An Interactive Plant List Model for Bio-retention Facilities: Using the Happy Plant Model to predict preferred plant species

by
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Abstract

An Interactive Plant List Model for Bio-retention Facilities:

Using the HPM to predict preferred plant species

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Bio-retention facilities are becoming an important component of stormwater best management practices. Vegetative health directly affects bio-retention facility success. Bio-retention facilities have characteristically harsh moisture conditions. Credit Valley Conservation is developing bio-retention construction guidelines. Identifying suitable plant species for bio-retention conditions is imperative in doing so. This study aims to use the Happy Plant Model (HPM), an Excel-based model that predicts moisture conditions in bio-retention facilities based on construction design, to predict preferred plant species pre-construction. Through a focused literature review, drought and saturation tolerances were found or estimated. Outputs from the HPM influence the plant species list that is generated. Results show that a preferred plant list can be produced for various moisture conditions based on facility design. With the HPM and Interactive Plant List Model, bio-retention facility designers can predict preferred plant species for pre-construction bio-retention facilities. This study provides a step towards effective bio-retention planting.

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Chapter 1: Introduction

The flow of water is changed when watersheds are developed. Urbanization modifies the land cover permeability which alters the flow of water and sediment through stream networks (Poff, Bledsoe & Cuhaciyan, 2006). Water flow depth and velocity are increased leading to increased risk of flooding and intensification in stream channel erosion and sedimentation. (Nelson and Booth, 2002). Impervious surfaces increase, which decreases groundwater recharge (Lee, Chen and Yeh, 2008). Urban stormwater runoff is a major source of non-point source pollutants including excess nutrients, trash, pesticides, oil and grease, sediment, bacteria and toxic metals in receiving waters (Hogan and Walbridge, 2007; Bedan and Clausen, 2009).

Stormwater Best Management Practices, such as bio-retention facilities, are designed to counter the negative impacts of urbanization on affected waterways. They do this by catching and treating stormwater onsite, rather than piping it offsite immediately (CVC, 2010; Trowsdale and Simcock, 2011). Proper design and maintenance are essential in constructing and sustaining a successful stormwater BMP (Lindsey, Roberts and Page, 1992; Nassauer, 2004). Proper planting design is an invaluable part of this (Shaw and Schmidt, 2003). In order to choose proper plants for a site it is important to know the moisture conditions (Whitlow and Harris, 1979; Shaw and Schmidt, 2003). The Happy Plant Model (HPM) is a model that predicts the moisture conditions of bio-retention facilities pre-construction (Paquette, 2012). Informed decisions can be made by designers to match predicted moisture conditions using the HPM. Few plants can survive in all environmental conditions. Therefore, knowledge of individual facility conditions is important in making informed planting decisions.

Credit Valley Conservation (CVC) is a leader in Ontario in designing, building and testing bio-retention facilities. They research bio-retention in order to pass their knowledge on to other conservation authorities and municipalities (CVC. Personal Communication October, 2013). This study was done as an extension of their research. The goal and objectives of the study were chosen to advance their knowledge of plant species in bio-retention facilities. This study uses CVC's knowledge and advancements in bio-retention design as well as the capacity of the HPM to do so.

1.1 Goal and Objectives

The goal of the study is:

- Increase the effectiveness and efficiency of bio-retention facility design by providing a means to easily and accurately predict preferred plant species for predicted facility moisture conditions.

Below are the objectives of the study. Completion of these will bring the goal a step closer.

- Survey current vegetation and document plant species health in existing bio-retention facilities in partnership with CVC.
- Determine if moisture data collected by CVC can be used to test and calibrate the HPM for successful prediction of moisture conditions for preferred plant choices.
- Assemble plant lists created for stormwater and floodplain planting in Ontario and create an amalgamated plant database that includes flood and drought tolerances.

- Create an interactive plant list model that identifies preferred plant species selections for moisture conditions according to bio-retention facility design using the predictive capacity of the HPM. In doing so, provide bio-retention designers with a means to predict preferred plant species for pre-construction bio-retention facilities based on moisture conditions.

1.2 Thesis Overview

Chapter 2 is a review of literature concerning the importance, purpose and design of bio-retention facilities. It includes a review of the HPM and its importance for the study in predicting the moisture conditions in a bio-retention facility. Methods are discussed in Chapter 3, including a field research, focused literature review, discussions with key informants and model development. Chapter 4 includes results and analysis gathered from each of the study methods. Chapter 5 discusses the usefulness and the limitations of the results. Finally, study accomplishments, implications, importance and study overview make up the Chapter 6 conclusion.

Chapter 2: Literature Review

This chapter will review literature on the effect of urbanization on stormwater issues. The effects of stormwater best management practices (BMPs) on urban stormwater, as well as the factors that influence the success of BMPs, are presented. Bio-retention facilities, a form of stormwater BMP, and the importance of vegetative health in said facilities will be reviewed. The Happy Plant Model (HPM) and its connection to healthy vegetation will be described. Finally, the effects of saturated and droughty soils on vegetation will be discussed.

2.1 Stormwater BMP's

Yesterday's cities are built in an efficient, industrial manner. A 'big pipe' approach was, and still is, used to transport stormwater out of urban and sub-urban centers (Chanan, Vigneswaran and Kandasamy, 2010). When a watershed is 'built up' with urban spaces, its hydrology is intrinsically changed. Anthropogenic changes in land use modify the land cover permeability which alters the flow of water and sediment through stream networks (Poff et al., 2006). Naturally-occurring vegetated surfaces slow water run-off by infiltrating water through the soil, catching water on vegetative surfaces and evapotranspiring. Vegetation also decreases erosion by slowing the flow of water and stabilizing soil particles. Lack of these vegetated spaces, along with increased paving and roofs, amplifies water run-off speed and quantity. In a 2013 study by Chu, Knouft, Ghulam, Guzman and Pan, it was found that an increase in urbanization in the Missouri Big River watershed increased water depth, velocity and discharge during significant storm events. The increase in urban run-off causes 'flashy' flow conditions which result in more frequent flooding. It also inhibits groundwater recharge and washes pollutants directly into receiving waterways. Hydrographs are commonly used to depict the change in stormwater flow conditions.

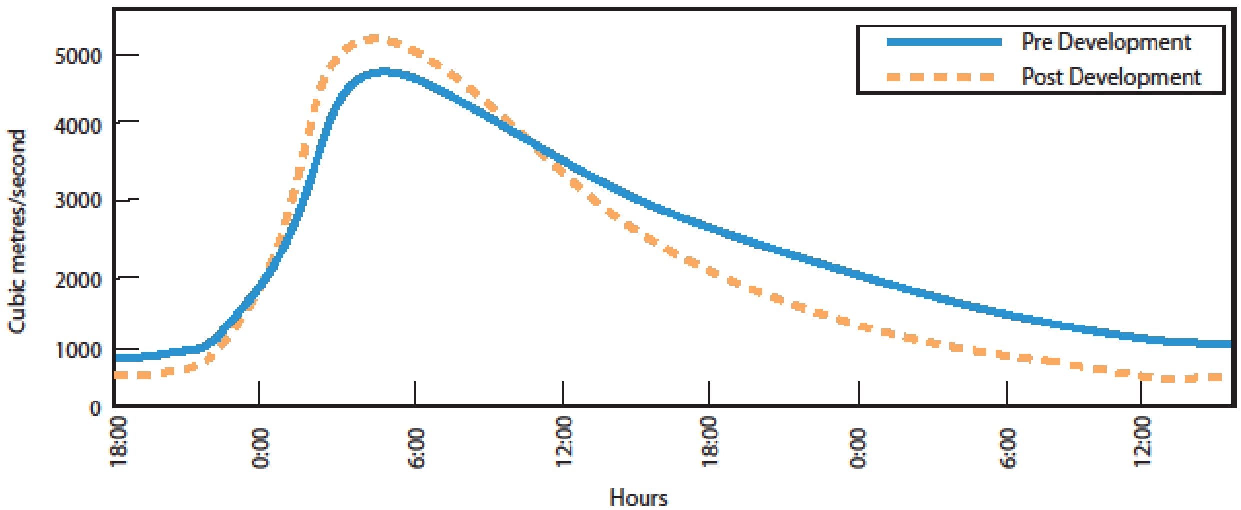

Figure 1: Pre/Post Development Hydrograph (Adapted from Farahmand, Fleming, and Quilty, 2007)

As is seen in Figure 1, post-development flow conditions reach a higher peak in a shorter time than pre-development conditions. Base-flow of post-development flow conditions is also lower.

2.1.1 Urbanization and Increased Water Flow

Increases in water depth, velocity and discharge during storm events amplify stream channel erosion and sediment load. Stream channels are enlarged permanently to accommodate for new flow volumes (Nelson and Booth, 2002). Streams and rivers unaffected by urbanization also change due to erosion and sedimentation. They are constantly morphing with the force of the water (van Duin and Garcia, 2006). Healthy waterways change very slowly, allowing vegetation to adapt and grow with the change. Healthy, well-established vegetation stabilizes riparian zones. Waterways meander at a rate related to their catchment area, channel width, volume and velocity of water, topography, substrate, imperviousness (Rosgen, 1994; van Duin and Garcia, 2006). When one or more of these factors changes drastically, the force of water on stream channels will also change. Stream banks in drastically changing waterways erode faster and are more unstable (van Duin and Garcia, 2006). Higher frequency and higher flow events inherent to urbanization cause stream bank instability and failure. Constantly changing urban environments cause constant transformations of the stormwater regime. The channel cannot achieve equilibrium in this environment. It will constantly change, reforming the land around it and sending sediment downstream (Van Duin and Garcia, 2006). In populated locations this can result in land loss hazards, damage to riparian livelihoods, destruction of river structures such as dams, undermining of bridge abutments and stormwater outfalls, and outflanking of bank armouring (Van Duin and Garcia, 2006; Chu et al., 2013).

2.1.2 Urbanization and Erosion/Sedimentation

Stream channel erosion, along with landslides, agriculture, urban land uses such as construction, landfills and quarries, and road surface erosion, are some of the major contributors to sedimentation (Nelson and Booth, 2002). Excessive sedimentation is connected to water quality problems downstream. Eutrophication occurring in ponds and lakes downstream is associated with the nutrient loading that accompanies fine sediment (Nelson and Booth, 2002;

Malaviya and Singh, 2012). Both flora and fauna are disturbed in high erosion and high sedimentation areas (Chu et al., 2013).

Waterway ecosystems are stressed by warming caused by excessive overland flow of urbanized settings. Water that runs over land into waterways is heated by solar radiation and atmospheric warmth. Water that enters a stream through a seep, spring or the water table, as in natural processes, is cooler. Warmer water causes stress in flora and fauna in the stream ecosystem (Cristea and Burges, 2010).

2.1.3 Urbanization and Ground Water Recharge

Groundwater recharge is the infiltration and percolation of water through the soil into the water table. Much of the rainfall in undeveloped settings passes through the ground surface and percolates into the unsaturated zone. Urbanization reduces the area of pervious surfaces and therefore decreases groundwater recharge (Lee et al., 2008). Water from the unsaturated zone percolates vertically into the deeper zone of the ground through gravity. Groundwater recharge happens when this gravitational flow reaches the water table. Recharge of the water table allows for water in the saturated zone to flow sideways as groundwater flow. This horizontal groundwater flow allows water to emerge from seeps and natural springs, where the water table meets the surface, in a steady constant manner that allows for relatively stable base flow (Lee et al., 2008). This process is demonstrated in the soil moisture model below (Figure 2).

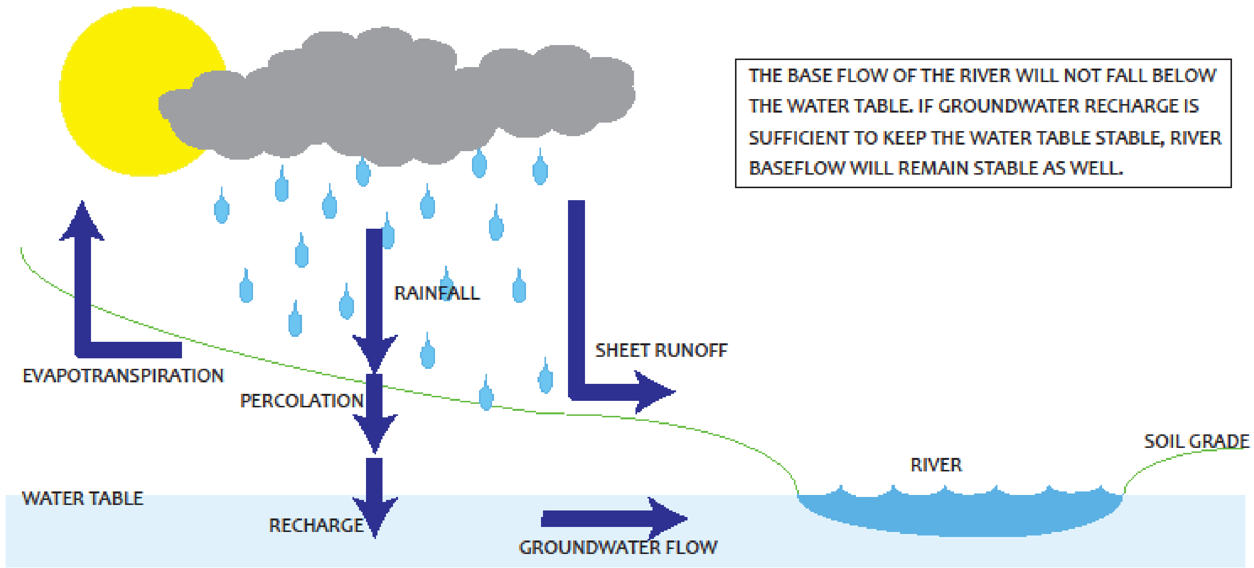

Figure 2: Hydrologic Cycling and the Effect of Recharge on Baseflow (Adapted from Lee et al., 2008)

Recharge of the water table to its pre-development level keeps streams that are level with the water table at a healthy base flow.

2.1.4 Urbanization and Water Pollution

In addition to issues with flooding, erosion, sedimentation and ground water recharge, increased urbanization and subsequent overland flow leads to amplified presence of non-point source pollutants running unfiltered into stream and river systems (Heasom, Traver and Welker, 2006). Non-point source pollutants refer to pollution washed from roads (automobile residues, road salt and grit), agricultural lands (fertilizer, animal waste and soils), and other dispersed sites. It does not have one specific source but, rather, is a culmination of many different sources that leads to a significant build-up. Non-point sources are responsible for many remaining water quality concerns in our waterways. Urban stormwater runoff is a major source of surface water contaminants including excess nutrients, trash, pesticides, oil and grease, sediment, bacteria and toxic metals in receiving waters (Hogan and Walbridge, 2007; Bedan and Clausen, 2009). The increase in urbanization means that not only are non-point sourced pollutants increasing, but also that impervious surfaces common to developed urban locales increase the quantity and rate of stormwater surface flow. Rain that falls in urban landscapes often finds itself quickly and efficiently into catch basins and stormwater pipes that transport it away from urban centres into surrounding waterways. In other words, with urbanization, increased pollution has a faster, more efficient means to travel into surrounding waters than in pre-development scenarios.

2.2 Response to Urban Stormwater Issues

Low impact development (LID) is a design strategy that uses any number of Best Management Practices (BMPs) in order to retain the storage, infiltration, runoff and groundwater recharge that existed pre-development. By using various stormwater BMPs, LIDs affect the surrounding ecology as little as possible while providing all the necessary amenities for human life. These strategies can include anything from bio-retention and grassed swales to cluster housing and public education (Bedan and Clausen, 2009).

BMPs were developed in response to the water-related issues caused by urbanization. Rather than piping storm and groundwater where it is a nuisance, stormwater BMPs are decentralized stormwater facilities that control flooding and water pollution, and in some cases increase groundwater recharge while having as little effect on hydrology as possible.

Stormwater BMPs are meant to mimic natural filtration and infiltration processes that occurred prior to development (Lindsey et al., 1992). Landscape architects must account for numerous issues when designing a stormwater BMP. Flood control continues to be one of the most important aspects. It represents the most immediate threat to human life and infrastructure damage. Detaining more water on site will reduce damage downstream by controlling high water surges. If designed with overflow strategies stormwater BMPs can be effective flood deterrents. Alteration of the hydrologic cycle must also be considered. Although it is less pressing than flood control, altering the hydrologic cycle will throw off the balance of downstream waterways that can damage waterside infrastructure and decimate aquatic life (Van Duin and Garcia, 2006; Chu et al., 2013).

