total land area in highly developed cities (Stovin, 2009). Van Seters et al. (2007) studied a large-scale green roof in Toronto, revealing that stormwater runoff and associated phosphorus concentrations are found to decrease in comparison to adjacent conventional roofs. In addition, green roofs provide natural habitat for birds, insects, native plants and possibly rare or endangered species (Brenneisen, 2003; Gedge, 2003). They also contribute to local biodiversity, promote cooling via evaporation during warmer months, sequester carbon and decrease urban heat island effects (Stovin, 2009). Specifically, Kerr Wood Leidal Associates (2009) suggest that inaccessible (minimal human intervention) extensive green roofs can be designed to create safe havens and provide wildlife corridors in the urban area for birds and insects. Other environmental benefits include air quality improvements from the mitigation of nitrous oxides and volatile organic compounds by plants and reductions in airborne particulate matter (Peck et al., 1999). Reductions of greenhouse gas emissions from energy savings within buildings and the potential for adaptation to negative climate change impacts are also important benefits which should be taken into consideration (Peck et al., 1999). Banting et al. (2005) estimates that green roofs could potentially save up to $2.5 million annually for the City of Toronto due to air quality improvements. Other social benefits of green roofs include improved aesthetics, health and horticultural therapy, improved safety and additional recreational opportunities (Peck et al., 1999).

6.5 Rain Barrels

Rain barrels provide a cost effective solution to residential stormwater runoff and can be implemented in an area where space is limited. Rain barrels sit beneath downspouts and collect up to 100% of precipitation (until capacity is reached), typically only requiring a $1m^2$ plot of land (Hager, 2003). Williams and Wise (2009) calculated that one inch of rainfall on a 1,000 square foot plot captures 2,358 litres of water. As a result, rain barrels are an important resource, which have been implemented as part of large-scale programs in major cities such as Toronto and Ottawa (Hager, 2003). Rain barrels have also gained acceptance as an effective LID practice, which resonates with the public, as many rain barrels have been installed privately, due to their low cost and high availability in comparison to other LID options (Hager, 2003; Williams & Wise, 2009).

Rain barrels have an excellent application for residential use as they can be attached to rain gutters or even green roofs to collect stormwater runoff. A model constructed by Sands & Chapman (2003) for the Milwaulkee Metropolitan Sewage District found that a residential area with approximately 40,000 single family homes, each with two 90 gallon (341 litre) rain barrels would capture 8.5% of average rainfall over the measured 78 events. Sands and Chapman (2003) note that rain barrels could aid in decreasing stormwater runoff and decrease costs for water treatment plants. Additional benefits noted by Hager (2003) and Williams and Wise (2009) are that rain barrels increase available water supply and reduce potable water use. These authors attribute this to the increased amount of rainwater harvested in rain barrels which can be used for personal irrigation purposes, for example, watering laws, gardens or trees (Hager 2003; Williams & Wise, 2009).

7.0 Barriers to LID Implementation

As outlined in the previous section, there are numerous benefits associated with the performance of each LID practice. However, for each type of LID practice noted, there still remain barriers to their use. This section outlines the barriers to implementation of each LID practice, as identified through frequency analyses, through consulting academic literature.

7.1 Bioswales

According to the frequency analysis, the top five barriers to bioswale implementation, in order of incidence, are design and location, lack of knowledge and awareness, monitoring and maintenance, flooding and inundation, and lack of incentives and policy (Appendix A). Each barrier will be addressed in the corresponding sub-sections.

7.1.1 *Design and Location*

The ability for bioswales to remove pollutants is directly related to design and location (Dietz, 2007). As a result, surrounding features such as vegetation type, cover extent, climate, land use, size of area, soil type, slope, imperviousness of contributing watershed and dimensions and slope, all play significant roles in the performance and ability of the system (Barrett, 1998; Dietz, 2007; Kaighn & Yu, 1996; NCTCG, 1993; Roseen, 2009; Walsh et al., 1998; Young et al., 1996; Yousef et al., 1985; Yu et al., 1993). Kaighn and Lu (1996) illustrate that the ability of bioswales with different slopes, traffic volumes, and vegetation heights to remove nutrients including total suspended solids, phosphorus, and zinc is directly related to design. Youself et al. (1985) suggest that effectiveness is dependent of the infiltration rate, shape and roughness of the swale, as well as the average flow through the swale. Bioswales require adequate area in order for them to be effective in reducing surface runoff (Yu et al., 1993). This may be a significant barrier in developed communities where space for such an application is limited.

7.1.2 ***Lack of Knowledge and Awareness***

Lack of knowledge and awareness of bioswales is another barrier to implementation. This includes misconceptions or a lack of understanding of the performance, benefits, overall design, management and quality control practices (Storey, 2009). Bioswale designs differ and thus, result in varying levels of performance outcomes. Furthermore, technical manuals for the construction of bioswales often contain little information on post-construction monitoring and maintenance (Storey, 2009). Storey (2009) suggests that a large barrier to their acceptance is due to a general misapprehension of the performance capabilities of these applications. Cappiella et al. (2008) concur, suggesting that the application of bioswales has been largely limited due to a lack of technical guidance or reliable data on performance.

7.1.3 ***Monitoring and Maintenance***

The efficiency of a well-designed swale can be expected to decrease if it is not maintained and monitored (Burch et al., 1985; Schueler et al., 1992). Schueler et al. (1992) found that the primary threat to the longevity of bioswales is maintenance problems. For example, runoff is prevented from entering into bioswales due to the gradual build-up of soil and grass adjacent to roads (Schueler et al., 1992). Periodic replanting of vegetation, thatch removal and mechanical aeration are also required to restore the permeability of the soil (Burch et al., 1985). Therefore, bioswales must be maintained to ensure their effectiveness at a recurring cost to taxpayers.

7.1.4 *Flooding and Inundation*

A common barrier to the establishment, growth and abundance of vegetation in bioswales is storm related inundation (Mazer, 2001). Prolonged inundation has been found to significantly suppress germination and growth within bioswales (Mazer et al., 2001). Field monitoring during the study revealed that heavy shade is the most significant environmental factor affecting establishment and growth (Mazer, 2001). Therefore, a strong inverse relationship between vegetation and organic litter biomass and the proportion of time bioswales are inundated above 2.5 cm depth is present where light is adequate (Mazer, 2001). Furthermore, Mazer et al. (2001) found that due to high flow velocity and hydraulic loading during storm events, the effectiveness of dense vegetation and abundant organic litter that facilitates sedimentation of silt and clay particles is low. Therefore, in areas susceptible to high precipitation events, the pollutant removal efficiency of bioswales is significantly reduced, especially during peak flow discharge (Storey, 2009).

7.1.5 *Lack of Incentives and Policy*

An extensive analysis of the barriers to LID implementation in the North Coast Redwood region of California revealed that a significant barrier for bioswale implementation is that conventional practices are institutionalized, while bioswale practices are not (Stockwell, 2009). Reform of the infrastructure policy and regulatory framework of a municipality requires resources and a willingness to accept new practices (Wulkan, 2008). A survey addressing the design practices and construction methods of 53 towns and municipalities in Ontario, Western Canada, and the United States, showed that only 50% of municipalities have experience with LID methods including the integration of bioswales into existing management plans (Abida, 2006). However, Abida (2006) notes that 76% of municipalities are willing to transfer to LID practices. This study affirms the long lag-time in reforming policy and people's willingness-to-accept new LID practices.

7.2 Permeable Pavement

According to the frequency analysis, the top five barriers to permeable pavement implementation, in order of incidence are the potential for clogging, high implementation cost, performance dependence on soil characteristics, reduced structural ability under heavy traffic use, and being prone to frost heave (Appendix A). Each barrier will be addressed in the corresponding sub-sections.

