Update on the Science of Volume Control BMPs:
A Literature Review for the McGaw Catalytic Project

October 2012

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INTRODUCTION

Stormwater volume reduction

Issues related to urban stormwater runoff begin when impervious cover of any type is placed over natural landscapes. In a natural system, most precipitation that falls to the ground is evaporated, transpired, or recharged into the soil, with approximately 10% of rainfall converted to runoff. Roadways, roofs, sidewalks, and tightly compacted soils under grass lawns and parking lots increase the amount of runoff that leaves an area as it urbanizes. In a traditional urban system with large amounts of impervious areas, most precipitation is converted directly to runoff which reduces infiltration, increases flows to downstream systems, and degrades water quality. Therefore, there is a greater realization by scientists and stormwater managers that anything that can be done to retain water where it falls in the watershed will help to mitigate these impacts by maintaining the natural hydrology of the site.

Developing stormwater management plans with an emphasis on volume control and runoff reduction will go a long way toward maintaining the natural hydrology of a site under post-development conditions. A volume reduction best management practice (BMP) is any technique that:

- Allows stormwater runoff to be absorbed (or recharged) into the ground;
- Makes water available for evaporation and/or transpiration;
- Stores water for re-use; or otherwise
- Diverts stormwater away from the downstream drainage system.

This basic concept is the premise behind such common sense approaches as Sustainable Development, Better Site Design (BSD), Low Impact Development (LID) and “design with nature”. While volume reduction of runoff is increasingly becoming an important goal of stormwater management, less is known about the performance, cost, and design of stormwater BMPs with a primary benefit of volume reduction compared to pollutant removal and peak flow reduction.

Objective of literature review

The objective of this literature review was to seek the most up-to-date information regarding the performance, cost, design, and suitability of BMPs with volume reduction benefits for the City of Fitchburg as well as the Capital Area Regional Planning Commission (CARPC). Since the focus on volume reduction as a key stormwater treatment approach is a relatively recent trend, the information related to volume reduction BMPs is an emerging and growing area of research. Given that an emphasis was placed on local sources of information, the findings presented in this literature review will be transferrable to other local units of government in the greater Madison Area.

The City of Fitchburg’s objective for conducting this literature review stems from CARPC’s volume control requirement for a portion of the McGaw Neighborhood Area. This literature review and the corresponding literature review matrix will be one of the tools developed by the City of Fitchburg to demonstrate how best the volume control standard can be met as the McGaw Neighborhood Area develops. As explained below, the literature review and corresponding matrix are intended to be used by City Staff, developers, engineers and designers as stormwater management plans are developed and reviewed for the McGaw Neighborhood Area.

Fates of infiltrated stormwater

Stormwater infiltration is a key mechanism for reducing stormwater runoff volume. From the groundwater management perspective, stormwater that reaches the water table or aquifer ("recharge") can be a key variable of interest. However, some infiltrated stormwater can be evaporated from soils or be transpired through plants. In this way, infiltrated water has many different fates within the hydrologic cycle (Figure 1). Surface water managers are often not as specific about the fate of the water that does not run off, so there can be some ambiguity in using the term "infiltration." To clarify the terminology in a hydrologic sense, precipitation that does not run off can have one of the following fates:

- Evaporation from wetted surfaces, soils, ponded water, and snowpack (sublimation),
- Transpiration through plants,
- Recharge of soil groundwater and aquifers.