BMPs are important to non-point source pollution control (Bedan and Clausen, 2009). Contaminants found in water runoff are most highly concentrated during the “first flush” of runoff that happens in a storm. Evidence shows that treating or storing the “first flush” of runoff from a storm is a more efficient pollution control technique than treating an even flow throughout the storm (Barco, Papiri and Stenstrom, 2008).

Groundwater recharge and water quality are enhanced by strategies encouraging infiltration. Infiltration capacity is a major aspect of many stormwater BMPs. Porous materials and extensive vegetative cover contribute greatly to water infiltration. This works to recharge ground water, leading to regulated stream base flows and more reliable urban water sources during dry periods (Heasom et al., 2006).

Maintenance costs and longevity factor heavily in the design of any stormwater management facility. Different facilities have different success rates. In a status report on varying BMP stormwater facilities in Maryland, it was found that around 64% of facilities were working as planned (Lindsey et al., 1992). If maintenance is not performed properly and regularly, the facility may not work according to the design intent. Proper maintenance also factors heavily into the attractiveness of the site (Nassauer, 2004).

Finally, public acceptance of stormwater BMPs should also be considered when designing. Sites that include 'cues to care' (obvious signs of human care of the landscape) and good spaces to enjoy nature are more likely to be perceived as attractive (Nassauer, 2004). "In a world dominated by humans, landscapes that are perceived as attractive are more likely to be sustained over time by human behavior" (Nassauer, 2004, p.756). However, research also suggests that if the function of a site is known (e.g., water treatment) and is important to people, they might be willing to compromise visual appearance (Wagner, 2008).

2.3 BMP Success in Urban Stormwater Issues

Below is a review of research regarding BMP success in mitigating urban stormwater issues. Each of the aforementioned urban stormwater issues is discussed.

2.3.1 Flood and Hydrologic Cycle Control

BMPs deal with water onsite in order to stop flooding and protect the current hydrologic cycle. In a 2009 study, Bedan and Clausen measured the difference in water quantity discharged from a traditional residential design compared to BMPs using several different designs. A traditional neighbourhood was built using typical subdivision standards (impervious roads draining directly to catch basin inlets) while BMPs were constructed including grass swales, cluster housing, shared driveways, rain gardens, and a narrower pervious concrete paver road. The researchers corrected for differences in year to year precipitation. They measured water flow through stormwater pipes that collected excess flow from the watershed. The traditional development increased water flow compared to predevelopment. Mean flow depth was increased by 16 times, likely due to the asphalt roads and stormwater drainage system that are designed to provide quick and efficient transport of water from urban areas. Post construction storm flow in the BMP watershed was reduced by 42% compared to pre-development (Bedan and Clausen, 2009). While the study gives solid numerical data on reduction of stormwater outflow in a traditional development compared to BMP, it does not emphasize why this reduction is important. This gap can be filled by other literature that states peak flows will increase, duration of near bank-full flows will decline and flow variability will increase with traditional impervious development because of increased runoff and reduce groundwater recharge (Poff et al., 2006). This means that during high intensity storms, streams in and downstream from highly developed traditional urban areas will receive increased levels of water (flooding potential) than those with little development or BMPs. It also means that in times of drought streams in and downstream from traditional developed urban areas will have lower base water levels.

Research shows that impervious development increases the volume and rate at which stormwater runoff leaves a site. Landscape architects can use BMPs to decrease this outflow, but they must be appropriately designed for type of BMP, location, size and plant species in order to have their desired effect. “Knowledge of the most effective location and quantity of BMPs can influence the cost, maintenance, aesthetics, and safety of a development design. It is beneficial to understand the effects that the location and quantity of BMPs can have for storm runoff characteristics” (Gilroy and McCuen, 2009, p. 235). Improving our knowledge of BMP facilities will increase their advantages. These advantages will be lost if landscape architects design based on misconceptions regarding the location and size of BMPs, as well as inadequate knowledge of proper vegetation (Shaw and Schmidt, 2003; Gilroy and McCuen, 2009).

2.3.2 Pollution Control

BMPs are important to non-point source pollution control. Urban stormwater runoff is one of the largest sources of surface water contaminants (Barco et al., 2008). The same study that measured the difference in water quantity discharge from a traditional residential development compared to a LID also examined pollutant content. They found that traditional residential development had increased water pollutant content in all categories examined compared to preconstruction. They concluded that BMPs can likely improve stormwater quality over traditional methods (Bedan and Clausen, 2009).

A 2007 study by Hogan and Walbridge looked at the difference in pollutant retention between stormwater detention basins designed simply for flood control, and those designed with

BMPs, including wetland topography and vegetation. Flood control urban catchment basins control peak stream flow, but will not reduce the pollutant content that eventually flows from the basins into streams. Flood control basins act as a check valve for flood water, but have no pollutant control measures. BMPs such as bio-retention facilities mimic natural riparian and floodplain settings. The BMPs were found in the study to reduce pollutant content and downstream sedimentation (Hogan and Walbridge, 2007). In addition, specific pollutants can be removed using specific soil textures and mulch in bio-retention. Thick mulch layers are found to enhance metal reduction in stormwater (Davis et al., 2001).

The aforementioned studies show the benefit of stormwater BMPs on water quality, as well as some theoretical and practical observations on which to base design. More research is needed on how to turn theoretical and practical observations into optimal design.

2.3.3 Ground Water Recharge

Ground water recharge is increased by BMP strategies encouraging infiltration. Infiltration capacity is a major contributing aspect of many BMPs. In their 2006 study, Heasom et al. attempted to measure the effectiveness of a bio-retention BMP. Bio-retention BMPs remove pollutants from rainwater as it percolates through the soil and joins the groundwater or base flow (Davis, Shokouhian, Sharma and Minami, 2001). The goal of BMPs is for water to be filtered of pollution and emerge as a steady contribution that will provide steady baseflow that can sustain aquatic and riparian flora and fauna. What concerned Heasom et al. was whether a bio-retention BMP, with the help of established vegetation, will be able to maintain its full infiltration capacity over time, and what maintenance will be needed to ensure this.

Ground water recharge through infiltration is hindered greatly by compacted soils. Urban areas have more impervious and compacted near-impervious surfaces. Strategies are available that encourage infiltration to recharge groundwater even in these circumstances. A 2008 study examined whether tree roots can penetrate compacted subsoil and increase infiltration rates (Bartens et al., 2008). They found that certain species of trees (specifically *Quercus velutina* (black oak) and *Acer rubrum* (red maple)) could penetrate the compacted sub soil and increased infiltration rates by 153%. They also found that *Fraxinus pennsylvanica* (green ash) even penetrated geo-textile into the subsoil and increased infiltration 27 times that of compacted soil with no vegetation. Infiltration that takes place in wooded areas happens predominantly along root paths. This process is hastened by dead and decomposing roots existing in the soil. (Bartens et al., 2008). Bartens et al. also found that new woody plants, that have not had time for root turn-over and decomposition, still infiltrate water more successfully than control soils with no plant life. Bartens et al. discovered attributes and benefits of planting vegetation for bio-filtration purposes, but more research is needed into successful stormwater BMP planting. When it comes to bio-infiltration for the purpose of groundwater recharge and diverting stormwater surges, one must consider the literature on soil type (Davis et al., 2001) and vegetative influence (Bartens et al., 2008) on the success of stormwater BMPs.

2.3.4 Continued Maintenance

Stormwater BMPs success is highly influenced by their standard of maintenance; as with engineered stormwater management, maintenance is needed before the system starts to break down. Timely maintenance was found to be very important in re-establishing proper function. If maintenance of issues such as erosion, dead vegetation and pipe clogging are ignored the facility will not perform as desired and may fall out of favour as a legitimate form of stormwater control (Lindsey et al., 1992).

2.3.5 Aesthetic Acceptance

Public acceptance of stormwater BMPs should be considered at the design stage. Research of this issue found two themes. The first, posited by Nassauer (2004) went says that what people perceive as attractive in nature does not necessarily have high ecological value. Wetlands that contribute to flood control, pollution control and infiltration, are not always considered an attractive landscape. Wetlands can appear weedy and abandoned rather than pristine and purifying. One major issue with designed wetland effectiveness is the tendency to mow plants to a level height and to kill wetland species that look like weeds. Cultural ideas of attractiveness are major players in the acceptance of LIDs that emulate wetlands. BMPs require public acceptance not only to be built, but also to ensure the commitment of the public and municipal officials which will maintain long term success. It was stressed in the study that ecological value should not be compromised, but the site must have some cultural cues (mown entrance, systematic planting, healthy vegetation and attractive flowering plants) in order to gain long term public acceptance and support (Nassauer, 2004).

The second theory on public acceptance of BMPs relates specifically to riparian buffers (waterside plantings). Results suggest variation between different stakeholder assumptions. They also suggest that simply knowing the function of the riparian buffer was more important to public acceptance than was perceived attractiveness (Wagner, 2008). People place a combination of environmental, social and economic values on riparian areas. Respondents to Wagner's survey recognized multiple important functions of riparian areas. The top three functions, in order, were filtering stormwater (76%), wildlife habitat (76%) and aesthetics (66%). The study still shows the importance of aesthetics, but shows that if people understand function, they will value function more than aesthetics. If people understand the use of dense riparian vegetation (not traditionally attractive) they will accept it (Wagner, 2008). This study is limited by its narrow focus. Not all BMPs include riparian buffer zones or an obvious natural cue such as a stream.

The combination of the two studies suggests that aesthetic appeal and public knowledge of the purpose of stormwater BMPs will increase their acceptance, and therefore their staying power as a stormwater control strategy. Design characteristics such as appropriate planting therefore play an important in this staying power, especially if the purpose of the site is not widely known.

2.4 What is a Bio-retention Facility?

Bio-retention facilities, also known as bio-filters and rain gardens, are the most widely used and promoted stormwater BMP (Trowsdale and Simcock, 2011). Bio-retention facilities filter rainwater. They temporarily store, treat and infiltrate runoff from nearby impervious surfaces. Bio-retention facilities are designed to capture small storm events (CVC, 2010). They successfully reduce peak flows, reduce pollution and increase groundwater recharge. They do this by catching and slowing water that would have flowed into catch basins, filtering the polluted water and infiltrating water into the sub-surface as groundwater or returning it to stormwater pipes filtered by the facility's soil media (Trowsdale and Simcock, 2011). Bio-retention facilities require at least 5% pervious surface area to be effective (Claytor and Scheuler, 1996)

The following design characteristics make up a traditional bio-retention facility as first developed by the Prince George's County, Maryland, Department of Environmental Resources in the 1990's (Claytor and Schueler, 1996). Not all the elements are included in all bio-retention facilities.

2.4.1 Design Characteristics

- Flow regulation and/or intake structure
    - These components ensure that stormwater is diverted to and captured by the bio-retention cell. The intake structure should allow for a non-erosive velocity of water into the cell while protecting against clogging. Curb cuts on a parking lot or

roadside are an example of a common intake structure. Strategic cuts are made to ensure water flows into the desired location (Claytor and Schueler, 1996).

- Pre-treatment filter strip
    - The pre-treatment filter strip can be used to reduce velocity of water entering the site and to capture coarser sediment particles. A vegetated filter strip can be used in combination with a sand or gravel diaphragm. This extends the site life by preventing erosion of other elements and by preventing the clogging of the planting soil bed (Claytor and Schueler, 1996).
- Pea-gravel overflow curtain drain
    - The pea-gravel overflow curtain drain allows for water in a large storm that overwhelms the shallow ponding area to overflow and infiltrate more rapidly. This element negates the cleansing quality of infiltration into vegetated organic soil, but it allows for more of the inflow to infiltrate and avoids excess overflow into catch basins (Claytor and Schueler, 1996).
- Shallow ponding area
    - The shallow ponding area allows for temporary surface storage of treatable water while the cell is saturated (Claytor and Schueler, 1996). The ponding area should be between 150-200mm deep. Maximum drainage area into a bio-retention cell should be 0.8ha. The bio-retention area itself should be at a ratio of 1:5 – 1:15 of the total drainage area (CVC, 2010). These are general guidelines that can be supplemented by using the runoff coefficient of the surrounding surfaces to calculate the amount of water that will enter the bio-retention cell during a given

storm. The depth of the ponding area should be such that no water is left on the surface after 24 hours (CVC 2010).

- Surface mulch layer
    - The mulch layer is important for maintaining moisture for plant growth. It acts as a filter for suspended particles and sustains an environment for microbes that facilitate the breakdown of runoff pollutants (Claytor and Schueler, 1996). Mulch should be applied at a thickness of 75mm (CVC, 2010).
- Planting soil bed
    - The planting soil bed absorbs water and provides nutrients for vegetation. The soil bed filters sediment and adsorbs various pollutants through cation exchange. Macropores in the soil provide additional water storage (Claytor and Schueler, 1996). The soil bed should possess the following characteristics. A depth of 1-1.25 metres. A mixture of 85-88% sand, 8-12% soil fines, and 3-5% organic matter. It should be free of stones and large debris and have an infiltration rate greater than 25mm/hour (CVC, 2010).
- Plantings
    - Appropriate, well adapted plantings are integral to the bio-retention cell's success. Vegetation absorbs nutrients and pollutants. It also disposes of water through evapotranspiration (Claytor and Schueler, 1996). They reduce erosion, increase infiltration and lend to the overall attractiveness and public acceptance of the site (Shaw and Schmidt, 2003; Bartens et al., 2008).
- Sand bed

  - The sand bed is located on geotextile above the under drain system and below the planting soil bed. It acts as a filter to prevent finer soil particles from washing out through the under-drain system (Claytor and Schueler, 1996). This is only necessary if an under drain system is included.

- Gravel under-drain system
  - An under drain system collects and distributes treated excess runoff. It keeps the soil from being saturated (Claytor and Schueler, 1996). It is necessary when native in-situ soils have an infiltration rate of less than 15mm/hour. The gravel layer should be at least 300mm deep. It should include a perforated 100mm plastic pipe located 100mm above the bottom of the gravel to convey excess treated water out of the bio-retention cell. The pipe should be separated from the planting bed soil using geotextile at some point to avoid inflow of smaller soil material (CVC, 2010).
- Overflow system
  - The overflow system conveys larger storm flow that cannot be infiltrated in time by the planting soil bed and the pea-gravel curtain drain, into nearby drainage systems by means of a catch basin or other inlet. It is a necessary means of flood protection without which a bio-retention cell would not be an effective flood deterrent in a larger storm situation (Claytor and Schueler, 1996).

