Planning For The Future: Framework Towards Achieving Co-Benefits Through Beneficial Management Practices In The Credit Valley Watershed, Ontario

by

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Abstract

As the population increases, development pressures, especially in large urban centers, have created a lot of stress on ecosystems, and the ecosystem functions and services that they provide. Issues such as loss of wetland and paving over pervious surfaces has led to increased runoff, low infiltration rates and degradation of the quality of source and non-point source water. Roads, parking lots and other forms of impervious cover are the most significant contributors to stormwater runoff.

Effective stormwater management is therefore crucial in such urbanized areas. Low Impact Development (LID) is an innovative stormwater management design philosophy and approach that is closely modeled after nature. Its main goal is to manage rainfall at the source using uniformly distributed, decentralized units such as permeable pavement, bioswales and green roofs. . The principle of LID is to mimic a site's pre-development hydrology by using design techniques that infiltrate, filter, store, evaporate and detain runoff close to the source. The term "Green Infrastructure" is also used when referring to LID. LID can be used individually or incorporated into conventional stormwater management systems to achieve maximum benefits.

Human health and well-being are fundamentally dependent on the services provided by the ecosystems that surround us. The field of ecohealth attempts to make this connection and use it to improve public health, promote resilient communities, and create more sustainable environments.

This paper attempts to analyze the connections between three selected Low Impact Development and its effects on the ecosystem services that ultimately affect the health and wellbeing of humans in the Credit River watershed in Southern Ontario, Canada. Ecohealth theories developed by the Millennium Ecosystem Assessment (MEA) (2005; 2003) and the cascade model of ecosystem services (Haines-Young & Potschin, 2010; Braat & de Groot, 2012; Potschin & Haines-Young, 2010) were used to help develop and illustrate the concepts and relationships being researched.

Foreword

The following paper was written in partial fulfillment of achieving some of the learning objectives of my plan of study as well to cover my overall area of concentration; Environmental Planning and Sustainable Development. My plan of study includes three main components: Environmental Planning; Sustainable Development & Environmental Resource Management and; Integrated Watershed Management and It's Relationship With Human Health and Well Being. Through this major paper I have managed to fulfill the learning objectives of all three components.

My first learning component was oriented to understand the basics of being an environmental planner. This included learning about the theories, regulations and policies that were involved in the field of environmental planning. For this project I was required to do a lot of background research not only on the theoretical framework of the Millennium Ecosystem Assessment and the ecosystems approach to health, but also on the various land use and stormwater management polices that were in place in Ontario. This was very educational for me in not only understanding the theories of the polices in place, but also to understand how to interpret legislature. In addition, for this project I met with a lot of professional environmental planners not only in the Credit Valley Conservation Authority (CVC) but also in the Toronto and Region Conservation Authority (TRCA). This gave me exposure and an insight into the work of an environmental planner working specifically in a conservation authority.

The second component of my plan of study was the main field in which I was interested in even before I started my MES degree, which was Sustainable Development and Environmental Resource Management. The third component of my plan of study however was added a couple of months into the program, which is Integrated Watershed Management and its Relationship with Human Health and Well-Being. Through this project I was introduced to watershed management, and I have found that the concepts of sustainable development and integrated watershed management are very complimentary. The addition of the human health and well-being component rounded up my plan of study and helped integrate similar disciplines that are often tackled separately: which is ecosystem health and human health. The project included an insight as to how nature greatly improves our mental, physical and social wellbeing and it is something that needs to be understood, especially in an increasingly urbanized environment where the disconnection between humans and nature is at its worst.

One of the main components of this paper is Low Impact Development (LID). Through this project I gained considerable knowledge on this subject and it has awakened a deep interest in me to study this subject further. The toolkits attached here as appendices provide in depth information on the health and well-being benefits of LID, while through the context paper I hope to address the concept of LID and how it will help in solving many environmental issues we face today in a highly urbanized landscape.

Acknowledgments

First of all, I would like to thank my supervisor Professor Martin Bunch in the Faculty of Environmental Studies at York University, for all the support and guidance that he has given me throughout this MES journey. I am thankful for his patience when dealing with tight deadlines and always being a very understanding professor to a flustered MES student!

I would also like to thank Tatiana Koveshnikova of CVC for acting as my field supervisor at CVC and providing me with much needed inputs and advice for my work on this project.

I want to thank my close friends and peers, especially Elizabeth Paudel and Kemal Kapetanovic, for all the support and motivation that you guys gave me throughout this journey. Thank you!

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CONTEXT PAPER:

URBANIZATION AND LOW IMPACT DEVELOPMENT (LID)

1.0 INTRODUCTION

Human health and well-being are greatly interconnected with our surrounding environment. The fundamental dependence that humans have on the ecosystems is clearly evident by the numerous ecosystem services that humans are dependent upon. The term "ecosystem service" refers to the delivery, provision, protection or maintenance of goods and benefits that humans obtain from ecosystem functions (Millennium Assessment, 2003; de Groot et al., 2002; Bolund and Hunhammar, 1999). These ecosystem functions include biotic, bio-chemical and abiotic processes within and between ecosystems (Turner et al., 2005; Brussard et al., 1998). In a non-exhaustive list, Groot et al. (2002) identified 32 ecosystem services including biological, physical, aesthetic, recreational and cultural services that are derived through fundamental ecosystem functions. Similarly, Costanza et al (1997) describe seventeen services and functions that benefit society, such as: climate regulation, water regulation, nutrient cycling, and pollination. These services have been also shown to be provided in urban settings by constructed landscapes (Bolund and Hunhammar 1999).

Rapport et al. (1998) saw that linking ecosystem health to the provision of ecosystem services, and determining how an ecosystems' health (or alternatively dysfunction) related to these services, is one of the means to identify how health, social and natural sciences interface together.

In recent years, concepts of bio mimicry, biophilia, Low-Impact Development (LID) and the re-intersection of the public health and planning professions have gained momentum in research and in practice. This is due to the increasing need to apply a holistic approach in understanding the function and services of ecosystems, and to reconnect humans into nature (Steele, Wendy, and Nidhi Mittal, 2012.)

This project was done in collaboration with the Credit Valley Conservation (CVC) authority, to determine how different landscape “interventions” or “conservation actions” help to improve the functioning of ecosystem functions and services in the Credit River watershed. Watersheds play a vital role in providing ecosystem services such as water filtration, flow regulation, waste treatment, recreation, wildlife habitat and flood control, and the proper function of these services are very important to maintaining human health and well-being.

This paper will focus on the set of interventions that I researched, which are collectively known as “Low Impact Development” (LID) techniques. Low impact development (LID) is a relatively new, innovative stormwater management practice and design strategy that attempts to mimic pre-development hydrological functioning in urban areas by managing rainfall at its source.

I will highlight how urbanization has brought forth many environmental impacts and how innovative techniques like LID can help mitigate these impacts, while providing benefits to human health and well- being that are not usual of a conventional stormwater management system. In this paper, I have referred to concepts such as sustainable development, resilience theory, systems thinking and the ecosystems approach to health (ecohealth) as a fundamental basis of development that can be achieved through integration of LID into urban planning. I have researched three separate LID interventions, namely: Permeable pavement systems, Bioretention Systems and Green Roofs.

I was part of a project team that employed the framework of the Millennium Ecosystem Assessment (MEA) (2005; 2003) and the cascade model of ecosystem services (Haines-Young & Potschin, 2010; Braat & de Groot, 2012; Potschin & Haines-Young, 2010) which give a foundation in which to make these connections. This project team was part of a larger project that is undertaken in collaboration with researchers from the Faculty of Environmental Studies at York University and experts from the Credit Valley Conservation authority (CVC) in order to raise awareness of the key factors affecting health and well-being of the population in the Credit River watershed. This project also aims to create a management tool to support watershed management practices that target key issues in the watershed while enhancing benefits to ecosystem and human health. This will be discussed in detail later into the paper.

Finally, this paper will also focus on the policies and programs (provincial and local) that encourage LID as a stormwater management and land use planning alternative.

2.0 ANTHROPOCENE: THE GROWTH OF URBANIZATION AND THE ACCUMULATION OF HUMAN IMPACTS ON EARTH'S ECOSYSTEMS

According to UN official data, more than half of the world's population now lives in cities (UN, 2014). The promise of better jobs, better opportunities in combination with growing populations and a number of other factors have contributed in this massive trend pulling people towards cities. It is projected that by 2050, two thirds of the world's population is expected to live in urban areas. Both the increase in and the redistribution of the earth's population are likely to affect the natural systems of the earth and the interactions between the urban environments and populations.

In light of this, geologists have suggested that a new epoch has begun which they call the "Anthropocene" (Zalasiewicz et al., 2008) though this has not been officially adapted. It is proposed that this era is characterised by human actions whose critical markers include disturbances of the carbon cycle and global temperature, ocean acidification, changes to sediment erosion and deposition, and species' extinctions. This period coincides clearly with the development of industrialisation and the global growth in urbanisation that resulted in an estimated 50% of the world's population who have ever existed living in cities by the year 2000. The current epoch, the Holocene, is the 12,000 years of stable climate since the last ice age during which all human civilization developed (Carrington, 2016). However, given the striking acceleration since the mid-20th century of carbon dioxide emissions and sea level rise, the global mass extinction of species, and the transformation of land by deforestation and development, experts argue that the earth is so profoundly changed that it would ideally mark the end of that slice of geological time, and thus the Holocene should give away to the Anthropocene. The term Anthropocene was coined only in 2000, by the Nobel prize-winning scientist Paul Crutzen, who believes the name change is overdue. While some geologists question the usefulness of declaring a new epoch and would rather coin "Anthropocene" as a cultural term, most agree with evidence that confirms that humanity's combined environmental impact on earth's atmosphere, oceans, wildlife and ecosystems in general (Vaughn, 2016). One of the most glaring impacts that can be seen is the unprecedented rate of climate change that is happening today. In a provisional statement on the status of the global climate in 2016, published by the World Meteorological Organization (WMO) 2016 has been noted the world's hottest year on record so far, with global temperatures even higher than that of the record breaking temperatures in 2015. According to an assessment by the WMO preliminary data has shown that 2016's global temperatures are 1.2 Celsius above the pre industrial levels. Atmospheric concentrations of major greenhouse gases continue to increase and have reached the highest levels in the instrumental record. The warming trend and an increasing number of disasters are expected to continue for several decades and thus emphasizes on the need to invest in innovative adaptation and mitigation measures.

However, on a positive note, the Parties to the UNFCC adopted the ground breaking Paris Agreement in December 12th 2015, and thus raise the hope that international efforts will be taken to reduce global emissions of green house gases into the atmosphere.

The overwhelming evidence of the impacts of human activities on the earth's ecosystems and the effects of climate change can be locally seen in the cities that we live in. As described by Sachs (2015) cities have several distinctive factors. These include: being places with higher concentrations of population, being relatively productive areas of national economy, being the locus of tremendous amount of innovative activities, often being located in coastal areas or estuaries of great rivers and most importantly often facing major challenges of "urban externalities" resulting from the high density of population and economic activities.

Exponential growth in urbanization has caused considerable stress on the environment. Urban areas with higher populations require considerable amount of infrastructure, and a diverse amount of goods and services. Through development that is done in an environmentally unsustainable manner, this causes many issues including, but not limited to; reduction of pervious land cover resulting in increased flood risk, degradation of surface and drinking water quality, degradation of air quality, increased pollution, reduction of and reduced access to green space and increased amount of physical and mental illnesses.

However, urbanization at its roots should not be interpreted as something that is negative. In fact, a key determinant of a city's productivity and environmental footprint is its density and the concentration of population per square kilometer (Sachs, 2015). Therefore, densely settled cities, if properly designed, tend to be more productive and emit fewer GHGs than sprawling low-density settlements. Cities also have more opportunity and funding to invest in smart infrastructure for essential services such as transportation, communication and water and wastewater management.

Urbanization is a key factor that was considered when selecting the conservation actions or interventions for the area of study in this project, which is the Credit River watershed that falls under the jurisdiction of the Credit Valley Conservation Authority (CVC). It is situated in Southern Ontario, in one of the most densely populated regions of Canada and extends roughly from Caledon in the east to Halton Hills in the West and from Orangeville south to Lake Ontario at Port Credit. The entire Credit River Watershed covers about 860 square kilometers. The Credit River watershed contains parts of 15 municipalities and regions in Ontario, with the majority located within the Regional Municipality of Peel (CVC, 2009). The watershed has a diverse range of landscapes including the Niagara Escarpment, Oak Ridges Moraine, and Lake Ontario shoreline. It is often categorized into three regions: the upper watershed, middle watershed and lower watershed. Land cover and land use differs considerably among these three zones.

The land use in the upper and middle watersheds consists of agriculture, open space and natural cover such as forests and wetlands. According to the Credit River Watershed Report Card (2013), the upper and middle watersheds have a considerably "good" to "fair" surface water quality and "fair" forest conditions. In contrast, the lower watershed has a very high urbanization rate, with over 80% of the watershed population living in the lower watershed lower watershed in the large urban centers of Mississauga and Brampton (CVC, 2009). This unique land use pattern dispersion is reflected in the watershed report card, with water quality ranking "poor" to "very poor" in certain sub-watersheds in the urbanized lower watershed. Lack of forest interior habitat in the lower watershed has also contributed to a "poor" to "very poor" forest conditions in the lower watershed.

Despite these statistics, urbanization across the watershed is increasing and has numerous effects on the health of the watershed as well as the health and well-being of its populace.

3.0 LOW IMPACT DEVELOPMENT (LID)- A SOLUTION FOR GROWING URBAN ISSUES?

Urban landscapes are typically characterized by large areas of impervious surfaces and low levels of vegetative cover. Impervious surfaces decrease the amount of water that infiltrates on the ground and increases the speed of delivery to streams resulting in many environmental impacts. Impervious surfaces that accumulate pollutants in runoff also impact the surface water quality. All of the above affect ecosystem functions and thus have a negative effect on the ecosystem services.

LID is a site design strategy with a goal of maintaining or replicating the pre- development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape. This is synonymously used with the term "Green Infrastructure", and through out this paper both of these terms will be used. Hydrologic functions of storage, infiltration, and ground water recharge, as well as the volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoff time (Coffman, 2000). LID principles are based on controlling stormwater at the source by the use of micro- scale controls that are distributed throughout the site. This is unlike conventional approaches that typically convey and manage runoff in large facilities located at the base of drainage areas. Although traditional stormwater control measures have been documented to effectively remove pollutants, the natural hydrology is still negatively affected (inadequate base flow, thermal fluxes or flashy hydrology), which can have detrimental effects on ecosystems, even when water quality is not compromised (Coffman, 2000). LID practices offer an additional benefit in that they can be integrated into the infrastructure and are more cost effective and aesthetically pleasing than traditional, structural stormwater conveyance systems.

Recent research (Aquafor Beech Ltd., 2006) has suggested that current practices to offset the hydrologic effects of urbanization are insufficient to prevent increased channel erosion and deterioration of aquatic habitats. In many cases, even small incremental changes in watershed hydrology commensurate with an increase in impermeable surfaces of 4%, can result in changes to stream channel characteristics and aquatic communities. To offset these impacts, an increased emphasis on maintaining natural water balance and replicating the predevelopment hydrologic cycle is required (Aquafor Beech Ltd., 2006).

Some basic LID principles include conservation of natural features, minimization of impervious surfaces, hydraulic disconnects, disbursement of runoff and phytoremediation. LID practices such as bioretention facilities or rain gardens, grass swales and channels, vegetated rooftops, rain barrels, cisterns, vegetated filter strips and permeable pavements perform both runoff volume reduction and pollutant filtering functions.

4.0 GREEN INFRASTRUCTURE AND HUMAN HEALTH- MAKING THE CONNECTION

The amount of literature that ties in the ecosystem services of green space to human health and well-being is quite large. Toronto Public Health recently released a very informative review about these studies. Most often "green infrastructure" in these cases relates more to the presence of green space, which is a component of LID, but not specifically on the functional attributes of LID such as infiltration. Most LID benefits are directly associated with the functions that it provides by increasing infiltration in urban ecosystems by increasing the area of perviousness.