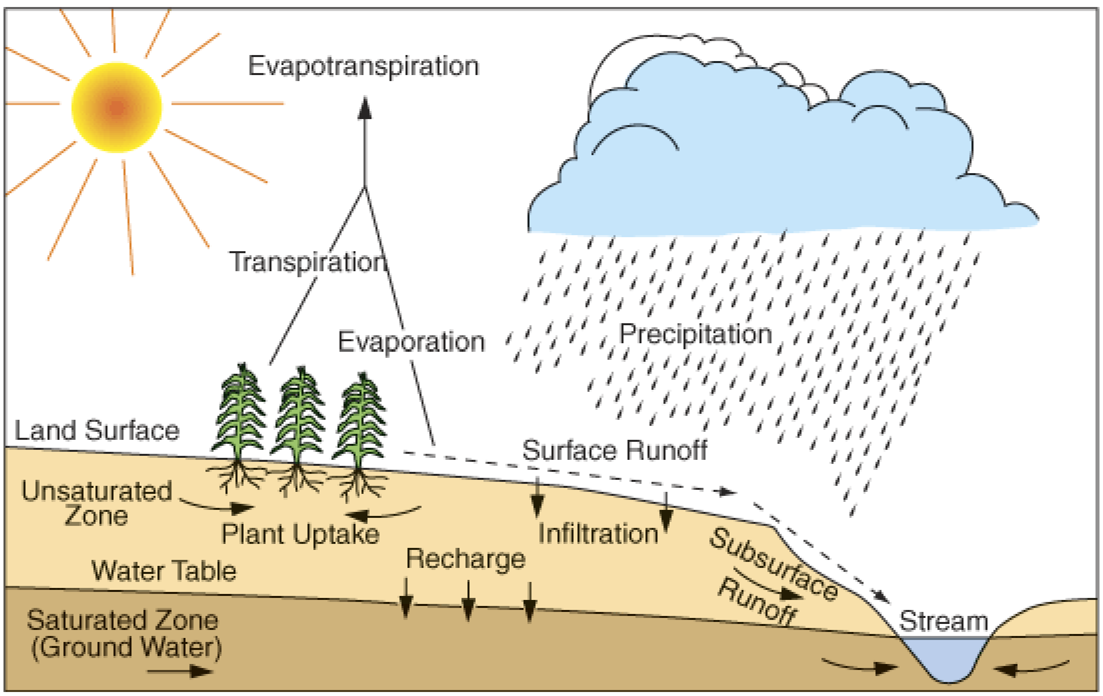

Figure 1. Fates of precipitation in the hydrologic cycle.
(Reproduced from the online Kansas Geological Survey, Public Information Circular (PIC) 22; <http://www.kgs.ku.edu/Publications/pic22/pic22_2.html>)

For many BMPs, stormwater runoff volume is reduced by a variety of the above mechanisms. As a result, we have grouped volume reduction BMPs by their type or location in the landscape:

1. **Source Control BMPs**: mimic natural conditions by catching precipitation or soaking rainfall into the ground close to where it falls
2. **Routing BMPs**: intercept stormwater runoff via surface soils and vegetation where it can be recharged, evaporated, or transpired
3. **Surface Treatment BMPs**: utilize landscaping and soils to treat stormwater by collecting runoff in shallow vegetated depressions for recharge, evaporation, or transpiration
4. **Subsurface Treatment BMPs**: mediate the recharge of stormwater runoff into underlying soils and eventually the water table or aquifers.
5. **Reuse BMPs**: store runoff for later irrigation, household, municipal or industrial uses

Harvesting and reuse of rainwater and stormwater are included separately because they represent an area of renewed interest in stormwater management. In addition, water reuse plays many roles in the hydrologic cycle, including source control of roof runoff (rainwater harvesting), reduction in potable water extraction and wastewater stream (in-building reuse), and evapotranspiration and/or recharge from irrigation reuses.

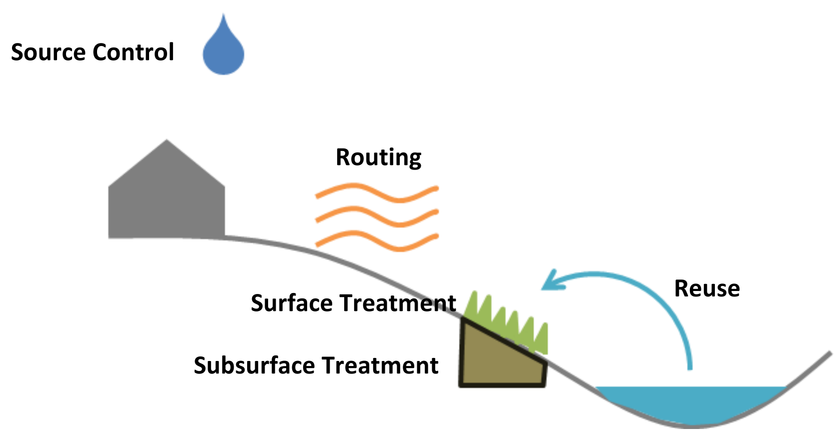

Figure 2. Volume reduction BMPs and their location in the landscape.
Source control BMPs (blue raindrop); Routing BMPs (orange wavy lines); Surface Treatment BMPs (green vegetation); Subsurface Treatment BMPs (brown soil); and Reuse BMPs (turquoise pond and arrow).

Format and use of document

This literature review is divided into 7 sections according to the following topics: Description, Performance, Cost-Benefit, Maintenance, Design Guidelines, Site Suitability, and Cold Climate Suitability. Each section includes an introduction of the topic, main findings for each BMP, and a reference summary that describes the hierarchy of most relevant sources and how they were chosen. This literature review was not intended to be a new, in-depth BMP manual, but rather a synthesis of existing BMP manuals and stormwater BMP literature reviews that are recent, local, and/or have a strong focus on the volume reduction benefits of stormwater BMPs in cold climates. Cited manuals and reports are conveniently linked throughout the text in brackets to the cited reference numbered list at the end of the document. Primary research papers are cited by author and publication year with complete bibliographic information listed at the end of the literature review.

A summary of the literature review is also available in matrix form in Excel. The content of the matrix was designed to be used by City Staff, developers, engineers and designers. The technical information contained in the matrix can be expanded or contracted, depending on the audience.

Terminology

One of the challenges in doing a literature review throughout a large area is that definitions of stormwater terminology can vary widely both in time (year) and in space (location). Since this Update is being presented as part of a project in the City of Fitchburg, Wisconsin (Dane County), the current local, county, and state regulatory definitions are included below, along with a synopsis of terminology generally used in the area.