Extensive guidelines for bio-retention facility design can be found in the Prince George's County Bioretention Manual. Bio-retention facilities can be designed in different forms and shapes, from highly formal with retaining walls and other above-ground built features, to highly informal vegetated areas (Prince George's County, 2007). Below is an example of an effective bio-retention design. Some sizing standards differentiate between sources. Figure 3 shows a

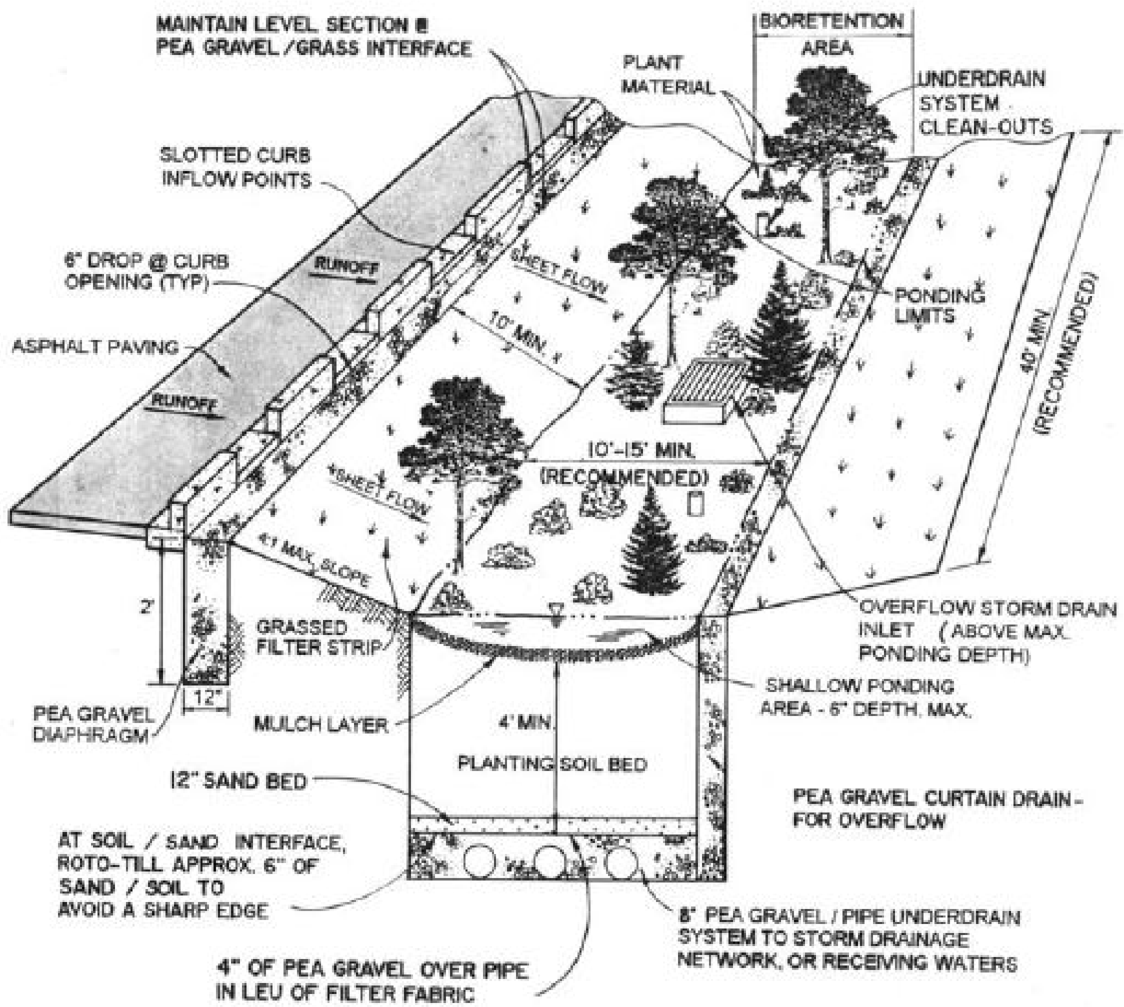

Figure 3: Bio-retention facility design (PDGER, 1993)

2.5 The Importance of Healthy Plants to Bio-retention

Bio-retention facilities are effective in deterring flooding and downstream peak flows (Bedan and Clausen, 2009), and reducing pollutant loads (Davis et al., 2001) and erosion in receiving waterways (Bedan and Clausen, 2009) and increasing groundwater recharge (Davis et al., 2001). Healthy vegetation plays a major role in the efficiency and success of a bio-retention facility. It can increase the level of the aforementioned benefits, while looking good and reducing the need for maintenance (Shaw and Schmidt, 2003). This increases the public acceptance of the facility (Nassauer, 2004; Wagner, 2008), while reducing the cost of management. Vegetation health, in the case of bio-retention design, depends in part on the choice of species by the site designer. Species selected to tolerate the urban stresses of a bio-retention facility are likely to survive. Expected pollutant loadings, highly variable soil moisture conditions, ponding water fluctuations and soil pH and texture need to be accounted for (Prince George's County, 2007). Other factors such as plant form/size/characteristics, sunlight needs, temperature zone tolerance, maintenance and site micro-climate also need to be considered when designing a planting plan.

Well-suited plants do the following for a bio-retention facility:

a. Increase rainwater infiltration rates (Bartens et al., 2008)
b. Limit erosion by increasing the strength and stability of soil (Shaw and Schmidt, 2003)
c. Absorb pollutants and excess nutrient loads (Heasom et al. 2006; Hogan and Walbridge, 2007; Bedan and Clausen, 2009)
d. Raise public acceptance of bio-retention facilities by appearing attractive (Nassauer, 2004)

e. Slow the flow of water allowing for increased sedimentation and infiltration (Shaw and Schmidt, 2003)
f. Reduce maintenance cost of replacing dead plants (CVC. Personal Communication October, 2013)
g. Reduce erosion caused by soil disturbance of replanting (CVC. Personal Communication October, 2013)
h. Provide habitat for reptiles, amphibians, birds and insects (Shaw and Schmidt, 2003)

Specific design characteristic of the bio-retention facility must be known in order to suggest what plants to use. Different facilities will have varying levels of soil moisture and ponding depths (Prince George's County, 2007). Designers must make informed decisions about plant characteristics to match these environmental factors. Few plants will be able to survive in all environmental conditions present across different bio-retention facilities and designs. Therefore, knowing the conditions of an individual bio-retention facility can aid in making informed planting decisions. In order to know the conditions of an individual bio-retention facility, predictions must be made based on the design of the facility, as well as the environmental conditions present in the area. The Happy Plant Model was created by Samantha Paquette in 2012 to predict the moisture regime of a bio-retention facility based on its design and the environmental conditions present.

2.6 The Happy Plant Model

The Happy Plant Model (HPM) is an Excel-based model that predicts the moisture regime of a bio-retention cell based on design, location and meteorological factors. It can be used to choose preferred plants for the bio-retention facility in question based on moisture conditions. It was created using a water balance equation from agricultural research modified for bio-retention using data from three categories: bio-retention facility construction, soil science and meteorology. The data collected for facility construction were drainage area, soil media depth, soil media texture, gravel storage depth, ponding depth, and native soil infiltration rate (Paquette, 2012).

Soil science data were gathered to establish which soil properties should be used to test the HPM. These data included porosity, field capacity, wilting point, saturated hydraulic conductivity, effect of soil water content on evapotranspiration rate and the capillary fringe. The above factors determine how soils interact with water in a bio-retention facility (Paquette, 2012).

Porosity is the maximum amount of water that a soil can hold. This is determined by the soil texture and the percentage of course and fine soil particles present (Gardner, 1988), as well as the level of compaction (Paquette, 2012).

Field capacity is the condition of the soil after gravitational drainage stops. It is holding the maximum amount of water that it can without losing any more to the force of gravity (Rawls et al., 1982).

Wilting point is when soil moisture decreases to the point that evapotranspiration stops. Plants wilt and potentially die at this point because they can no longer uptake water (SCS, 1991).

Saturated hydraulic conductivity is the rate of water infiltration and movement under saturated conditions. Initial infiltration occurs at an increased rate. This is because rainwater is moving through the open pores of the soil. As open pores are filled the infiltration rate slows. Once all pores are filled the soil is considered saturated. At this point the infiltration rate levels and water begins to infiltrate at a steady rate. It is measured based on the porosity of the soil (SCS, 1991).

The capillary fringe occurs when water drains from a layer of fine-textured soil into a layer of coarse-textured soil. The water will stop at the meeting point and create a near-saturated condition because the attractive force of the fine-textured particles will be greater than the combined attractive forces of gravity and the coarse-textured particles (Gardner, 1988). The water will begin to move through this condition once the water reaches a certain height/weight and gravity forces it down (Paquette, 2012).

Meteorological data were collected from the National Climate Data and Information Archive (2012) for a 30 year period (1981-2010) at Pearson International Airport in Toronto, Ontario, in order to represent the climate normal. The model, with its current inputs, should be used in similar climates in order to yield valid results. The 30 year period was thought to account for weather variability and show an overall trend. Meteorological data collected included daily rainfall, daily minimum and maximum temperature and daily snow on the ground (Paquette, 2012). Data that could have been used to calculate evapotranspiration, including relative humidity, daily solar radiation, and wind speed, were unavailable. Rainfall intensity, which could have helped calculate the ratio of runoff to overflow, was also unavailable. The landscape coefficient, which indicates the rate of evapotranspiration of individual plants based on species and location are indicated, as is the local conversion parameter, which measures the local microclimate's effect on evapotranspiration rates (Paquette, 2012).

The HPM used equations related to the bio-retention facility construction, soil science data and meteorological data. In designing the HPM, key informants were asked to judge the validity of the model based on their professional expertise. The key informants approved of the equations and design of the HPM (Paquette, 2012).

Data were brought into the HPM to calculate the depth of water in the bio-retention facility for each day of the 30 year period. Each day was assigned a plant status based on the amount of water in the facility. These include saturated, no stress, moderate stress, high stress and extreme stress. Design inputs possible in the HPM include soil media depth, soil media texture, gravel storage, ponding depth, rooting depth, landscape coefficient, drainage area and native soil infiltration. The output (number of days in the growing season in each moisture state) is directly affected by the design inputs (Paquette, 2012).

Shortcomings of the HPM include that it was not calibrated using moisture data from an existing bio-retention facility. Each design input was theoretically tested based on expected outcomes, but it was never tested using field data. The model should be validated using data from an existing facility. An original intent of the study, using the HPM to determine what plants a designer should use based on the moisture conditions, was also not achieved (Paquette, 2012).

2.7 The HPM and Preferred Plants for Bio-retention Facilities

Currently, the HPM can be used to output predicted moisture conditions in a bio-retention facility. This is based on the number of saturation, no stress, moderate stress, high stress and extreme stress days that will occur based on the meteorological data gathered from 1981-2010. Stress levels of plants are based on the field capacity of the existing soil texture. As water exits the soil through evapotranspiration, plants are left with less and less plant available water (PAW) for uptake. PAW is water that plants are able to uptake through their roots. It does not include water that will infiltrate by gravity or water existing in soil pores too small for roots to access and uptake. As PAW reduces, the drought stress increases. ‘Saturated’ indicates that all pores are filled with water. ‘No stress’ indicates that there is between 50% PAW-field capacity. ‘Moderate stress’ indicates 25-50% PAW. ‘High stress’ indicates 12.5-25% PAW and ‘Extreme stress’ indicates less than 12.5% PAW.

Firstly, these outputs allow designers to construct a bio-retention facility with a less extreme moisture regime. Secondly, it allows designers to make assumptions about what plants will survive and thrive in a particular bio-retention facility. Paquette suggests a few resources that can be used to choose proper plant species for a bio-retention facility based on their wetness coefficient (a measure of how likely it is a species will grow in a particular moisture environment). These include the wetness coefficient (Herman et al., 2001); *Native Trees, Shrubs* *and Vines for Urban and Rural America* (Hightshoe, 1988); and *Plants for Stormwater Design* (Shaw and Schmidt, 2003). These resources are helpful, but do not utilize the efficiency that a model with direct outputs could offer. In order to effectively use the HPM it should be adapted to link with an interactive plant list that offers suggestions for planting based on wetness coefficient (Paquette, 2012).

There is a wealth of knowledge available on construction techniques and capacities, but limited information is available on plant species that will survive in particular bio-retention facilities (Shaw and Schmidt, 2003). Plant survivability is essential to the success of a bio-retention facility. It is important to match plant species with the predicted moisture conditions (Prince George's County, 2007). How can those conditions be predicted? An educated guess is involved when creating a plant list for a bio-retention facility without adequate knowledge of the future moisture conditions. Environmental groups throughout North America that are spearheading the implementation of bio-retention facilities warn that the harsh environment present in bio-retention facilities causes stress for vegetation. Credit Valley Conservation, located in Mississauga Ontario, has indicated the need for more effective means by which to choose and monitor vegetation in bio-retention facilities (CVC. Personal Communication October, 2013). This study is taking place with data and guidance from Credit Valley Conservation to address the need for better suited, more bio-diverse plantings for bio-retention facilities. Plant lists offered by most environmental groups do not address the issue that different bio-retention facilities have different moisture conditions. Designers are left to choose from a small number of plants that can survive in most moisture conditions. These lists often lack biodiversity. A list that interacts with outputs from the HPM could provide a wider gamut of plant species choices that will be preferred for the moisture conditions present in the bio-retention facility.

2.8 The Effects of Saturation and Drought on Vegetation

Flood tolerance in plants can be better understood by looking at the changes that soils undergo in saturated conditions, the most elementary of which is the absence of oxygen for the chemical and biological processes necessary for vegetative health. Four significant conditions occur in vegetation when soils are flooded. Oxygen is excluded from roots, carbon dioxide accumulates, toxins are produced and soil assumes an anaerobic condition (Whitlow and Harris, 1979). These conditions alter the pH and Eh (measure of electron availability that is essential to all inorganic and organic chemical reactions (Reddy and Delaun, 2005)) which in turn effects the availability and total amounts of nutrients (Whitlow and Harris, 1979). Plants respond with hormonal, metabolic, anatomical and morphological changes when faced with saturated soil conditions. Flood tolerant species adapt and can even thrive with these changes. Species intolerant of flooding do not, and suffer some of the following ailments: leaf wilting, chlorosis, leaf, flower and fruit abscission, decreased shoot and root growth, and decreased nutrient and water uptake (Whitlow and Harris, 1979). If the plant continues to undergo flooding for which it is not adapted, the result will be death.

Plants also respond physiologically to periods of prolonged drought. Plants will close stomata, resulting in lowered evapotranspiration and a limited ability to regulate internal temperature. Reduction of water in the soil also results in lowered uptake of nutrients; nutrients are integral to photosynthesis. Without this process a plant will not have the energy to support its actions. Plants more able to limit water loss and maximize water uptake are able to tolerate drought more efficiently (Chaves, Maroco and Pereira, 2003). Plants that have limited physiological response to lack of water and increased heat will be susceptible to drought and will die if drought is prolonged in excess of their adaptability (Chaves et al., 2003).

This chapter presented a review of the literature concerning stormwater management. More specifically it reviewed the role of stormwater BMPs in current stormwater issues. The important role of plant health in bio-retention was reviewed. Also, the HPM was reviewed, as was its role in predicting bio-retention moisture conditions and affecting plant health in bio-retention facilities

Chapter 3: Methods

This chapter discusses the methods undertaken to complete the study. The research process is introduced. Methods for completing the four main objectives of the study are discussed. These include vegetation surveys done for Credit Valley Conservation (CVC), a determination of CVC data functionality and field test of the HPM, investigation of plants suited to bio-retention facilities and the creation of the Interactive Plant List Model (IPLM).

3.1 Research Process

Research took place as follows:

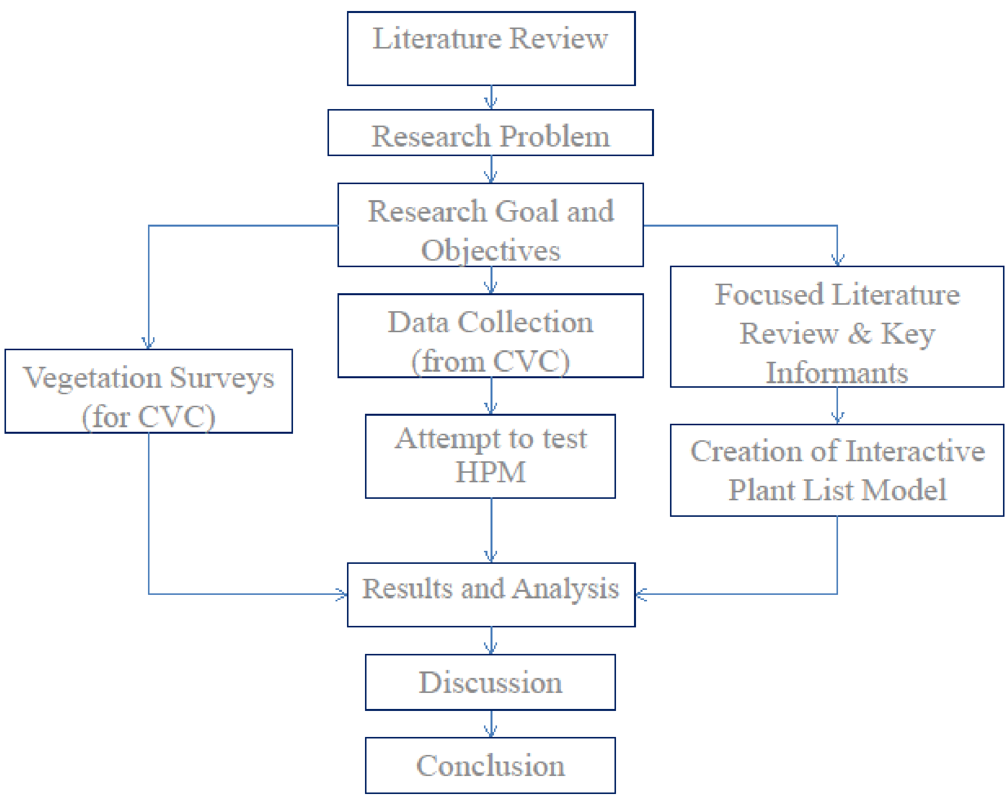

Figure 4: Research Process

3.2 CVC Vegetation Surveys

CVC has been building and testing bio-retention facilities in order to improve their effectiveness and promote them to municipalities and other Conservation Authorities. CVC has been dealing first hand with the issue of vegetative health in bio-retention facilities. CVC's goal was to learn more about plant survivability in bio-retention facilities.