Since I have discussed the health and well being benefits of the LID interventions in the toolkit, I will not go into detail to discuss the benefits here. (For detailed review of benefits please see appendices I to III.)

While the many examples in literature provide great research findings on the relationship between human health and green space and other natural elements, this paper will focus more on how LID affects human health and wellbeing. While stormwater management is seen as an important element of planning and watershed management, its relationship with human health is not greatly understood. This is because stormwater management is mostly understood as a means to manage an urban issue that is stormwater runoff, but not seen as a means to improve or even affect overall health and well-being of humans.

The first step in making the connection between LID and human health and wellbeing is to understand the basic concept behind LID. As explained previously, LID is an ecologically friendly approach to site development and stormwater management that aims to mitigate development impacts to land, water, and air. This is done through mimicking a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source.

Instead of conveying and managing/treating stormwater in large scale, end-of-pipe facilities located at the bottom of drainage areas, LID addresses stormwater thorough smaller, cost effective landscape features located at lot level (EPA, 2000). What makes LID stand out is that most components of an urban environment, such as parking lots, sidewalks and rooftops, have the potential to serve as a LID (Prince George’s County, Maryland Department of environmental Resources, 2000).

5.0 HYDROLOGICAL CYCLE- THE EFFECTS OF URBANIZATION AND POTENTIAL SOLUTIONS THROUGH LID

As mentioned above, the goal of LID is to mimic the natural hydrological cycle. Therefore it is beneficial to understand the processes of this cycle, and associated ecosystem functions and services.

The hydrological cycle, also known as the water cycle, is the continuous exchange of water between land, water bodies and the atmosphere. When precipitation falls over the land, it follows various routes: some of this water evaporates, some return to the atmosphere, some seeps into the ground and remainder becomes surface water that travels to oceans and lakes through water bodies.

Rapid urbanization has increased the amount of impervious cover and thus, that changes the amount of water that penetrates and infiltrates into soil thus changing the natural amount of water that takes each route. Urban landscapes are typically characterized by large areas of impervious cover and low levels of vegetative cover. Impervious surfaces in urban landscapes include rooftops, paved driveways, sidewalks and parking lots.

These impervious surfaces reduce the amount of water that infiltrates into the ground, increases the amount of stormwater runoff and speed the delivery of runoff to streams or other receptors and, thus result in a variety of environmental impacts (ORMCP Technical Paper Series). This includes a decline of groundwater levels and stream base-flows and the increase of the magnitude of storm flows and frequency of bank-full flows increase.

Stormwater peak discharges in urban watersheds with large amounts of impervious cover have a larger volume and faster rate of discharge than in less developed watersheds. In addition to this, increased runoff and reduced stream base-flows also alter stream water temperature regimes. All these changes result in significant implications on the quantity of fresh clean water available for humans, fish and wildlife, increased flood risk and habitat damage.

Imperviousness is a direct result of urbanization and it has been proposed as a unifying theme and general environmental indicator of change due to urban growth and implications to watershed management (ORMCP Technical Paper Series).

When green infrastructure is proactively planned, developed and maintained, it has potential to guide urban development by providing a framework on economic growth and nature conservation (Walmsley, 2006; Schrijnen, 2000; van der Ryn and Cowan, 1996). This type of planned approach provides opportunities for integration between urban development, nature conservation and public health promotion.

6.0 LID THROUGH THE LENSE OF SUSTAINABLE DEVELOPMENT, RESILIENCE THEORY AND ECOHEALTH

Sustainable Development

Prior to the popularization of the ecosystems approach to health, or Ecohealth, there were several other theories that dealt directly and indirectly with the implications that ecosystem degradation had on humans. For example, given the high population growth, increase of urbanization and depleting natural resources, it had become acceptable among many practitioners of environmental planning and management that sustainable development should be the foundation upon which future development is carried out. The Oxford dictionary defines sustainable development as “economic development that is conducted without the depletion of natural resources”. However, the term came into the spotlight after the publication and circulation of “Commission on Environment and Development: Our Common Future”, also commonly known as the Bruntland Report in 1987. This lay down the groundwork for the United Nations Conference on Environment and Development (UNCED) also known as the Rio Summit in 1992. The Bruntland report defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (Berke and Kartez 1995; Healey and Shaw 1993). Consisting of three pillars, sustainable development seeks to achieve, in a balanced manner, economic development, social development and environmental protection.

In 2012, Charron proposed to expand the three pillars of field of Ecohealth to six principles: systems thinking, transdisciplinary research, participation, gender, social equity, knowledge to action and, finally, sustainability. Therefore there is a clear linkage between sustainable development and the field of ecohealth and will be discussed further into this report.

In this case, LID can be seen as a means of sustainable development that is needed in order to mitigate and adapt to challenges that are faced through urbanization and climate change.

Resilience Theory

Another concept that had similar ground is resilience theory. The concept of resilience also ties well with the idea of sustainability and various debates and arguments surrounding it. According to Holling, in a seminal article published in 1973 “resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change of state variable, driving variables, and parameters, and still persist” (Holling, 1973). Resilience focuses on how socio-ecological systems change due to disturbances. This research considers urban regions as social-ecological systems. This means that human and natural systems within urban contexts are interconnected and interdependent and mutually affecting one another. The concept of resilience is linked to systems thinking that is also a part of the six principles of Ecohealth.

Walker and Salt (2006) proposed three steps to manage for and enhance resilience of social-ecological systems. First, is to understand the drivers of the system under a certain condition.; second, is to know the thresholds of drivers and third, is to enhance aspects of the system that enable it to maintain its resilience.

As Abunnasr, Yaser (2013), pointed out, in the context of urban regions, the drivers of transformation are the change of land use from pervious to impervious surfaces. The adaptive capacity or the threshold of the drivers can be seen as the amount of pervious surfaces in an urban region and at what point the threshold is passed, and finally the aspects that make the system enable to maintain its resilience are the Green Infrastructure or LID systems, that increase the resilient capacity of communities through providing ecosystem functions and services such as water storage and regulation, flood protection and thermal regulation.

Ecosystem approach to health (Ecohealth)

The ecosystem approach to health, or ecohealth approach, connects ideas of environmental and social determinants of health with ideas of ecology, systems thinking and resilience theory into an action- research framework applied mostly within the context of social and economic development (Charron, 2012). The importance of ecohealth is that is recognizes how human health and well-being is influenced in dynamic and complex ways by interactions between people, socio-economic conditions and ecosystems (Charron, 2012).

The ecosystem approach to health has six basic principles, namely: Systems Thinking, Transdisciplinary Research, Participation, Sustainability, Gender and Social Equity and Knowledge-To-Action (Charron, 2012). These principles highlight how various schools of thought and fields are integrated into the Ecohealth framework.

In particular, systems thinking helps make some sense of the complex reality of health in the context of social–ecological systems (Charron, 2012). These complex relationships and interactions between societies and ecosystems can be considered as coupled social–ecological systems (Berkes and Folke 1998). As Parkes et al. (2003) points out, linked actions that address both biophysical and social environments potentially create a “double-dividend” that improves human health by addressing socio- economic and environmental determinants, while also promoting sustainable development.

7.0 THE METHODOLOGY AND PROJECT

As mentioned earlier, the project team employed the framework of the Millennium Ecosystem Assessment (MEA) (2005; 2003) and the cascade model of ecosystem services (Haines-Young &

Potschin, 2010; Braat & de Groot, 2012; Potschin & Haines-Young, 2011) which give a foundation in which to make these connections.

The MEA conceptual framework articulates the relationships between human health and well-being in relation to ecosystems (Hassan et al. 2005). The many reports of the MEA series make substantial strides forward in integrating human well-being and ecosystems, particularly the Health Synthesis (Hassan et al. 2005, Corvalán et al. 2005) published by WHO.

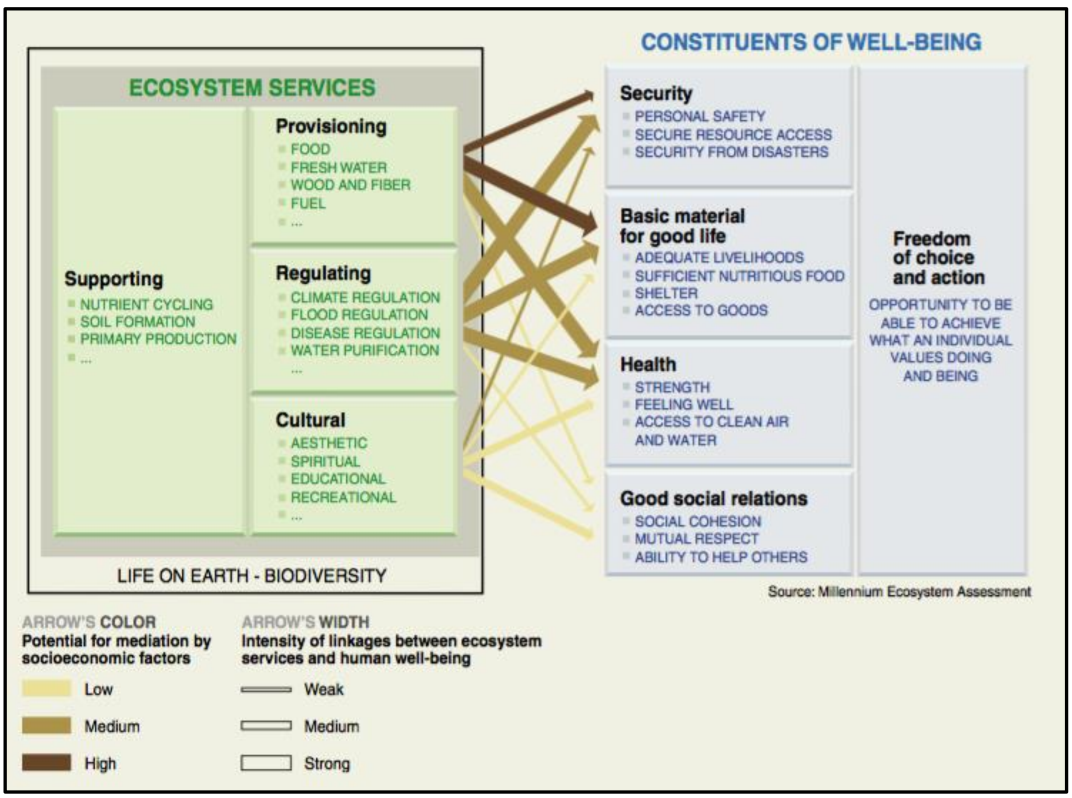

Figure 1 Millennium Ecosystem Services Framework (MEA) Synthesis Report (MEA, 2005)

The above diagram shows the four ecosystem services that are mentioned in the MEA: supporting, provisioning, regulating and cultural services. These are connected to constituents of well-being, namely, security, basic material for good life, health, good social relations and freedom of choice and action.

This helped make a connection between ecosystem services and the final benefits that the services can be translated into. While making connections between provisioning, regulation and cultural services and human health was not difficult, the connections between supporting services and human health and well-being were a bit more complex since they do not directly benefit people, but are often a mechanism or process that generates these services. Several researchers including Boyd and Banzhaf (2005, 2006) and Wallace (2007), have noted this issue of ambiguity in the MEA framework and while some attempts to provide more systematic approaches have been introduced, these suggestions have not yet been included into the framework. The main problem with the MEA typology, according to Wallace (2007, 2008), is that it confuses ends with means; that is, the benefit that people actually 'enjoy' and the mechanisms that give rise to that service. A service is something that is consumed or experienced by people.

Due to these issues, and also because of the anthropocentric nature of the MEA framework, we used the typology of the cascade model (Haines-Young & Potschin, 2010) to make a more linear connection between the ecosystem functions that actually provide the ecosystem services and the final well-being benefit to humans.

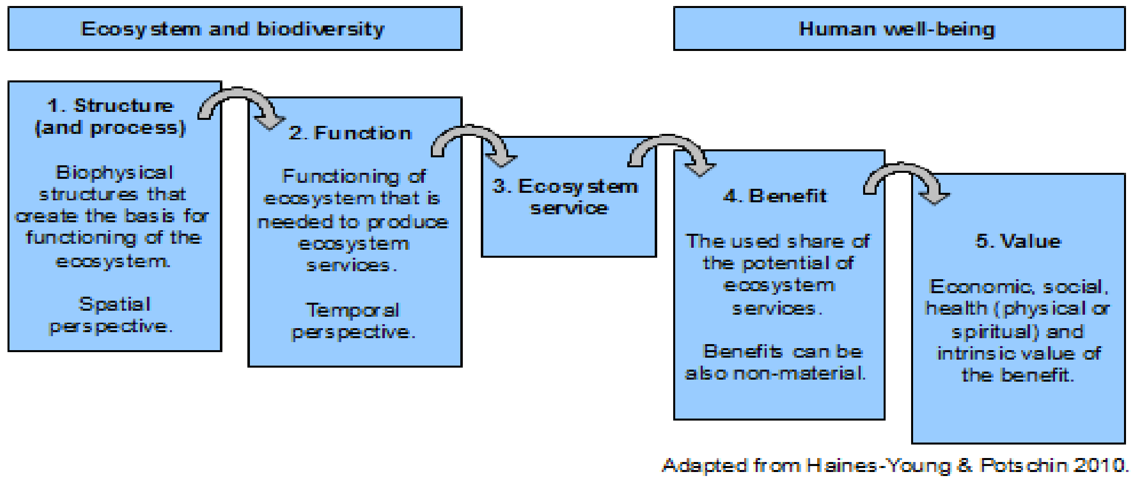

Figure 2 Cascade model (Haines-Yong & Potschin, 2010)

Through the combination of the above two models, we formulated a methodology that would help in synthesizing information about the selected interventions (in my case, for LID) into this framework, or matrix, to identify the final benefits that are provided by the interventions. The main purpose of this framework is to aggregate data from a variety of interdisciplinary fields using the principles of Ecohealth, and thereby make tangible connections of how sustainable ecosystem management, through implementation of various land use and water resource interventions, can promote human health and well-being while mitigating and adapting to issues faced in the Credit River watershed. Another objective of this framework is to specifically identify the bundle of ecosystem services that each intervention mobilizes for human health and ecosystem health.

The information was obtained through academic literature review, review of literature published by CVC and other conservation authorities, municipalities in the Credit River watershed and beyond, official guidelines and handbooks of LID and BMP interventions that have already been published, related case studies as well as success stories, lessons learnt and other relevant information discovered through personal communication with experts at CVC.

The findings have been compiled into toolkits that are attached as appendices.

8.0 BROADER SCOPE OF PROJECT:

The research that I have undertaken for this major paper is part of a broader project that is done in collaboration with researchers from the Faculty of Environmental Studies in York University and experts from CVC.

The broader project, "The CVC/York University Watershed Well-being Project", aims to raise awareness on key factors that affects the health and well-being of the people living in the Credit River watershed. In order to increase public awareness while also encouraging public participation and environmental stewardship, an online web-mapping tool was created by researchers of the project team that helps illustrate the human-nature relationships in the watershed through open-source GIS mapping. For example, the tool shows users information on nearby trails and green spaces, accompanied by short literature review of the benefits of green space on human health and well-being. The public is encouraged to use this tool and have the opportunity to upload their own stories about their relationship with specific locations in the watershed.

While the web GIS tool provided awareness and stewardship opportunities for the public, the broader project also entailed the formulation of a management tool that would help decision makers, especially the CVC, in taking watershed management decisions that would increase the co-benefits derived for both the ecosystem and human health and well-being in the watershed. In order to do so, three team members, including myself, researched on three separate types of beneficial management practices and how each type can be related to human health and well-being. The beneficial management practices that I have researched falls under “Low Impact Development Interventions”. The other two types researched by the project team included interventions related to naturalization and agricultural management. The methods used are described in detail in the previous section.

The next step of this project is to feed this information into a scenario-planning tool. A multi-criteria process will be taken in order to identify the impact of each intervention in different scenarios in the watershed.