Best Management Practice (BMP) - structural or non-structural measure, practice, technique or device employed to avoid or minimize soil, sediment or pollutants carried in runoff to waters of the state (*from NR 151 & NR 216*). A practice, technique, or measure that is an effective, practical means of preventing or reducing soil erosion or water pollution, or both, from runoff both during and after land development activities. These can include structural, vegetative or operational practices (*from Dane County Chap. 14 and Fitchburg Chap. 30, Article II*).

Biofiltration swale (or Bioswale) - A long, gently sloped, vegetated ditch designed to filter pollutants from stormwater. Grass is the most common vegetation, but wetland vegetation can be used if the soil is saturated.

Bioretention – A water quality practice that utilizes landscaping and soils to treat stormwater by collecting it in shallow depressions and then filtering it through a planting soil media.

Design storm – A hypothetical discrete rainstorm characterized by a specific duration, temporal distribution, rainfall intensity, return frequency and total depth of rainfall (*from NR 151*). The precipitation amounts that occur over a 24-hour period that have a specified recurrence interval for Dane County, Wisconsin. For example, one-year, two-year, 10-year and 100-year storm events mean the precipitation amounts that occur over a 24-hour period that have a recurrence interval of one, two, 10 and 100 years, respectively (*from Dane County Chap. 14 and Fitchburg Chap. 30, Article II*).

Groundwater - Water below the earth's surface, usually between saturated soil and rock. Groundwater usually originates from the recharge component of infiltration. In some instances groundwater may discharge to springs at the ground surface or directly into streams, creeks, and rivers.

Hydrologic cycle - The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Impervious surface – An area that releases as runoff all or a large portion of the precipitation that falls on it, except for frozen soil. Rooftops, sidewalks, driveways, parking lots and streets are examples of surfaces that typically are impervious (*from NR 151*). Any land cover that prevents rain or melting snow from soaking into the ground, such as roofs (including overhangs), roads, sidewalks, patios, driveways and parking lots. For purposes of this chapter, all road, driveway or parking surfaces including gravel surfaces, shall be considered impervious, unless specifically designed to encourage infiltration and approved by the City Engineer (*from Fitchburg Chap. 30, Article II*).

Infiltration – The entry and movement of precipitation or runoff into or through soil (*from NR 151*). Any precipitation that does not leave the site as surface runoff (*from Dane County Chap. 14 and Fitchburg Chap. 30, Article II*).

Infiltration System – A device or practice such as a basin, trench, rain garden or swale designed specifically to encourage infiltration, but does not include natural infiltration in pervious surfaces such as lawns, redirecting of rooftop downspouts onto lawns or minimal infiltration from practices, such as swales or road side channels designed for conveyance and pollutant removal only (*from NR 151, NR 216, Dane County Chap. 14, and Fitchburg Chap. 30, Article II*).

Peak flow – The maximum rate of flow of water at a given point in a channel, watercourse, or conduit resulting from the predetermined storm or flood (*from Fitchburg Chap. 30, Article II*).

Pervious surface – An area that releases as runoff a small portion of the precipitation that falls on it. Lawns, gardens, parks, forests or similar vegetated areas are examples of surfaces that typically are pervious (*from NR 151*). Any land cover that permits rain or melting snow to soak into the ground (*from Fitchburg Chap. 30, Article II*).

Recharge - The portion of the average annual rainfall that infiltrates the soil and becomes groundwater. Recharge does not include evaporation, transpiration, or runoff from the site (*from Dane County Chap. 14 and Fitchburg Chap. 30, Article II*).

Runoff - Storm water or precipitation including rain, snow, ice melt or similar water that moves on the land surface via sheet or channelized flow (*from NR 151*). The waters derived from rains falling or snowmelt or icemelt occurring within a drainage area, flowing over the surface of the ground and collected in channels, watercourses or conduits (*from Dane County Chap. 14 and Fitchburg Chap. 30, Article II*).

Sediment - Settleable solid material that is transported by runoff, suspended within runoff or deposited by runoff away from its original location (*from NR 151 & NR 216*). Solid earth material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity or ice, and has come to rest on the earth's surface at a different site (*from Fitchburg Chap. 30, Article II*).

Stormwater – Runoff from precipitation including rain, snow, ice melt or similar water that moves on the land surface via sheet or channelized flow (*from NR 216*). The flow of water which results from, and which occurs during and immediately following, a rainfall, snow- or ice-melt event (*from Fitchburg Chap. 30, Article II*).

Stormwater facility - Facilities that control the quantity and/or quality of stormwater discharge. Stormwater facilities included storage facilities (ponds, vaults, underground tanks, and infiltration systems); water quality facilities (wet ponds, biofiltration swales, constructed wetlands, sand filters, and oil/water separators); and conveyance systems (ditches, pipes, and catchbasins).

Once constructed, stormwater facilities require on-going maintenance to ensure they continue to perform as intended. Maintenance of storage facilities typically includes the removal of accumulated sediment and debris, routine mowing, and minor repairs to mechanical appurtenances. Management of water quality facilities is more complex, requiring intensive vegetation management, inspection and maintenance of flow control features, and restoration or replacement of filter media.