7.2.1 *Potential for Clogging*

For permeable pavement to work optimally, surface pores must be open such that water can infiltrate (Dietz, 2007). This presents problems in areas which are prone to high amounts of aerosol dust or in cold climates where roads are salted and sanded during the winter (Brattebo & Booth, 2003; Scholz & Grabowiecki, 2007; Swisher, 2002). Over time, fine particles can clog surface pores significantly reducing the performance of the pavement system. This is compounded by road traffic grounding in particles and winter road crews adding excess particles accelerating the process of clogging (Drake et al., 2010). As a result, permeable pavement requires frequent maintenance to retain its pervious qualities at a recurring cost to taxpayers (Drake et al., 2010; Giuliani, 2002).

7.2.2 *High Cost*

One of the greatest barriers to any infrastructure project is its initial and residual cost (Bing et al., 2004). The use of permeable pavement is no different, as permeable pavement typically costs 10-20% more per unit area than a comparable traditional pavement, with some estimates suggesting upwards of 300% more per unit area (Cahill Associates Inc., 2005). This initial cost, combined with maintenance costs such as cleaning and de-clogging, can be significantly more expensive than traditional methods. As a result, regardless of long-term fiscal gains, the initial cost of permeable pavement may be too large for smaller municipalities to consider it as a feasible LID option. This limits its use to residential or resort settings.

7.2.3 Effectiveness Depends on Soil Type

Since the Muskoka River watershed is located within the Canadian Shield, it has many areas of exposed granite bedrock or areas of trace amounts of topsoil above the bedrock (MWC, 2010b; O'Conner et al., 2009). This is a significant barrier since effective infiltration through permeable pavement is dependent on the amount and type of soil. Additionally, Swisher (2002) suggests that permeable pavement should have at least one meter of soil between it and either bedrock or the water table to allow for proper filtration and storage of precipitation. This presents a number of challenges significantly limiting locations where permeable pavement can be used within the Muskoka River watershed.

7.2.4 *Reduction in Loading Ability*

Further criticism identified by the literature is that permeable pavement should not be used for areas of heavy traffic (Briggs, 1996; Jordon, 2010; Kaczmarowski, 2010). Although some research suggests that there is little concern in this area, the vast majority of articles advise that because permeable pavement is so porous, it lacks the durability and integrity of traditional pavement (Drake et al., 2010; Kaczmarowski, 2010). As a consequence, permeable pavement will begin to 'rut' if placed under the stress of high traffic flow or heavy truck use (Briggs, 1996; Swisher, 2002). Furthermore, permeable pavement has been shown to be less resistant to abrasion, resulting in aesthetic surface damage (Dierkes, 2002). This can result from a number of things, but abrasion due to snow removal is the most common occurrence in cold climates (Swisher, 2002). These elements restrict the use of permeable pavement typically to low traffic roads and parking facilities.

7.2.5 *Prone to Frost Heave*

Permeable pavement is a general term used to describe a number of different pervious techniques, including interlocking blocks as well as porous asphalts and concrete (Dietz, 2007). As a result, various permeable pavements react differently; some are prone to frost heave and others not (Campbell, 2009). It is vital that the pavement is constructed deep enough into the soil so it is below the frost line (Campbell, 2009). If this is not the case, when the ground freezes during the winter, water will not properly infiltrate. As a result, water can freeze within the pores of the pavement or become trapped within the pavement and expand resulting in frost heave (Transports Quebec, 2007). This can lead to interlocking blocks being displaced or in extreme circumstances, the cracking of asphalt and concrete (Brattebo & Booth, 2003; Transports Quebec, 2007). This is a serious problem for use in Muskoka River watershed as it can experience a number of freeze-thaw cycles throughout the winter, potentially increasing the risk of frost heave (MWC, 2010a).

7.3. Bioretention Gardens

According to the frequency analysis, the top five barriers to implementing bioretention gardens in order of incidence are terrain gradient, soil depth above the water table, minimum effective size requirements, soil permeability, and reduced performance in cold climates (Appendix A). Each barrier will be addressed in the corresponding sub-sections.

7.3.1 *Terrain Gradient*

The most frequent barrier to bioretention gardens is the terrain gradient (ACCWP, 2010; Barr Engineering Company, 2001; ESD, 2007; IDEQ, 2005; MDEP, 2006; TRCA, 2010). Since bioretention gardens provide a permeable area for surface water runoff to infiltrate, they must be made with minimal topological relief such that water has sufficient time to penetrate (Hinman, 2005). As a result, the maximum slope for bioretention gardens has been suggested to be anywhere from 5 degrees (ACCWP, 2010) to 20 degrees (IDEQ, 2005). Water flows down gradient, at a velocity directly related to the geographic slope (IDEQ, 2005); therefore the topographical relief of potential sites should be taken into consideration when implementing bioretention gardens. This will be pertinent to the Muskoka River watershed, especially as terrain can vary significantly on the shield regions (Parks Canada, 2009).

7.3.2 *Soil Depth Above Water Table*

A large portion of the reviewed literature indicates that the amount of soil above the water table was another major constraint when dealing with the implementation of bioretention gardens (ESD, 2007; Hinman, 2005; IDEQ, 2005). The general recommendation is a minimum 0.9 metres of soil between the water table and the bioretention garden (Campbell, 2009; Dreelin et al., 2006; Swisher, 2002). This precautionary measure is designed to allow nutrients, sediments or any pollutants to filtrate out and avoid any possible ground water contamination (Hinman, 2005). Furthermore, Peters et al. (1995) suggest that an impervious layer be either naturally or artificially inserted between bioretention gardens and the water table. Consequently, the shallow topsoil present in many parts of Muskoka River watershed is of great concern. Additionally, the depth to water table should be quantified prior to implementation (Peters et al., 1995). This potentially limits suitable locations for bioretention gardens within the watershed.

7.3.3 *Minimum Effective Size*

A number of articles suggest that a minimum area is required for effective drainage and performance of bioretention gardens (ACCWP, 2010; Barr Engineering Company, 2001; Hyder Consulting Limited, 2005; IDEQ, 2005; TRCA, 2010). Most studies suggest that bioretention gardens should be at least 5 to 10% of the total area being drained (ACCWP, 2008; Barr Engineering Company, 2001; Hyder Consulting Limited, 2005; IDEQ, 2005). In rural and suburban locations, the minimum area required should not be an issue, however, integrating bioretention gardens into existing urban plans may present itself as a challenge.

7.3.4 *Soil Permeability*

Characteristics of local soil properties are identified as a potential barrier for bioretention garden implementation (CWP, 2010; IDEQ, 2005; Jones Edmunds & Associates Inc., 2009; Roy-Poirier et al., 2010). If infiltration rates are slow as a result of low permeability, water may pool for extended periods of time, increasing the risk of localized flooding. Conversely, if the rate of infiltration is too rapid, there may be a risk for groundwater contamination, as the soil will not have sufficient time to filter pollutants (IDEQ, 2005). As a result, soil quality and permeability are important factors, which must be taken into consideration when identifying potential bioretention garden locations.

7.3.5 *Reduced Performance in Cold Climate*

It has been identified that during winter months in cold climates there is potential for bioretention failure (Roy-Poirier et al., 2010). Once the ground is frozen, water infiltration is reduced drastically or stops altogether. Roy-Poirier et al. (2010) explains that uncertainty surrounding the use of bioretention systems in arid and cold climate locations continue to exist. Research on how the cold climate impacts the Muskoka River watershed is needed to determine its effectiveness in this region.

7.4 Green Roofs

According to the frequency analysis, the top five barriers to green roof implementation, in order of incidence are high initial costs, technical issues and building requirements, lack of incentives and policies, a general lack of knowledge and awareness, and a lack of climate-related data (Appendix A). Each barrier will be addressed in the corresponding sub-sections.