For example, each scenario will be made up of a set of interventions that will have an effect on a certain type of ecosystem service. The number and configuration of the interventions will change across the scenarios, and interventions can be done to different extents in different scenarios (e.g. scenario 1 plants 100 trees per hectare of project land, while scenario 2 also plants trees as one of its interventions but only plants 50 per hectare). An impact matrix will be used to show how each scenario affects the selected ecosystem service. Through the completion of this management tool and through pilot testing, this will allow decision makers to see how each intervention affects the human population and ecosystem services of the watershed and plan interventions to achieve the desired results.

Integration of the scenario-planning tool into the web-GIS portal, will also help to track, manage and measure the ecosystem services derived through interventions in the credit river watershed.

In conclusion, this project will help to increase awareness of co-benefits derived through interventions while also supporting decision makers and policy makers to include human health and well-being into the field of land use planning.

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TOOLKIT DISCLAIMER

POLICIES AND PROGRAMS THAT ENCOURAGE LID AND CVC'S INVOLVEMNT WITH LID PROJECTS

The Credit Valley Conservation Authority has done a considerable amount of research and produced many guidelines on Low Impact Development, its implications, and applications.
They have also partnered with TRCA to create a very detailed LID and stormwater management guidelines. Most of the information on this toolkit is based off this information and guidelines, especially technical terms.

LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT PLANNING AND DESIGN GUIDE- Version 1.0

This document – the Low Impact Development Stormwater Management Planning and Design Guide – has been developed by Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA) as a tool to help developers, consultants, municipalities and landowners understand and implement sustainable stormwater planning and practices in the CVC and TRCA watersheds.

POLICIES AND PROGRAMS THAT ENCOURAGE LID

The following section gives a brief overview of policies and programs that encourage LID that are in effect in Ontario. Some of these policies and programs are not under the direct jurisdiction of the Credit River watershed, for example certain policies that are in effect in the City of Toronto, however, these policies and programs can be considered as important precedents for future policy development for the area.

1. Water Opportunities and Water Conservation Act, 2010

Designed to foster innovative stormwater technologies, services and practices in the public and private sectors, this act recognizes the need for integrated long term planning of water and stormwater. This also opens the door for the Province to require municipalities and other water service providers to prepare municipal water sustainability plans.

2. Showcasing Water Innovation (SWI) Program

This is a $17 million grant program that runs to March 2014 to support Ontario's Water Opportunities Act and Water Conservation Act, 2010. This grant provides funding to projects that demonstrate leading edge and cost effective water management solutions that help in establishing green infrastructure as a means to achieve water conservation in Ontario and develop Ontario-based technologies and create jobs. For example, on Lake Ontario, the Credit Valley Conservation Authority is receiving provincial funds to collaborate with public and private sector partners on projects that encourage Low Impact Development approaches to managing stormwater and conserving water. The conservation authority is installing and testing green infrastructure to better understand how it performs, and producing green infrastructure guides that municipalities can use for their projects.

3. Climate Ready: Ontario's Adaptation Strategy and Action Plan

This action plan identifies a need for increased resilience of municipal stormwater systems in light of climate change induced alterations to rainfall intensities and storm patterns. The ministry is currently reviewing best management practices in other jurisdictions for additional guidance and information on adapting water systems to deal with impacts cased by climate change. Source control, that include reuse and LID are some of the system issues and practices that are under review. The Ministry is proposing to partner with municipalities to develop guidance on how LID approaches can be used to manage stormwater in the development of business/industrial parks.

4. Lake Simcoe Protection Plan

This plan was a result of the Lake Simcoe Protection Act passed by the Government of Ontario in December 2008, and was released by the MOE in June 2009. This act aims to address the ever increasing loading of phosphorous into Lake Simcoe from urban runoff. It encourages the use of Green Infrastructure to reduce phosphorous loading through vegetative uptake and filtering of runoff. This estimates that green infrastructure could prevent 2.7 tonnes per year of phosphorous from entering Lake Simcoe.

5. Ontario's Great Lakes Strategy, 2012

This strategy represents a good opportunity for Green Infrastructure to be mainstreamed. With 20% of the world's freshwater surface water, the Great Lakes, including Lake Ontario, are a global treasure. This strategy has made reference to various economic studies that demonstrate the high return on investment of restoration and protection of Great Lakes. For example, it references studies that indicate that LID that minimizes stormwater runoff indicates and average

2:1 return on investment compared to traditional development practices (Ontario's Great Lakes Strategy, 2012). In addition the strategy recognizes the impacts of the changing climate and the need to protect water for human and ecological health, as well as the need to ensure environmentally sustainable economic opportunities and innovation.

5. Provincial Policy Statement, 2014 (PPS)

The PPS provides policy direction on matters of provincial interest related too land use planning. The Government of Ontario requires a five-year review of the PPS to ensure that the Province's land use policies remain relevant to the issues at hand. The most current Provincial Policy Statement, 2014 has recognized climate change as a major issue and has included policy direction that can be used to help mitigate and adapt to climate change and ensure that communities are resilient to climate change impacts. This is done through encouraging Green Infrastructure (policy 1.6.2) in order to reduce the reliance on traditional, end-of-pipe stormwater facilities, supporting land use and development patterns that reduce greenhouse gas emissions and support climate change policy (policy 1.8.1) and strengthening stormwater management requirement as important components of broader infrastructure planning (policy 1.6.6.7). These policies aim to maintain the natural hydrologic cycle, prevent increased risk of flooding, prevent erosion and promote stormwater best practices like LID.

6. The Co-ordinated Land Use Planning Review 2015/2016- Growth Plan for the Greater Golden Horseshoe, the Greenbelt Plan, the Oak Ridges Moraine Conservation Plan; and the Niagara Escarpment Plan.

The province initiated co-ordinated land use review of the above 4 land use plans began in 2015. The guide to the proposed changes titled "Shaping Land Use in the Greater Golden Horseshoe" that was released in May 2016 highlights some the proposed changes that are in consideration.

As the largest economic engine of Canada, planning ahead for the prosperity of The Greater Golden Horseshoe is imperative for sustainable development. The review has addressed climate change as one of the most pressing issues of our time. As a means to respond to climate change, specifically as means of climate change adaption, proposed new policies in the Growth Plan, Greenbelt Plan and Oak Ridges Moraine Conservation Plan, it would Require municipalities to develop plans for managing stormwater in their settlement areas that would incorporate Green Infrastructure and low impact development techniques. This encourages the integration of green space in design strategies and the use of natural water systems to generate less runoff from developed land. As a means to support the implementation of the proposed changes in the four plans, guidance material will be produced for several thematic areas including watershed management and stormwater management.

7. The Toronto Green Standards (TGS)

This has been developed by the City of Toronto to address the impacts associated with urbanization. It is a two-tier set of performance measures for sustainable site and building design. Tier 1 identifies the minimum sustainable performance measures that will be secured during Planning Act application approval processes and Tier 2 identifies enhanced sustainable performance measures that raise the bar and encompass whole building performance.

TGS attempts to encourage the greening of new development to help reduce the future infrastructure demands and environmental impacts to make a healthier and more livable city. This aims to integrate environmental performance requirements to improve air and water quality, reduce green house gas emissions and enhance urban ecology and minimize solid waste to landfill.

The importance of green infrastructure and LID is highlighted in the green standards through several points. To reduce the Urban Heat Island (UHI) effect at grade for new mid to high-rise residential and all industrial, commercial and institutional (ICI) development, it is required to use a combination of open grid pavement with at least 50% perviousness and high albedo surface material with high solar reflectance index (SRI). It is also required that for non residential uses, a minimum of 50% of parking space should be under cover, and any roof that is used to shade to cover the parking should have high SRI (at least 29), covered by solar panels or should be a green roof.

For Urban Heat Island reduction on or from rooftops, Toronto has initiated a green roof by law that requires installation of a green roof to meet the requirements of the by-law. (This will be discussed in detail below)

An important find in this report is that a 2008 cost-benefit study of TGS found that the benefits derived from green development overwhelmingly outweigh the associated costs.

Marginal additional costs upfront significantly improve the environmental, social and economic outcomes of development both for the city and the region in which it is situated.

8. Toronto Green Roof By Law

The City's Green Roof Bylaw applies to new commercial, institutional and many residential development applications. Toronto is the first city in North America to have a bylaw to require and govern the construction of green roofs on new development. Toronto City Council adopted it in May 2009, under the authority of Section 108 of the City of Toronto Act. The Bylaw applies to new building permit applications for residential, commercial and institutional development made after January 31, 2010 and will apply to new industrial development as of April 30, 2012. The Bylaw requires green roofs on new commercial, institutional and residential development with a minimum gross floor area of 2,000 m^2 as of January 31, 2010. Starting April 30, 2012, the Bylaw will require compliance for new industrial development.

The City has also released a set of guidelines for bio-diverse green roofs; "City of Toronto Guidelines for Bio Diverse Green Roofs", that identify, describe and illustrate best practices for creating habitat and promoting biodiversity on green roofs in Toronto. These guidelines are supplied in addition to the "Toronto Green Roof Construction Standard Supplementary Guidelines", and, thus, illustrate the importance and multi dimensional benefits of green infrastructure.

9. Eco-Roof Incentive Program:

The program is a key element of the City's Climate Change Action Plan. It is designed to promote the use of green and cool roofs on Toronto's commercial, industrial and institutional buildings. Performance criteria for the Eco-Roof Incentive Program are consistent with the Green Roof Bylaw and the Toronto Green Standard.

Since 2009, the City's Eco-Roof Incentive Program has helped fund the installation of more than 250 green and cool roofs on buildings across the city. Eligible green roof projects will receive $100 / m^2 to a maximum of $100,000.

10. Peel Climate Change Strategy (PCCS)

This strategy continues to expand the understanding of emerging climate change strategies science and technologies for GHG reduction and climate adaptation focusing on the Peel region.

This strategy also recognizes the urgent need to respond to climate change at the local level.

11. Sustainable Neighbourhood Retrofit Action Plan (SNAP)

The Sustainable Neighbourhood Retrofit Action Plan (SNAP) is an innovative pilot program led by Toronto and Region Conservation in collaboration with regional, municipal and community partners. With the SNAP approach, program promotion and communications are designed based on an in-depth research analysis of the specific physical and sociological characteristics of the neighbourhood. SNAPS are integrated sustainability planning process for an existing neighbourhood to address environmental, social and economic goals.

Typical SNAP neighbourhood actions address common environmental goals for energy conservation, urban forest enhancement, water conservation, improved stormwater management and local food production.

While TRCA has been involved in many green infrastructure related retrofit programs through this initiative, TRCA also provides planning and advisory services that enable new SNAP plans within and external to TRCA's jurisdiction. Currently, at the time of writing, TRCA is advising Credit Valley Conservation on the development of its first SNAP: Fletchers Creek SNAP, Brampton. This will be done to advance the recommendations of other related master plans and studies including: Fletchers creek restoration study, Brampton Grow Green Environmental Master Plan, Brampton Natural Heritage and Environment Management Strategy, Peel Climate Change Strategy and Peel Urban Forest Strategy. This SNAP program recommends inclusions such as rainwater harvesting for irrigation, greener streetscapes that include urban forest and boulevard bioswales, habitat restoration and "green" parking lots.

FURTHER DEVELOPMENT AND STUDIES THAT HAVE HELPED INCLUDE MORE LID INTO THE LEGISLATION FRAMEWORK:

1. **"Health, Prosperity and Sustainability: The Case for Green Infrastructure in Ontario"**

The joint report done by Coleen Cirillo of Green Infrastructure Ontario Coalition and Liat Podolsky of Eco Justice titled "Health, Prosperity and Sustainability: The Case for Green Infrastructure in Ontario" has also outlined more recent developments that have encouraged the inclusion of LID in the consultative and legislative policy review process in Ontario. For example, in 2011, the Green Infrastructure Ontario Coalition carried out an extensive consultation process consisting of surveys and workshops that engaged a large and diverse group of green infrastructure professionals. This workshop was done in partnership with the City of Windsor, EcoSuperior (Thunder Bay), Grand River Conservation Authority (Cambridge), Peterborough Green-Up and Toronto and Region and Conservation/LEAF (Toronto). In addition to this, also in 2011, Green Infrastructure Ontario Coalition and Ecojustice conducted an in-depth analysis of legislative instruments that provide support or act as barriers to the mainstream use of green infrastructure in Ontario. As a result of this information, paired with the feedback gained through the workshops, Green Infrastructure Ontario Coalition have come up with a list of recommendations for the Province to implement green infrastructure into policy.

2. Ecosystem services Valuation Studies

There is a assumption in neo-classical economics that if an item or process does not contribute to the Gross Domestic Product (GDP), it does not have value. Although most goods have a GDP value, most ecosystem services do not. In an attempt to bring ecosystems services on par with thin the dominant economic systems, ecosystem services valuation has been gaining ground in Ontario, with interest and investment from provincial ministries, conservation authorities and non-governmental organizations. In 2011, local experts and enthusiasts in the field of ecosystem services formed a group called Ontario Network for Ecosystem Services (ONES). ONES is governed by by-laws, which are modeled upon the requirements of a not-for-profit corporation in Ontario. As specified in the by-laws, ONES is administered by a volunteer Board of Directors, from which three officers are chosen

The US department of Agriculture's Forest Service introduced a state of the art software suite named "Urban Forests Effects Model" or "i-Tree Eco", which analyses the urban forests and assess their benefits such as carbon sequestration, air pollution removal and energy savings. This has been employed by a number of cities in Southern Ontario including Ajax, Brampton, Caledon, Markham, Mississauga, Oakville, Pickering, Richmond Hill, Toronto and Vaughan.

Researchers in Ryerson University have also developed an interactive tool named the "Ontario Residential Tree Benefits Estimator" that quantifies the ecological services provided by a single tree.

There have also been several ecosystem valuation studies that have been done on Ontario that highlight the value and importance of ecosystem services to communities in Ontario. These studies include: “Lake Simcoe Basin’s Natural Capital: The Value of the Watershed’s Ecosystem Services” and “Ontario’s wealth, Canada’s future: Appreciating the Value of the Greenbelt’s Eco-services”, both which have been done through the David Suzuki Foundation. Some other studies include: “Estimating Ecosystem Services in Southern Ontario”, a valuation study commissioned by the Ontario Ministry of Natural Resources to estimate the economic value of ecosystems in Southern Ontario that was published in 2009. There has also been an ecosystem valuation study done specifically for the Credit River watershed by the title of “Natural Credit: Estimating the Value of Natural Capital in the Credit River Watershed” done through the partnership of the Pembina Institute and Credit Valley Conservation and published in 2009. This study estimates the economic value of ecosystem services to watershed residents to be a minimum of $371 million per year.

INVOLVEMENT OF CVC IN LID:

In addition to the design guide, CVC also has several programs that offer LID services to various stakeholders such as engineers, landscape architects, contractors and municipal staff. For example some of the programs that CVC has partnered with include the following:

- Partners in Project Green- Offers LID and pollution prevention services to industrial, commercial and institutional clients for new construction, redevelopment and retrofits.
- Leaders for Clean Water- offers LID and pollution prevention for residential development community and municipalities
- Making it Work: Professional Training- provides training to municipal staff, development community and planning professional training on LID
- Save the Leopard Frog- CVC's community Engagement Program- Conducts interactive programs to help watershed residents and community based organizations to understand LID techniques through LID demonstration projects and other community involvement programs

Currently there are 44 "Green Projects" listed in the CVC website that include practices that include LID practices such as grass swales, infiltration trenches, perforated pipes, pollution prevention, thermal best management practices, bioretention/rain gardens, green roofs, permeable pavement, rainwater harvesting and other innovative stormwater management practices. These practices are located in various land use types including public land, residential lands, industrial and commercial lands and road right-of-ways.

There are also several case studies that have gone into detail on the entire process of LID implementation from planning and regulation and design to maintenance and long-term performance.

Some of the notable case studies include:

1. Elm Drive (road right of way)- permeable pavement and bioretention

The Elm Drive project incorporates both permeable paver lay-bys within the road right of way (on City of Mississauga property) and bioretention planters on the adjoining property owned by the Peel District School Board (PDSB). Runoff flows from Elm Drive West onto the permeable paver lay-by and into the bioretention planters.