Stormwater management - Any measures taken to permanently reduce or minimize the negative impacts of stormwater runoff quantity and quality after land development activities (*from Fitchburg Chap. 30, Article II*).

Watershed - A geographic area in which water, sediments, and dissolved materials drain to a common outlet, typically a point on a larger stream, a lake, an underlying aquifer, an estuary, or an ocean. A watershed is also sometimes referred to as the "drainage basin" of the receiving waterbody.

Wetland - An area inundated or saturated by ground or surface water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (*U.S. Army Corps of Engineers Regulation 33 CFR 328.3 (1988)*).

I. DESCRIPTION

Introduction

Fifteen volume reduction BMPs were encountered in the literature and were the focus of this literature review, grouped into five major categories: Source Control, Routing, Surface Treatment, Subsurface Treatment, and Reuse. Commonly used stormwater BMPs that were not included in the literature review because they have already been well documented and only have volume reduction benefits as a secondary or incidental factor were: wet swales, stormwater wetlands, and detention ponds. A short description of the five major BMP categories and the associated volume reduction BMPs are given below. Other common names for the volume reduction BMPs are given in parantheses after the description title and are used in this literature review in summaries of reference material as they appear in the cited work. Key references available for each BMP are summarized in the following section and in Table 1 at the end of the section.

Volume Reduction Best Management Practices (BMPs)

A volume reduction BMP is any technique that reduces stormwater runoff through recharge into underlying soils, evaporation and/or transpiration, water re-use, or in any way diverts stormwater away from the drainage system or downstream.

Source Control BMPs

Source control BMPs mimic natural conditions by catching precipitation or soaking rainfall into the ground close to where it falls.

Impervious Cover Reduction

Impervious cover reduction is the practice of reducing the total area of impervious cover created at a development site, including: narrower streets, slimmer sidewalks, smaller cul-de-sacs, shorter driveways, and smaller parking lots. This includes incorporating natural and reintroduced vegetation in a landscape to intercept and infiltrate rainfall and reduce stormwater runoff volume.

Soil Amendments/ Decompaction

Post-development soil amendments (media, compost, etc.) and/or decompaction improve soil porosity and increase soil moisture holding capacity (reduce water demand of lawns and landscaping), thereby increasing infiltration and reducing runoff.

Pervious Pavement Systems

Pervious pavement systems increase recharge through load-bearing surfaces, including:
1) *Pervious Pavements* – pervious surfaces that recharge water across the entire surface (i.e. pervious asphalt and pervious concrete pavements);
2) *Pervious Pavers* – impervious modular blocks or grids separated by spaces or joints that water drains through (i.e. block pavers, plastic grids, etc.);
3) *Pervious Turf Systems* – lattice structure in the soil to distribute loads and avoid compaction with turf growing in the voids.
There are also hybrids and variations on the above systems, but this provides an overview of most commonly used pervious pavement systems.

Downspout Disconnection
Downspout disconnection is the process of separating roof downspouts from the sewer system or away from connected impervious surfaces (e.g. driveways) and redirecting roof runoff onto pervious surfaces, most commonly a lawn.

Green Roofs
Green roofs consist of a series of layers that create an environment suitable for plant growth that reduce roof runoff by collecting rainwater and releasing it via plant evapotranspiration.

Routing BMPs
Routing BMPs intercept runoff via surface soils and vegetation where it can be recharged, evaporated, or transpired.

Level Spreaders
Level spreaders are structures such as flush curbs that spread flow evenly over the same grade and mediates infiltration of riparian buffers, downslope vegetated filter strips or bioretention devices.

Filter Strips
Filter strips are the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban stormwater but require the presence of sheet flow across the entire strip to be effective.

Dry Swales
Dry swales are structural stormwater channels that capture, temporarily store, and route stormwater runoff through a prepared soil filter bed often using check dams. Vegetated swales are usually long, gently sloped, vegetated ditches designed to filter pollutants from stormwater. Grass is the most common vegetation, but other vegetation can be used depending on soil conditions.

Surface Treatment BMPs
Surface treatment BMPs utilize landscaping and soils to treat stormwater by collecting it in shallow vegetated depressions for recharge, evaporation, or transpiration.

Bioretention Devices (also called Bioretention Cells or Raingardens)
A bioretention device is an infiltration device consisting of an excavated area that is back-filled with an engineered soil, covered with a mulch layer and planted with a diversity of woody and herbaceous vegetation. Storm water directed to the device percolates through the mulch and engineered soil, where it is treated by a variety of physical, chemical and biological processes before it is recharged, evaporated, or transpired. If the native soil has low infiltration rates, under drains can be added to aid recharge. Bioretention devices can be placed in a variety of locations including in yards, parking lot islands, road medians, and traffic islands.

Tree Trenches (also called Tree Box Filters or Tree Filters)
Tree trenches are in-ground structural systems typically filled with bioretention type soil media with street trees planted in the trenches in urban areas. Runoff is directed to the tree trench,

where it is filtered by vegetation and soil before either being taken up and used by the tree (natural irrigation) or infiltrating (if underlying soils are suitable) or entering a catch basin.