7.4.1 *High Cost*

The most frequently identified barrier for green roof implementation is high cost (Clark et al., 2008; Dietz, 2007; Richardson & Lynes, 2007; Simcock, 2006; Williams et al., 2010; Zhen et al., 2006). There are several aspects of how the various costs of green roofs represent barriers towards adoption. First, the initial cost of a green roof is more expensive than traditional roofs, deterring many individuals from this technology (Duda, 2009; Richardson & Lynes, 2007). As Duda (2009) states, because green roofs require site-specific design, the cost of additional consultation will always be greater than those offering conventional materials and treatments. Green roofs are expensive and without monetary incentives, few private individuals are currently willing to make the investment (Sihau, 2008). Currently the market does not recognize or appropriately account for the benefits of green roofs, and rather than adopting a life cycle assessment which includes accounting for the environmental and social benefits, the economic case is the only aspect considered (Wilkinson & Reed, 2009). These factors keep green roof implementation out of reach for most private individuals and may not be fiscally viable for many businesses.

7.4.2 *Technical Requirements*

The second most frequently identified barrier in the literature for green roof implementation is the rigorous technical requirements (Carter & Fowler, 2008; Castleton et al., 2010; Duda, 2009; Stovin, 2010; Williams et al., 2010). There are many building requirements for green roofs such as the loading capacity, flooding susceptibility, lack of specialized products on the market, lack of specialized vegetation for specific climate-related regions and potential irrigation (Peck et al., 1999). It can also be technically difficult and risky to adapt existing roofs to carry the weight of a garden if structural requirements are not known. Other technical uncertainties may be related to relationships to other buildings (shading, wind, microclimate, etc.), the effect of green roofs (pollen, leaves and dirt) on mechanical units and maintenance requirements and costs (Peck et al., 1999).

7.4.3 *Lack of Incentives and Policies*

Lack of incentives and policies to promote green roof technology was identified as the third most frequent barrier for green roof implementation (Carter & Jackson, 2007; Duda, 2009; Getter & Rowe, 2006; Richardson & Lynes, 2007; Wilkinson & Reed, 2009). In North America, there are few policies and incentives to support green roof systems, despite their many proven public benefits (Peck et al., 1999; Wilkinson & Reed, 2009). As a result of the previously mentioned barrier of high costs, adoption of green roof technologies will be slow and difficult without incentives and policies promoting their implementation. Similarly, the energy savings and improved durability do not necessary justify the high initial cost and long payback period for the building owners (Liu, 2004). Unfortunately, the current market fails to address some of the non-monetary benefits green roofs offer on a community level (Liu, 2004). In this case, Liu (2004) asserts that the government should be responsible for taking leadership and providing investment to account for the market failure as well as acknowledge the significant social and environment benefits that green roofs offer.

7.4.4 *Lack of Knowledge and Awareness*

The forth most frequently identified barrier for green roof implementation is the lack of knowledge and awareness of the technology (Getter & Rowe, 2006; Goom, 2003; KWL, 2009; Richardson & Lynes, 2007; Sihau, 2008; Williams et al., 2010). Green roofs are most frequently applied in locations where they remain unnoticed, such as on top of underground parking garages or shopping malls (Peck et al., 1999). Hence, Peck et al. (1999) state that the many benefits of green roofs, both quantitative and qualitative, are not well known among the development industry, professionals, politicians and the general public.

According to Peck et al. (1999), there are four main groups of stakeholders who require additional knowledge of green roofs: policy makers, how-to professionals, researchers and the general public. First, policy makers (politicians and staff at all levels of government) require knowledge regarding the traditional and social costs and benefits of green roofs (social, environment and economic) (Peck et al., 1999). Second, the North American construction industry is poorly integrated, as every task requires a different sub trade, union and sometimes a different contract and warranty period (Peck et al., 1999). The green roof industry requires bricklayers, roofers, framers, landscapers and mechanical contractors to complete the final product. This issue can be overcome if companies arise to implement the complete project, as has been done in Europe (Peck et al., 1999). Thirdly, Peck et al. (1999) note that researchers must familiarize themselves with the existing body of knowledge so they can make meaningful contributions, such as information on detailed energy savings, appropriate growing media and vegetation befitting of the surrounding environment. The last group in need of knowledge and awareness of green roofs is the general public. The public requires knowledge about the many benefits (social, environmental and economical) of green roofs which will in turn help create a political demand for government incentives, as well as demand for residential, commercial and industrial applications (Peck et al., 1999).

7.4.5 *Lack of Climate-Related Data*

The fifth most frequently identified barrier for green roof implementation is the lack of climate-related data for specific regions (Dvorak & Volder, 2010; Simcock, 2006; Stovin, 2010; Williams et al., 2010). Connelly & Liu (2005) state that further technical research is required to understand the necessary site level performance and regional scale benefits of green roofs specific to each region. Kerr Wood Leidal Associates (2009) note that insufficient record keeping and performance monitoring of green roofs are common. Such research is necessary to establishing standards, policies and programs to support broader implementation (Connelly & Liu, 2005).

7.5 Rain Barrels

According to the frequency analysis, the top five barriers to rain barrel implementation, in order of incidence are high costs, lack of incentives and policy, lack of knowledge and awareness, the holding capacity of rain barrels and site planning (Appendix A). Each barrier will be addressed in the corresponding sub-sections.

7.5.1 *High Costs*

A significant barrier to the implementation of rain barrels is cost (Aad et al., 2010; Farahbakhsh et al., 2009; Jones & Hunt, 2010; Meder & Kouoma, 2010; Sands & Chapman, 2003; Thruston et al., 2010; Zhen et al., 2006). This is due to the fact that in most cases, the majority of the cost for rain barrels falls directly on the homeowner. Research conducted by Farahbakhsh et al.

(2009) found that 80% of respondents identified cost as the most significant barrier to rain barrel implementation. Similarly, studies conducted by Thurston et al. (2010) found that less than 55% of homeowners were willing to pay for a rain barrel on their property. Furthermore storage costs may range from $100 to $3500 depending on the size of the barrel, degree of filtration system and distance between the storage unit and place of use (Waterfall, 1998). Therefore, without financial help from the government or other sources, homeowners consider cost a large barrier to the adoption of rain barrels.

7.5.2 *Lack of Incentive and Policy*

Lack of incentive and policy resulting in low public participation was often found to be a hurdle to implementation of rain barrels (Farahbakhsh et al., 2009; Guo & Baetz, 2007; Jones & Hunt, 2010; Meder & Kouma, 2010; Sands & Chapman, 2003; Thruston et al., 2010). A study conducted by Meder & Kouoma (2010) found that only 16% of homeowners were interested in installing a rain barrel on their property. The major reason for low public participation is a product of the accumulation of the additional barriers discussed and a lack of incentive programs implemented to increase public participation (Meder & Kouma, 2010). Furthermore, long term care by the homeowner is required to maintain rain barrels (Sands & Chapman, 2003). These activities, which include emptying the rain barrel after precipitation activity as well as disconnecting and storing rain barrels’ over the winter, have been identified as a cause to homeowners’ decreasing willingness to participate in implementing this LID (Sands & Chapman, 2003). Farahbakhsh et al. (2009) identified through a public survey that an absence of public education resulted in a lack of public awareness and acceptance of rain barrel, decreasing implementation.

7.5.3 *Lack of Knowledge and Awareness*

A lack of public education on the benefits of rain barrels is found to be a barrier to implementation (Jones & Hunt, 2010; Meder & Kouma, 2010; Sands & Chapman, 2003; Thurston et al., 2010). Furthermore, a lack of education focusing on the benefits of rain barrels, installation, maintenance and their function were found to be a deterrent (Thurston et al., 2010). In fact, Meder & Kouoma, (2010) found that only 25% of the general public was familiar with rain barrels. As a result, many private citizens may be unaware of the benefits of rain barrels or their function and purpose.