2. CVC head office (public land)- permeable pavement and rainwater harvesting

The building also features numerous low impact development (LID) practices, such as permeable parking lots and a rainwater harvesting (RWH) system supplying non-potable water to toilets, urinals and outdoor hose taps. The LID practices at CVC Head Office has been showcased through numerous events and site tours, and represent LID practices that can be installed at a typical medium sized commercial office building.

3. Imax Parking lot retrofit- (public land)-permeable pavement, dry swales (bioswales), grassed swales

In 2012 IMAX retrofitted its parking lot with a variety of innovative low impact development (LID) stormwater management technologies. These technologies collect, adsorb and filter pollutants from stormwater runoff before it is discharged into Sheridan Creek, Rattray Marsh (a provincially significant wetland) and eventually Lake Ontario, the source of drinking water for eight million people.

It incorporates a variety of LID technologies, including permeable pavement, dry swales (bioswales), grassed swales, and other proprietary systems.

4. Terra Cotta Conservation Area (TCCA) Rain Garden- bio retention rain garden

In the summer of 2011, a rain garden was constructed next to the Visitors Welcome Centre at TCCA. This rain garden was similar to what would typically be constructed on a residential property

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Appendix 1:
Permeable Pavement Systems

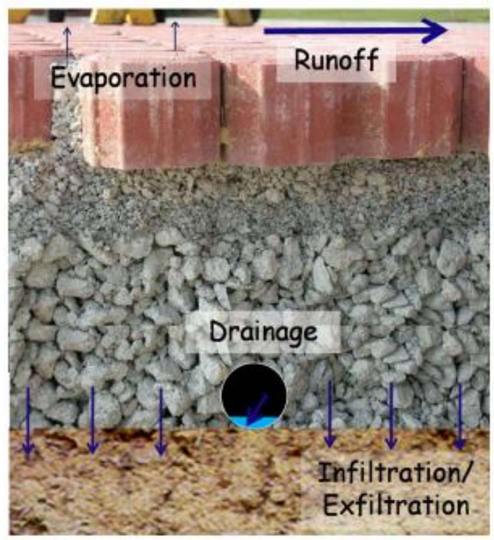
TOOL KIT-

PERMEABLE PAVEMENT SYSTEMS

Porous Asphalt (PA), Pervious Concrete (PC), and Permeable Interlocking Concrete Pavers (PICP) and Grid Pavement Systems (plastic or concrete)

I. OVERVIEW:

1. Description of LID/BMP:



Cross section of a typical permeable pavement system

Numerous problems associated with urbanization, such as flooding, channel erosion and destruction of aquatic habitats are directly linked to the loss of water-retaining function of soil in urban landscape. As imperviousness increases, a storm-water runoff reservoir of tremendous volume is removed. Water that may have lingered in this reservoir for anywhere from a few hours to many weeks now flows rapidly across land surfaces and arrives at stream channels in short, concentrated bursts.

Permeable pavement is a term used for a number of LID practices that can be used in place of conventional asphalt or concrete pavement. These alternatives contain pore spaces or joints that allow storm-water to pass through to a stone base where it is infiltrated into the underlying native soil or temporarily detained. Due to the increased void ratio, water is conveyed through the surface and allowed to (1) infiltrate, (2) evaporate, whereas conventional surfaces will not do so. (NCDWQ, 2007).

Permeable pavements allow rainwater, snowmelt and air to pass through the matrix, recharging the groundwater table and refreshing soil nutrients. This reduces total volume of runoff flows leaving the paved surface. The void space captures water and slowly releases it to infiltrate the subgrade. This filtration process reduces the total quantity and concentration (generally) of pollutants that would otherwise runoff the paved surface and require treatment, volume control and flow attenuation. Typical pollutants removed or improved are hydrocarbons and heavy metals, (Hun-Dorris, 2005) as well as a number of other chemical compounds (Geosyntec Consultants and Wright Water Engineers, 2008).

The air voids also allow for evaporation, which offers a cooling process on the surface and to the storm-water runoff. This is especially beneficial in cities which experience extremely high temperatures in summer - traditional "blacktop" temperatures can make some public spaces unusable in warmer weather. (Hun-Dorris, 2005). Permeable pavements help improve the quality of urban storm-water by allowing water to percolate through the subsurface media and trapping or breaking down contaminants through filtration, adsorption, microbial decomposition and other chemical and biological reactions within the soil or granular media (Pitt *et al.*, 1996).

There are several pavement options, including Porous Asphalt (PA), Pervious Concrete (PC), and Permeable Interlocking Concrete Pavers (PICP) and Grid Pavement Systems (plastic or concrete). Porous asphalt and pervious concrete appear the same as traditional pavement from the surface, but are manufactured without "fine" materials, and incorporate void spaces to allow infiltration. PICP consists of impervious units designed with small permeable joints. Grid pavement systems usually consist of concrete or plastic units with large surface openings filled with permeable joint material.

Depending on the native soils and physical constraints, the systems may be designed with no underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for a no-infiltration or detention and filtration only practice.

2. Key issues faced by the watershed that can be addressed through implementation LID/BMP (A brief overview: will be discussed in detail in part II)

- Effects of storm-water runoff

- Urbanization and spread of low density development
- Erosion and sedimentation
- Flood risk
- Water quality issues
- Urban Heat island effect
- Non-point source pollution

3. Policy recommendations that encourage the LID/BMP

Please refer to "Toolkit Disclaimer" in the previous section where a detailed list of policies and programs that support LID have been included

4. Main stakeholder/s involved

- Municipalities- 11 municipalities
- Conservation Authority- CVC
- Developers and investors
- General public

II. CO-BENEFITS: ACHIEVING A DOUBLE DIVIDEND

What Co-benefits Exist Through Implementation, How Does It Happen Through LID/BMP and Where Do The Benefits Occur

1. INCREASED TOTAL IMPERVIOUS AREA (TIA)

a. Benefits to nature:

i. Increasing Infiltration and groundwater recharge

- More permeable surface increases groundwater recharge as opposed to conventional storm-water management systems such as impervious surfaces. Infiltration results in more water available fro nearby vegetation. Infiltration through layer (base/subbase/uncompacted soil) provides water quality treatment.
- Porous paving and permeable paver with storage bed systems may also be used to meet the groundwater recharge requirements of a watershed. However, it is recommended that no infiltration designs should be used if the soil depth-to-groundwater is insufficient to offer adequate filtering and treatment of storm-water related pollutant (Eisenberg et. al, 2015). A minimum 0.61m (2 feet) separation from groundwater is recommended.
- Long-term studies and simulations of permeable pavement pollutant distributions have revealed low risks of subsoil pollutant accumulation and groundwater contamination (Dierkes 2002; Legret 1999; Van Seters 2007).

ii. Reduces runoff volumes and peak discharge rates

- Porous pavements with infiltration provide an excellent means of capturing and in infiltrating runoff and the discharge resembles shallow depth groundwater drainage, which is a main goal for low impact development designs such as this. In infiltration and runoff reduction is possible for a range of soil types, including low conductivity soils.
- Reduced volumes and peak discharge rates result in reduced flood and erosion possibilities that harm human and natural ecosystems both.
- A runoff volume reduction of 25% was observed for an underdrained porous pavement with hydrologic group C soils, while 92% was measured for a site with hydrologic group B soils (UNHSC 2009). Properly designed PICP systems can provide effective management of runoff volumes and peak runoff rates from extreme storm events. A runoff volume reduction of 28% was observed for an underdrained pavement over impermeable soils (Fassman 2010), while a 100% reduction was measured for a site with no underdrains overlying hydrologic group A soils (Bean 2007).
- The storm-water bed below the pervious pavement acts as a storage reservoir during large storm events, even while runoff infiltrates into the underlying soils. Outlet structures can be designed to manage peak rates with the use of outlet controls, and carefully designed systems can manage peak rates for storms up to and including the 100-year storm (Eisenberg et al., 2015).

b. Benefits to humans:

i. Reduction of flood and erosion impacts on humans and property

- Permeable pavement systems reduces the total storm-water runoff volumes and spreads the volume over longer time period compared to impervious pavement, helping reduce flooding impacts. It also reduces the discharging of municipal storm drainage systems and conveyance channels and helps reduce the combined sewer overflows (CSO) and conveyance system impacts.
- Rainfall timing can be important when evaluating permeable pavement potential to infiltrate water from surrounding areas. The time delay between the rainfall on these areas (with some infiltration) and the time the water enters the permeable pavement surface during the peak rainfall intensity can also reduce the peak out flow, thereby conserving the need for larger storm drain system pipes and reducing potential downstream flooding or erosion (Eisenberg et al., 2014).
-

2. **WATER QUALITY IMPLICATIONS**

a. Benefits to Nature:

i. Pollutant removal and water quality improvement

- Pervious systems are effective in reducing certain pollutants such as total suspended solids (TSS), metals, oil, and grease. Large particles are caught on the surface for vacuum cleaning. Small particles are caught in the aggregate base.

Oils and grease adsorb to the concrete and aggregate. They are reduced through evaporation, UV degradation, and microbial action. The immediate 0.6 m (2 ft) of underlying natural soil is biologically-active, helping to reduce oils, greases, and other pollutants such as nutrients associated with fertilizers (Eisenberg et al., 2014).

- A study on Porous asphalt conducted by the UNHSC showed more than 95% reduction for total suspended solids, total petroleum hydrocarbons, and total zinc as well as a 25% removal for total phosphorus, but no significant treatment for nitrogen. Additionally, a study in Texas examined the quality of runoff from a conventional asphalt pavement and an open-graded friction course (OGFC). This study indicated that even the thin porous asphalt layer above the conventional highway pavement removes a significant amount of the pollutants normally associated with runoff from pavement (Barrett 2007).
- A study by Dierkes (2002) found that most heavy metals were captured in the top 2 cm (0.75 in.) of the aggregates in the joints in PICP. Studies at the University of Guelph in Ontario, have also observed greater pollutant loads from asphalt surfaces than from concrete or permeable pavers. They have found that a permeable paver made up of interlocking concrete blocks can significantly reduce the surface runoff loads of such contaminants as nitrite, nitrate, phosphate, phosphorus, metals, BOD, and ammonium.
- Soluble contaminants such as deicing salts are not treated, but there is typically a reduced need for their application as the permeable surface takes in the melted ice and snow (Houle 2009).

b. Benefits to Humans:

i. Reduction of pollutant loads that enter surface water

3. Runoff from urban and rural areas contributes pollutants to the Credit River Watershed, as well as discharges from wastewater treatment plants and other point sources of pollution. All water that enters the storm sewer system goes, untreated, into the Credit River or Lake Ontario. Water for drinking purposes is taken from surface and ground water: The municipalities of Brampton and Mississauga use water from Lake Ontario. Areas west of Brampton, including Georgetown, mostly rely on groundwater aquifers for their municipal water supply needs. The rest of the watershed relies on groundwater aquifers or smaller surface water features for water use (CVC, 2009).
4. The occurrence of permeable pavements and various sub bases contributes to the removal of heavy metals, oils/grease and nutrient loads that are carried on to the surface water. Studies conducted in University of Guelph in Canada with laboratory tests since 1993 have found that a permeable paver made up of interlocking concrete blocks can significantly reduce the surface runoff loads of such contaminants as nitrite, nitrate, phosphate, phosphorus, metals, BOD, and ammonium.
5. Reduces the risk of illnesses resulting from consuming contaminated water. Drinking water outbreaks have been linked to runoff; more than half of the documented waterborne diseases outbreaks since 1948 have followed extreme

rainfalls in the United States (Currieiro et al., 2001). However since all kinds of runoff enters surface water the effects of runoff coming specifically from permeable pavements only cannot be effectively measured and thus reported.

3. IMPLICATIONS ON URBAN HEAT ISLAND EFFECT AND TEMPERATURE REGULATION

In urban environments, much natural groundcover, including trees and meadows, has been replaced with pavement and buildings. These hard surfaces absorb more radiation and are incapable of evapotranspiration, and therefore lead to higher temperatures. This effect is referred to as the urban heat island (UHI) effect. UHI is directly correlated with urbanization as predevelopment land cover is transformed from hydrological active surfaces to impervious surfaces.

a. Benefits to nature:

i. Reduces storm-water temperature and negative effects on aquatic life

- Permeable pavements can reduce thermal pollution (Karasawa et al., 2006) compared to conventional asphalt. The decrease was between 10o F and 25o F. This is in great part due to the dark color of the pavement. However, only results for PICP have been published in a peer-reviewed format, so it is possible that not all permeable pavement types, such as PA, will have such an impact.

b. Benefits to humans:

i. Reduction of Heat stress caused by UHI

- Research has shown that there is an association between increased daily temperatures and increased counts of deaths, illnesses and hospitalizations (Vutcovici, Goldberg & Valois, 2013)
- A review on heat-mortality relationships in cities found that in almost half of the locations studied, the risk of mortality increased between one percent and three per cent for every 1°C change in high temperature (Hajat & Kosatky, 2010).
- A Toronto-based study found that, on average, for every one-degree C increase in maximum temperature, there was a 29 per cent increase in ambulance response calls for HRI (Bassil et al., 2010). For every one-degree increase in mean temperature, there was a 32 per cent increase in ambulance response calls for HRI (Bassil et al., 2010).
- Research shows that a pervious concrete system (pervious concrete and aggregate base) with a measured solar reflectance index (SRI) of 14 stores less energy than a conventional concrete pavement with a SRI of 37 (Haselbach 2011). Because of this research, the International Green Construction Code (IGCC) applies pervious concrete as a heat island mitigation option independent of surface color (IGCC 2012).
- Complimenting this, researches (James 1996; Karasawa 2006) have shown that permeable pavements can cause a reduction of thermal pollution compared to conventional asphalt.

4. NOISE POLLUTION

b. Benefits to Humans

i. Noise pollution reduction

- According to the National Center for Asphalt Technology at Auburn University, the porosity and rubber or polymer modifiers found in PFC overlays significantly reduce the noise generated from tire-pavement contact (Rasmussen et al. 2007).
- Some researchers found that the thicker the PFC layer, the lower the noise levels at the tire/pavement surface, while other studies reported that noise levels increase with an increase in surface layer thickness (Liu et al. 2010).

5. BIODIVERSITY AND INCLUSION OF VEGETATION

Permeable pavements does not directly involve a the inclusion of a significant amount of vegetation when compared to various practices related to urban forestry or even compared to other LID strategies like green roofs and bioretention. However, the implementation of permeable pavement in one location may help preserve the natural landscape that might have been replaced by more conventional storm-water management practices such as detention/retention ponds. However, it can be concluded that biodiversity or addition of green space is not a significant direct benefit of permeable pavements.

a. Benefits to nature:

i. Enables inclusion of vegetation/greenery in storm-water management

- Permeable pavement types such as grid pavers enable parking and emergency access lanes to be grassed thus enabling permeable surfaces to blend into adjacent vegetated areas. It also promotes tree survival by providing air and water to tree roots.
- The choice of grass variety is important to longevity under tires and drought. A limited amount of research on concrete grid pavers by Sherman (1980) has shown that grasses within grids can recuperate from tire traffic damage faster than without grids.
- However, a study done in Vaughn that evaluated the performance of permeable pavements in cold climates (Drake, J., Bradford, A., Van Seters, T., & MacMillan, G. et al., 2012) assessed the vegetation colonization of Permeable Pavements and concluded that rapid colonization of grass on new interlocking pavement is not common. It is possible that the large void areas of the PC surface, as well as, a high pH from the concrete may limit opportunities for plant establishment.
- Can result in preservation of the natural landscape that might have been replaced by detention/retention ponds.