Infiltration Basins

An infiltration basin is defined as an open impoundment (greater than 15 feet wide in its minimum dimension) created either by excavation or embankment with a flat, densely vegetated floor dedicated to the infiltration of runoff through the ground surface.

Subsurface Treatment BMPs

Subsurface treatment BMPs mediate the infiltration and recharge of stormwater runoff into underlying soils and eventually the water table or aquifers. Since they typically do not have much if any vegetation component, water lost to evapotranspiration is not a treatment mechanism.

Below-ground Recharge Systems (also called Infiltration Trenches and Chambers)

Below-ground recharge systems are underground trenches or linear soakaways that mediate recharge of runoff into underlying native soils, including:
1) *Perforated Pipe Systems* – perforated pipes installed in clean granular stone beds; and
2) *Recharge Trenches* or *Soakaways (Dry Wells)* – rectangular or circular excavations filled with clean granular stone or other void forming material.

Reuse BMPs

Reuse BMPs store runoff for later irrigation, household, municipal or industrial uses.

Rainwater Harvesting

Rainwater harvesting and reuse is the practice of collecting rain water from relatively uncontaminated impervious surfaces, such as rooftops, and storing for future high quality water uses, such as household and municipal uses. There are a number of systems used for the collection and storage of rainwater including rain barrels and cisterns. Collected rainwater generally has high water quality and can be used for irrigation, toilet flushing, and machine washing with little to no pre-treatment.

Stormwater Harvesting

Stormwater reuse is similar to harvesting but typically the input water quality is less controlled. The relatively new practice in non-arid areas consists of collecting stormwater runoff from impervious surfaces and pervious landscapes and storing for future low quality water uses, such as irrigation and industrial operations. A number of systems are used for the collection and storage of stormwater, including wet ponds, detention basins, and above ground or underground cisterns. Distribution systems vary according to stormwater reuse.

Relevant Manuals and Databases

Many stormwater BMP manuals and literature reviews already exist and the objective of this literature review was not to repeat those efforts. The following references were chosen for their recent and local nature, and/or strong focus on stormwater BMPs with volume reduction benefits. Individual guidelines are not yet widely available for Stormwater Reuse, Tree Trenches, and Soil Amendments/ Decompaction as they are relatively new stormwater BMPs. A visual summary of the key references used in this literature review is found in Table 1. Sources are listed below in order of importance/relevance, with a description from each source.

General BMP Manuals:

[1] The **2008 Minnesota Stormwater Manual** contains detailed design guidance for Low Impact Development and traditional stormwater BMPs in the context of Minnesota climate and regulations. This reference contains information on the following volume reduction stormwater BMPs:

- Bioretention
- Filtration
- Infiltration

[2] The pollution prevention fact sheets contained in the **Pollution Prevention and the MS4 Program Guide on Utilizing Pollution Prevention Activities to Meet MS4 General Permit Requirements** provide communities regulated under the Minnesota Municipal Separate Storm Sewer Systems (MS4) General Permit with basic tools and information that will lead to increased use of pollution prevention activities within stormwater pollution prevention programs and local stormwater programs. This reference contains information on the following volume reduction stormwater BMPs:

- Reducing Impervious Surfaces
- Pervious Pavement Systems
- Volume Control Using Compost Materials/ Soil Amendments
- Green Roofs
- Rainwater Harvesting/ Stormwater Reuse & Rain Barrel Programs
- Urban Forestry & Stormwater Management
- Vegetated Swales & Buffer Strips

[3] The **Credit Valley Conservation/ Toronto and Region Conservation Authority (CVC/TRCA) 2010 Low Impact Development Planning and Design Guide** contains detailed design guidance for Low Impact Development activities in the context of the Toronto climate and regulations. The CVC is noted for its progressive use of Low Impact Development site design strategies. This reference contains information on the following volume reduction stormwater BMPs:

- Low Impact Development Site Design Strategies
- Permeable Pavement
- Downspout Disconnection
- Soakaways, Infiltration Trenches and Chambers
- Vegetated Filter Strips
- Dry Swales
- Bioretention

- Green Roofs
- Rainwater Harvesting

[4**]** The **Wisconsin DNR Technical Note for Sizing Infiltration Basins and Bioretention Devices to meet State of Wisconsin Stormwater Infiltration Performance Standards** includes several tools approved by the Wisconsin Department of Natural Resources to design infiltration basins and bioretention devices capable of meeting the state of Wisconsin stormwater infiltration performance standards contained in ss. NR 151.12(5)(c) and NR 151.24(5), Wis. Adm. Code. This reference contains the following volume reduction stormwater BMP Conservation Practice Standards:

- Site Evaluation for Stormwater Infiltration (1002)
- Infiltration Basin (1003)
- Bioretention for Infiltration (1004)