7.5.4 *Holding Capacity*

Holding capacity of rainfall was found to be a barrier to implementation (Aad et al., 2010; Guo & Baetz, 2007; Jones & Hunt, 2010; Waterfall, 1998). In many cases, it was found that spills from the rain barrel storage unit have occurred, resulting in damage to the surrounding area (Guo & Baetz, 2007). Overflow and water pooling results in damage to the foundation and other surrounding structures (Sands & Chapman, 2003). Jones and Hunt (2010) found that 62% of precipitation events producing rainfall greater than 1 cm generated an overflow which could not be contained by rain barrels. Furthermore, it was found that the majority of rain barrels overflowed during storm events when connected to a roof area larger than 10 m^2 (Jones & Hunt, 2010). As a result, large storms may require greater holding capacity, resulting in a greater area required and additional cost to the homeowner.

7.5.5 *Site Planning*

Finally, site planning and suitability is identified as a barrier for rain barrel implementation (Guo & Baetz, 2007; Sands & Chapman, 2003; Waterfall, 1998; Zen et al., 2006). Inadequate site planning leads to leakage into nearby building foundations and basements as a result of overflow and water pooling of rain barrels located too close to a residence (Sands & Chapman, 2003). Furthermore, spatial constraints also further impede implementation (Sands & Chapman, 2003). Site planning including direction of water flow, site analysis information on catchment area size, distance from vegetation, and aesthetics of rain barrel location are also identified as barriers to implementation (Waterfall, 1998).

8.0 Case Studies and Solutions

The various LID practices with their subsequent benefits and barriers have been studied extensively, illustrating advantages and obstacles for the implementation of stormwater management. An essential component to a comprehensive analysis of LID practices is examining case studies to evaluate instances and situations where the techniques were utilized. The following section outlines how empirical examples will be integrated into the report to address specific barriers and to assist in providing recommendations for a successful LID implementation program. Examples illustrating practical scenarios will be crucial in outlining major areas of attention for the adoption of LID practices in the Muskoka River watershed.

The classification of LID barriers in the previous section identified several barriers that overlap between the multiple practices, while others are exclusive to specific LID methodology. Certain barriers such as permeable pavement being unable to withstand heavy traffic, or bioretention gardens requiring a certain depth of soil to the water table are site limitations that will not necessarily have solutions. These are constraints that site planners and engineers must identify for each site prior to developing implementation plans. Physical constraints such as these examples illustrate that some barriers previously mentioned do not have case studies demonstrating ways to overcome their limitations, as certain site conditions are not conducive to certain LID practices. To remedy similar situations, it is useful for planners to have multiple LID practices at their disposal. Some of the more generic and encompassing barriers such as high costs, appropriate site planning and lack of policy incentives are not easy to overcome, however have been extensively discussed in the literature.

8.1 General Barriers

This section will address the barriers present for multiple LID practices identified by the frequency analysis. These include high initial cost, lack of policy and incentives, lack of public participation and understanding and issues stemming from cold climates.

8.1.1 High Initial Cost

Because LID practices are often unconventional, new and innovative, the costs of implementation are perceived as high. This is often correlated to the established efficiency of conventional stormwater management techniques. This barrier was associated with installing green roofs, rain barrels, permeable pavement and bioretention gardens.

Although cost was identified as a barrier to implementation in the majority of the LID practices, further examination of the literature often proved this to be false. Increased costs associated with the implementation of various LID practices depend on the type of projects, the combination of LID practices used and other variables incorporated into the cost analysis (including monitoring and life cycle analysis). Furthermore, costs associated with LID practices vary, as they are dependent on site-specific factors (MacMullan & Reich, 2007). For a majority of cases, compared to conventional stormwater techniques, LID practices are often more cost-efficient (Brewer & Fisher 2004; Hume & Comfort 2004; Liptain & Brown 1996; MacMullan & Reich 2007). Liptain and Brown (1996) compared the construction costs of LID practices versus conventional stormwater methods in the Village Homes development project, Davis, California. By implementing bioswales along with various other LID techniques, Liptain and Brown (1996) note that the developer saved an estimated $192,000 (US).

MacMullan and Reich (2007) observe a variation in cost associated with four development projects: a commercial development, an elementary school as well as high and medium residential developments. LID practices compared to conventional methods are more cost efficient to implement in residential developments. However, no difference was found in cost between the two stormwater management methods in school and commercial development areas. When examined from the municipal stormwater management perspective in which both construction and associated stormwater volume costs are considered, LID practices are more cost efficient. This example illustrates that all aspects must be examined when investigating the cost of implementing LID practices.

An investigation of the construction of bioretention areas and bioswales along streets in the Summerset Community of Prince George's County, Maryland, reveals an estimated $900,000 (US) in savings to the developer as a result of substituting conventional stormwater management methods for LID (MacMullan & Reich, 2007). A study conducted by CH2M Hill, Inc. (2001) address the issue of increased maintenance costs associated with LID practices, finding that the overall implementation for the homeowner was cost efficient, as a result of a decrease in stormwater and water fees. Furthermore, Braden and Johnson (2004) conclude that LID practices increase property values by an estimated two to five percent. Additionally, a study conducted by Johnston et al. (2006) reveals an economic benefit of as much as $7,800 (US) per acre, to the overall property value as a result of reduced flooding potential. Finally, the EPA (2007) observed the retrofits of two parking lots in Bellingham, Washington, where bioretention gardens were implemented in place of conventional subterranean vaults. When comparing the cost of both options, it is found that LID practices result in a total savings of $62,000 (US) compared to conventional methods.

Table 3-Summary of cost comparisons between conventional and LID approaches in ten large scale public work projects. Adapted from EPA (2007).

Project	Conventional Development Cost	LID Cost	Cost Difference	Percent Difference
2nd Avenue Sea Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,285	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Parking Lot Retrofits	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Laurel Springs	$1,654,021	$1,149,552	504,469	30%
Mill Creek	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	2,700,650	$461,510	15%

Although cost savings vary across projects and LID practices, it has been concluded that proper planning and consultation can improve overall cost savings for projects (MacMullan & Reich, 2007). Research conducted by the EPA (2007) of 12 case studies comparing conventional stormwater methods to LID. The EPA (2007) find that implementing LID practices in the majority of cases, results in cost savings for communities, property owners and developers, with savings ranging from 15% to 80% as illustrated in Table 3.

It has been shown that mitigating high initial costs for LID techniques is feasible in a number of situations. Although high construction costs are the most apparent, Roy et al. (2008) propose that maintenance costs, costs of removing current infrastructure, and the opportunity cost on the property being used are seldom considered. Solutions to these costs have ties regarding the lack of policy and incentives available for homeowners, which will be covered next.

8.1.2 Lack of Policy and Incentives

Since the implementation of LID practices is generally low, there is little policy or incentives available for homeowners who desire or seek out installation of these stormwater management techniques. Several examples exist where communities have developed programs that have motivated the individual to incorporate LID on their property, thereby helping preserve water quality in their locality.

The goal of incentive-based policies for managing stormwater through LID techniques is to financially assist individuals and companies to employ these technologies (Roy et al., 2008). The public should absorb this, as benefits derived from the implementation of LIDs (healthy waterways, clean water) are public goods (Roy et al., 2008).