The first objective of the study was to survey current vegetation and document species health in existing facilities in partnership with CVC. Vegetation surveys were conducted by the author on eight bio-retention sites built and monitored by CVC. The sites include O'Connor Park, Portico Community Church, Lakeside Park, Green Glade Senior Public School, Lakeview (First and Third Street), the Unitarian Congregation and Elm Drive, all in Mississauga, Ontario, as well as the Terra Cotta Conservation Area in Terra Cotta, Ontario. Up-to-date planting plans were used to identify plants on site. Each site was visited in October 2013 before the first sub-zero temperatures of the season. A simple five point scale was used to rate plants existing in the bio-retention sites. The scale went as follows: Thriving Vigorously (TV – Growing and prosperous to its full biotic potential), Thriving (T – Growing and prosperous), Surviving (Su – Alive but not thriving), Struggling (St – Alive but under stress), Dead (D – Muerto). The scale was created for use by amateurs and professionals without horticultural diagnostic skills. All plants onsite were evaluated. They were given one of the five rankings based on the condition of the majority of plant species present. The solar availability of each site was noted, but no other conditions were examined. As-built data from each site was provided by CVC and can be found in Appendix D. Examples and descriptions of each state can be found in Appendix A. Results were presented to CVC for use in further research and presentations.

3.3 Testing the HPM

The second objective of the study was to determine if existing bio-retention facility moisture data collected by CVC can be used to test and calibrate the HPM to successfully predict moisture conditions. This includes methods for data collection as well as means by which tests were attempted.

3.3.1 Data Collection

The moisture condition data were collected by a team at CVC. They collected water level data with Hobo water level loggers and barometric pressure loggers. Water pressure is measured with one logger, and barometric pressure is measured with another logger. Those two values are combined to determine the saturation level at Metres Below Ground Surface (MBGS). These loggers are located within a piezometer observation point in the bio-retention facility.

3.3.2 The Data

The data collected by CVC include water level, pressure and temperature. Water level can be used to determine the moisture content of soil. An attempt was made to use a soil water retention curve calculation to determine the moisture conditions (Plant Available Water (PAW)) at root level. The Rosetta V1.0 Mathematical Model was used to calculate the unsaturated hydraulic properties of the soil based on soil textures provided by CVC (USDA, 1999).

Data were analyzed and modified to correspond with the inputs of the HPM. In its raw form, the data show saturation level at five minute intervals between April and October 2013. In order to correspond with and test the outputs of the HPM, the multiple daily entries of data were averaged to indicate saturation level once daily.

3.3.3 Meteorological Data

The Happy Plant Model uses 30 years of meteorological data from 1981 to 2010. This data include daily rainfall, daily minimum and maximum temperatures and daily snow on the ground. The data were collected from the National Climate Data and Information Archive from their data collection site at Toronto Pearson International Airport in Mississauga, Ontario (Paquette, 2012).

To test the model using the moisture condition data gathered between April and October of 2013 from bio-retention facilities in Mississauga, Ontario, daily rainfall, minimum and maximum temperature and daily snow on the ground were obtained either onsite or from a nearby location.

Minimum and maximum temperature and daily snow on the ground data were not available from on-site monitoring. It was instead obtained for April-November 2013 from the National Climate Data and Information Archive for Toronto Pearson International Airport in

Mississauga, Ontario. This was the closest and most reliable source of daily minimum and maximum temperature and daily snow on the ground data available. Precipitation data were gathered onsite from each individual location by CVC (CVC. Personal Communication November, 2013).

3.3.4 Determining As-built Construction Data

In order to obtain accurate outputs from the HPM, as-built construction data from the bio-retention facilities in question were needed. This information was provided by the CVC (Personal Communication November, 2013), who had contracted the job to a water resource-based engineering and environmental consulting firm Emmons and Olivier Resources Inc (EOR). EOR measured three site parameters: the contributing run-off area, the surface area of the bio-retention facility and the available surface storage volume. EOR charted as-built data for the bio-retention facilities. Of the design inputs necessary to use the HPM, soil media depth, gravel storage, ponding depth and drainage area were measured by EOR and provided by CVC (CVC. Personal Communication November, 2013).

Of the design inputs necessary to use the HPM, this provides soil media depth, gravel storage, ponding depth and drainage area. Other design inputs necessary for use include soil media texture, rooting depth, landscape coefficient and native soil texture. Soil media texture was collected for most of the facilities. On average the mixture includes 71-92% by weight course sand (2.0-0.25mm dia.), 0-17% by weight fine sand (0.25-0.05mm dia.), 8-12% by weight silt or clay (<0.05mm dia. Or sieve 270), and 3-5% by dry weight organic matter (leaf and yard compost, not manure) (CVC, Personal Communication December 2013).

3.3.5 Data Input

All necessary data, including meteorological and as-built construction data were inputted. The model outputs were to be compared to the real time synthesized moisture condition data collected by CVC. This would allow for the outputs to be validated by measuring for accuracy. A key informant in the field of soil science was contacted to provide insight into soil moisture characteristics. Unstructured interviews were conducted to evaluate the efficacy of calculating PAW in unsaturated soil based on the saturation level below and soil texture. A soil water retention curve calculation model was suggested to calculate PAW in unsaturated soils.

3.4 Plant Database

The third objective of the study was to assemble plant lists created for stormwater and floodplain planting in Ontario and create an amalgamated plant database that includes flood and drought tolerances. Below are the methods undertaken to do so.

3.4.1 Key Informants

Key informants were used to gather information on stormwater and floodplain vegetation native to Ontario, Canada. Key informants impart knowledge and expertise from their particular field of study, and are generally spoken to in the context of an interview or informal conversation (Given, 2008). In this case key informants from all thirty-six conservation authorities in Ontario were emailed and asked to provide a list of plant species that they recommend for use in stormwater facilities and floodplains.

3.4.2 Focused Literature Review

A focused literature review was performed to collect drought and saturation tolerance data for each plant. Data were collected from academic literature, as well as various horticultural groups across North America. In cases where direct information on drought and saturation tolerance was unattainable from literature, assumptions are made based on the individual plant's Wetland Indicator Status and drought tolerance ranking. A key informant in the realm of plant ecology suggested that the Wetland Indicator Status was one way, in cases where specific studies have not been done, to predict a plant's success in saturated conditions. Wetland Indicator Status is the likelihood that a plant will exist in a wetland (Lichvar, 2013).

'Days Saturated' and 'Days Drought' categories were created for each plant species to correspond with the outputs of the model. These represent the predicted number of days that an individual plant species will tolerate saturation and drought respectively without suffering lasting damage from stress. This provides the designer with a list of plants that is most likely to survive in the predicted moisture conditions. Plants experiencing 50% or less plant available water were considered to be under drought stress. Less than 50% PAW corresponds with the HPM's determination of moderate stress. Drought conditions also include the HPM's outputs of High

Stress (25%-12.5% PAW) and Extreme Stress (<12.5%PAW). Saturated conditions and Normal (Field Capacity-50% PAW) categories were also used from the HPM (Paquette, 2012).

3.5 Interactive Plant List Model

The fourth objective of the study was to create the IPLM to identify preferred plant species selections for moisture conditions according to bio-retention facility design using the predictive capacity of the HPM. In doing so it allows designers to predict preferred plant species for pre-construction bio-retention facilities. Below are the methods undertaken in creating the IPLM. The IPLM, being linked to the HPM, exists as an Excel-based model.

3.5.1 Linking Outputs to Plant Species

The outputs of the HPM link to the plant species 'Days Saturated' and 'Days Drought' categories using Excel-based calculations. The five moisture condition outputs produced by the model include saturated, no stress, moderate stress, high stress and extreme stress. Each day of the growing season is given one of the five ratings. The model outputs on which days each condition was present for thirty growing seasons (1981-2010). The IPLM takes those outputs and places them in three categories: drought, normal and saturated. It then calculates the maximum number of consecutive days that each category was present in the bio-retention facility over the thirty-year period. This gives the maximum consecutive number of days a plant will be forced to tolerate each condition in the previous thirty-year period. If a plant species will tolerate more drought and more saturation days than are predicted to be present, then the plant will be considered to be a viable planting for the facility. If the plant's wetness coefficient will tolerate either less saturation days, less drought days or both, the plant will not be considered a viable planting. The IPLM exists as a separate file.

Chapter 4: Results and Analysis

The following chapter contains the results and analysis of the four study objectives. This includes the CVC vegetation survey, the determination of functionality for CVC moisture data in testing the HPM, the plant database and the Interactive Plant List Model (IPLM).

4.1 CVC Vegetation Survey

The full results of the vegetation surveys performed for CVC are included in Appendix B. A list of the plants labeled as Thriving Vigorously (TV) in one or more bio-retention facility located in full sun is provided in Table 1. Full sun means at least six hours of direct sun during each day of the growing season (Hightshoe, 1988).

Table 1: Full sun plants succeeding in CVC bio-retention facilities.

Full Sun Conditions		
Botanical Name	**Common Name**	**State**
Trees:		
Pyrus calleryana 'Chanticleer'	Chanticleer Pear	TV
Thuja occidentalis	White Cedar	TV
Graminoids:		
Myrica pensylvanica	Bayberry	TV
Pennisetum alopecuroides ‘Hameln’	Foxtail Fountain Grass	TV
Panicum virgatum	Switch Grass	TV
Schizachyrium scopartum	Little Bluestem	TV
Forbs/Ferns:		
Aster cordifolius	Heart-leaved Aster	TV
Aster novae-angliae	New England Aster	TV
Aster pilosus	White Heath Aster	TV
Coreopsis lanceolata	Lance-leaved coreopsis	TV

Helenium autumnale	Sneezeweed	TV
Iris versicolor	Blue Flag Iris	TV
Rudbeckia fulgida	Black-Eyed Susan	TV
Solidago gigantea	Late Goldenrod	TV
Solidago nemoralis	Gray Goldenrod	TV
Thalicatrum pubescens	Tall Meadow-Rue	TV
Veronicastrum virginicum	Culver's Root	TV

Plants labeled as Thriving Vigorously (TV) in one or more bio-retention facilities located in shade or part shade are provided in Table 2. Part shade means between 3-6 hours of sun during each day of the growing season. Shade indicates 3 hours or less (Hightshoe, 1988).

Table 2: Part sun to full shade plants succeeding in CVC bio-retention facilities.

Shade to Part Shade Conditions		
Botanical Name	**Common Name**	**State**
Shrubs:		
Cephalanthus occidentalis	Buttonbush	TV
Cornus sericea	Red-Osier dogwood	TV
Graminoids:		
Carex grayi	Gray's Sedge	TV
Forbs/Ferns:		
Allium cernum	Nodding Onion	TV
Iris versicolor	Blue Flag Iris	TV

Not all plants found in the eight bio-retention sites were native to Ontario. Therefore, not all plants species listed will be found in the complete plant list found in Appendix C. Some plants, such as New England Aster, which succeeded in one or more facilities, were unsuccessful in others. While a plant can be a successful addition to a bio-retention facility, it is also necessary to know the site’s environmental factors, such as moisture availability, pollution levels and amount of sun. The vegetation surveys give evidence of general success, based on non-diagnostic visual review. Solar availability was analyzed in the vegetation surveys. Other environmental factors were not noted. This includes moisture conditions, pollution levels and more.

The results of the vegetation studies can be used as anecdotal evidence of successful bio-retention plant species. Future research could input the bio-retention design characteristics into the HPM to determine whether the IPLM results include the list of successful plant species. Bio-retention design characteristics can be found in Appendix D.

4.2 Testing the HPM

According to a key informant, soil water retention curves can be used to determine unsaturated soil conditions based on the elevation at which the soil is saturated. There were a number of issues that arose with testing the HPM using a soil water retention curve.

First, as one key informant from the soil sciences field indicated, for the equation to work the saturation level must be at static equilibrium. The saturation level in the bio-retention facilities rarely was; it was constantly fluctuating based on the rate of incoming and outgoing stormwater. Second, the soil water retention curve does not indicate the environmental effects on surface soil moisture. It does not incorporate solar radiation or evapotranspiration and therefore could not give an accurate estimate of conditions near the surface. Third, the bio-retention facilities being used for the study were too small for the equation to be accurate. Testing of the

HPM was not possible using the saturation data from CVC. Therefore, further research is needed to test and calibrate the HPM for accuracy.

A soil moisture meter that measures moisture conditions at a precise point is necessary to accurately test and calibrate the HPM. Measurements could be taken at the precise root depth. This would be more accurate than the soil water retention curve equation, and would nullify the need to account for any environmental factors.

4.3 Plant Database and Interactive Plant List Model

Seventeen of the thirty-six conservation authorities responded to the request for recommended plant lists. This represents a potential bias. Respondents could have had different responses than what non-respondents would have had. Ten of those seventeen provided unique plant lists. The plant database was taken from these and organized into five categories. A number of the conservation authorities suggested specific books that they use to form their planting plans. Contents of these books were left out of the plant database due to time restrictions. The database includes trees, shrubs, forbs/ferns, graminoids (grass/sedge) and vines. There are forty-seven trees, including eleven coniferous and thirty-six deciduous. There are sixty-two shrubs, including three coniferous and fifty-nine deciduous. There are ninety-six forbs/ferns, including five ferns and ninety-one forbs. There are forty-two graminoids and seven vines. The original database was larger, but was pared down to delete duplicates, non-natives and plants with little to no documented research. The full list can be found in Appendix C.

The plant database indicates botanical and common name. It also indicates five other categories: Days Saturated, Days Drought, Garden Setting, Solar Requirement and Viability.

4.3.1 Days Saturated

Results for 'Days Saturated' were produced in two ways. The majority were taken directly from the focused literature review, but some were estimated based on the Wetland Indicator Status (WIS). As seen in Table 3, WIS is a rating system documenting the likelihood that a plant species will occur in a wetland. There is a 99% chance that an Obligate (OBL) will naturally occur in a wetland. Whereas, with Facultative species there is a 34-66% chance it will occur in a wetland. In some WIS rating systems a (+) or (–) can be found with the ratings. A status accompanying a (+) will trend toward the wetter end of the category, while one accompanying a (-) will trend towards being drier. For example, a FACW+ indicates wetter conditions than a FACW (Lichvar, 2013). The (+) and (-) trends were not used in this study, as the reference lists did not include them.

Table 3: Wetland Indicator Status ratings. (Lichvar, 2013)

Indicator status	% occurrence in wetlands
Obligate (OBL). Occur almost always under natural conditions in wetlands.	99%
Facultative Wetland (FACW). Usually occur in wetlands but occasionally found in non-wetlands.	67–99%
Facultative (FAC). Equally likely to occur in wetlands and non-wetlands.	34–66%
Facultative Upland (FACU). Usually occur in non-wetlands but occasionally found in wetlands.	1–33%
Upland (UPL). Occur in wetlands in another region, but occur almost always under natural conditions in non-wetlands in the region specified.	1%

There are many factors that affect how long a plant can survive in saturated conditions. The number of days assigned to each plant in this category is merely a prediction. Plants of the same species will react differently to saturated conditions depending on age, size, nutrient availability, oxygen availability and even individual genetic variance. Therefore, the number present in the 'Days Saturated' is not to be seen as an absolute. Rather, it should be viewed as an approximate around which a plant could be struggling enough to cause permanent damage or death.