6. DESIGN RELATED IMPLICATIONS

b. Benefits to humans:

i. Resilience to cold weather conditions

- Studies at the University of New Hampshire Storm-water Center (UNHSC) and in northern Europe have shown that surface infiltration rates are maintained despite a frozen subsurface. This is due to the open-graded materials and a reduced duration of frost within porous asphalt (Roseen et al 2012).
- Porous asphalt pavements have been found to be less susceptible to damage as a result of freeze and thaw cycles than conventional pavements (Backström 1999). In somewhat frost-susceptible soils, increasing the minimum base depth to 35 to 55 cm (14 to 22 in.) may be warranted depending on loading and specific soil conditions.
- Additionally, porous asphalt is less likely to form black ice, often requiring less plowing and fewer deicing chemicals. This is mostly due to the dark color of the pavement and high porosity. This also reduces chances of slips and falls as well as increases vehicle safety (in warmer weather this reduces the standing water in pedestrian walkways which in turn is a safety feature for pedestrians).
- NHSC found that a porous asphalt parking lot reduced the need for winter maintenance salt by approximately 50% to 75% (Roseen and Ballestero 2008; UNHSC 2009).

- Many years of experience and monitoring have demonstrated that PICP does not heave when frozen. This is evidenced by many PICP projects in Chicago, Minneapolis, and Toronto remaining stable during freezing and thawing climates.

ii. Buffering from acidic rainfall

- Permeable pavements can buffer acidic rainfall pH (Collins 2008; Dierkes 2002; James 1996; Pratt 1995), which is likely due to the presence of calcium carbonate and magnesium carbonate in the concrete pavement and aggregate materials. Pervious concrete provides a greater buffering capacity than conventional asphalt due to the cement and contours in the pavement geometry and the additional coarse aggregate layer through which water migrates

iii. Reduces drainage system infrastructure costs in the long term

- Reduces or eliminates the need for catch-basins, manholes, and storm drains for a piped drainage system resulting in cost savings (initial, operation, and maintenance costs)
- Can result in a reduction or elimination of a storm-water utility fee

iv. Sustainable Design credits

- Permeable pavements that use life cycle assessment to quantify energy use and other environmental impacts can qualify for credits in sustainable road rating systems. These rating systems include the University of Washington's Green

Roads, the Federal Highway Administration's (FHWA) sustainable highways evaluation tool called INVEST, the Ontario Canada Ministry of Transportations Greenpave Program and the Institute for Sustainable Infrastructure's Envision program.

- Permeable pavements can also be utilized to obtain LEED credits in both Canada and US Green Building councils.

III. LAND USE & GEOGRAPHICAL CHARACTERISTICS OF POTENTIAL AREAS:

1. **Which category does it fall under?**

    a. Urban (residential, commercial, mixed use)- mostly

2. **Different types of the proposed LID**

1. **Porous asphalt-** Porous asphalt pavements include a permeable asphalt surface underlain by an open-graded aggregate choker course and a reservoir bed. Porous asphalt systems allow for storm-water infiltration/infiltration and storage as well as a structural pavement in a single system. The bed depth is based on structural load, desired storage and frost depth requirements. Permeable pavement systems are usually placed on un-compacted subgrade to facilitate in infiltration, but may include an underdrain and liner if necessary.

    Another method of porous asphalt use is on top course over standard impermeable asphalt. This is called a permeable friction course (PFC) overlay. Since the 1970s, permeable (or porous) friction course overlays, also known as open-graded friction courses (OGFC), have been installed on selected roadways in an e ort to make them quieter and safer.

    PFC is applied only as a thin drainage layer of about 25 to 50 mm (1 to 2 in.) in thickness over existing impermeable asphalt roadways with no infiltration into the subsurface. In contrast, the installation of porous asphalt allows storm-water runoff to infiltrate into the ground and recharge groundwater.

2. **Pervious concrete-** Pervious concrete consists of a hydraulic cementitious binding system combined with an open-graded aggregate to produce a rigid, durable pavement. This pavement typically has 15% to 25% interconnected void space that allows rapid in infiltration of storm-water to the underlying soil and/or aggregate storage layer.

3. **Permeable interlocking concrete pavement (PICP)** –

PICP consists of manufactured concrete units that reduce storm-water runoff volume, rate, and pollutants. The impervious units are designed with small permeable joints. The openings typically comprise 5% to 15% of the paver surface area and that maintain high permeability with small-sized aggregate ll. The joints allow storm-water to flow into a crushed stone aggregate bedding layer and base/sub-base that support the pavers, while providing water storage as well as runoff quantity and quality treatment.

PICP is visually attractive, durable, easily repaired, requires low maintenance, and can withstand heavy vehicle loads.

4. Grid pavements – Grid pavements are comprised of concrete or plastic open-celled paving units. The “cells” or openings penetrate their entire thickness so they can accommodate aggregate, topsoil, or grass. Concrete and plastic grids are intended for light vehicular loading applications and are typically constructed over a dense-graded aggregate base. Both types of grids are often used for emergency access drives and parking/drive lanes with occasional use, where a natural turf appearance and in infiltration are desired as well as where high intensity uses or loads are not expected. In some cases, open-graded aggregate within the grid openings and an open-graded base are used with these products for additional storm-water storage and in infiltration.

3. Physical suitability and constraints (key constraints and design mitigation strategies)

- Commonly used for walkways, driveways, patios, courtyards, sidewalks, parking lots, alleys, and low volume roadways, generally with posted speed limits of 55kph or lower.
- Used in recreational and park-related applications such as playground spray pools, areas around water fountains, or as permeable buffers around tree beds and planters.
- Used to support outdoor uses that require benefit from storm-water/water infiltration from paved surfaces as opposed to ponding and /or runoff- ie: entryways to eliminate ponding at doors

- Can be used in retrofit applications to provide storm-water management in space-limited locations
- Can be strategically located to accept clean run-on from adjacent uses such as walkways or roofs.

It is recommended that no infiltration designs be used if the following conditions are present:

- The distance between the permeable pavement and water supply wells is less than 30m (100 ft). Designers should consult local regulatory agencies for additional guidance or varied regulations.
- The soil depth-to-groundwater is insufficient to offer adequate filtering and treatment of storm-water related pollutants. Local regulations often require a minimum flow rate through a minimum depth of soil. This will vary given the use of the pavement, depth of sub-base layers, soil permeability, and depth- to-groundwater. A minimum 0.61m (2ft) separation from groundwater is recommended.
- The system is directly over solid rock or impermeable rock/soil layer such as compacted glacial till with no loose permeable rock layer above it.
- The system is near drinking-water aquifers without the minimum 2-foot vertical separation or sufficient soil permeability rates to filter pollutants before they enter the groundwater.
- The system is over some fill soils that have unacceptable stability when exposed to in infiltrating water such as expansive soils or poorly compacted fill soils.

- The pavement is adjacent to fill or natural slopes where soil conditions may result in lateral breakout of the storm-water on the slope (a lateral impermeable barrier may overcome this situation and allow the design of a full- or partial-in infiltrating system).
- The location is in an area where storm-water may be exposed to hazardous materials as a result of land use or the potential for an accidental spill of hazardous materials is higher than normal (i.e., “storm-water hotspot”). Some examples include fueling stations and salvage yards.
- The location is in an area with karst geology with limestone deposits subject to sinkhole development due to underground artesian water movement. A geotechnical engineer is required in these areas as some sites may not be compatible with any permeable pavement.
- The pavement systems near building foundations and basements are subject to flooding. They are not recommended for use if within 3m (10ft) unless adequate perimeter drainage, waterproofing, and geotechnical designs are completed and approved.

IV. DESIGN TEMPLATE FOR LID/BMP

1. Application: which land use characteristics best suit BMP etc.

- Porous pavements are best suited for low traffic areas, such as parking lots and sidewalks. The most successful installations of alternative pavements are found in coastal areas with sandy soils and flatter slopes (Center for Watershed Protection, 1998)
- Porous pavement may also have some application on highways, where it is currently used as a surface material to reduce hydroplaning.
- Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Porous pavement is a good option for these areas because they consume no land area.
- Properly designed, installed and maintained permeable pavements have been shown to reduce frost heave, icing, pollutant loading and runoff and to increase pavement longevity (Gunderson, 2008; Hun-Dorris, 2005).

2. Geometry and site layout

Porous pavement has site constraints as other infiltration practices. A potential porous pavement site needs to meet the following criteria:

Soils need to have permeability between 0.5 and 3.0 inches per hour. The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface. Porous pavement should be located at least 2 to 5 feet above the seasonally high ground-water table, and at least 100 feet away from drinking water wells. Porous pavement should be located only on low-traffic or overflow parking areas, which do not expect to be sanded during wintertime conditions

Design Considerations:

Few basic features should be incorporated into all porous pavement practices:

1. Pre-treatment: In most porous pavement designs, the pavement itself acts a pre-treatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the pavement surface is critical to prevent clogging. Another pre-treatment element is a fine gravel layer above the coarse gravel treatment reservoir. The effectiveness of both of these pre-treatment measures are marginal, which is one reason frequent vacuum sweeping is needed to keep the surface clean.

2. One design option incorporates an “overflow edge,” which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, storm-water will flow over the surface and into the trench, where some infiltration and treatment will occur.

3. Treatment: The stone reservoir below the pavement surface should be composed of layers of small stone directly below the pavement surface, and the stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, porous pavement is sized to treat a small event, such as the water quality storm (i.e., the storm that will be treated for pollutant removal) which can range from 0.5 to 1.5 inches. Like infiltration trenches, water can only be stored in the void spaces of the stone reservoir.

4. Conveyance: Water is conveyed to the stone reservoir through the surface of the pavement and infiltrates into the ground through the bottom of this stone reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs also need some method to convey larger storms to the storm drain system. One option is to set storm drain inlets slightly above the surface elevation of the pavement. This allows for temporary ponding above the surface if the surface clogs but bypasses larger flows that are too large to be treated by the system.

5. Maintenance Reduction - One non-structural component that can help ensure proper maintenance of porous pavement is the use of a carefully worded maintenance agreement that provides specific guidance to the parking lot, including how to conduct routine maintenance and how the surface should be repaved. Ideally, signs should be posted on the site identifying porous pavement areas.

6. Landscaping - The most important landscaping objective for porous pavements is to ensure that its drainage area is fully stabilized, thereby preventing sediment loads from clogging the pavement.

Regional Adaptations:

In cold climates, the base of the stone reservoir should extend below the frost line to reduce the risk of frost heave.

Maintenance:

Porous pavement requires extensive maintenance compared with other practices. In addition to owners not being aware of porous pavement on a site, not performing these maintenance activities is the chief reason for failure of this practice. Typical requirements follow below:

Monthly:

- Ensure that paving area is clean of debris
- Ensure that paving dewaters between storms
- Ensure that the area is clean of sediments

As Needed:

- Mow upland and adjacent areas, and seed bare areas

- Vacuum Sweep frequently to keep the surface free of sediment (typically three to four times per year)

Annual:

- Inspect the surface for deterioration or spalling

v. COST BREAKDOWN

1. Maintenance and construction cost:

Table B-5 Permeable Pavements Surface Cost Comparison

POROUS PAVEMENT TYPE	TYPICAL INSTALLED COST ($/SF)	TYPICAL COST RANGE ($/SF)
Porous Asphalt (5 cm [2 in.] surface course, 7.62 cm [3 in.] ATPB)	$6.00	$4.00 – $8.00
Pervious Concrete (6 in.)	$8.00*	$6.00 – $10.00
Interlocking Permeable Pavers & Rigid Open Cell Pavers (including 5 cm [2 in.] bedding layer)	(small hand installation) $13.00	$10.00 – $20.00
	(large mechanical installation) $6.50	$5.00 – $10.00
Open Cell/Grid Paving Systems	$7.00	$5.00 – $9.00
Proprietary Porous Pavement Products	Vary by manufacturer	

Note: Based on data provided by CH2M Hill for 17 actual bids with unit materials costs for permeable pavements (excluding open celled/grid lattice) from projects 2011–2013. General Estimates for installed permeable pavement surfaces with no sub-surface storage. Prices vary greatly with pavement depth, base/subbase and drainage variations.

*Estimate provided by National Ready Mix Concrete Association 2013

VI. DRAWBACKS AND LIMITATIONS OF LID/BMP

- Maintenance requirements are high compared to other LID-BMP storm-water management facilities
- Costs to build permeable pavements are high compared to other storm-water management facilities
- Mainly a small drainage area is treated
- They are susceptible to clogging where anti-skid material is applied
- Performance is reduced if freezing occurs while the surface is saturated
- They are unsuitable for use in areas where heavy sediment loads are expected or in active construction or excavation areas that are not fully stabilized
- They are unsuitable for use in areas with heavy vehicle traffic, unless specifically designed for heavy loads.
- Care also needs to be taken when applying salt to a porous pavement surface since chlorides from road salt may migrate into the ground water.

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Structure		Ecosystem function	Ecosystem service (P, R, C, S)	Final Benefit	Well-being domain**
Before (Existing)	After (post intervention)				
Usage of impermeable surfaces such as asphalt and concrete in public and residential areas (ex: sidewalks, driveways, parking areas etc.)	Increased % of permeable surface Simulation of natural hydrological cycle	Increased infiltration Reduced runoff volume and peak discharge rate	R: Water regulation, Erosion regulation	Protection of people and property from floods, riverbank erosion Protection of agricultural soils	Security, Health
		Increased groundwater recharge	R,S: Water regulation, Water cycling	Secure resource access (access to clean water)	Basic material for good life
		Pollutant removal: - large particles captured in joints - oils and grease adsorbed to concrete and aggregate -immediate underlying soil layer reduces pollutants through microbial activity (TSS, metals, heavy metals, oil, grease, NOx, P, PO_4^{-3}, Ammonium)	R: Water purification and treatment, disease regulation		Security, Health
				intermediate benefit- Reduced need for soluble contaminants such as de-	

Structure		Ecosystem function	Ecosystem service (P, R, C, S)	Final Benefit	Well-being domain**
Before (Existing)	**After (post intervention)**				
				icing salts	
	Pervious concreate and aggregate bases with lesser SRI* (Solar Radiation Index)	Stores less energy than conventional pavement (absorbs less heat)- reduces urban heat island effect	R: Thermal regulation/Climate regulation	Comfort, lowered temperature, reduced heat stress	Health
	Porosity and rubber/polymer modifiers in the PFC overlays	Porosity and rubber/polymer modifiers in the PFC overlays absorb noise	R: Noise Regulation	Comfortable noise level	Health
	Dark colour porous pavement (PICP)	Reduces storm-water temperature and it's adverse effects on aquatic life	R: Thermal regulation/Climate regulation	Recreation (through fishing in healthy waters), Nature appreciation	Health
	More/added calcium carbonate, magnesium carbonate in porous concrete pavement, contours in pavement geometry and additional coarse aggregate layer	Buffering from acid rainfall – Calcium reacts with acid rain components- *detailed description of effects on Calcium cycle in "Co-benefits" section written separately*	S: Nutrient Cycling	Protection of people and property from damages	Health, Security
Less/no vegetation in road right of ways, parking lots,	Enables more vegetation to be added into urbane	Micro climate regulation, photosynthesis	C: Education, Inspiration Aesthetic value	Nature appreciation, Improved mood and self esteem	Health, Good social

Structure		Ecosystem function	Ecosystem service (P, R, C, S)	Final Benefit	Well-being domain**
Before (Existing)	After (post intervention)				
emergency access lanes etc.	areas, more opportunity for connectivity (grass pavers)		S: Photosynthesis (limited)		relations
Natural landscape that may have to be replaced with detention/retention ponds	Preservation of natural landscape	Infiltration through porous material	R: Cultural heritage value (If landscape in question held value for certain stakeholders) Aesthetic value (Note- aesthetic value may be an insignificant benefit in most cases due to the lack of vegetation incorporated in permeable pavement design)	Nature appreciation, Improved mood, Stewardship opportunities (Note- aesthetic value may be an insignificant benefit in most cases due to the lack of vegetation incorporated in permeable pavement design)	Basic material for good life, Good social relations

Appendix 2:
Bioretention Systems

TOOL KIT-

BIORETENTION SYSTEMS-

Bioretention Cells, Rain Gardens, Stormwater Planters, Extended Tree Pits & Curb Extensions

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I. OVERVIEW:

1. Description of LID/BMP

Bioretention systems are vegetated practices that temporarily store, treat and infiltrate stormwater runoff. The most important component of these practices is the bioretention soil media. The bioretention soil media is made up of a specific ratio of sand, fine soils and organic material (CVC, 2012). Also referred to as “grass swales”, “vegetated swales” or “filter strips”.