To assist in the implementation of LID practices, there are a variety of policy options that municipal governments can consider to create incentives for developers and property owners. Parikh et al. (2005) identify four policy-pricing instruments that can be used: stormwater user fees, runoff charge, cap and trade stormwater runoff allowance market and a voluntary offset program. These policy tools can be used to decrease stormwater runoff to a desired target (Parikh et al., 2005). Price incentives determine charges based on the quantity of stormwater runoff that each parcel generates, and must be set to the point where marginal cost equals the runoff charge (Parikh et al., 2005; Stavins, 2001).

A common tool used to create incentive-based policies is a fee and rebate program. This system encourages homeowners to take responsibility for the stormwater created on their properties. This program charges fees in proportion to stormwater generated on private property, while rebates are given to those utilizing abatement technologies such as LID (Roy et al., 2008).

Thurston (2006) claims that the fee and rebate mechanism closely resembles the traditional Pigouvian tax method, as a uniform local tax increase is coupled with a rebate to reward a desirable behaviour. A pigouvian tax is where a levy is applied such that individuals bare the full marginal social costs of their activities (Eskeland, 1994). Social costs include externalities such as pollution control. For successful adoption of a fee and rebate program, the rebate and fee that homeowners are eligible for must be significant enough to encourage the adoption of LID practices. Successful cases of this policy tool exist in the U.S.; however, the majority of the programs are available exclusively for commercial participation (Thurston, 2006). There are examples of municipalities which have used this approach, however stormwater fees were small, ranging from $0.26 - $2.70 per month (Doll & Lindsey, 1999; Doll, Scodari, & Lindsay, 1998), resulting in minimal impact on homeowner incentives. Therefore, economic incentives must be appropriately priced to encourage homeowner mitigation of stormwater management.

Initial cases of LID incorporation in municipal policies are found in British Columbia, Canada. Zoning bylaws in the cities of Port Coquitlam and Richmond enforce the construction of green roofs on all large-scale commercial and industrial roofs (KWL, 2009). However, insurance companies were originally apprehensive about insuring these buildings. Only until recently has a building in Vancouver received a commitment from a major insurer (KWL, 2009). This was an important success in overcoming another barrier in policy implementation. Similarly, financial incentives for green roofs have been offered in Toronto, Ontario, with the Green Roof Incentive Pilot Program (KWL, 2009). Industrial, commercial and large-scale residential units received a greater incentive than the single family (\$50/m^2 vs. \$20/m^2), due to the potential for a greater overall impact on stormwater retention. Regardless, this initiative has promoted the development of green roofs for all building owners.

The city of Portland, Oregon, has also incorporated a green roof mandate for all new public buildings into a program that sets aside finances for managing stormwater (KWL, 2009). Portland also has developed a unique incentive system, providing floor area ratio bonuses, which essentially increases a building's allowable area (KWL, 2009). Depending on the green roof percentage of the building's footprint area, owners are rewarded by the opportunity to add floor area in excess of local building regulations. This incentive is powerful in areas where land is scarce and expensive. The New York State Legislature passed a bill that provides a tax credit for installing green roofs and the City of Chicago has initiated a grant program that has helped launch the cities goal to become the U.S. leader of green roof area (KWL, 2009).

Certain areas, most notably in German municipalities, charge residents fees for the amount of impervious area on the property (KWL, 2009). It has been shown that green roofs have helped reduce fees by up to 50% (KWL, 2009). Furthermore, municipal jurisdictions can promote the implementation of LID practices by updating zoning codes and building inspection standards to specifically address LID stormwater controls, decreasing risk and transaction costs for developers (Coffman et al., 2000; Foss 2005; Lewis 2006; MacMullan & Reich, 2007; NAHB, 2003).

A case study conducted by Meder and Kouma (2010) in the City of Lincoln, Nebraska, observes the effects of implementing homeowner incentives to promote the adoption of LID. The city implemented a pilot project that focused on increasing incentives to encourage and assist homeowners to employ rain barrels and rain gardens. The City of Lincoln, though more urban-intensive, contains a similar population size to the Muskoka River watershed of 248,000, has implemented the Holmes Lake Watershed Improvement Program. This aims to inform and create incentives for private homeowners to implement LID. The program included educational materials for single-family residences and an application process for rain garden or rain barrel installation.

After a public meeting regarding this program, over 55 applications for rain gardens and 30 applications for rain barrels were received. The program funded 90% of the cost of the rain barrels and gardens. Further educational programs included public meetings, a general awareness campaign and direct mailings of educational material to the public. Overall, the cities incentive program increased homeowner interest in the installation of a rain gardens by 12% and rain barrels by 24%. In addition, homeowner awareness and familiarity with rain barrels increased by 42% and rain gardens by 34%. Furthermore, rain barrel sales increased more than 800% between 2008 and 2009. Overall, examining these case studies and incorporating aspects of the policy and incentive programs can assist the MWC in the implementation of an LID stormwater management plan.

8.1.3 Lack of Public Participation and Understanding

Lack of public participation and understanding was identified as a major barrier for green roofs, rain barrels and bioswales. Regardless of the economic incentives used to encourage LID implementation, if communities have limited experience with LID technologies, professional training, education and design, adoption will be difficult (Roy et al., 2008). Roy et al. (2006) and Thurston et al. (2010) note the potential of the general public, specifically homeowners, in which they can significantly influence the implementation of LID. Brown and Clarke (2007) state that new stormwater management techniques must be socially embedded in the local institutional context, as they cannot sustain themselves in isolation. This requires participation from all stakeholders involved.

The City of Lincoln developed a community-based program for public empowerment, participation and education (Meder & Kouma, 2010). After two years of education and public awareness, opinion polls illustrate significant increases in the number of citizens who both understand issues pertaining to degraded surface water and who have increased interest in incorporating LID on their property (Meder & Kouma, 2010). To increase community awareness on green roofs, the City of Portland provided resources to help individuals and building owners install these systems through funding, demonstration projects, technical support and the creation of local education and outreach (KWL, 2009). These case studies illustrate the effectiveness of public education to reinforce citizens' understanding and acceptance of LID. Gaining acceptance and momentum from all stakeholders is imperative for the approval of widespread LID implementation.

8.1.4 Issues with Cold Climates

Issues with site planning extend to seasonality, especially in northern climates such as the Muskoka River watershed. Cold climate can be a barrier for many LID practices (green roofs, permeable pavement and bioretention gardens), as many rely on the infiltration of stormwater into permeable ground (Denich & Bradford, 2008). Similarly, LID practices may be vulnerable to freeze-thaw cycles (permeable pavement) and the reduction of filtering performance from dormant soil organisms (Roseen et al., 2009).

From an experiment in Guelph, Ontario, Denich and Bradford (2008) show how infiltration can still occur in bioretention gardens under frozen conditions. Although the uppermost layer may freeze in these designs, sufficient insulation is provided by the soil to ensure deep freezing does not occur, allowing infiltration to continue (Denich & Bradford, 2008).

At the University of New Hampshire Stormwater Centre, a cold climate study illustrates that filtration systems (such as bioretention gardens, green roofs and permeable pavement) did have frost penetration; however, the frost did not affect the overall hydraulic performance (Roseen et al., 2009). Although frost can alter these LID systems, it is concluded that frozen ground still possesses a significant level of porosity to allow effective infiltration (Roseen et al., 2009). Furthermore, Roseen et al. (2009) illustrate that with the exception of nitrate, seasonal contaminant removal performance does not vary for the LID practices.

8.2 Barrier to Implementing a Watershed-Based Approach

This section will address the barrier of implementing LID on a watershed scale. This barrier was not identified in the frequency analysis of each LID method; however is included in the discussion due to its importance to the success of LID implementation in the Muskoka River watershed.

In the Muskoka Watershed Management Strategy, it is well documented that the District Municipality of Muskoka recognizes the necessity of having a watershed-based strategy to deal with issues pertaining to water quality (Aquafor Beech Limited, 2008). This is reiterated, as a focus group consisting of numerous stakeholders in the region, stressed the need for a “made in Muskoka approach” (Aquafor Beech Limited, 2008).