Most research does not give exact overarching numbers on plant species survivability. Two types of research are commonly found. In the first, researchers will state their findings based on field or experimental research that discovered a plant species (age and whereabouts) survived a particular period of time in saturated/flooded conditions. In the second, researchers or professionals in the horticultural fields will give a broad-stroke prediction of saturation tolerance based on professional experience or likelihood of a plant species' existence in wetland situations. In this case, plant species are labelled as tolerant, intolerant or some intermediary (Hightshoe, 1988; Missouri Botanical Garden, 2014).

Saturation tolerance in days was available in the literature for most trees, shrubs and graminoids. In this case, predictions were taken directly from the literature and inputted into the 'Days Saturated' category. With the majority of forbs/ferns and vines, and with some trees, shrubs and graminoids, predictions were made based on Wetland Indicator Status (WIS). For example, if one shrub had a saturation tolerance of 60 days and a WIS of Facultative Wetland (FACW) then similar plants with the same WIS of FACW were also given a saturation tolerance of 60 days. The full list of 'Days Saturated' predictions can be found in Appendix C.

Unfortunately, in many of the studies from which data were taken tree age, health and establishment prior to saturation was not known, not available or varied from study to study. This raises questions of validity for the category of 'Days Saturated.' Fortunately, saturated soil conditions follow a pattern of change over time, therefore the reaction of plants of similar age, health and establishment should also follow a pattern (Whitlow and Harris, 1979). This lends credibility to the saturation data, as long as the days tolerated is seen as a threshold after which the plant species in question will be under stress, potentially to the point of permanent damage or death. This leads to the conclusion that plants undergoing a length of saturation longer than their numerical ranking should not be planted because if they undergo that length of saturation they may need replacement.

4.3.2 Days Drought

The 'Days Drought' category of the plant list should be viewed in a similar way to the 'Days Saturated' category. It is a series of predictions that represent a norm or threshold for drought tolerance, but in no way can predict the survival of all members of that species to the day. There was minimal literature predicting drought tolerance in terms of days. The majority of results in this category are stated in terms of rank (None, Low, Medium, High). Each plant was assigned a drought tolerance prediction based on its ranking. This 'Days Drought' prediction was judged based on a few plants with the ranking ‘Low’, ‘Medium’, and ‘High’ that had drought tolerance information in terms of days. Drought tolerance predictions should be seen as thresholds after which it is likely that plants will suffer some lasting stress. The full list of ‘Days Drought’ predictions can be found in Appendix C.

A key informant from the field of plant ecology stated that many factors, such as humidity and solar radiation, make it difficult to predict accurately what amount of drought an individual plant can tolerate. The predictions are neither as reliable nor valid as those in the ‘Days Saturated’ category. Data were estimated for most plant species based on a few studies on drought tolerance. This research is a rudimentary start to predicting plant success in a bio-retention facility. Extensive research on drought tolerance in concrete terms was not available and, short of experimenting with plant species in a controlled setting, it represents the extent of literature available. Plant species in the plant database (Appendix C) with grey shading are estimates based on the literature. Plant species with no shading are taken from the focused literature review.

4.3.3 Garden Setting and Solar Requirement

‘Days Saturated’ and ‘Days Drought’ are instrumental in determining whether the plant will be viable in the bio-retention facility based on HPM outputs. ‘Garden Setting’ and ‘Solar Requirement’, on the other hand, are simply present to affect choices on garden style and location. Two garden types are suggested: formal (F) and naturalized (N). Plants were listed as either F or N based on professional opinion and a review of descriptions by the Missouri

Botanical Garden Plant Finder (2014). The list can be filtered using these categories. Bio-retention designers using the IPLM can eliminate all viable plants that do not fit their setting. Similarly with Sun/Shade, users can filter the viable plants in order to find ones that fit their location relative to light levels. The full list of 'Garden Setting' and 'Solar Requirement' categorizations can be found in Appendix C.

4.3.4 Viability

The final category is 'Viability.' Viability is based on data outputs from the HPM. As previously noted, design characteristics of the bio-retention facility in question can be entered into the HPM 'Design Inputs' table. This includes impervious drainage area, bio-retention area, soil media depth, gravel storage depth, pea gravel depth, ponding depth, in-situ soil texture, soil media texture, whether an under-drain exists, nearest location and rooting depth. The interactive plant list does not take rooting depth into account. Species, planting density and microclimate factor can also be predicted based on information found in the model. The design inputs lead to daily plant status predictions. As previously stated, the daily plant status predictions are based on Plant Available Water (PAW). The maximum consecutive number of days in drought and saturated conditions were calculated based on the daily predictions. These findings are then compared to the 'Days Saturated' and 'Days Drought' categories to predict plant species viability.

'Viability' displays a 'Yes' if the consecutive days of drought and consecutive days of saturation outputted from the HPM are both less than the 'Days Saturated' and 'Days Drought' that the plant can withstand. This means that the plant is a viable option for the bio-retention design. The 'Viability' category displays a 'No' if either output (HPM output of consecutive days of saturation or drought) is higher than the 'Days Saturated' and 'Days Drought' that the plant can withstand. This means that the plant is not recommended for this bio-retention design. Using the consecutive days method makes the list of viable plant species react to the model outputs in a straightforward manner. Extensive calculations that measure subtler moisture trends would allow for more nuanced predictions, but because of time constraints this was not possible. In the model the 'Viability' list can be filtered to show only the 'Yes' plant species.

4.3.5 Sample Results

Two sample bio-retention facility designs are explored in this section. Note the difference in design input values between Table 4 and Table 6. As well, note the effect of the design inputs in Table 4 and Table 6 have on consecutive days of saturation and drought. The resulting plant list is found in Table 5.

Table 4: Happy Plant Model design input sample 1. (Paquette, 2012)

Design Input	Value	Unit
Drainage Area	**50**	m^2
Bioretention Cell Area	**10**	m^2
Depth of Soil Media	**400**	mm
Depth of Gravel Storage	**0**	mm
Depth of Pea Gravel	**0**	mm
Ponding Depth	**150**	mm
Texture of *in situ* soil*	**Sandy clay loam**	
Texture of Soil Media*	**Sand**	
Underdrain	**No**	
Landscape Coefficient (See Table)		
Species Factor	**Moderate**	unitless
Density Factor	**High**	unitless
Microclimate Factor	**High**	unitless
Rooting Depth	**250**	mm
Nearest Location (See map)	**Rockwood**	

Table 5 shows the preferred plant list for Table 4 design inputs. It has been filtered to include only recommendations for a formal garden setting and plants with a solar requirement of full sun to part shade. All other potential plants have been excluded.

Table 5: Preferred plant list for Table 4 design inputs.

Plant Status	**Highest Consecutive Run of Days**
Field capacity -50%PAW (No Stress)	49
50%PAW - Wilting Point (Drought)	32
Saturated	5

Botanical Name	Common Name	Days Saturated	Days Drought	Formal/Natur-alized Garden (F/N)	Solar Requirement (1=Sun, 2=Part Shade, 3=Shade)	Viability (Yes/No)
Trees						
Acer rubrum	Red Maple	60	65	F	1,2	Yes
Acer saccharinum	Silver Maple	60	65	F	1,2	Yes
Acer x freemanii	Freeman Maple	8	65	F	1,2	Yes
Carya ovata	Shagbark Hickory	50	65	F	1,2	Yes
Celtis occidentalis	Common Hackberry	220	65	F	1,2	Yes
Fraxinus nigra	Black Ash	220	65	F	1,2,3	Yes
Fraxinus pennsylvanica	Green Ash	220	65	F	1	Yes
Gleditsia triacanthos var. inermis	Honey Locust	30	65	F	1	Yes
Juniperus virginiana	Eastern Red Cedar	30	65	F	1	Yes
Picea mariana	Black Spruce	220	65	F	1	Yes
Platanus occidentalis	Sycamore	220	65	F	1	Yes
Quercus bicolor	Swamp White Oak	220	65	F	1	Yes

Quercus macrocarpa	Bur Oak	30	65	F	1	Yes
Quercus palustris	Pin Oak	220	65	F	1	Yes
Thuja occidentalis	Eastern White Cedar	220	65	F	1,2	Yes
Ulmus americana	American Elm	30	65	F	1	Yes

Shrubs

Amelanchier sanguinea	Roundleaf Serviceberry	21	65	F	2,3	Yes
Arctostaphylos uva-ursi	Bearberry	8	65	F	1,2,3	Yes
Aronia melanocarpa	Black Chokeberry	220	65	F	2	Yes
Ceanothus americanus	New Jersey tea	21	65	F	1,2	Yes
Cornus foemina spp. Racemosa	Gray Dogwood	42	65	F	2	Yes
Cornus sericea	Red-Osier Dogwood	68	65	F	1,2	Yes
Diervilla lonicera	Bush Honeysuckle	21	65	F	1,2	Yes
Hypericum kalmianum	Shrubby St. Johns-wort	68	65	F	1	Yes
Juniperus communis	Common Juniper	8	65	F	1	Yes
Juniperus horizontalis	Creeping Juniper	8	65	F	1	Yes
Lonicera canadensis	Fly Honeysuckle	21	65	F	1,2,3	Yes
Myrica pensylvanica	Bayberry	220	65	F	1,2	Yes
Physocarpus opulifolius	Ninebark	68	65	F	1,2,3	Yes
Potentilla fruticosa	Shrubby Cinquefoil	68	65	F	1,2	Yes
Rhus aromatica	Fragrant Sumac	8	65	F	1,2,3	Yes
Rhus typhina	Staghorn Sumac	8	65	F	1,2,3	Yes
Rubus idaeus ssp. strigosus	Common Red Raspberry	42	65	F	1,2,3	Yes
Sambucus canadensis	Common Elderberry	68	65	F	1,2	Yes

Vaccinium angustifolium	Low Sweet Blueberry	68	65	F	1,2,3	Yes
Viburnum dentatum	Arrowwood	60	65	F	1,2	Yes
Viburnum lentago	Nannyberry	60	65	F	1,2	Yes
Viburnum trilobum	Highbush Cranberry	220	65	F	1,2	Yes

Forbs and Ferns

Amsonia tabernaemontana	Eastern Bluestar	45	65	F	1,2	Yes
Armeria maritima 'Dusseldorf Pride'	Dusseldorf Pride Sea Thrift	7	65	F	1	Yes
Aster ericoides	Heath Aster	7	65	F	1	Yes
Coreopsis lanceolata	Lance-leaved Coreopsis	7	65	F	1,2,3	Yes
Gaillardia aristata	Great Blanket-flower	7	65	F	1	Yes
Geranium maculatum	Wild Geranium	7	65	F	1,2	Yes
Helianthus strumosus	Pale-leaf Sunflower	7	65	F	1,2,3	Yes
Monarda fistulosa	Wild Bergamot	7	65	F	1,2	Yes
Penstemon digitalis	Foxglove Beard-tongue	15	65	F	1,2	Yes
Podophyllum peltatum	Mayapple	7	65	F	2,3	Yes

Graminoids

Andropogon gerardii	Big Bluestem	14	65	F	1	Yes
Andropogon scoparius	Little Bluestem	7	65	F	1,2	Yes
Bouteloua gracilis	Blue Grama	7	65	F	1	Yes
Calamagrostis acutiflora 'Karl Foerster'	Karl Foerster Feather Reed Grass	15	65	F	1	Yes
Sorghastrum nutans	Indian Grass	7	65	F	1	Yes

Spartina pectinata	Prairie Cordgrass	45	65	F	1,2	Yes

Vines

Clematis virginiana	Virgin's bower	60	65	F	1,2	Yes
Parthenocissus quinquefolia	Virginia Creeper	68	65	F	1,2,3	Yes

Note: References for Table 5 can be found in Appendix C

Note the effect of the design inputs in Table 6 on consecutive days of saturation and drought. The resulting plant list is found in Table 7.

Table 6: Happy Plant Model design input sample 2. (Paquette, 2012)

Design Input	Value	Unit
Drainage Area	**150**	m^2
Bioretention Cell Area	**10**	m^2
Depth of Soil Media	**400**	mm
Depth of Gravel Storage	**300**	mm
Depth of Pea Gravel	**0**	mm
Ponding Depth	**150**	mm
Texture of *in situ* soil*	**Clay loam**	
Texture of Soil Media*	**Silt Loam**	
Underdrain	**No**	
Landscape Coefficient (See Table)		
Species Factor	**Moderate**	unitless
Density Factor	**High**	unitless
Microclimate Factor	**High**	unitless
Rooting Depth	**250**	mm
Nearest Location (See map)	**Rockwood**	

Table 7 shows the preferred plant list for Table 6 design inputs. It has been filtered to include recommendations for both formal and naturalized garden setting, but only plants with a tolerance of full shade are included. All other potential plants have been filtered out in the IPLM.

Table 7: Preferred plant list for Table 6 design inputs.

Plant Status	**Highest Consecutive Run of Days**
Field capacity -50%PAW (No Stress)	17
50%PAW - Wilting Point (Drought)	0
Saturated	198

Botanical Name	Common Name	Days Saturated	Days Drought	Formal/Natur-alized Garden (F/N)	Solar Requirement (1=Sun, 2=Part Shade, 3=Shade)	Viability (Yes/No)
Trees						
Betula alleghaniensis	Yellow Birch	220	20	F	2,3	Yes
Fraxinus nigra	Black Ash	220	65	F	1,2,3	Yes
Salix nigra	Black Willow	220	65	N	1,2,3	Yes
Shrubs						
Cephalanthus occidentalis	Buttonbush	220	20	F	2,3	Yes
Lonicera oblongifolia	Swamp fly honeysuckle	220	20	F	2,3	Yes
Rosa palustris	Swamp rose	220	20	N	1,2,3	Yes
Salix amygdaloides	Peach-leaved Willow	220	20	N	1,2,3	Yes
Salix bebbiana	Bebb's Willow	220	20	N	1,2,3	Yes
Salix lucida	Shining Willow	220	65	N	1,2,3	Yes

Spiraea alba	Narrow-leaved Meadow-sweet	220	65	N	1,2,3	Yes

Forbs and Ferns

Calla palustris	Water Arum	220	0	F	2,3	Yes
Caltha palustris	Marsh Marigold	220	0	F	1,2,3	Yes
Chelone glabra	Turtlehead	220	20	N	1,2,3	Yes
Impatiens capensis	Spotted Touch-me-not	220	0	F	2,3	Yes
Impatiens pallida	Pale Touch-me-not	220	0	F	2,3	Yes
Lobelia siphilitica	Great Blue Lobelia	220	0	F	1,2,3	Yes
Lycopus americanus	Water Horehound	220	0	N	3	Yes
Onoclea sensibilis	Sensitive Fern	220	0	F	2,3	Yes
Osmunda cinnamomea	Cinnamon Fern	220	31	F	2,3	Yes

Graminoids

Calamagrostis canadensis	Canada Bluejoint	220	0	F	1,2,3	Yes
Carex bebbii	Bebb's Sedge	220	20	N	1,2,3	Yes
Carex crinita	Fringed Sedge	220	0	F	2,3	Yes
Carex hystericina	Porcupine Sedge	220	0	N	1,2,3	Yes
Carex lacustris	Lake-bank Sedge	220	0	N	1,2,3	Yes

Vines

Vitis riparia	Riverbank Grape	220	65	N	1,2,3	Yes

Note: References for Table 7 can be found in Appendix C

Any number of sample bio-retention designs and resulting plant lists could be produced. Tables 4 – 7 show the dynamic nature of the IPLM. These sample tables came from the IPLM. The IPLM is an Excel-based model linked to the HPM.

Chapter 5: Discussion

Uses, limitations and future research potential for this study will be discussed in this chapter. This includes implications for the vegetation surveys completed for Credit Valley Conservation (CVC), the attempt at testing the HPM, the plant database and the Interactive Plant List Model (IPLM) linked to the outputs of the HPM.

5.1 CVC Vegetation Survey

Vegetation surveys were completed together with CVC to find successful plant species for bio-retention facilities by surveying the status of current vegetation. The vegetation surveys indicate vegetation success and failure. They indicate plant species and vitality, as well as a verbal description of the bio-retention facility in question, but do not indicate the moisture conditions of the site. They indicate general success based on a small sampling of facilities with undefined moisture conditions. They are limited by a lack of diagnostic analysis. Plant species were only judged visually.