[5] The **Charles River Watershed Association (CRWA) 2008 Low Impact Best Management Practice (BMP) Information Sheets** provide summaries of the current understanding of the benefits, performance, installation costs, maintenance needs and costs, and additional concerns regarding several Low Impact Development BMPs. In addition, the CRWA developed three matrices to help municipal officials, developers and others with the selection of stormwater BMPs, including stormwater management goals, physical and site specific constraints and opportunities, and installation, operational, and maintenance costs and requirements. This reference contains information on the following volume reduction stormwater BMPs:

- Pervious Pavement (Concrete, Asphalt)
- Pervious Pavers
- Rain Gardens (Bioretention)
- Tree Filter
- Vegetated Swale
- Green Roof
- Rainwater Harvesting

[6] The **2001 Minnesota Urban Small Sites BMP Manual** provides information on tools and techniques to assist Twin Cities' municipalities and Watershed Management Organizations (WMOs) in guiding development and redevelopment. The manual includes detailed information on 40 BMPs that are aimed at managing stormwater pollution for small urban sites in a cold-climate setting. This reference contains information on the following volume reduction stormwater BMPs:

- Impervious Surface Reduction (Cul-de-Sac, Parking Lot, and Street Design)
- Turf Pavers
- Green Rooftops
- Bioretention Systems
- Filter Strips
- Infiltration Basins
- On-lot Infiltration
- Infiltration Trenches

Individual BMP Guidelines:

Stormwater Harvesting

[7] The **Mississippi WMO-Minnehaha Creek WD Joint Watershed Research 2012 Stormwater Reuse Feasibility Study** quantifies the volume reduction and phosphorus removal benefits of stormwater and reuse for a range of land use and drainage size typical of Minneapolis, Minnesota.

[8] The **Metropolitan Council 2012 Stormwater Reuse Guide** provides step-by-step instructions and introduces effective alternative techniques for stormwater reuse for the purpose of reducing demand on Twin Cities metropolitan area potable water supplies. Tailored for city planners, engineers, and green thinkers, the Guide describes how to bring a stormwater reuse project from concept through assessment to implementation.

Tree Trenches and Soil Amendments

[9] The **2007 City Trees: Sustainability Guidelines & Best Practices (Pilot Version)** were developed to support the new and innovative project, Hawthorne Eco Village, in the City of Minneapolis. The guidelines were specifically developed to work in conjunction with and build on the Green Communities Criteria and the accompanying Minnesota Overlay (www.greencommunitiesonline.org/Minnesota). The goal of these guidelines was to provide much-needed direction and recommendations for how to accommodate, care for, and locate urban trees, both within the public right-of-way and on private property.

[10] The **2008 Managing Stormwater for Urban Sustainability Using Trees and Structural Soils Manual** is the result of a series of research studies carried out at Virginia Tech, Cornell University, and the University of California at Davis. This research evaluated multiple aspects of the novel stormwater BMPs Trees and Structural Soils. This manual introduces the stormwater management system and its attributes and limitations, provides information on designing a system with structural soils and trees based on the needs of individual sites, and describes surface treatments that can be used in conjunction with this stormwater management BMP, namely turf and pervious pavement.

Table 1. Summary of key reference manuals for volume reduction BMPs
Note: An '**X**' denotes the inclusion of a BMP in the guidance manual. Shaded boxes denote the source of the summary fact sheet found in the appendices at the end of this document.

<table>
<tr><th></th><th></th><th>Minnesota Stormwater Manual [1]</th><th>Pollution Prevention Fact Sheets [2]</th><th>Low Impact Development Planning and Design Guide [3]</th><th>Wisconsin Conservation Practice Standards [4]</th><th>CWRA LID BMP Information Sheets [5]</th><th>Minnesota Urban Small Sites BMP Manual [6]</th><th>BMP Specific [7, 8, 9, 10]</th></tr>
<tr><td rowspan="5">SOURCE CONTROL</td><td>Impervious Cover Reduction</td><td></td><td>X</td><td>X (LID)</td><td></td><td></td><td>X</td><td></td></tr>
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<tr><td>Green Roofs</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td rowspan="3">ROUTING</td><td>Level Spreaders</td><td></td><td></td><td rowspan="2">X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Filter Strips</td><td>X</td><td>X</td><td rowspan="2">X</td><td></td><td>X</td><td></td></tr>
<tr><td>Dry Swales</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td rowspan="3">SURFACE TREATMENT</td><td>Bioretention Devices</td><td>X</td><td></td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Tree Trenches</td><td></td><td>X</td><td></td><td></td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Infiltration Basins</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>SUB-SURFACE TREATMENT</td><td>Below-ground Recharge Systems</td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">REUSE</td><td>Rainwater Harvesting</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Stormwater Harvesting</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
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II. PERFORMANCE

Introduction

The performance of volume reduction stormwater BMPs was assessed based on the following metrics:

1. *Runoff Reduction*: the percent of runoff volume reduced through evaporation, plant transpiration, and recharge (volume reduction);
2. *Surface Water Pollutant Removal*: the percent reduction of major nutrient and heavy metal concentrations (or loads) from BMP surface outflow; and
3. *Soil and Groundwater Quality*: the potential impacts of BMP outflow on soil and groundwater quality.