To implement effective watershed-based programs; legislative, institutional, economic, and social goals need to be consistent (Roy et al., 2008). Roy et al. (2008) further suggests that implementing watershed-scale management of stormwater has seven major barriers, which are summarized in Table 4 along with solutions to overcoming the impediments.

Table 4-Major impediments and solutions to sustainable stormwater management at the watershed-scale. Adapted from Roy et al. (2008).

Impediment	Solution
Uncertainties in performance and cost	Conduct research on costs and watershed-scale performance - Particularly on costs and benefits - Comparing LID to conventional methods - That LID technologies throughout watersheds will improve stream quality
Insufficient engineering standards and guidelines	Create a model ordinance and promote guidance documents - Set performance standards maintaining natural/near-natural hydrological conditions - Gives developers and engineers the flexibility to use most suitable method
Fragmented responsibility	Integrate management across levels of government and the water cycle - Create incentives for collaboration between agencies - Increase communication between stormwater managers, urban designers, stream managers, and water supply managers
Lack of institutional capacity	Develop targeted workshops to educate professionals - To train engineers, planners, and policy makers about importance of watershed-scale approach - How to prioritize management, importance of consistent application, tools to incentivize runoff mitigation
Lack of legislative mandate	Use grassroots efforts to garner support for ordinances and regulations
Lack of funding and effective market incentives	Address hurdles in market approaches to provide funding mechanisms - Place fee and rebate values high enough to encourage abidance - Use of reverse auctions
Resistance to change	Educate and engage the community through demonstrations - Educate on need to secure water supply - Potential increases in property value - LID can be very aesthetically pleasing in developments

The Etowah Basin is a case where a watershed based approach was successfully developed. Although this program was initiated to mitigate stormwater runoff to protect endangered fish species, its relevance to Muskoka's need for a watershed based approach cannot be overlooked. The Etowah Basin established a Runoff Limits Program where the river basin is segmented into differing priority areas depending on the proximity to the threatened species (Wenger et al., 2006). High priority areas were required to limit stormwater runoff to what would occur in forested conditions, while lower priority areas were permitted increases in runoff equivalent to 5% impervious cover (Roy et al., 2008). Also included in this program were small developmental areas with low standards for runoff; however these locations were established based on modeling for the least sensitive areas of the watershed (Wenger et al., 2006). In these zones, the developers were required to utilize LID measures to return runoff to the soil close to where it is generated (Ray et al., 2008). Although this program was based on a threatened aquatic species, the design will be useful for the Muskoka River watershed. It will allow for a tailored approach, considering both regions with more sensitive or damaged environments, and areas of dense populations.

Melbourne, Australia was one of the first cities to get involved with LID technologies, and their need is well recognized in the community (Brown & Clarke, 2007). In order for a watershed-based program to be successful, there is still a gap in incorporating these techniques into everyday practice (Roy et al., 2008). The Clearwater Program was initiated to provide information on stormwater management using a participatory approach by providing training workshops on construction, stormwater modeling tools, and negotiation skills (Roy et al., 2008). Also, a heavy emphasis is placed on encouraging local municipalities to incorporate LID into their projects, such as road construction and renewal of commercial areas (Roy et al., 2008). On top of government co-operation, they used a participatory approach by running workshops on construction and stormwater modeling for engineers and other related professionals (Brown & Clarke, 2007). The development of working relationships between these groups created incentives to collaborate and also reduced the fragmentation of responsibilities (Brown & Clarke, 2007). This case study highlights the importance of having a top-down (regulatory) and a bottom-up (assistance) approach in employing LID practices (Roy et al., 2008). It will be vital that the interests of individual property owners, developers, and municipal and provincial sectors all be considered during the development of an LID strategy for the Muskoka Watershed. This multi-tiered approach has been proven effective in numerous instances because of consistent social, economic, institutional, and legislative agreements (Roy et al., 2008).

9.0 Advancing Low Impact Development Initiatives: Solutions and Tools

Throughout this report, data has been presented through content analysis of literature studies to outline benefits and barriers derived from the use of LID. The recommendations presented are based on current literature to be treated as a foundation for further policy development and literature guidance for LID implementation. Finally the programs and solutions recommended are formed on the basis of their success in similar case study situations; however given the nature of these programs, it is expected that an inherent level of modification will be required for their practical implementation.

Stormwater systems whether traditional or LID, are a large undertaking by any governmental body and as a result require a significant level of dedication. It is expected that there will be a large preliminary capital investment in order to initiate a project of this magnitude. There will also be significant continuing costs through the full implementation of this project, as various barriers identified will need to be overcome. This section outlines recommendations for a project to effectively implement LID systems throughout the Muskoka River watershed, as it progresses through its full execution.

9. 1 Low Impact Development in the Short Term: Reaching Out

Stormwater management is a serious undertaking as it requires significant resources and commitment. Projects of this magnitude require a considerable level of confidence by members of the public, as it is the taxpayers who ultimately fund this project. As a result, it is important to ensure that the public fully understands the benefits and risks of LID prior to its widespread implementation. Therefore public education is important for major projects taken on by local governments and even more so when implementing a technology that is perceived as novel, or unfamiliar to the daily lives of the general public. Such is the case in alternative stormwater management. Programs designed to educate the public should be a first step, focusing on:

- How most common LID systems work (rain barrels, bioretention gardens, etc.)
- Benefits provided by LID systems, relative to other more traditional options
- Perceived barriers to LID systems and how the Muskoka River watershed plans to overcome
- The ecological and environmental importance of having an effective stormwater mitigation plan
- Identifying strategic policy direction for further implementation

An educational program involving the above could be in the form of public town hall presentations, media advertisements, or mailed brochures.

An education program could be made more effective if coupled with a high profile public LID project, for example a highly publicized green roof system on a local public building (Peck et al., 1999). This not only allows members of the public to witness firsthand how LID works, but also allows for a chance to understand the multiple benefits. A public display also shows the amount of initiative the municipality is willing to undertake to implement LID within the community.

Additional steps suggested to be taken in the short term are of equally importance. The Muskoka Watershed Council should take responsibility for the designation and prioritization of areas of specific concern. By identifying highly impermeable areas, it will be easier to focus the locations of initial LID systems in order to be more effective and allow for more readily observed results. These sites will most likely be focused in areas of highest urban concentration (Appendix C). It is recommended that the short term be used to layout a framework of public co-operation and understanding so implementation of physical systems can be properly facilitated.

9.2 Low Impact Development in the Mid Term: A Progression Forwards

Once a framework is in place to promote public understanding and confidence, the next step is the implementation of physical infrastructure and to further push the development of local policy. This will help ensure that LID can transition from being a simple novelty to a common building practice. The mid term should focus on a wider scale implementation of LID on public and private lands as well as areas identified as locations of specific concern.

Individual LID systems will be determined by site specific requirements and insurmountable barriers, as illustrated in Section 7.0 Barriers. However, it is likely that in most locations, in order to maximize efficiency of stormwater mitigation, multiple LID systems should be used in combination. An example is illustrated in Figure 9 where a permeable pavement slopes in such a way that it slowly drains into a bioretention garden.

Figure 9 - An illustration on the combination of permeable pavement and a bioretention garden in a parking lot. Adapted from ERTH Products (2009).

Combinations such as this allow for more efficient runoff mitigation and pollutant filtration as well as reduce stress applied on any individual system during peak storm events.