The vegetation surveys will be used, short of more meaningful data, to inform the future planting of bio-retention facilities by CVC. They have been used in conjunction with a vegetation survey protocol (also produced by the author) in presentations for the 2013 Latornell Conservation Symposium.

The vegetation surveys can also be incorporated into further research. Future researchers could input the CVC bio-retention design details into the HPM to determine whether the IPLM results include the list of successful plant species from the vegetation surveys. This would test for discrepancies in results. Efforts could then be made to resolve them. CVC bio-retention design details can be found in Appendix D.

5.2 Testing the HPM

The objective of the soil moisture test was to determine if moisture data collected by CVC can be used to test and calibrate the HPM to successfully predict moisture conditions for preferred plant choices. The attempted testing of the HPM based on CVC bio-retention facilities was not successful. This failure indicates that saturation level cannot be used to predict moisture conditions of unsaturated soil in a traditional bio-retention setting. Precise moisture condition readings are needed at a controllable elevation in order to test the HPM properly. The information gathered can be used for future research. Using site data from CVC moisture condition tests could be performed in order to test the HPM.

5.3 Plant Database and Interactive Plant List Model

The plant database and interactive plant list model were created to assist CVC and other bio-retention designers in predicting preferred plant species for pre-construction bio-retention facilities.

5.3.1 Plant List Representativeness

The plant list gathered from various conservation authorities is representative of a wide variety of native plant species used in stormwater management and floodplain settings. It includes a number of suggested cultivars of native species. Many cultivars of native species are available via local nurseries. The plant list does not include most of them. This is not a comment on their worth, but rather an indication of how many cultivars exist. Only plants suggested by the conservation authorities were included. This is because of time constraints, as well as a decision to rely on the expertise of the conservation authorities. The list also excludes plant species for which adequate information did not exist in the reviewed literature. This eliminates species that are not easily researched, but it also eliminates species that will not be as commercially available. The full plant database can be found in Appendix C.

5.3.2 Days Saturated Category

The 'Days Saturated' category in the plant list indicates the maximum number of consecutive days a plant species can tolerate saturated soil. There was information in the literature regarding days of tolerance for many species. Some of the data in this category were estimated based on Wetland Indicator Status (WIS). Estimates were made when information for 'Days Saturated' could not be found in concrete numbers. In this case, species were given a prediction based on the data from another species with concrete numbers from the literature. This was based on having an identical WIS. For instance, if *Acer saccharum* is FACU and can withstand 3 days of saturation (according to data from literature), then *Betula papyrifera*, also FACU, should also withstand 3 days of saturation.

For the purpose of the interactive plant list, it is assumed that plant species equally likely to exist in a wetland will also be able to withstand a similar number of saturation days. Further research is needed to determine the accuracy of this assumption. Until further research is done, the category of 'Days Saturated' and the estimates used therein can be used as a guide, rather than a concrete determination of plant species tolerance of saturation.

5.3.3 Days Drought Category

The 'Days Drought' category in the plant list indicates the maximum number of consecutive days a plant species can tolerate droughty soil. The majority of this category was estimated based on drought tolerance rankings (None, Low, Medium, High) as found in the literature. A few plant species had information on drought tolerance in number of days. These plant species with direct numbers were used to estimate the rest of the 'Days Drought' category. This calls into question the accuracy of the majority of data on drought tolerance because estimates are made based on a small number of original data. Research is needed on plant species in droughty soils at a controlled Plant Available Water (PAW) percentage in order to make more concrete conclusions on drought tolerance in a format compatible with the HPM. Until then, the estimates used in 'Days Drought' can be used as an approximate guide, rather than a concrete determination of plant species tolerance of saturation.

5.3.4 Viability Category

The interactive plant list will filter out plant species that do not fit the moisture conditions of the bio-retention design. It takes the maximum number of consecutive growing season days in both drought and saturated conditions. It then cross references those numbers against the numerical ranking of each plant species in the 'Days Saturated' and 'Days Drought' categories. If the plant species has a higher ranking than the maximum consecutive number of predicted drought and saturation days in both categories, the 'Viability' category will say 'Yes.' This means that the plant species in question is considered viable for the bio-retention design. If the plant species has a lower ranking in either or both of the 'Days Saturated' and 'Days Drought' categories the 'Viability' category will say 'No.'.

This method was chosen for a number of reasons. First, it is impossible to guarantee to the day how long a plant will survive in saturation and drought conditions. One can predict a threshold after which a plant species will be stressed in such conditions. The consecutive days method gives a prediction of how long that period is, based on existing literature. The use of plants that might be stressed in said conditions are not discouraged because they are guaranteed to die. In some cases they will die, but in others cases stressful conditions will weaken the plant species to the point of lasting damage or susceptibility to other stressors. Repetitions of similar drought or saturation length in future years will further stress the plant species in question, leading to increased likelihood of decline (Lilly, 2010). These plant species should be substituted for more applicable choices.

Second, the consecutive days method was chosen because of the availability of data in the literature, as well as the ease with which data could be extracted from the HPM and synthesized for use. In short, it was the most time effective form of data synthesis. Tendency of a bio-retention design towards drought or saturation conditions could be used, but this would not link as effectively with the available literature.

The consecutive days method does have limitations. It does not measure tendency of a bio-retention facility towards drought or saturated conditions. Rather, it assumes that a bio-retention design with a high predicted consecutive days drought will also have a tendency to be droughty more often. Similarly, designs with high predicted consecutive days of saturation are assumed to trend towards saturated conditions. Proof of repeated drought or saturation conditions enhances the need to use plant species that are considered viable by the interactive plant list. Further analysis could be used to bolster this assumption and lend credibility to the consecutive days method.

5.3.5 Uses and Benefits

The interactive plant list has numerous benefits and uses. It is an extensive compilation of plant species native to Ontario. It includes botanical and common names, as well as solar requirements and suggested garden setting (formal/naturalization) for each species. More importantly, each plant species has a prediction for how long it can exist comfortably in consecutive days of saturation and drought conditions. This can be found in Appendix C. Further information for each species can be found in the IPLM. This includes the WIS and drought tolerance ranking for each species.

The IPLM is capable of predicting preferred plant species for pre-construction bio-retention facilities based on their moisture needs and solar requirements. This is based on a few assumptions. This includes the validity of the theoretically-based HPM, the accuracy of estimated saturation and drought tolerances and the assumption that plant species in bio-retention facilities react to drought and saturation in the same way as plant species found in the literature. The predictive capacity of the IPLM can be used as a guide by bio-retention designers to inform bio-retention planting design. This includes professional designers such as landscape architects building facilities for conservation authorities, municipalities and private organizations promoting and utilizing bio-retention. It can also include individual property owners looking to construct alternatives to traditional catch-basin and pipe stormwater management methods. This research, as well as the IPLM, will be presented to CVC for their use in promoting and building future bio-retention facilities. Refinement and distribution of the IPLM could be another step towards the increased prevalence of bio-retention in the stormwater management landscape. Information from the IPLM can also be used on its own as a stand-alone list.

5.3.6 Limitations

The IPLM has a number of limitations. The HPM, on which it relies for moisture condition outputs, is untested. It is based on a water balance equation from agricultural research that was modified to work in a bio-retention facility. It was theoretically tested based on the expert knowledge of key informants. In order for the HPM to prove valid it must be cross-referenced with the moisture conditions of existing bio-retention facilities. Until then, its credibility is based on theory.

The predictions for ‘Days Saturated’ and ‘Days Drought’ also have limitations. Predictions, as previously stated, are based on field research and experimentation, as well as estimated from WIS and drought tolerance rankings. Estimates have not been tested, which calls into question the precision of the IPLM. Additionally, most predictions do not control for plant age, previous stressors and various other situational factors. This represents a significant limitation in the study, as these factors play a major role in determination of plant survivability. Research used to determine drought and saturation tolerance did not, in many cases, offer a standard for situational factors and their effect of tolerance. Further experimentation in an existing bio-retention facility could lend further credibility to the drought and saturation tolerance data.

A number of useful categories have been left out of the IPLM. The five categories (see Appendix C) are a good start, but additional categories, such as pollution tolerance and pH tolerance, are important factors in choosing plant species. They could be added as filterable categories but have not been because of time constraints. Additionally, the HPM controls for root depth but the IPLM does not. Root depth is important because the moisture condition of soil varies with elevation. Deeper roots experience different moisture conditions than more shallow roots

5.4 Completion of Goal and Objectives

The goal of the study was to increase the effectiveness and efficiency of bio-retention facility design by providing a means to easily and accurately predict preferred plant species for facility moisture conditions. In order to do this, the objectives of the study first need to be met. The first objective was to aid CVC in choosing ideal plant species for bio-retention facilities by surveying current vegetation and documenting species health in existing facilities. This was done and results were presented to CVC.

The second objective was to test and calibrate the HPM to successfully predict moisture conditions for ideal plant choices. Data limitations led to the failure of this objective. Further research is needed to meet this objective.

The third objective was to investigate plant lists created for stormwater and floodplain planting in Ontario and create an amalgamated plant database that includes flood and drought tolerances. This plant database was completed to work in the IPLM. It can be used interactively in the IPLM, but can also exist as a stand-alone list.

The fourth objective was to create an interactive plant list model that outputs preferred plant species selections according to bio-retention facility design using the predictive capacity of the HPM. In doing so, it could provide bio-retention designers with a means to predict preferred plant species for pre-construction bio-retention facilities based on moisture conditions. There are limitations, but this objective was completed with the creation of the IPLM.

Reaching the goal of the study is brought one step closer with the creation of the IPLM. With refinement, it can be used by CVC in promotion and construction of bio-retention facilities. The goal of the study reaches beyond the IPLM. It is a small part of the success of bio-retention as an alternative form of more responsible stormwater management.

Chapter 6: Conclusion

An overview of research is discussed in this chapter. This includes Credit Valley Conservation (CVC) vegetation surveys, the attempted field test of the Happy Plant Model (HPM) and the creation of the plant database and Interactive Plant List Model (IPLM). There will be a review of the study accomplishments and limitations, after which implications for design and importance of the study will be discussed.

6.1 Study Overview

The study attempted to complete four objectives. The first was to aid CVC in choosing ideal plant species for bio-retention facilities by surveying the status of current vegetation. Information from these surveys has been presented to CVC to inform future bio-retention planting design. The second was to examine and calibrate the HPM to successfully predict moisture conditions. This could not be done due to deficiencies in data. The third was to investigate plant lists created for stormwater and floodplain planting in Ontario and create an amalgamated plant database that includes flood and drought tolerances. This was completed. The fourth was to create an interactive plant database to aid CVC and other bio-retention designers to predict preferred plant species for pre-construction bio-retention facilities. This objective has been completed with the creation of the IPLM, which outputs preferred plant species based on outputs from the HPM.

6.2 Study Accomplishments

The study has succeeded in a number of ways. It is a continuation of the original research involved with creating the HPM. The original research called for an interactive plant list (Paquette, 2012). The IPLM represents an answer to that call. The IPLM is easy to use, with refinement and distribution it could become a useful tool for those designing bio-retention planting plans. Plant species well suited for the predicted moisture conditions are outputted by the IPLM. Designers can input bio-retention design details and have a list of preferred plant species available to filter. The full plant list found in Appendix C succeeds as a stand-alone list of stormwater facility appropriate vegetation. The vegetation survey results found in Appendix B can also be used as anecdotal evidence of vegetation success in bio-retention facilities.

6.3 Study Limitations and Implications

The limitations of the study have implications for further research. Much of the data on saturation and drought tolerance is estimated based on WIS and drought tolerance rankings. Field tests could give more accurate insight into saturation and drought tolerance, especially if the percentage of Plant Available Water (PAW) was controlled. Pollution and pH tolerances were not included in the study because of time constraints. If information on these is available in the literature they could be added to the IPLM as filterable columns. Root depth is also not accounted for when using the IPLM. This was not done because of time constraints and because information on rooting depth is not readily available in the literature. Finally, and importantly, the HPM still has not been tested or calibrated. This should be done in order to confidently predict moisture conditions. Similarly, the IPLM outputs should be tested to prove reliability or initiate calibration.

6.4 Study Importance

This study represents an important step in understanding and designing for the unreliable moisture conditions found in bio-retention facilities. Organizations such as CVC are trying to better understand and design bio-retention facilities in order to provide a form of stormwater management that mimics natural processes (CVC. Personal Communication October, 2013). This is in response to a changing hydrologic system seen in urban landscapes (Poff et al., 2006; CVC. Personal Communication October, 2013). Healthy plants are an important part of a successful bio-retention facility (Prince George's County, 2007). The IPLM predicts viable vegetation for pre-construction bio-retention facilities. It guides designers, both professional and amateur, in choosing appropriate vegetation that are likely to be well suited to life in their bio-retention facility.

6.5 Advice to Landscape Architects

Bio-retention represents a significant change from traditional stormwater management strategies. The entire context of stormwater management should be taken into account when implementing these changes. This includes social aspects such as functional understanding and aesthetic acceptance by officials and the public. It also includes full understanding of the bio-retention process, why it is important to stormwater management and how to maximize facility effectiveness. Landscape architects can play a major role in improving the functionality and aesthetic of bio-retention facilities by more fully understanding their purpose and process, as well as the means by which to achieve public acceptance of an alternative form of stormwater management. This starts with a critical look at current bio-retention practices. Plant health, as suggested by this study, plays a major role in bio-retention success. It is dependent on proper species choice and facility design. A critical look should be taken at what plants are being used in bio-retention facilities and what can be done about the harsh moisture environment present in most facilities. An alignment should also be researched between planting in bio-retention facilities and the wider realm of planting design.

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Appendix A: Pictorial ranking of vegetation for surveys completed for CVC.

Five rankings exist, Thriving Vigorously, Thriving, Surviving, Struggling and Dead. They are defined below along with a pictorial example. Pictures are of the plant species Black-eyed Susan, they represent each of the rankings.

1) Thriving Vigorously (TV): Not only growing and prosperous, but flourishing to the point of filling all given space to its full biotic potential.

Black-eyed Susan Thriving Vigorously. Conservation Garden Park. http://conservationgardenpark.org/plants/5/black-eyed-susan/

2) Thriving (T): Growing and prosperous.

Black-eyed Susan Thriving . Conservation Garden Park. http://conservationgardenpark.org/plants/5/black-eyed-susan/

3) Surviving (Su): Alive, but not growing to its biotic potential.

Black-eyed Susan Surviving . Missouri Botanical Garden Plant Finder. http://www.missouribotanicalgarden.org
/PlantFinder/PlantFinderDetails.aspx?taxonid=261675&isprofile=1&basic=rudbeckia.

4) Struggling (St): Alive, but under stress. May be exhibiting symptoms of stress such as discoloured, misshapen leaves or limited flowering and fruiting.

Black-eyed Susan Struggling . Fisher, K. http://cabininthemountains.blogspot.ca/ 2011 08 01 archive.html

5) Dead (D): Died because of environmental factors present in the bio-retention site.

Black-eyed Susan Dead . Fisher, K. http://cabininthemountains.blogspot.ca/ 2011 08 01 archive.html

Appendix B: Full results of vegetation surveys completed for CVC

O'Connor Park, Mississauga:

Conditions – Full sun surrounded by permeable pavers and asphalt.

Botanical Name	Common Name	State
Graminoids:		
Pennisetum alopecuroides 'Hameln'	Foxtail Fountain Grass	TV
Forbs/Ferns:		
Rudbeckia fulgida	Black-Eyed Susan	TV

Portico Community Church, Mississauga:

Conditions – Full sun surrounded by permeable pavers and asphalt.