The results from this analysis are summarized below and in Table 2.

Main Findings

Runoff Reduction

The runoff volume reduction of a BMP is the fraction of stormwater captured by a BMP that is not released to downstream waters. Many studies have published data on the runoff volume reduction performance of BMPs but these depend on the sizing of a BMP. Not knowing the sizing parameters used, the underground recharge basin, recharge depression, and bioretention device (without an under drain) BMPs had the highest stormwater runoff volume reduction performance, followed by, in order of decreasing performance, green roofs, pervious pavement systems, and soil amendments. These BMPs are designed to enhance infiltration into the soil for recharge or evapotranspiration, and consequently have a greater ability to reduce overall stormwater runoff volumes than other BMPs.

BMPs with lower reported volume reduction performance were downspout disconnection, impervious cover reduction, filter strips, dry swales, bioretention devices with under drains, and rainwater harvesting. The benefits of downspout disconnection and impervious cover reduction are difficult to quantify due to wide variations in their design. The volume reduction performance of rainwater and stormwater harvesting is directly related to storage size and so the actual reported performance may be less than the potential performance due to storage size limitations and costs. Filter strips and dry swales are expected to perform poorly with respect to stormwater runoff volume reduction because their primary benefit is nutrient removal through filtration. Filter strips and dry swales may more correctly be considered as pretreatment for volume control BMPs as part of a treatment train approach.

Surface Water Pollutant Removal

The specific pollutant removal performance of individual stormwater BMPs has been compiled and discussed extensively by other reviews (listed in the next section) and a brief summary of these data are provided in Table 2. However, pollutant removal data has many inconsistencies and biases due to discrepancies between load-based versus concentration-based estimates and the lack of correlation between influent nutrient loads and percent removal. For example, BMPs with high percent removal rates can still have high effluent concentrations due to high influent concentrations. As a result the International Stormwater Database, the leader in synthesizing

BMP performance studies and data, has recently omitted the use of percent removal as a measure of BMP performance. The data reported in Table 2 should be used with caution and are provided in this literature review for reference only. More information on this topic can be found in the white paper titled “Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance?” [15]

One prominent source of available data was excluded from Table 2 as potential outliers were from one of the first studies on the effectiveness of LID when LID was relatively new and not widespread [16]. Most of the available data were from studies using simulated rainfall events in Prince George's County, Maryland, and the report noted that the analysis of actual long-term rainfall events would produce more reliable data. Nutrient percent removals from this report ranged from 0–87% reductions in phosphorus, 37–80% reductions in Total Kjeldahl Nitrogen, <0–92% reductions in ammonium, and <0–26% reductions in nitrate. These nutrient reduction ranges were more variable than ranges from other more recent studies included in Table 2.

Table 2. Volume Reduction BMP Performance Summary

Volume Reduction BMP		Runoff Volume Reduction	Surface Water Pollutant Removal				Notes
			TP	*TN*	*TSS*	*Metals*	
SOURCE CONTROL	**Impervious Cover Reduction**	[12] 40% [17] 40%	[12] 55% [17] 30%	[12] 64%			[17] Values for parking lot wetland depressions
SOURCE CONTROL	**Soil Amendments/ Decompaction**	[12] 50-75%	[12] 50-75%	[12] 50-75%			
SOURCE CONTROL	**Pervious Pavement Systems**	[3] 45-85% [12] 45-75%	[1] 80% [12] 59-81% [22] 30-65%	[1] 80% [12] 59-81%		[1] 90%	[3] Range lists reduction for systems without an under drain (low estimate) to systems with an under drain (high)
SOURCE CONTROL	**Downspout Disconnection**	[12] 25-50%	[12] 25-50%	[12] 25-50%			
SOURCE CONTROL	**Green Roof**	[3] 45-55% [5] 70-90% [12] 45-60%	[1] 100% [3] -248% [12] 45-60%	[1] 20% [3] 91% [12] 45-60%	[1] 90% [3] 69-86% [5] 90%	[1] 80% [5] 80%	[3] reductions based on a green roof relative to a conventional roof; higher TP in green roof runoff due to leaching of the growing medium; TN reduction based on nitrate only
ROUTING	**Level Spreaders**	[12] 50-75% [13] 52 (18-85)%	[12] 50-75%	[12] 50-75%			
ROUTING	**Filter Strips**	[3] 25-50% [12] 50-75% [13] 37 (0-88)%	[1] 30-55% [22] 50-80%	[1] 35%	[1] 75-90%	[1] 80%	[3] Reductions depend on soil type
ROUTING	**Dry Swales**	[3] 10-20% [12] 40-60% [13] 48 (19-85)%	[12] 52-76% [22] 15-45%	[12] 55-74%			[3] Reductions depend on soil type; Reductions listed for grass channel