Bioretention gardens are often used interchangeably with rain gardens. They are almost the same practice, except with one main difference - bioretention gardens have underneath drainage, while rain gardens depend on the soil for proper drainage.

Rain gardens are built with native soils mixed with compost or a special soil mix, while bioretention basins have special soil mix and gravel beneath the soil to hold more water. Furthermore, rain gardens do not have a buried perforated pipe.

A bioswale is similar to a bioretention area in the way it is designed with layers of vegetation, soil and a perforated pipe within the bottom stone layer. Bioswales typically are located along a roadway and can be planted like gardens or covered in turfgrass.

Bioswales typically take stormwater runoff from nearby paved surfaces and hold the water long enough to allow it to slowly soak into the deep soil and possible rock drainage layer. Unlike ditches, bioswales purposely slow and filter stormwater before it enters the stormwater system.

As stormwater flows down the length of the bioswale, the natural processes of plants and soils work together to improve water quality by trapping and storing sediment, and by filtering contaminants and nutrients. Excess filtered water not used by the plants infiltrates into the native soil below or collects in the drainage pipe located under the drainage layer. This drainage layer pipe connects to the existing stormwater system to carry excess filtered stormwater back to the river.

The primary component of the practice is the filter bed which is a mixture of sand, fines and organic material. Other elements include a mulch ground cover and plants adapted to the conditions of a stormwater practice. Bioretention is designed to capture small storm events or the water quality storage requirement. An overflow or bypass is necessary to pass large storm event flows.

Bioretention systems filter storm water via the following processes:

1. Passing through surface vegetation
2. Percolating through prescribed filter media, which provides treatment through fine filtration, extended detention treatment and some biological uptake
3. Disconnecting impervious areas from downstream waterways
4. Providing protection to natural wetland systems from frequent storm events

2. Key issues faced by the watershed that can be addressed through implementation LID/BMP (A brief overview: will be discussed in detail in part II)

- Effects of stormwater runoff
- Urbanization and spread of low density development
- Erosion and sedimentation
- Flood risk
- Water quality issues
- Non-point source pollution
- Lack of green space in road right-of-ways

3. Policy recommendations that encourage the LIP/BMP

Please refer to "Toolkit Disclaimer" in the previous section where a detailed list of policies and programs that support LID have been included

4. Different scales of stakeholders

- Municipalities- 11 municipalities

- Conservation Authority- CVC
- Developers and investors
- General public

II. CO-BENEFITS: ACHIEVING A DOUBLE DIVIDEND

What Co-benefits Exist Through Implementation, How Does It Happen Through LID/BMP and Where Do The Benefits Occur

1. NON-POINT POLLUTANT REMOVAL

a. Benefits to nature:

i. Pollutant removal from natural ecosystems

- A number of physical, chemical, and biological processes facilitate pollutant removal in biofiltration systems. For example, vegetation enhances the biological activity in the soil, thus increasing pollutant removal when compared to that of a typical sand filter.
- Pollutants are removed through Adsorption to soil particles and plant uptake (dissolved metals and soluble phosphorus, small amounts of nutrients including phosphorous and nitrogen), Microbial processes (organics, pathogens), Exposure to sunlight and dryness (pathogens), Infiltration of runoff and Sedimentation and filtration (TSS, floating debris, trash, soil-bound phosphorous, some soil-bound pathogens) (Prince George's County Bioretention Manual, 2007).
- Numerous studies confirm that vegetated filters achieve higher removals of nutrients when compared to non-vegetated filters (Bratieres et al. 2008; Davis et al. 2001; Glaister et al. 2014; Henderson et al. 2007; Lucas and Greenway

2008; Read et al. 2008)

- Vegetation also helps to maintain the hydraulic conductivity of bio-filters over time (Hatt et al. 2009), and a thicker root morphology may decrease the impact of clogging (Le Coustumer et al. 2012).
- The presence of vegetation has been linked with an order of magnitude increase in nitrification and denitrification 16S rDNA gene concentrations in soil cores. This indicated a greater potential for nitrogen transformations and removal (Chen et al. 2013).
- Sources of nitrogen in highway stormwater runoff include fertilizers, vegetation decay, and animal excrement (Burns 2012). In a study focused on dissolved constituents, vegetated columns resulted in twice as much removal of TN (63-77%) as non-vegetated columns (Henderson et al. 2007).
- Studies have also confirmed nitrate leaching from bio-filtration experiments (Davis et al. 2006; Zinger et al. 2013). One study measured increasing concentrations of dissolved nitrogen with depth in the filter media (Hatt et al. 2006). Leaching may be due to the decomposition of organic matter and the oxidation of captured ammonia to nitrate.
- Sources of phosphorus in highway storm water runoff include leaf decay from trees, fertilizers, and lubricants Studies have shown that total phosphorus can be greatly reduced within a bio-filter because a majority of phosphorus is associated with particulate matter (Glaister et al. 2014; Hatt et al. 2007).
- In many bio-filtration studies, indicator heavy metals have included copper, lead, and zinc. Common sources of copper include wear of bearings and brake

linings, moving engine parts, fungicides, and insecticides (Burns 2012). Lead sources include automobile exhaust, wear of tires and bearings, and lubricating agents while zinc sources include oil, grease, and wear of tires (Burns 2012).

- Results from multiple studies showed that metals removal was very high in bio-filtration systems (Hatt et al. 2009; Hsieh and Davis 2005; Mitchell et al. 2011; Zinger et al. 2013). Removal was typically attributed to accumulation in soil and mulch due to their high organic matter content.
- Sources of solids include wear of pavements and vehicles as well as atmospheric depositions (Burns 2012). Studies reviewed indicated a minimum of 76% TSS removal by bio-filtration (Barrett et al. 2013; Bratieres et al. 2008; Hatt et al. 2009; Hsieh and Davis 2005; Mitchell et al. 2011).
- Little data exists on the ability of bio-retention to reduce bacteria concentrations, but preliminary laboratory and field study results report good removal rates for fecal coliform bacteria (Rusciano and Obropta, 2005; Hunt et al., 2008; TRCA, 2008b)

b. Benefits to humans

i. Reduction of pollutant loads that enter surface water

- Reduces the risk of illnesses resulting from consuming contaminated water containing the above mentioned contaminants. Drinking water outbreaks have been linked to runoff; more than half of the documented waterborne diseases outbreaks since 1948 have followed extreme rainfalls in the United States (Gaffield, Stephen J. et al., 2003). However since all kinds of runoff enters surface water the effects of runoff coming specifically through bioretention systems cannot be effectively measured and thus reported.

2. WATER BALANCE: RUNOFF VOLUME REDUCTION

a. Benefits to nature:

i. Reduction of runoff volume

- Bio-retention has been shown to reduce runoff volume through evapotranspiration and infiltration of runoff.
- Several studies have shown that bio-retention systems without an underdrain, and therefore rely on full infiltration into soil, have higher percentage of runoff reduction that bio-retention systems with underdrain (Dietz and Clausen, 2005) Bio-retention with underdrain North Carolina 40 to 60% (Smith and Hunt, 2007)
- However, aside from underdrain, many other factors also impact the reduction of runoff, such as native soil infiltration rate, rainfall patterns, and sizing criteria (CVC, 2010).
- The linkage between runoff volume capture and quality performance is strong, and designing for relatively small storms is effective. (Prince George County, 2009)

- The feasibility of storing the channel erosion control volume within bioretention areas will be dependent on the size of the drainage area and available space. It may prove infeasible due to the large footprint needed to maintain the recommended maximum ponding depth of 200 mm (CVC, 2010).
- However, through runoff volume reduction, this reduces peak flow and thus the effects of stream channel erosion.

3. PERFORMANCE UNDER COLD CLIMATE CONDITIONS

b. Benefits to humans:

i. Effective treatment of snowmelt runoff

- In cold climates, bioretention areas can be used for temporary snow storage. When used for this purpose, or to treat parking lot runoff, the bioretention area should be planted with salt tolerant, non-woody plant species.

- Bioretention is only marginally effective for treating snowmelt runoff because of the dormancy of the vegetation during the cold season; treatment may still occur as long as a flow path is available and the filter media are not frozen solid. The problem with infiltration or filtration in cold weather is that ice forms both on top of the facility and within the soil interstices (Minnesota, 2005).

4. THERMAL REGULATION

a. Benefits to nature:

i. Reduces stormwater temperature and negative effects on aquatic life

- Reduction of stormwater temperature, through thermal attenuation is achieved by filtering runoff through the protected soil medium of a bioretention facility. One study showing thermal attenuation attributable to bioretention found that the temperature of input runoff was reduced from 33 degrees Celsius to about 22 ° C (Minami and Davis 1999). Bioretention facilities have an advantage over shallow marshes or ponds with respect to thermal attenuation. Thermal pollution of streams from urban runoff increases the likelihood of fish kills and degraded stream habitat.

5. BIODIVERSITY AND INCLUSION OF VEGETATION

a. Benefits to Nature

i. Increased ecosystem resiliency:

- Typical recommendations for bio-filtration construction indicate that a variety of warm season and cool season species should be planted to encourage year-round growth and consistent performance (AMEC Earth and Environmental et al. 2001; Department of Water and Swan River Trust 2007). Species should also be tolerant of flood and drought conditions to prevent frequent replanting. Wetland species may also be considered based on the site characteristics (WEF et al. 2012).

- When possible it is advised to use native plants as vegetation. Most bioretention systems can be urban gardens. Trees in these urban gardens provide nesting sites and breeding habitat to urban wildlife.
- A diversity of native plants, animals and micro-organisms increased the ecosystems resiliency and sustainability (MNRF, 2000; Zak, Holmes, White, Peacock, & Tilman; Hector et al., 1999; Tilman et al., 2001).
- Plants will provide enhanced environmental benefit over time as root systems and leaf canopies increase in size and pollutant uptake and removal efficiencies. Soils, however, begin filtering pollutants immediately and can lose their ability to function in this capacity over time. Therefore, evaluation of soil fertility is important in maintaining an effective bioretention system.
- However, the role of vegetation and associated microbial processes in maintaining infiltration in bio-retention facilities is not well understood in Ontario. Further research is needed to identify the types of vegetation best suited to meeting the stormwater treatment and runoff control functions of bio-retention (Van Seters, 2014).

b. Benefits to Humans

i. Better sense of personal identity and psychological well-being:

- People had a better sense of personal identity and perspective when in areas with more diverse habitats, indicating that biodiversity can positively impact psychological well-being (Fuller et al., 2007) and improved mood (Routledge, 2015)
- Green space has been found to provide restoration from stress and attention fatigue, an improved ability to cope with stress and reported reduction in stress (Grahn & Stigsdotter, 2003; Hartig et al., 2003; Kuo, 2010; Lottrup, Grahn, & Stigsdotter, 2013) which leads to improved health.
- Maas et al. (2006) found that the percentage of green space inside a one kilometre and a three kilometre radius of residences had a significant relation to perceived general good health and the relationship was more pronounced for lower socioeconomic groups. Maas et al. (2009) tried to clarify these findings with more specific measures and found that people with more green space in their living environment reported less loneliness, which can have negative health impacts

ii. Place attachment:

- Studies have shown that trees, vegetation, and other natural views provide a sense of connection to nature and the bioregion, protection, and safety (Peckham, Duinker, & Ordóñez, 2013; Ulrich, 1986).

- Green space can have health benefits through a range of exposures, from experiencing green space while not being physically present (i.e. viewing nature through a window), engaging in another activity (e.g. biking through a park) or intentionally engaging in the green space (e.g. gardening, hiking, camping, etc.) (James et al., 2015).

iii. Improved attention:

- Studies have also shown that people with views to nature are more relaxed, better able to focus, and perform better on attention and cognitive related tasks (Tennessen & Cimprich, 1995; Hartig, Mang, & Evans, 1991).

III. LAND USE & GEOGRAPHIC CHARACTERISTICS

1. Which category does it fall under?

a. Urban (residential, commercial, mixed use)- mostly

2. Different types

According to most manuals that deal with the practice of bio-retention, including the LID SWM guide published by CVC and TRCA, there are four major types of bioretention systems, as described earlier in the introduction. These include:

- Bio-retention cells- used in development types with large landscaping areas, parks, parking lot island and in areas without tight space constraints
- Rain gardens- Used to capture roof, lawn and driveway runoff from low to medium density residential lots in a shallow depression in the front, side, or rear yard of the home depending on the development's drainage pattern.
- Stormwater planters- used in ultra urban areas adjacent to buildings and in plazas
- Extended tree pits- located within road-right-of-ways to take advantage of the landscaped space between the sidewalk and the street
- Curb extensions- similar to extended tree pits, these are installed in road right-of-ways and also act as road calming device. These are constructed in place of a raised concreate surface and constructed as a depression with vegetation used for stormwater treatment.

Types of bio retention systems can also be classified according to the performance type (Prince Georges County, 2009). These include:

- Infiltration/recharge facility- s recommended for areas where high recharge of groundwater would be beneficial. Because there is no underdrain, the in situ soils need to have a high infiltration rate to accommodate the inflow levels.
- Filtration/partial recharge facility- This facility is designed with an underdrain at the invert of the planting soil mix to ensure that the facility drains at a desired rate. The facility allows for partial recharge, as an impervious liner is not used. The facility type is suitable for areas and land uses that are expected to generate nutrient and metals loadings (residential, business campus, or parking lots).
- Infiltration/filtration/recharge- This type of facility is recommended for areas where higher nutrient loadings (particularly nitrates) are anticipated. The facility is designed to incorporate a fluctuating aerobic/anaerobic zone below the raised underdrain discharge pipe. This fluctuation created by saturation and infiltration into the surrounding soils will achieve denitrification. With a combination of a fresh mulch covering, nitrates will be mitigated through the enhancement of natural denitrification processes. This type of facility would be suitable for areas where nitrate loadings are typically a problem (residential communities).
- Filtration only facility-this is recommended for areas that are known as “hot spots” (gas stations, transfer sites and transportation depts.). An

important feature of this type of facility is the impervious liner designed to reduce or eliminate the possibility of groundwater contamination. This facility type can be used to capture accidental spills and contain the level of contamination

3. Physical suitability and constraints

The following points should be considered when constructing bioretention systems. This information is taken directly from LID SWM guide published by CVC and TRCA.

- Wellhead Protection: Facilities receiving road or parking lot runoff should not be located within two (2) year time-of-travel wellhead protection areas.
- Available Space: Designers should reserve open areas of about 10 to 20% of the size of the contributing drainage area.
- Site Topography: Bioretention is best applied when contributing slopes are between 1 to 5%. Ideally, the proposed treatment area will be located in a natural depression to minimize excavation. The surface of the filter bed should be flat to allow flow to spread out and not concentrate in one area of the practice. However, for linear bioretention practices, such as those along roadways, the longitudinal slope must be considered
- Available Head: If an underdrain is used, then 1 to 1.5 metres elevation difference is needed between the inflow point and the downstream storm

drain invert. This is generally not a constraint due to the standard depth of storm drains. For bioretention without an underdrain, the design will only require enough elevation difference to move large event flows through the overflow or bypass without generating a backflow or flooding problem.

- Water Table: Bioretention should be separated from the seasonally high water table by a minimum of one (1) metre to ensure groundwater does not intersect the filter bed, as this could lead to groundwater contamination or practice failure
- Soils: Bioretention can be located over any soil type, but hydrologic soil group A and B soils are best for achieving water balance benefits. Facilities should be located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than 1x10-6 cm/s) an underdrain is required.
- Drainage Area and Runoff Volume: Bioretention cells work best for smaller drainage areas, as flow distribution over the filter bed is easier to achieve. Typical drainage areas are between 100 m^2 to 0.5 hectares. The maximum recommended drainage area to one bioretention facility is approximately 0.8 hectares (Davis et al., 2009).
- Pollution Hot Spot Runoff: To protect groundwater from possible contamination, source areas where land uses or human activities have the potential to generate highly contaminated runoff (e.g., vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites) should not be treated

by bioretention facilities designed for full or partial infiltration. Facilities designed with an impermeable liner (filtration only facilities) can be used to treat runoff from pollution hot spots.