Botanical Name	Common Name	State
Trees:		
Acer rubrum 'Franksred'	Franksred Maple	T
Betula pendula 'Royal Frost'	Royal Frost Birch	2T/2D
Cercis canadensis 'Hearts of Gold'	Hearts of Gold Eastern Redbud	Absent
Shrubs:		
Cotinus obovatum	American Smokebush	St
Hibiscus moscheutos 'Summer Storm'	Summer Storm Hibiscus	T
Hydrangea quercifolia	Oakleaf Hydrangea	D
Ilex verticillata 'Red Sprite'	Red Sprite Sparkle Berry	St
Potentilla fruiticosa 'Red Ace'	Shrubby Cinquefoil	St
Sambucus nigra 'Eva'	Black Lace Elder	St/D
Graminoids:		
Andropogon gerrardii	Big Bluestem	T
Panicum virgatum 'Cloud Nine'	Cloud Nine Switch Grass	TV
Panicum virgatum 'Shenandoah'	Shenandoah Switch Grass	TV
Forbs/Ferns:		
Asclepias incarnata	Swamp Milkweed	T
Aster novae-angliae 'Vibrant Dome'	Vibrant Dome New England Aster	TV
Bergenia cordifolia 'Magic Giant'	Magic Giant Pigsqueek	St
Caltha palustris	Marsh Marigold	Absent

Hosta 'Sum & Substance'	Sum & Substance Hosta	St
Sedum spectabile 'Autumn Joy'	Autumn Joy Stonecrop	Su
Spartina pectinata 'Aureomarginata'	Variegated Cord Grass	Absent

Lakeside Park, Mississauga:

Conditions – Currently full sun with small trees providing little shade. Surrounded by asphalt, a planted stand of Staghorn Sumac and grass.

Botanical Name	Common Name	State
Trees:		
Celtis occidentalis	Common Hackberry	St/D
Pyrus calleryana 'Chanticleer'	Chanticleer Pear	TV
Thuja occidentalis	White Cedar	TV
Shrubs:		
Cornus sericea	Red-Osier Dogwood	T
Cornus sericea 'Kelseyi'	Kelsey Dogwood	T
Potentilla fruticosa 'Goldfinger'	Goldfinger Potentilla	Absent
Rhus aromatica	Fragrant Sumac	Su
Rosa blanda	Meadow Rose	Su
Spirea x bumalda 'Goldflame'	Goldflame Spirea	T
Graminoids:		
Panicum virgatum	Switch Grass	TV
Pennisetum alopecuroides 'Hameln'	Foxtail Fountain Grass	TV
Forbs/Ferns:		
Hemerocallis 'Stella D'Oro'	Stella D'Oro Daylily	T
Monarda fistulosa	Bee Balm	Absent
Rudbeckia fulgida	Black-Eyed Susan	Su

Green Glade Senior Public School, Mississauga:

Conditions – Mostly shade conditions next to the two storey school building and under a large pine tree. Receives runoff from downspouts.

Botanical Name	Common Name	State
Shrubs:		
Cephalanthus occidentalis	Buttonbush	TV
Cornus sericea	Red-Osier Dogwood	T
Potentilla fruticosa	Shrubby Cinquefoil	St
Graminoids:		
Carex grayi	Gray's Sedge	TV
Forbs/Ferns:		
Allium cernum	Nodding Onion	TV
Andropogon scoparius 'The Blues'	The Blues Little Bluestem	T
Iris versicolor	Blue Flag Iris	TV

Lakeview (First & Third Street), Mississauga:

Conditions – Full sun for most beds. Receives runoff from grass lawns and asphalt.

Botanical Name	Common Name	State
Graminoids:		
Festuca 'Boulder Blue'	Boulder Blue Fescue	T
Forbs/Ferns:		
Coreopsis 'Zagreb'	Yellow Tickseed	T
Gaillardia x grandiflora 'Goblin'	Goblin Blanket Flower	Su
Helictotrichon 'Saphirsprudel'	Saphire Fountain Blue Oat Grass	T
Iris versicolor	Blue Flag Iris	TV
Physostegia virginiana	Obedient Plant	T
Rudbeckia fulgida	Black-Eyed Susan	TV

Unitarian Congregation in Mississauga:

Conditions – Full sun surrounded by permeable pavers and asphalt.

Botanical Name	Common Name	State
Trees:		
Acer rubrum	Red Maple	T
Populus tremuloides	Trembing Aspen	T
Quercus rubra	Red Oak	T

Shrubs:		
Physocarpus opulifolius	Eastern Ninebark	T
Rhus typhina	Staghorn Sumac	T
Forbs/Ferns:		
Asclepias tuberosa	Butterfly milkweed	T
Aster novae-angliae	New England Aster	TV
Fragaria virginiana	Wild Strawberry	T
Coreopsis lanceolata	Lance-leaved Coreopsis	T
Rudbeckia hirta	Black-Eyed Susan	Su
Solidago gigatea	Late Goldenrod	TV
Solidago nemoralis	Gray Goldenrod	TV
Thalicatrum pubescens	Tall Meadow-Rue	TV
Veronicastrum virginicum	Culver's Root	TV

The list provided was more extensive, but a number of the plants could not be located without a plan and have therefore not been evaluated.

Elm Drive, Mississauga:

Conditions – Currently full sun with small trees providing little shade. Beds recessed in troughs formed by pre-cast cement blocks. Receive rainwater through plastic pipe inlet from catch basin in adjacent road.

Botanical Name	**Common Name**	**State**
Trees:		
Acer rubrum 'Franksred'	Franksred Red Maple	T
Shrubs:		
Hydrangea panuculata 'Pinky Winky'	Peegee Hydrangea	T
Myrica pensylvanica	Bayberry	TV
Physocarpus opulifolius 'Dart's Gold'	Dart's Gold Ninebark	T
Sambucus nigra 'Eva'	Black Lace Elder	T
Graminoids:		
Schizachyrium scopartum	Little Bluestem	TV
Forbs/Ferns:		
Asclepias tuberosa	Butterfly Milkweed	Absent
Aster pilosus	White Heath Aster	TV
Aster cordifolius	Heart-leaved Aster	TV
Coreopsis lanceolata	Lance-leaved coreopsis	TV

Helenium autumnale	Sneezeweed	TV
Iris versicolor	Blue Flag Iris	TV
Rudbeckia hirta	Black-Eyed Susan	Su

Terra Cotta Conservation Area, Terra Cotta:

Conditions – The site is mostly shaded by nearby mature maple trees, and is surrounded by mown grass. It receives rainwater via a downspout from a nearby building.

Botanical Name	**Common Name**	**State**
Shrubs:		
Cornus sericea	Red-Osier Dogwood	TV
Sambucus canadensis	Elderberry	T
Forbs/Ferns:		
Aster novae-angliae	New England Aster	Su
Anemone canadensis	Canada Anemone	T
Onoclea sensibilis	Sensitive Fern	Su
Rudbeckia fulgida	Black-Eyed Susan	St
Thalictrum pubescens	Tall Meadow Rue	Absent

Appendix C: Full Plant List

BOTANICAL NAME	COMMON NAME	Days Saturated	Days Drought	Formal/Natur-alized Garden (F/N)	Solar Requirement (1=Sun, 2=Part Shade, 3=Shade)	Viability (Yes/No)
Trees						
Abies balsamea	Balsam Fir	28	20	F	1,2,3	Yes
Acer nigrum	Black Maple	3	20	F	2,3	Yes
Acer rubrum	Red Maple	60	65	F	1,2	Yes
Acer saccharinum	Silver Maple	60	65	F	1,2	Yes
Acer saccharum	Sugar Maple	3	20	F	1,2,3	Yes
Acer x freemanii	Freeman Maple	8	65	F	1,2	Yes
Betula alleghaniensis	Yellow Birch	220	20	F	2,3	Yes
Betula papyrifera	Paper Birch	3	31	F	1,2,3	Yes
Carpinus caroliniana	Blue Beech	30	20	F	2,3	Yes
Carya cordiformis	Bitternut Hickory	3	31	F	1,2,3	Yes
Carya ovata	Shagbark Hickory	50	65	F	1,2	Yes
Celtis occidentalis	Common Hackberry	220	65	F	1,2	Yes
Fagus grandifolia	American Beech	3	20	F	2,3	Yes
Fraxinus americana	White Ash	30	31	F	1	Yes
Fraxinus nigra	Black Ash	220	65	F	1,2,3	Yes
Fraxinus pennsylvanica	Green Ash	220	65	F	1	Yes
Gleditsia triacanthos var. inermis	Honey Locust	30	65	F	1	Yes

Juglans cinerea	Butternut	30	31	F	1	Yes
Juglans nigra	Black Walnut	30	65	N	1	Yes
Juniperus virginiana	Eastern Red Cedar	30	65	F	1	Yes
Larix laricina	Tamarack	220	65	N	1	Yes
Liriodendron tulipifera	Tulip Tree	35	20	F	1	Yes
Ostrya virginiana	Ironwood	30	31	F	1,2	Yes
Picea glauca	White Spruce	28	31	F	1	Yes
Picea mariana	Black Spruce	220	65	F	1	Yes
Picea pungens	Colorado Spruce	10	20	F	1	Yes
Pinus banksiana	Jack Pine	28	65	N	1	Yes
Pinus resinosa	Red Pine	90	31	N	1	Yes
Pinus strobus	Eastern White Pine	3	20	F	1,2	Yes
Platanus occidentalis	Sycamore	220	65	F	1	Yes
Populus deltoides	Eastern Cottonwood	220	65	N	1	Yes
Populus grandidentata	Large-toothed Aspen	30	31	N	1	Yes
Populus tremuloides	Trembling Aspen	3	31	N	1	Yes
Prunus serotina	Black Cherry	3	65	F	1,2,3	Yes
Prunus virginiana	Choke Cherry	3	65	F	1,2	Yes
Quercus alba	White Oak	3	31	F	1	Yes
Quercus bicolor	Swamp White Oak	220	65	F	1	Yes
Quercus macrocarpa	Bur Oak	30	65	F	1	Yes
Quercus muehlenbergii	Chinquapin Oak	3	65	F	1	Yes
Quercus palustris	Pin Oak	220	65	F	1	Yes
Quercus rubra	Red Oak	3	65	F	1	Yes
Salix nigra	Black Willow	220	65	N	1,2,3	Yes

Thuja occidentalis	Eastern White Cedar	220	65	F	1,2	Yes
Tilia americana	American Basswood	30	20	F	1,2	Yes
Tsuga canadensis	Eastern Hemlock	3	20	F	2,3	Yes
Ulmus americana	American Elm	30	65	F	1	Yes
Ulmus thomasii	Rock Elm	3	31	F	1,2,3	Yes

Shrubs

Alnus incana spp. rugosa	Speckled Alder	220	20	F	1,2	Yes
Amelanchier alnifolia	Saskatoon Berry	21	20	F	1,2	Yes
Amelanchier arborea	Juneberry	21	20	F	1,2	Yes
Amelanchier laevis	Allegheny Serviceberry	21	20	F	1,2	Yes
Amelanchier sanguinea	Roundleaf Serviceberry	21	65	F	2,3	Yes
Apocynum androsaemifolium	Spreading Dogbane	8	65	N	1,2,3	Yes
Arctostaphylos uva-ursi	Bearberry	8	65	F	1,2,3	Yes
Aronia melanocarpa	Black Chokeberry	220	65	F	2	Yes
Asclepias syriaca	Common Milkweed	8	65	N	1	Yes
Ceanothus americanus	New Jersey Tea	21	65	F	1,2	Yes
Cephalanthus occidentalis	Buttonbush	220	20	F	2,3	Yes
Cornus alternifolia	Alternate Leaved Dogwood	21	20	F	2,3	Yes
Cornus amomum ssp. obliqua	Silky Dogwood	68	31	N	1,2	Yes
Cornus foemina spp. Racemosa	Gray Dogwood	42	65	F	2	Yes
Cornus sericea	Red-Osier Dogwood	68	65	F	1,2	Yes
Corylus americana	American Hazelnut	21	31	F	1,2	Yes
Corylus cornuta	Beaked Hazelnut	21	31	F	1,2,3	Yes

Cotoneaster apiculatus	Cotoneaster	3	31	F	1	Yes
Diervilla lonicera	Bush Honeysuckle	21	65	F	1,2	Yes
Hamamelis virginiana	Witch-hazel	21	20	F	1,2	Yes
Hydrangea arborescens 'Annabelle'	Annabelle Hydrangea	21	20	F	2	Yes
Hypericum kalmianum	Shrubby St. Johns-wort	68	65	F	1	Yes
Ilex verticillata	Winterberry	68	31	F	1,2,3	Yes
Juniperus communis	Common Juniper	8	65	F	1	Yes
Juniperus horizontalis	Creeping Juniper	8	65	F	1	Yes
Lindera benzoin	Spicebush	42	20	F	1,2,3	Yes
Lonicera canadensis	Fly Honeysuckle	21	65	F	1,2,3	Yes
Lonicera dioica	Wild Honeysuckle	21	20	F	1,2,3	Yes
Lonicera oblongifolia	Swamp Fly Foneysuckle	220	20	F	2,3	Yes
Myrica pensylvanica	Bayberry	220	65	F	1,2	Yes
Physocarpus opulifolius	Ninebark	68	65	F	1,2,3	Yes
Potentilla fruticosa	Shrubby Cinquefoil	68	65	F	1,2	Yes
Rhus aromatica	Fragrant Sumac	8	65	F	1,2,3	Yes
Rhus glabra	Smooth Sumac	8	65	N	1,2,3	Yes
Rhus typhina	Staghorn Sumac	8	65	F	1,2,3	Yes
Rosa blanda	Smooth Wild Rose	8	31	F	1	Yes
Rosa palustris	Swamp Rose	220	20	N	1,2,3	Yes
Rubus allegheniensis	Common Blackberry	42	65	N	1,2,3	Yes
Rubus idaeus	Wild Red Raspberry	42	65	N	1,2,3	Yes
Rubus idaeus ssp. strigosus	Common Red Raspberry	42	65	F	1,2,3	Yes
Rubus odoratus	Purple Flowering Raspberry	21	31	N	1,2,3	Yes

Rubus pubescens	Dwarf Raspberry	68	31	N	1,2,3	Yes
Salix amygdaloides	Peach-leaved Willow	220	20	N	1,2,3	Yes
Salix bebbiana	Bebb's Willow	220	20	N	1,2,3	Yes
Salix candida	Hoary Willow	220	20	N	1,2	Yes
Salix discolor	Pussy Willow	220	20	F	1	Yes
Salix exigua	Sandbar Willow	220	31	N	1,2	Yes
Salix humilis	Upland Willow	60	65	N	1	Yes
Salix lucida	Shining Willow	220	65	N	1,2,3	Yes
Sambucus canadensis	Common Elderberry	68	65	F	1,2	Yes
Sambucus racemosa	Red Elderberry	21	20	F	1,2,3	Yes
Shepherdia canadensis	Buffalo-berry	8	65	N	1,2,3	Yes
Spiraea alba	Narrow-leaved Meadow-sweet	220	65	N	1,2,3	Yes
Symphoricarpos albus	Snowberry	8	31	F	1,2,3	Yes
Taxus canadensis	Canadian Yew	8	20	F	1,2,3	Yes
Vaccinium angustifolium	Low Sweet Blueberry	68	65	F	1,2,3	Yes
Viburnum acerifolium	Maple-leaved Viburnum	8	31	F	1,2,3	Yes
Viburnum cassinoides	Witherod Viburnum	68	31	F	1,2,3	Yes
Viburnum dentatum	Arrowwood	60	65	F	1,2	Yes
Viburnum lentago	Nannyberry	60	65	F	1,2	Yes
Viburnum trilobum	Highbush Cranberry	220	65	F	1,2	Yes
Zanthoxylum americanum	Prickly Ash	8	65	N	1	Yes

Forbs and Ferns

Achillea millefolium ssp. lanulosa	Common Yarrow	7	65	N	1,2	Yes

Acorus americanus	Sweet Flag	220	0	N	1	Yes
Actaea pachypoda	White Baneberry	0	20	N	2,3	Yes
Alisma plantago-aquatica	Water Plantain	220	0	N	1	Yes
Allium schoenoprasum var. sibiricum	Wild Chives	7	20	F	1,2	Yes
Amsonia tabernaemontana	Eastern Bluestar	45	65	F	1,2	Yes
Apocynum androsaemifolium	Spreading Dogbane	0	65	N	1,2,3	Yes
Anemone canadensis	Canada Anemone	220	20	N	1,2	Yes
Anemone virginiana	Tall Anemone	7	65	N	1,2	Yes
Angelica atropurpurea	Great Angelica	220	0	N	1,2	Yes
Aquilegia canadensis	Wild Columbine	7	31	N	1,2	Yes
Arisaema triphyllum	Jack-in-the-Pulpit	15	20	N	2,3	Yes
Armeria maritima 'Dusseldorf Pride'	Dusseldorf Pride Sea Thrift	7	65	F	1	Yes
Asclepias incarnata	Swamp Milkweed	220	0	N	1	Yes
Asclepias syriaca	Common Milkweed	0	31	N	1	Yes
Asclepias tuberosa	Butterfly Milkweed	0	65	F	1	Yes
Aster cordifolium	Heart-leaved Aster	7	31	N	1,2	Yes
Aster ericoides	Heath Aster	7	65	F	1	Yes
Aster laevis	Smooth Aster	7	65	N	1	Yes
Aster novae-angliae	New England Aster	45	31	F	1	Yes
Aster oolentangiensis	Sky Blue Aster	0	65	F	1,2	Yes
Aster puniceus	Swamp Aster	220	0	F	1	Yes
Athyrium filix-femina	Lady Fern	45	20	N	2,3	Yes
Baptisia alba	White Wild Indigo	7	65	N	1,2	Yes
Baptisia australis	Blue Wild Indigo	7	65	N	1,2	Yes