Education programs should continue throughout the implementation of the LID program, however; if it is felt that the general public has an adequate comprehension of the program, a shift from focusing on the public to identifying short falls in industry education can occur. Dietz (2007) identified that for many LID systems, experienced or skilled installers are required. This is especially true when dealing with technical LID systems such as green roofs or permeable pavement. By refocusing educational efforts to local industry professionals, technically demanding LID systems are possible without costly outsourcing (van Roon, 2007). It is also the intent that by educating contractors and site planners on the benefits of LID systems, stormwater management will begin to be incorporated into building plans, without additional policy incentive.

9.3 Low Impact Development in the Long Term: Steps Toward Sustainability

As the Muskoka Watershed Council continues to move forward in implementing an alternative stormwater program, it can slowly make the progression from concentrated implementation to wide spread employment, as well as general operation and maintenance. It is in the long term where LID systems will show their true worth and significant cost savings (Dietz, 2007). Cost savings allows for a great deal of flexibility in how programs can be structured in the long term. However, flexibility presents a cross roads in how the Muskoka Watershed Council can manage stormwater. The Muskoka Watershed Council can decide to keep the implementation of LID and management of stormwater a strictly public responsibility, much as convention dictates with traditional stormwater systems. Alternatively, the Muskoka Watershed Council can allow for the decentralization of stormwater, in which public and private LID implementation combine for the benefit of the public as well as the environment.

9.3.1 ***Hybrid Management of Stormwater***

Historically the management of stormwater has been a strictly public responsibility. This is a large task for municipalities and is typically run at great expense to the taxpayer. LID alternatively is cost efficient and if the Muskoka Watershed Council decides that in the long run it would like to maintain its full control and responsibility over stormwater management, there are a number of options available. By relying solely on public resources, the Muskoka Watershed Council would have to maximize the use of public lands for the placement of LID systems. This would place a significant amount of limitation on the effectiveness of LID systems as technical constraints (see 7.0 Barriers) which would restrict locations suitable for placement. Consequently the Muskoka Watershed Council would in all likelihood have to alternatively turn to placement on private lands for efficient stormwater management. In a hybrid public/private management system, both the municipality and private citizens would be responsible for management and mitigation of stormwater. One suggestion would be the implementation of a tax system similar to one found in some German municipalities (Roy et al., 2008), in which residential and commercial landowners must pay a tax in proportion to the amount of impervious surface found on their property. This option would promote a reduction in impervious area, reducing stormwater runoff, however it could be met with significant opposition from the public (Kollmann & Schneider, 2010; Metcalf, 2008). An alternative is the promotion of private LID efforts in the form of a subsidy or rebate. Positive reinforcement through a subsidy or rebate is typically well received in comparison to negative reinforcement like taxation measures. Cost savings generated from the initial implementation of LID would be able to initiate a fund to either help finance private LID projects or assist in compensating private citizens who reduce their stormwater impact. By having private citizens take initiative on LID projects, the

Muskoka Watershed Council can reduce its liability for maintenance and monitoring without compromising its goal of reducing the impacts of stormwater runoff.

The Muskoka Watershed Council, while responsible for stormwater within its boundaries can play a pivotal role in facilitating stormwater management protocols throughout Ontario. Currently there is a profound lack of stormwater management policy in Ontario and although programs such as the Source Water Protection Act exist, which aim to reduce water contamination threats, there are very few which deal with reducing the effects of stormwater directly. As the Muskoka Watershed Council builds up a municipal policy framework to deal with stormwater, it is important that they work with other levels of government. They must not only identify the need for wide ranging policy but also look to other levels of government as a potential funding source. This may be an important way to relieve the cost of implementing alternative stormwater infrastructure similar to the financial assistance, which is in place for traditional waste and stormwater systems (Ministry of Energy, 2010).

The final recommendation is the development of a report card system for stormwater management in the Muskoka River watershed. This would follow a similar format to the watershed report card (MWC, 2010a) in which frequent monitoring of the watershed and areas of high concern are assessed on a reoccurring basis. A report card in this fashion would be able to illustrate to both the public and professionals the effects of LID in a transparent fashion. This would also allow the Muskoka Watershed Council to continually reassess and focus efforts such that stormwater's effects are properly mitigated for the benefit of the entire watershed.

10.0 Conclusion

This report successfully identifies both benefits and barriers to implementing an LID program in the Muskoka River watershed. Overall, the literature identifies significant benefits to implementing LID systems, citing vast improvement in water quality and providing considerable economic savings. There are however a great number of important barriers which must be addressed, specifically alleviating public misconceptions and physical constraints. The Muskoka Watershed Council must forge specific short and long term goals to overcome key barriers such that the implementation of an LID program is feasible.

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Appendix A- Tables & Figures for LID System Frequency Analysis

The results of the frequency analysis for each of the five LID practices identified (Bioswales, Permeable Pavement, Bioretention Garden, Green roofs, and Rain Barrels). Shown below, each practice has a figure illustrating top five barriers as identified by the frequency analysis, a table listing all barrier types identified through the analysis, and a frequency table with all journal sources and total frequency of barrier types.

Table E.1- Barrier description key for bioswales

Barrier Type	Barrier Description
Type 1	Design & Location
Type 2	Lack of Knowledge & Awareness
Type 3	Monitoring & Maintenance
Type 4	Flooding & Inundation
Type 5	Lack of Incentives & Policy
Type 6	Retention of Certain Pollutants Only
Type 7	Seasonal Variations in performance

Table A.2- Barrier description key for permeable pavement

Barrier Type	Barrier Description
Type 1	Clogging
Type 2	Higher Implementation Cost
Type 3	Effectiveness Depends on Soil Type
Type 4	Not For Heavy Traffic Use
Type 5	Prone to Frost Heave
Type 6	Potential for Groundwater Contamination
Type 7	Reduced Lifespan
Type 8	Increased Maintenance Cost
Type 9	Prone to Abrasion
Type 10	Must Have Low Slope
Type 11	Reduced Infiltration Capacity in Cold Weather
Type 12	Limited Information on Long Term Performance
Type 13	Sinkholes Can Develop in Calcarious Areas
Type 14	Experienced Installers Required
Type 15	Require Modified Roadbeds

Table A.3- Barrier description key for bioretention gardens

Barrier Type	Barrier Description
Type 1	Terrain Gradient
Type 2	Depth to Water Table
Type 3	Minimum Effective Size Requirement
Type 4	Soil Permeability
Type 5	Reduced Performance in Cold Climates

Table A.4-Barrier description key for green roofs.

Barrier Type	Barrier Description
Type 1	Cost
Type 2	Technical Requirements
Type 3	Lack of Incentives & Policies
Type 4	Lack of Knowledge & Awareness
Type 5	Lack of Climate-Related Data
Type 6	Lack of demonstarated feasibility
Type 7	Risks associated with uncertainty
Type 8	Benefits not represented in the market
Type 9	Lack of communication between professionals
Type 10	Lack of relevant and reliable research
Type 11	Widely diverging municipal management practices
Type 12	Absence of third party testing and verification of green roof systems
Type 13	Asthetics

Table A.5-Barrier description key for rain barrels.

Barrier Type	Barrier Description
Type 1	Cost
Type 2	Lack of Incentives and Policy
Type 3	Lack of Knowledge and Awareness
Type 4	Capacity
Type 5	Site Planning
Type 6	Overflow
Type 7	West Nile / mosquitos
Type 8	Liability
Type 9	Limited use
Type 10	Pollution

Table A.6-Individual responses from the frequency analysis of barriers for bioswales based on 20 journal articles.