- Proximity to Underground Utilities: Designers should consult local utility design guidance for the horizontal and vertical clearances required between storm drains, ditches, and surface water bodies
- Overhead Wires: Designers should also check whether maximum future tree canopy height in the bioretention area will not interfere with existing overhead phone and power lines.
- Setbacks from Buildings: If an impermeable liner is used, no setback is needed. If not, a four (4) metre setback from buildings should be applied.

IV. DESIGN TEMPLATE

1. Applications

Bioretention areas can be located in most open spaces of a development site. It is more common in road right-of-ways. Some of the similar applications for bioretention areas include:

- Parking lot islands
- Street medians
- Traffic circles
- Cul-de-sacs
- Roadside swale features (e.g., between the curb and sidewalk)
- Shared facilities located in common areas for individual lots
- Common landscaped areas in apartment complexes or other multifamily housing designs
- Commercial setbacks, and
- Site entrance or buffer features

2. Geometry and site layout

- Key geometry and site layout factors include: The minimum footprint of the filter bed area is based on the drainage area. Typical drainage areas to bioretention are between 100 m^2 to 0.5 hectares. The maximum recommended drainage area is 0.8 hectares. Typical ratios of impervious drainage area to treatment facility area range from 5:1 to 15:1. Bioretention can be configured to fit into many locations and shapes. However, cells that are narrow may concentrate flow as it spreads throughout the cell and result in erosion. The filter bed surface should be level to encourage stormwater to spread out evenly over the surface (CVC, 2010).

- Current TRCA/CVC guidelines on bioretention systems recommend that the drainage area to bioretention facilities should be no more than 15 times the size of the facility footprint to ensure optimal performance over the life of the facility**.**

V. COST BREAKDOWN

Every site is unique, requiring specific cost estimating to account for the variability. In estimating the cost of using bioretention, a number of factors need to be considered:

- Site restrictions—both physical and regulatory
- Availability of materials, equipment, and labor
- Scheduling tasks for efficiency

VI. DRAWBACKS AND LIMITATIONS

- Bioretention systems are particularly sensitive to clogging of the filter medium. If there are moderate to high levels of silts and clays in the runoff, pre-treatment is required. Runoff from industrial/commercial hotspots requires pre-treatment or source control practices upstream of bioretention areas.

- It is important to restrict any traffic over the bioretention area and carefully manage construction activities to avoid damaging the vegetation and compacting and clogging the filter medium. This can be done through the application of appropriate erosion and sediment control measures in the tributary catchment, appropriate selection of vegetation, and/or through isolation methods such as fencing. It may be necessary to provide a protective cover such as a geofabric over the bioretention area during construction.

- Inverts of the existing storm drain system can be a limiting factor. In general, a 1.2 m to 1.8 m elevation above the invert of the storm sewer system is required to drive stormwater through bioretention areas (CVC, 2010).

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INTERVENTION OVERVIEW MATRIX

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	**After (post intervention)**				
Conventional stormwater management systems	Structural changes: • Bioretention with no underdrain (in-situ soils with high infiltration rate- type A,B)	Water balance benefit- infiltration through porous soils. Aids in groundwater recharge	Regulation: water regulation, water filtration	Protection of people and property from floods and erosion , reduces stress on stormwater infrastructure and sewers , Access to clean water (indirect)	Security, Health
	• Bioretention with underdrain- areas/land use types that generate nutrient and metal loadings	Water balance benefit- partial, based on available storage volume beneath the underdrain and soil infiltration date(CVC) Aids in the control of overflow	Regulation: water regulation	Protection of people and property from floods and erosion , reduces stress on stormwater infrastructure and sewers, Access to clean water (indirect)	Security, Health
	• Bioretention with underdrain and impermeable liner- areas with potential for accidental spills and contamination	Water balance benefit- partial, some volume reduction through evapotranspiration. reduces/eliminates groundwater contamination (CVC)	Regulation: water regulation	Protection of people and property from floods and erosion , reduces stress on stormwater infrastructure and sewers, Access to clean water (indirect)	Security, Health

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	**After (post intervention)**				
	• Bioretention facility with fluctuating aerobic/anaerobic zone:	Vegetation consisting of highly nitrogen efficient plant species and the presence of an anoxic saturated zone and additional compost in saturated layer aids in nitrogen removal. (Zinger et al. 2007, 2013; Hunt et al. 2006).	Supporting: Nutrient Cycling Regulation: Water regulation, Water filtration	Protection of people and property from floods and erosion , reduces stress on stormwater infrastructure and sewers, Access to clean water (indirect)	Security, Health
Increased burden on municipal sewage systems due to high percentage of pollutants in stormwater and lack of pre-treatment and non-point source pollutant removal	Increased ability for non-point source pollutant removal through bioretention conveyance systems	Non-point source pollutant removal through: • Adsorption to soil particles and plant uptake (especially through phytoremediation)- dissolved metals, soluble phosphorous, small amounts of nutrients including phosphorous and nitrogen • Microbial processes- organics, pathogens • Exposure to sunlight and dryness- pathogens • Infiltration of runoff • Sedimentation and filtration- TSS, floating debris, trash, soil-bound phosphorous, soil-bound	Regulation: Disease regulation, water regulation, water filtration	Protection of people from threat of diseases, access to clean water (indirect)	Security, Health, Basic material for good life good life

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	After (post intervention)				
		pathogens			
No vegetation- only grey infrastructure	Added vegetation- highly nitrogen effective plants, native plants, species that are more tolerant to flooding and water logging	Water storage and accumulation- vegetation in the bioretention facility adds roughness to the channel, reducing the velocity. This delays the peak runoff. In addition the ponding capability of the system also aids in reduction of peak flow.	Regulation: water regulation, erosion regulation, flood regulation	Protection of people and property from floods, access to clean water (indirect)	Security, Health, Basic material for good life
		Decreased downstream/riverbank erosion	R: Erosion regulation	Protection of property	Security
		Reduction of runoff temperature: thermal attenuation is achieved through filtering runoff through protected soil medium. Some studies have shown that temperature of input runoff was reduced from 33 to 22 Celsius in bioretention facilities (Minami and Davis 1999). Reduces thermal pollution of streams and ill effects to aquatic habitat.	Regulation: water regulation, Climate regulation Provisioning: Fish (indirect)	Opportunities for active recreation through fishing in healthy stream habitats (indirect)	Health, Basic materials for good life

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	**After (post intervention)**				
		Carbon sequestration – vegetation absorbs CO_2 and reduces the effects of climate *change*	R: Climate regulation, Supporting ES *(Link cannot be made at a local level)*	Comfort, Lowered temperature, reduced heat stress *(Link cannot be made at a local level)*	Security, Health, Basic material for good life, Good social relations
		Provides habitat to wildlife-pollinators such as native bees, butterflies and hummingbirds (mainly in rain gardens) , as well as other insects, etc.	Supporting ES (through biodiversity) R: Pollination, Invasion resistance, C: Aesthetic	Increases biodiversity, increases aesthetic value, increases mental and physical wellbeing through reduction of stress	Basic material for good life, Good social relations
Façade and infrastructure that neglects environmental concerns and diversity	Landscape diversity in the streetscape through addition of bioretention facilities	Vegetation provides shade (through increased canopy cover) and wind breaks, absorbs noise and improves site's landscape.	R: Noise regulation, Cultural: aesthetic, educational, recreational (passive)	Increases aesthetic value, increases mental and physical wellbeing through reduction of stress	Basic material for good life, health, good social relations
				Encourages environmental stewardship	Basic material for good life, health, good social relations

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	After (post intervention)				
				Sense of place (when featuring plants native to the area etc.)	Basic material for good life, health, good social relations
				Increased accessibility to green space (passive recreation)	Basic material for good life, health, good social relations
				Improved mood and self esteem	Basic material for good life, health, good social relations
				Increased real estate value by using aesthetically pleasing landscape	
				Reduction of infrastructure maintenance cost	

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain
Before (Existing)	**After (post intervention)**				
				Ability to meet objectives of Green development standards (City of Mississauga, Town of Caledon) and to obtain LEED credits	

Appendix 3:
Green Roofs

TOOL KIT-

GREEN ROOFS

I. OVERVIEW:

1. Description of LID/BMP

Green roofs, also known as “living roofs” or “rooftop gardens”, consist of a layer of vegetation and growing medium installed on top of a conventional flat or sloped roof (CVC, 2010).

There are two types of green roofs: intensive and extensive (Dunnett and Kingsbury, 2008).

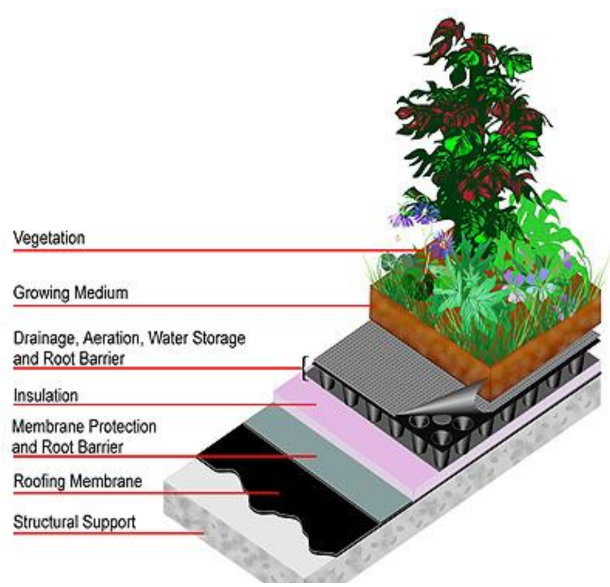

Figure 3 Cross Section of a Typical Green Roof (Source: CVC)

Intensive green roofs are constructed with deeper growing media generally greater than 25 cm (10 in.) and can include water features, concrete walking pathways, pergolas and other amenities (Currie, 2005). Because of their increased soil depths, intensive roofs can support a great variety of vegetation such as trees and shrubs as well as a greater capacity for carbon sequestration, water retainment, habitat preservation, heat island reduction and building insulation. Intensive roofs are more expensive to construct and usually require considerable maintenance and irrigation. This type of roof is generally constructed for installations where structural load restrictions are negligible or can be incorporated into the initial building design.

Extensive green roofs tend to be thinner with typically 5 - 15 cm (2 - 6 in.) of substrate (Currie, 2005). Typically, extensive green roofs are composed of a smaller number plant species. Drought-resistant, hardy perennials such as stonecrops (Sedum spp.) are commonly used in extensive green roof designs. Due to the relatively less amount of biomass when compared to intensive green roofs, these systems offer fewer environmental benefits than intensive green roofs. The main advantage of extensive green roof systems is that it can be installed on new or existing buildings including heritage buildings as they are lightweight, relatively inexpensive and may require less irrigation and maintenance after initial plant communities are set up (Dunnett and Kingsbury, 2008). This has made green roof technology more feasible for a diverse selection of buildings.

Green roofs have many environmental benefits and have the potential to greatly improve and enhance biodiversity in urban areas.

2. Key issues faced by the watershed that can be addressed through implementation LID/BMP (A brief overview: will be discussed in detail in part II)

- Lack of biodiversity and green space
- Lack of habitat for urban wildlife
- Stormwater management
- Urban Heat Island (UHI) Effect
- Energy Conservation
- Urban Agriculture

3. Policy recommendations that encourage the LIP/BMP

Please refer to "toolkit disclaimer" for detailed description

4. Different scales of stakeholders

- Municipalities- 11 municipalities
- Conservation Authority- CVC
- Developers and investors
- General public

II. CO-BENEFITS: ACHIEVING A DOUBLE DIVIDEND

What Co-benefits Exist Through Implementation, How Does It Happen Through LID/BMP and Where Do The Benefits Occur

1. BIODIVERSITY

a. Benefits to nature:

i. Biodiversity- provides habitat for species

- While enhancing biodiversity had not been viewed as a primary driver in green roof policy in North America, in many parts of Europe, green roofs have been studied extensively for the ecological potential that it has to provide habitats for multitudes of species (Gedge, 2003; Gedge and Kadas, 2004; Brenneisen, 2008). This has prompted more discussion on the aspects of biodiversity enhancement through implementation of green roofs in cities such as Toronto, which is the first City in North America to adopt a bylaw to require and govern the construction of green roofs in 2009.
- Studies of green roofs in Zurich, Switzerland, have shown that the use of natural soils can encourage biodiversity through their suitability for locally and regionally endangered species (Brenneisen, 2008).
- Studies of green roofs and biodiversity in both Europe and North America suggest that substrate depth and composition, topography, vegetative composition, green roof age and local landscape context are variables that can be incorporated into green roof

design and location in order to target opportunities for biodiversity (Somerville and Counts, 2007).

- Mimicry of natural habitats through topographic variation by the addition of pre-vegetated mat systems with augmentations in substrate depths/ shapes/ mounds, added bird boxes, snag nests (tree limbs) and stones for terrain variation and moisture retention has further abilities to enhance the capacity for green roofs to act as habitats for various species (Dunnett and Kingsbury, 2008).
- Green roofs provides habitat for native plants and also provides habitat for conservation of heritage species and their seeds (City of Toronto, 2010)
- Green roofs provide a special benefit for rare and sensitive plant species by making the habitats less susceptible to disturbances than on the ground
- Aids in migratory and breeding bird conservation- provides/enhances stopover habitat for migratory birds and foraging, nesting and mating needs of breeding birds (Dougan & Associates and North-South Environmental, 2008; Birds of Toronto ,2007)
- Island biogeography- While urban development have created isolated "islands" across urban tracts due to roads, buildings and other obstructions, Earn et al, (2000) suggests that a lack of connectivity may in fact be important in protecting certain plant or animal communities. Green roofs thus provide a degree of isolation from other ecosystems and may be effective in preserving some species populations. This is based on the concept of "island biogeography" that suggests that isolation may have played a role in protecting endemic species that are excluded from completion with other species that may be present in other areas.

- Thin, shallow substrates commonly used in the creation of extensive green roofs reduce the ability of a roof to support biodiversity by intensifying the already extreme ecological conditions of roof environments. These roof environments are typically subject to intense temperature and moisture changes and tolerant pioneer species have found this design to be a suitable form of habitat (Grant, 2006). However, some reviewers have shown that even these shallow, monoculture green roofs can support a measure of diversity (Dunnett et al., 2008; Hahn, 2009).

b. Benefits to humans:

i. Better sense of personal identity and psychological well-being:

- People had a better sense of personal identity and perspective when in areas with more diverse habitats, indicating that biodiversity can positively impact psychological well-being (Fuller et al., 2007) and improved mood (Routledge, 2015)
- Green space has been found to provide restoration from stress and attention fatigue, an improved ability to cope with stress and reported reduction in stress (Grahn & Stigsdotter, 2003; Hartig et al., 2003; Kuo, 2010; Lottrup, Grahn, & Stigsdotter, 2013) which leads to improved health.
- A study of tenents at 401 Richmond Ltd, a building with green roofs instaleed, reveled that building occupant greatly value acces to their green roofs and view it as an “oasis in the city” (Cohnstaedt, Shields & McDonald, 2003).