Bidens cernua	Nodding Beggar-ticks	220	20	N	2	Yes
Bidens frondosa	Common Beggar-ticks	220	20	N	2	Yes
Boltonia asteroides	Boltonia	45	31	N	1	Yes
Calla palustris	Water Arum	220	0	F	2,3	Yes
Caltha palustris	Marsh Marigold	220	0	F	1,2,3	Yes
Chelone glabra	Turtlehead	220	20	N	1,2,3	Yes
Chelone lyonii	Pink Turtlehead	220	0	F	1,2	Yes
Coreopsis lanceolata	Lance-leaved Coreopsis	7	65	F	1,2,3	Yes
Coreopsis rosea	Pink-flowered Tickseed	45	31	F	1,2	Yes
Decodon verticillatus	Swamp Loosestrife	220	0	N	1	Yes
Echinacea purpurea	Eastern Purple Coneflower	0	65	F	1,2	Yes
Eupatorium maculatum	Joe-Pye-Weed	220	20	N	1	Yes
Eupatorium perfoliatum	Boneset	220	20	N	1,2	Yes
Eupatorium purpureum	Purple Joe-pye Weed	220	20	N	1	Yes
Eupatorium rugosum	White Snakeroot	15	31	N	1,2	Yes
Euphorbia corollata	Flowering Spurge	0	65	N	1	Yes
Gaillardia aristata	Great Blanket-flower	7	65	F	1	Yes
Gentiana andrewsii	Bottle Gentian	45	20	N	2	Yes
Geranium maculatum	Wild Geranium	7	65	F	1,2	Yes
Geum triflorum	Prairie Smoke	7	65	N	1	Yes
Helenium autumnale	Sneezeweed	45	20	F	1	Yes
Helianthus giganteus	Tall Sunflower	45	20	F	1	Yes
Helianthus strumosus	Pale-leaf Sunflower	7	65	F	1,2,3	Yes
Heliopsis helianthoides	Oxeye Sunflower	7	31	F	1	Yes

Hibiscus moscheutos	Swamp Rose-mallow	220	0	F	1,2	Yes
Impatiens capensis	Spotted Touch-me-not	220	0	F	2,3	Yes
Impatiens pallida	Pale Touch-me-not	220	0	F	2,3	Yes
Iris versicolor	Blue Flag Iris	220	0	F	1,2	Yes
Lespedeza capitata	Round-head Bush-clover	7	65	N	1	Yes
Liatris spicata	Prairie Blazing Star	15	20	F	1	Yes
Lilium michiganense	Michigan Lily	45	20	F	1,2	Yes
Lilium philadelphicum	Wood Lily	15	31	F	1,2,3	Yes
Lobelia cardinalis	Cardinal Flower	220	31	F	1,2	Yes
Lobelia siphilitica	Great Blue Lobelia	220	0	F	1,2,3	Yes
Lycopus americanus	Water Horehound	220	0	N	3	Yes
Lysimachia thyrsiflora	Tufted Loosestrife	220	0	N	2	Yes
Matteuccia struthiopteris	Ostrich Fern	15	0	F	2,3	Yes
Mimulus ringens	Square-stemmed Monkey-flower	220	0	F	1,2	Yes
Monarda fistulosa	Wild Bergamot	7	65	F	1,2	Yes
Oenothera biennis	Common Evening-primrose	7	31	N	1,2,3	Yes
Onoclea sensibilis	Sensitive Fern	220	0	F	2,3	Yes
Osmunda cinnamomea	Cinnamon Fern	220	31	F	2,3	Yes
Penstemon digitalis	Foxglove Beard-tongue	15	65	F	1,2	Yes
Penstemon hirsutus	Hairy Beardtongue	0	65	F	1,2,3	Yes
Podophyllum peltatum	Mayapple	7	65	F	2,3	Yes
Polystichum acrostichoides	Christmas Fern	7	31	F	2,3	Yes
Pontederia cordata	Pickerelweed	220	0	F	1	Yes
Pycnanthemum virginianum	Virginia Mountain-mint	45	0	F	2	Yes

Ratibida pinnata	Grey-headed Coneflower	0	65	F	1	Yes
Rudbeckia fulgida	Orange Coneflower	15	31	F	1	Yes
Rudbeckia hirta	Black-eyed Susan	7	31	F	1	Yes
Rudbeckia laciniata	Green-headed Coneflower	45	65	N	1,2	Yes
Sagittaria latifolia	Broad-leaved Arrowhead	220	0	F	1	Yes
Sagittaria rigida	Stiff Arrowhead	220	0	F	1	Yes
Sanguinaria canadensis	Bloodroot	7	65	N	2,3	Yes
Sisyrinchium montanum	Strict Blue-eyed-grass	15	31	F	1,2,3	Yes
Solidago caesia	Blue-stemmed Goldenrod	7	65	N	1,2	Yes
Solidago flexicaulis	Zig-zag Goldenrod	7	31	N	1,2,3	Yes
Solidago rugosa	Rough-stemmed Goldenrod	15	31	N	1	Yes
Spiranthes cernua	Nodding Ladies-tresses	45	0	F	1	Yes
Thalictrum dioicum	Early Meadow Rue	7	20	F	1,2	Yes
Thalictrum pubescens	Tall Meadow-Rue	45	20	N	2,3	Yes
Thelypteris palustris	Marsh Fern	220	31	N	1	Yes
Thymus serpyllum	Mother-of-Thyme	0	65	F	1	Yes
Tiarella cordifolia	Foam Flower	7	20	N	2,3	Yes
Tradescantia virginiana	Virginia Spiderwort	0	31	F	2,3	Yes
Verbena hastata	Blue Vervain	220	0	F	1	Yes
Verbena stricta	Hoary Vervain	0	65	N	1	Yes
Vernonia gigantea	Tall Ironweed	15	20	F	1,2	Yes
Veronicastrum virginicum	Culver’s Root	15	20	F	1	Yes
Zizia aurea	Common Alexanders	15	20	F	1,2	Yes

Graminoids

Andropogon gerardii	Big Bluestem	14	65	F	1	Yes
Andropogon scoparius	Little Bluestem	7	65	F	1,2	Yes
Bouteloua gracilis	Blue Grama	7	65	F	1	Yes
Bromus ciliatus	Fringed Brome	45	20	F	1,2,3	Yes
Calamagrostis acutiflora 'Karl Foerster'	Karl Foerster Feather Reed Grass	15	65	F	1	Yes
Calamagrostis canadensis	Canada Bluejoint	220	0	F	1,2,3	Yes
Carex aquatilis	Aquatic Sedge	220	0	N	1,2	Yes
Carex bebbii	Bebb's Sedge	220	20	N	1,2,3	Yes
Carex crinita	Fringed Sedge	220	0	F	2,3	Yes
Carex grayi	Gray Sedge	220	20	F	2	Yes
Carex hystericina	Porcupine Sedge	220	0	N	1,2,3	Yes
Carex lacustris	Lake-bank Sedge	220	0	N	1,2,3	Yes
Carex stipata	Awl-fruited Sedge	220	0	N	1	Yes
Carex stricta	Tussock Sedge	220	0	F	1	Yes
Carex vulpinoidea	Fox Sedge	220	0	N	1	Yes
Chasmanthium latifolium	Upland Sea Oats	45	31	F	1,2	Yes
Deschampsia cespitosa	Tufted Hairgrass	45	20	F	2	Yes
Dulichium arundinaceum	Three-way sedge	220	0	N	2	Yes
Eleocharis obtusa	Spike Rush	220	0	N	1	Yes
Eleocharis smallii	Spike Rush	220	0	N	1	Yes
Elymus canadensis	Canada Wild-rye	14	31	F	1	Yes
Elymus hystrix	Bottle-brush Grass	7	65	N	1,2	Yes

Elymus virginicus	Virginia Wild Rye	45	31	N	2	Yes
Glyceria borealis	Northern Manna Grass	220	0	N	1	Yes
Glyceria striata	Fowl Manna Grass	220	0	N	1	Yes
Helictotrichon sempervirens	Blue Oat Grass	0	65	F	1	Yes
Leersia oryzoides	Rice Cut-grass	220	0	N	2	Yes
Panicum virgatum	Switch Grass	15	31	F	1,2	Yes
Poa palustris	Fowl Meadow Grass	45	20	N	2	Yes
Schoenoplectus tabernaemontani	Soft-stem Bulrush	220	0	F	1	Yes
Scirpus atrovirens	Green bulrush	220	0	N	1	Yes
Scirpus cyperinus	Wool Grass Bulrush	220	0	N	1	Yes
Scirpus pendulus	Pendulus Bulrush	220	0	N	1	Yes
Scirpus pungens	Common Three-square Bulrush	220	0	N	1	Yes
Scirpus validus	Softstem Bulrush	220	0	N	1	Yes
Sorghastrum nutans	Indian Grass	7	65	F	1	Yes
Sparganium americanum	American Bur-reed	220	0	N	2	Yes
Spartina pectinata	Prairie Cordgrass	45	65	F	1,2	Yes
Sporobolus cryptandrus	Sand Dropseed	7	31	N	1,2	Yes
Typha angustifolia	Narrow-leaved Cattail	220	0	N	1,2	Yes
Typha latifolia	Broad-leaf Cattail	220	0	N	1,2	Yes
Zizania aquatica	Wild Rice	220	0	N	1	Yes

Vines

Clematis virginiana	Virgin's Bower	60	65	F	1,2	Yes
Echinocystis lobata	Wild Cucumber	68	20	N	1	Yes

Lonicera hirsuta	Hairy Honeysuckle	42	31	F	1,2	Yes
Menispermum canadense	Canada Moonseed	60	31	F	1,2,3	Yes
Parthenocissus quinquefolia	Virginia Creeper	68	65	F	1,2,3	Yes
Smilax hispida	Greenbrier	220	65	N	1,2	Yes
Vitis riparia	Riverbank Grape	220	65	N	1,2,3	Yes

Note: Data for Plant list from Niagara Peninsula Conservation Authority. (Personal Communication January, 2014), Halton Region Conservation Authority. (Personal Communication January, 2014), Nottawasaga Valley Conservation Authority. (Personal Communication January, 2014), Rideau Valley Conservation Authority. (Personal Communication January, 2014), Toronto Region Conservation Authority. (Personal Communication January, 2014), Upper Thames River Conservation Authority. (Personal Communication January, 2014). Credit Valley Conservation Authority. (Personal Communication January, 2014). Data for saturation and drought tolerance from Missouri Botanical Garden, 2014; Lady Bird Johnson Wildflower Center, 2014; Shaw & Schmidt, 2003; Meyers, Brown & Zins 2007; Walters & Yawney n.d.; McClean, 2000; Hightshoe, Coyle, Harshbarger & Ritland,1988; Tear, Higginbotham, Mayo, 1982; Hansen & Ahlgren, 1957; Chaves, Maroco & Pereira, 2003; Iles, 1993; Delaune & Reddy, 2005; Jull, 2008; Zwack, Graves & Townsend, 1999; Prince George's County Maryland, 2007; Land Trust for the Mississippi Coastal Plain, n.d.; Gilman & Watson, 1994; Hauser, 2008; City of Philadelphia, 2014; Kozlowski, 1997; City of Saskatoon, 2012; Geyer, Dickerson & Row, 2010; Whitlow & Harris, 1979; USDA, 2014; Rossi, Simard, Rathgeber, Deslauriers & De Zan, 2009. Data for garden setting from Missouri Botanical Garden, 2014; Lady Bird Johnson Wildflower Center, 2014. Data for Sun/Shade from Missouri Botanical Garden, 2014; Lady Bird Johnson Wildflower Center, 2014.
Note: Data cells with no fill from Key Informants and Literature. Data cells with grey fill estimated using WIS and drought tolerance rankings. See IPLM for more details.

Appendix D: CVC Bio-retention facility data (coincides with facilities from Appendix B)

				Lakeside		Unitarian		Portico		O'Connor		Green Glade		Terra Cotta		Elm Drive OP-2		Elm Drive OP-3		Elm Drive All		
				Design	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	***Design***	***As-Built***	
Bioretention Basin Dimensions	A	Bioretention Area (m2)	[Input]	165	165	250	227.5	253	235	89	111	11	9	15	15		24	22.5	19	135	129.5	A
	B	Total Depth (mm below surface)	[= I + J + K]	700	565	1000	890	1200	855	530	770	1200	1180	350	350		2170	1450	1960	varies	varies	B
	C	Total Volume (m3)	[= A * (B / 1000)]	115.5	93.2	250	202.5	303.6	200.9	47.17	85.5	13.2	10.6	5.3	5.3		52.1	32.625	37.2	varies	varies	C
	D	Underdrain Depth (mm below surface)	[Input]					677	920	630							1365	900	1228	varies	varies	D
Storage Volumes	E	Surface (m3)	[Input]		1.9	50	24.6		14.9		0		0.8	3	0		4.0		2.8	20.3	26.0	E
	F	Above Drain (m3)	[= A * (D / 1000)]					171.281	216.2	56.07							32.8	20.25	23.3	varies	varies	F
	G	Below Drain (m3)	[= A * (B - D) / 1000]					132.319	-15.3	-8.9							19.3	12.375	13.9	varies	varies	G
	H	Total (m3)	[= E + F + G]		95.1	300	234.2	303.6	215.8		85.5		11.5	8.3	5.3		56.1		40.0	varies	varies	H
Mulch and Media Characteristics	I	Mulch Thickness (mm)	[Input]	75	75	75	75	100	100	50	50	75	75	50	50		75	50	75	varies	varies	I
	J	Media Thickness (mm)	[Input]	325	490	925	815	1100	755	480	720	1125	1105	300	300		2095	400	1885	varies	varies	J
	K	Other Thickness - gravel, etc. (mm)	[Input]	300														1000				K
	L	Media Infiltration Rate (mm/hr)	[Input]					60		25		50								varies	varies	L
	M	Media Bulk Density (g/cm3)	[Input]																	varies	varies	M
	N	Media Porosity	[= 1 - (L / 2.65)]																	varies	varies	N
	O	Geotextile Lined? (y/n)	[Input]									NO	NO							YES	YES	O
	P	Subsoil Infiltration Rate (mm/hr)	[Input]							0.036		75	75	14	14					varies	varies	P
Hydrologic Parameters	Q	Contributing Area (m2)	[Input]	6900	3670	2300	2766.6	5500	7560	1800	1877	317.9	42	120	120		244		219	5330	3048	Q
	R	Design Storm (mm)	[Input]	25	25	25	25			5	5			25	25	25	25	25	25	25	25	R
	S	Water Quality Volume (m3)	[= P * (Q / 1000)]	172.5	91.75	57.5	69.165			6.3	9.385			6	3		6.1		5.475	73.6	76.2	S
	T	Subsurface Drawdown Time (hours)	[Input]	72	5.5	72	15.5		24	24			15.5	72	1.7		5.5	72	5.5	varies	varies	T
Surface Ponding	U	Maximum Ponded Depth (mm)	[Input]	50 - 150	60	200	100		262	0 - 50	0		200	200			167	150	146	varies	varies	U
	V	Pond Surface Drawdown Time (hours)	[Input]	24		24								24				24		varies	varies	V

Note: Data for Appendix D Bio-retention construction data from Credit Valley Conservation Authority. (Personal Communication November, 2013). Data was presented to CVC by a third party. To interpret data or fill in missing data please contact Credit Valley Conservation.