	Bioswales - Barrier Type							
Source	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	**Total**
Abida & Sabourin, 2006	✓	✓	✓	✓	✓	✓		6
Barrett et al., 1995	✓		✓	✓		✓		4
Barret, 1998	✓		✓	✓				3
Cappiella et al., 2008	✓	✓	✓		✓			4
Dietz, 2007	✓	✓	✓			✓		4
Elfering, 2002	✓							1
Kaighn and Yu, 1996	✓		✓					2
Mazer et al., 2001	✓	✓	✓	✓		✓	✓	6
NCTCOG, 1993	✓	✓		✓				3
Roseen et al., 2009	✓	✓					✓	3
Schueler et al., 1992			✓		✓	✓		3
Thurston et al., 2010		✓			✓			2
Stockwell, 2009		✓		✓	✓			3
Storey et al., 2009	✓	✓	✓					3
Walsh et al., 1998	✓				✓		✓	3
Wulkan, 2008	✓	✓	✓		✓			4
Vlotman et al., 2007	✓	✓		✓	✓			4
Young et al., 1996	✓		✓			✓		3
Yousef et al., 1985	✓	✓		✓		✓		4
Yu et al., 1993	✓	✓	✓	✓				4
Frequency	17	13	12	9	8	7	3	69

Table A.7-Individual responses from the frequency analysis of barriers for permeable pavements based on 20 journal articles.

	Permeable Pavement - Barrier Type															
Source	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10	Type 11	Type 12	Type 13	Type 14	Type 15	**Total**
van Duin et al., 2008	✓										✓	✓				3
Brattebo & Booth, 2003	✓	✓			✓			✓								4
Dunn, 2010		✓														1
Scholz and Grabowiecki, 2007	✓						✓					✓				3
Swisher, 2002	✓	✓	✓						✓	✓			✓			6
Broadword & Rhinehart, 2010		✓	✓							✓						3
Dietz, 2007	✓				✓	✓					✓			✓		5
Kaczmarowski, 2010	✓	✓		✓				✓								4
Jordan, 2010	✓			✓												2
Drake et al., 2010	✓	✓	✓				✓	✓								5
Gregerson, 2010		✓					✓									2
Obla, 2010	✓								✓							2
Campbell, 2009	✓	✓	✓	✓	✓											5
Biggs, 1996	✓	✓		✓	✓	✓										5
Dierkes et al., 2002	✓				✓	✓			✓						✓	5
Montalto et al., 2007		✓					✓									2
Urbonas, 1999	✓					✓										2
Dreelin, 2006	✓		✓	✓						✓						4
Boving, 2008	✓					✓										2
Giuliani, 2002	✓							✓								2
Frequency	16	10	5	5	5	5	4	4	3	3	2	2	1	1	1	67

Table A.8-Individual responses from the frequency analysis of barriers for bioretention gardens based on 20 journal articles.

	Bioretention Garden - Barrier Type					
Source	Type 1	Type 2	Type 3	Type 4	Type 5	Total
Knox County, 2010	✓	✓	✓			3
Toronto & Conservation Region, 2010	✓	✓	✓			3
Puget Sound Action Team, 2005	✓	✓				2
Massachusetts Department of Environmental Protection, 2006	✓	✓	✓			3
Idaho Department of Environmental Quality (IDEQ), 2005	✓	✓	✓	✓		4
Alameda Countywide Clean Water Program, 2008	✓	✓	✓			3
California Stormwater Quality Association, 2003	✓	✓	✓		✓	4
Environmental Services Division, 2007	✓	✓				2
Metropolitan Area Planning Council, 2010	✓	✓				2
Dublin City Council, 2005	✓	✓	✓			3
Los Angeles County Department of Public Works, 2002	✓	✓				2
Metropolitan Council, 2001	✓	✓	✓			3
LID Local Regulation Assistance Project, 2009	✓	✓				2
Washington State University Pierce County Extension, 2005	✓	✓				2
Center for Watershed Protection, 2010	✓			✓		2
Poirier. A. R., Champagne. P., and Filion. Y., 2010	✓	✓	✓	✓	✓	5
Washington State Department of Transportation, 2006	✓	✓		✓		3
Jones Edmunds & Associates, Inc, 2009	✓	✓		✓		3
Department of Environmental Resource, 1999	✓	✓		✓		3
Frequency	19	18	9	6	2	54

Table A.9-Individual responses from the frequency analysis of barriers for green roofs based on 20 journal articles.

	Green roofs - Barrier Type													
Source	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10	Type 11	Type 12	Type 13	**Total**
Peck et al., 1999	✓	✓	✓	✓			✓	✓						6
Connelly & Liu, 2005					✓	✓						✓		3
Richardson & Lynes, 2007	✓	✓	✓	✓					✓			✓		6
Wiliiams et al., 2010	✓	✓	✓	✓	✓	✓				✓				7
Carter & Fowler, 2008	✓	✓	✓				✓							4
Clark et al., 2008	✓										✓			2
Dietz, 2007	✓	✓				✓								3
Dvorak & Volder, 2010					✓	✓								2
Zhen et al., 2006	✓													1
Carter & Jackson, 2007			✓						✓	✓				3
Duda, 2009	✓	✓	✓				✓	✓		✓				6
Lui, 2004	✓		✓					✓						3
Sihau, 2008	✓	✓	✓	✓			✓						✓	6
Stovin, 2010	✓	✓	✓		✓	✓	✓				✓			7
Wilkinson and Reed, 2009	✓	✓	✓	✓	✓	✓		✓			✓			8
Getter & Rowe, 2006	✓	✓	✓	✓	✓	✓			✓					7
Simcock, 2006	✓	✓		✓	✓		✓		✓					6
Castleton et al., 2010	✓	✓												2
Goom, 2003	✓	✓		✓										3
Metro Vancouver, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	11
Frequency	17	14	12	9	8	8	7	5	5	4	3	2	2	96

Table A.10-Individual responses from the frequency analysis of barriers for rain barrels based on 10 journal articles.

	Rain Barrels - Barriers Type										
Source	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type 10	**Total**
Thurston et al., 2010	✓	✓	✓								3
Waterfall, 1998				✓	✓						2
Aad et al., 2010	✓			✓		✓					3
Meder and Kouma, 2010	✓	✓	✓								3
Sands and Chapman, 2003	✓	✓	✓		✓		✓				5
Guo and Baetz, 2007		✓		✓							2
Farahbakhsh et al., 2001	✓	✓						✓	✓	✓	5
Zhen et al., 2006	✓			✓							2
Jones and Hunt, 2010	✓	✓	✓		✓						4
Frequency	7	6	4	4	3	1	1	1	1	1	29

Appendix B- Additional information regarding private landowner implementation of LID systems in the City of Lincoln, Nebraska.

Table B.1-General public survey results on familiarity with LID terms, before and after public education programs (2008-2009). Adapted from Meder & Kouma, 2010.

Number of Respondents	General Public 2008 n=302	General Public, 2009 n=257	Percentage Difference (%)
Rain Barrel	25%	67%	+42%
Rain Garden	7%	41%	+34%
Both	33%	36%	+3%

Table B.2- Total in rain barrel sales at various outlets from (2008-2009), including the percent change over that time period. Adapted from Meder & Kouma, 2010.

Retailer Type	2008	2009	% Change	Total
Commercial Retailers	48	235	390	283
Recycled Retailer	0	305	N/A	305
KNB Materials Exchange	47	200	325	247
Rain Barrel Classes	20	161	705	181
Artistic Rain Barrel Auction	0	25	N/A	25
Total (Number of Barrels)	**115**	**926**	**705**	**1,041**

Table B.3- Inventory of locations supplying rain barrel (2007-2009). Adapted from Meder & Kouma, 2010.

Retailer Type	2007	2008	2009
Commercial Retailers	5	7	11
Recycled Retailer	0	0	2
KNB Materials Exchange	1	3	3
Rain Barrel Classes	0	2	16
Artistic Rain Barrel Auction	0	0	1
Total (Number of Locations)	**6**	**12**	**33**

Appendix C-Figure C.1
Map of the District of Muskoka. Areas of urban intensification outlined in red.