- Maas et al. (2006) found that the percentage of green space inside a one kilometre and a three kilometre radius of residences had a significant relation to perceived general good health and the relationship was more pronounced for lower socioeconomic groups. Maas et al. (2009) tried to clarify these findings with more specific measures and found that people with more green space in their living environment reported less loneliness, which can have negative health impacts

ii. Place attachment:

- Studies have shown that trees, vegetation, and other natural views provide a sense of connection to nature and the bioregion, protection, and safety (Peckham, Duinker, & Ordóñez, 2013; Ulrich, 1986).
- Green space can have health benefits through a range of exposures, from experiencing green space while not being physically present (i.e. viewing nature through a window), engaging in another activity (e.g. biking through a park) or intentionally engaging in the green space (e.g. gardening, hiking, camping, etc.) (James et al., 2015).

iii. Improved attention:

- Studies have also shown that people with views to nature are more relaxed, better able to focus, and perform better on attention and cognitive related tasks (Tennessen & Cimprich, 1995; Hartig, Mang, & Evans, 1991).

iv. Opportunity for urban agriculture

- Deep soil, intensive (less for extensive) green roof systems provide space for urban agriculture.
- Research done in Michigan has shown that that it is possible to produce tomato, bean, cucumber, pepper, basil, and chive in an extensive green roof on a small scale with irrigation and minimal fertilizer input (Whittinghill, L. J., Rowe, D. B., & Cregg, B. M. ,2013)
- Ex: Fairmont Royal York Hotel, Toronto and Lufa farms, Montreal

v. Higher property value

- According to a 2010 study titled "The Monetary Value of the Soft Benefits of Green Roofs" by Dr. Ray Tomalty et al. homes adjacent to public parks have about a 20% higher property values than similar homes distant from parks. The study estimates that the property value will increase by approximately 11%, depending on the size and access to a green roof. Having a view of a green roof with trees is estimated to increase property values by as much as 9%. Higher property values translate into higher tax revenues.

2. STORMWATER MANAGEMENT IMPLICATIONS- WATER QUALITY AND QUANTITY

Urban landscapes that are dominated by impervious surfaces typically find rainfall and snowmelt more problematic than in rural environments. Due to the lack of pervious surfaces, urban runoff reaches receiving waters as sudden and uncontrolled surges. Many surface contaminants are also picked up as water passes over areas such as roadways. Management of water quantity and quality of runoff is one f the major concerns when it comes to urban runoff.

a. Benefits to Nature:

i. Increased retention of storm water

- The opportunity for green roofs to act as source level stormwater management devices is logical since flat rooftops create open space, previously at ground level, that has otherwise been eliminated for vegetation (Jennings et al. 2003)
- Green roofs are able to manage both quantity and quality of stormwater runoff. A study in Vancouver (Graham and Kin, 2003) showed that suitably designed green roofs have great potential benefit in terms of protecting stream health and reducing flood risk to urban areas.
- Studies have also found that green roofs are able to filter contaminants out of rainwater that has flowed across the roof surface (Dramstad et al., 1996) but can also degrade contaminant, by direct plant uptake, or by binding them within the growing medium itself (Johnston and Newton, 1996)
- Typical extensive green roofs, depending on substrate depth, can retain 60% to 100% of stormwater they receive (Thompson, 1998)
- In research conducted in North Carolina, Jennings et al. (2003) showed that green roofs could retain up to 100% of precipitation that falls on it in warm

weather. However, the percentage retained decreased when there was not adequate time between each storm event. Similarly, Rowe et al. (2003) founds results that indicated that green roofs on average retain about 61% rainfall: 98% during light rainfall and only 50% on heavy rain events.

ii. Pollutant reduction

- According to USEPA (2003), runoff from urbanized areas is the lading source of water quality impairments to surveyed estuaries and third largest impairment to surveyed lakes. This is because most stormwater runoff enters water bodies directly without treatment and also has a higher surface temperature that can be damaging to aquatic habitats.
- The substrate of the green roofs are able to retain particulate matter in stormwater and reduce the quantity of runoff and as a result, the total load of pollutants that enter water bodies.
- Dramstad et al. (1996) demonstrated that the physical and chemical properties of growing substrate, as well as the green vegetative cover, help control nitrogen, phosphorous and contaminants generated by industrial activities.
- In most cases the heavy metals and nutrients that exist in stormwater are bound to the green roof substrate, and in some case taken up and broken down by the plants themselves (Johnston, 1996).
- However, nitrogen and phosphorous leaching can impact green roof runoff water quality. Studies have indicated that phosphorus discharges usually exceed EPA’s freshwater standard, while most of the time nitrogen, although

more leachable than phosphorus, is lower than the standard. Heavy metals, BOD, TSS, turbidity, and other minor pollutants are, at present, considered insignificant and as such to pose no risk to the environment; however, there is relatively little data available on this factor (Yanling Li and Roger Babcock, 2015).

- Further research work in plant selection as well as growth media types, quality requirements, and meteorological conditions need to be studied in order to further understand how to manage leaching reduction in green roofs (Yanling Li and Roger Babcock, 2015).

b. Benefits to Humans:

i. Reduction of pollutant loads that enter surface water

V. Runoff from urban and rural areas contributes pollutants to the Credit River Watershed, as well as discharges from wastewater treatment plants and other point sources of pollution. All water that enters the storm sewer system goes, untreated, into the Credit River or Lake Ontario. Water for drinking purposes is taken from surface and ground water: The municipalities of Brampton and Mississauga use water from Lake Ontario. Areas west of Brampton, including Georgetown, mostly rely on groundwater aquifers for their municipal water supply needs. The rest of the watershed relies on groundwater aquifers or smaller surface water features for water use (CVC, 2009).

VI. Reduces the risk of illnesses resulting from consuming contaminated water.

Drinking water outbreaks have been linked to runoff; However since all kinds of runoff enters surface water the effects of runoff coming specifically from green roofs only cannot be effectively measured and thus reported.

3. IMPLICATIONS ON URBAN HEAT ISLAND EFFECT AND TEMPERATURE REGULATION

In urban environments, much natural groundcover, including trees and meadows, has been replaced with pavement and buildings. These hard surfaces absorb more radiation and are incapable of evapotranspiration, and therefore lead to higher temperatures. This effect is referred to as the urban heat island (UHI) effect. UHI is directly correlated with urbanization as predevelopment land cover is transformed from hydrological active surfaces to impervious surfaces.

b. Benefits to humans

i. Reduction of Urban Heat Island (UHI) Effect

- Research has shown that there is an association between increased daily temperatures and increased counts of deaths, illnesses and hospitalizations (Vutcovici, Goldberg & Valois, 2013)
- A review on heat-mortality relationships in cities found that in almost half of the locations studied, the risk of mortality increased between one percent and three per cent for every 1°C change in high temperature (Hajat & Kosatky, 2010).
- A Toronto-based study found that, on average, for every one-degree C increase in

- maximum temperature, there was a 29 per cent increase in ambulance response calls for HRI (Bassil et al., 2010). For every one-degree increase in mean temperature, there was a 32 per cent increase in ambulance response calls for HRI (Bassil et al., 2010).
- Designs to reduce heating of surfaces are especially seen as useful in overcoming the UHI effect. Tree planting programs in urban areas have been significant in cooling the air as well as reducing green house gases (Parker, 1982; Landsberg, 1981; Oke, 1987) However, the lack of space in cities have made it difficult to expand this program. Green roofs present a viable opportunity to expand vegetated surfaces in urban areas with limited space.
- Researchers have tried to mathematically model the effect of green roofs on UHI in Toronto, however, the assumptions used and the case study choices created unexpectedly low reductions (Bass et al., 2002). Therefore, this aspect should be further researched.

ii. Air quality impacts

- Green roofs provide opportunity to reduce local air pollution levels by lowering extreme temperatures (as discussed above) and through trapping particulates and other gases.
- Akbari at al. (2001) and Kats (2003) discuss cool roofs and green roofs in terms of their potential effect of reducing Carbon Dioxide emissions from power plants due to reduction in the demand for summer-time peak cooling needs.

- Yok and Sia (2005) in a study done in a green roof project in Singapore note air quality improvements due to reduction of Sulfur Dioxide by 37% and Nitrous Dioxide by 21%.
- Urban forestry studies done by Johnson and Newton (1996), estimate that 2,000 m^2 of unmowed grass on a roof could remove as much as 4,000kg of particulates from the surrounding air by trapping it in its foliage.

iii. Energy Conservation

- Green roofs can provide a general cooling effect of the surrounding air, due to plant respiration, which can reduce overall cooling costs in summer months. In winter months, the vegetation will increase a building's insulation value, leading to 5 reduced heating costs. One study showed standard green rooftops can provide up to a 15% reduction in overall cooling (Banting et al. 2005).
- By making roofs cooler, designers can reduce the amount of absorbed solar energy, and thus reduce the amount of heat conduction into buildings. This reduces daytime net energy inputs and demand for air conditioning (Akbari and Konopacki, 2004; Akbari et al., 2001)
- In a Canadian study in Ottawa, Liu and Baskaran (2003) reported that green roofs were more effective at reducing heat gain than heat loss. The case study reported that the green roof reduced temperature fluctuations and also modified heat flow through the roofing system by more than 75%.

- Due to its design specifications, such as having a waterproofing membrane, green roofs extends the life of infrastructure. Acks (2003) shows that a green roof will have a service life up to about 40 years, but variations may exist including 20 years to 60 years.

iv. Opportunity for obtaining LEED credits

- Green roofs can facilitate a significant improvement in the LEED certification of a building. Depending on the design and level of integration, green roofs can contribute to up to 15 credits. When used in conjunction with other sustainable building elements, green roofs can help in obtaining points for direct and indirect LEED credits under the categories such as: stormwater management, landscape design that reduces urban heat island effect and innovative wastewater technologies. (US Green Building Council, 2016)

III. LAND USE & GEOGRAPHIC CHARACTERISTICS

4. Which category does it fall under?

a. **Mostly urban -** commercial, institutional and residential developments

5. Different types

Intensive and extensive (described earlier)

6. Physical suitability and constraints

- The load bearing capacity of the roof structure must be sufficient to support the soil and plants of the green roof assembly, as well as the live load associated with maintenance staff accessing the roof.

- Green roofs may be installed on roofs with slopes up to 10%. On sloped roofs additional erosion control measures may be necessary to stabilize drainage layers.

The plant material should confirm to the following:

- Type of root preparation, sizing, grading and quality: should comply with the Canadian Standards for Nursery Stock, 2006 Edition, published by the Canadian Nursery Trades Association.
- Source of plant material: should be grown in Zone 4 in accordance with Agriculture Canada's Plant Hardiness Zone Map.

- Plant material: should be free of disease, insects, defects or injuries and structurally sound with strong fibrous root systems. Should have been root pruned regularly, but not later than one growing season prior to arrival on site.
- Bare root stock: should be nursery grown, in dormant stage, not balled and burlapped or container grown.
- Seed mixes: should be Common No.1 Canada certified in accordance with Government of Canada Seeds Act and Regulation.

IV. DESIGN TEMPLATE

3. Applications: Which land use characteristics best suit different types?

Green roofs can be installed in new and retrofit buildings in urban areas.

4. Geometry and site layout

Green roofs are composed of multiple layers that include:

• A roof structure capable of supporting the weight of a green roof system;

• A waterproofing membrane system designed to protect the building and roof structure;

• A drainage layer that consists of a porous medium capable of water storage for plant uptake;

• A filter layer to prevent fine particulate from the growing medium and roots from clogging the drainage layer;

• Growing medium with appropriate characteristics to support selected green roof plants; and

• Plants with appropriate tolerance for harsh roof conditions and shallow rooting depths

5. Sizing of BMP

Green roofs reduce the effective impervious cover by providing a surface that hydrologically responds like a pervious area. Green roofs are typically sized based on the available roof area, as opposed to treatment volume requirements. However, flow restrictors can be added to the design to meet channel erosion control discharge criteria, which is determined by using the methodology in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010).

V. COST BREAKDOWN

The estimated cost for extensive green roofs is $65 to $230 CAD per square meter (TRCA, 2007a), not including the base roof, with modular systems in the lower end of the range. While green roofs are initially more expensive than traditional roofs, their lifecycle costs may be comparable to traditional roofs, when energy savings and extended roof longevity are factored in (TRCA, 2007a). Operation and maintenance costs are generally higher during the first two years of operation than in subsequent years as the vegetation becomes established. Literature estimates of annual maintenance costs during the first two years range from $2.70 to $44.00 per square meter (Peck and Kuhn, 2002; Stephens, et al., 2002; TRCA, 2007a)

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INTERVENTION OVERVIEW MATRIX

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain**
Existing	**Post intervention**				
Grey infrastructure surfaces (on existing buildings)	**Structural components of green roof system:** • Waterproofing membrane on top of roof structure that minimizes leaking • Drainage layer and moisture retention mat	• Rainwater storage for supplemental irrigation		• Less cost for infrastructure: Extends roof life (up to 40-60 years) • LEED credits (up to 15- stormwater retention, reducing heat island effects, energy efficiency, water use efficiency (Canada Green Building Council CGBC)	Security, Health
	• Native and non-native, non-invasive plants	• Protects roof from elements- photodegredation from sunlight and mechanical degradation from temperature extremes. • Retains stormwater and returns portion of water to the atmosphere through evapotranspiration	R: Water storage and regulation, erosion control	• Reduces stormwater run-off • Reduces Combined Sewer Overflow (CSO) • Retention and delay of run-off eases stress on infrastructure and sewers	Security, Health
		• Evapotranspiration-	R: Micro	• Reduces Urban Heat	Health

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain**
Existing	Post intervention				
		plants and growing media reduces ambient air temperature and generates a net-cooling effect *for surrounding buildings*	climate regulation	Island (UHI) effect.	
		• Evapotranspiration- in combination with effects of shading, reflection, thermal mass transfer and insulation reduces heat *gain within buildings.* • Lower ambient temperatures supply intake air to roof-mounted HVAC systems	R: Micro climate regulation	• Energy efficient- reduced air conditioning cost, intake air from roof-mounted systems increases efficiency	Health
		• Growing media and vegetation provides additional insulation	R: Micro climate regulation	• Energy efficient: Reduces winter heating costs	Health
		• Pollutant removal: water-vegetation, growing media and	R: Water purification and waste	• Relatively cleaner runoff from green roofs • Improved water quality	Health

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain**
Existing	Post intervention				
		added pollution control media reduces the concentration of ammonia, nitrate and nitrite and other pollutants, removes nitrogen pollution from rain and neutralizes acid rain effect	treatment		
		• Pollutant removal: air-vegetation takes up air pollutants and intercepts particulate matter	R: Air quality regulation	• Improved air quality	Health
		• Smog reduction-cooling effect of vegetation lessens smog formation by slowing the reaction rate of nitrogen oxides and volatile organic compounds	R: Air quality regulation		Health

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain**
Existing	**Post intervention**				
	Deep soil, intensive (less for extensive) greenroof systems that provide space for urban agriculture	• Research done in Michigan has shown that that it is possible to produce tomato, bean, cucumber, pepper, basil, and chive in an extensive green roof on a small scale with irrigation and minimal fertilizer input	P: Food, ornamental resources R: Pollination	• Food production • Community gardens • Recreational space • Increases aesthetics • Provides recreational amenity spaces • Provides community collaboration (if it is a community garden) • Transforms dead space into green space	Basic material for good life, Good social relations
	Structures/practices that aid in biodiversity: • Pre-vegetated mat systems with augmentations in substrate depths/ shapes/ mounds where practical. • Added Bird boxes, bat boxes, trap • Added snags nests (tree limbs) and stones for terrain variation and moisture retention	• Rare and sensitive plant species may benefit in rooftops that are less susceptible to disturbances than on the ground • Provides habitat for native plants • Aids in migratory and breeding bird conservation- provides/enhances stopover habitat for migratory birds and foraging, nesting and mating needs of	Cultural: Recreation, Aesthetics and spiritual, education and stewardship, social R: Pollination S: photosynthesis, primary production	• Education and stewardship opportunities • Increases aesthetic appearance • Provides recreational spaces • reduces stress and improves mood • Benefits associated with working in improved work environments with view/access of nature	Health, Good social relations

Structure		Ecosystem function	Ecosystem services	Final Benefit	Well-being domain**
Existing	**Post intervention**				
	• Native species , Non-invasive non-native species • Grasses and herbaceous plants that provide energy sources for migratory birds • Local materials in substrate blends • Varied substrate depths and range regimes to create different microhabitats on and below the surface • Varied substrate depths by adding berms/mounds, bare areas, physical substrate connections to promote heterogeneity and species movement	breeding birds) • Supports edge habitats • Connects existing habitats • Island biogeography- important in protecting certain plant or animal communities • Supports conservation source sinks			