Volume Reduction BMP		Runoff Volume Reduction	Surface Water Pollutant Removal				Notes
			TP	TN	TSS	Metals	
SURFACE TREATMENT	Bioretention Devices (without under drain)	[3] 85% [12] 80% [13] 65 (35-94)%	[12] 90%	[12] 92%		[3] 30-99%	
SURFACE TREATMENT	Bioretention Devices (with under drain)	[3] 45% [12] 40%	[1] 65% [12] 55%	[1] 45% [12] 64%	[1] 85%	[1] 95%	
SURFACE TREATMENT	Tree Trenches	[5] variable	[5] 74%	[5] 68%	[5] 85%	[5] 82%	[5] Systems usually designed to capture runoff from small, frequently-occurring storms
SURFACE TREATMENT	Infiltration Basins	[12] 50-90%	[12] 63-93% [22] 15-45%	[12] 57-92%			
SUB-SURFACE TREATMENT	Below-ground Recharge Systems	[3] 85%	[3] 50-70% [22] 50-80%	[3] 40-70%	[3] 70-90%	[3] 70-90%	
REUSE	Rainwater Harvesting	[3] 40% [12] 40%	[12] 40%	[12] 40%			[3] Reductions listed for dual use cisterns
REUSE	Stormwater Harvesting	[7] 22-74%	[7] 46-95%				[7] Reductions based on systems designed for high performance

Note: Values reported as medians, or median - 75th percentile.
Total phosphorus (TP); Total nitrogen (TN); Total suspended solids (TSS)

Impacts on Soil and Groundwater Quality

With the emphasis on volume control BMPs in recent years, the issue of soil and groundwater contamination is gaining much more attention as reflected in the increasing number of research projects. Stormwater runoff from urban areas has much higher concentrations of pollutants than from natural sources for many constituents. Many stormwater BMPs are designed to filter out pollutants from stormwater runoff, but accumulating pollutants in soils and groundwater adjacent to stormwater BMPs is a growing concern among water resource managers, especially when large amounts of stormwater runoff are recharged in areas with sandy soils or shallow water tables. The following is a brief summary of recent research studies that have investigated the impacts of stormwater recharge on groundwater quality.

Paved areas are sources of metals, hydrocarbons, and chloride, and some studies of stormwater BMPs have found some decrease in groundwater quality due to stormwater recharge. A recent study on the effects of urban runoff on groundwater quality found a clear link between increased groundwater recharge rates and decreased groundwater quality downstream of an urban area ([33] Carlson *et al.* 2011). Infiltration basins draining light industrial and residential areas have underlying groundwater that are well within drinking water guidelines for toxic metals, nutrients, and pesticides ([26] Appleyard 1993), but infiltration basins and vegetative filter strips draining major roads often have soils contaminated with heavy metals in depths of 30 cm up to 1.5 m ([28] Barraud *et al.* 1999, [42] Legret *et al.* 1999, [64] Winiarski *et al.* 2006, [45] Mikkelsen *et al.* 1997). In addition, other studies have shown higher chloride levels ([63] Wilde 1994, [60] USEPA 2009) and greater hydrocarbon and pesticide detection frequency ([39] Fischer *et al.* 2003) in groundwater, and accumulation of lead ([50] Nightingale 1987), metals, hydrocarbons, and nutrients in soils underlying stormwater BMPs ([29] Barraud *et al.* 2005; [36] Dechesne *et al.* 2005). However, the leaching of heavy metals into groundwater may be limited ([45] Mikkelsen *et al.* 1997) due to the immobility of lead in soil ([51] Norrström 2005). Soil cores below bioretention devices during the first 5 years of operation in the Greater Toronto Area showed comparable metal and hydrocarbon levels to un-impacted sites ([58] TRCA 2008). BMPs receiving runoff from metal roofs have been found to be at high risk for zinc contamination of soils ([65] Zimmermann *et al.* 2005).

However, recent research has improved the outlook on the risks of soil and groundwater contamination due to stormwater recharge. While pavements are a source of hydrocarbons to runoff, naturally occurring microbial communities growing on pervious pavements are capable of degrading hydrocarbons. Moreover, research has shown that microbial degradation of hydrocarbons is assisted by the geotextile layer below the base course layer of pervious pavements ([48, 49] Newman *et al.* 2006a, b). Another study found that the levels of road salt derived chlorides in groundwater dropped quickly during the spring and eventually leveled out in the summer due to dilution with runoff low in chlorides ([41] Kwiatkowski *et al.* 2007). Finally, long-term (20 years or more) studies of groundwater below infiltration basins have shown no adverse effects from infiltrating stormwater ([56] Salo *et al.* 1986; [44] Mikkelsen *et al.* 1994) and other monitoring data indicate that small distributed stormwater infiltration practices do not contaminate underlying soils, even after 10 years of operation ([58] TRCA 2008). Due to the lack of observations of significant contamination of underlying groundwater after 20 years of service ([20] TRCA 2009), it has been noted that "the risk of groundwater contamination from infiltration practices can be properly managed through appropriate screen of suitability, siting, and design."

To reduce potential for groundwater contamination due to stormwater infiltration, [52] Pitt *et al.* (1999) recommended diverting the first runoff following periods of pollutant build-up, such as periods of dry weather and spring snowmelt. In addition, pretreatment of stormwater runoff from critical pollutant source areas was recommended.

The Low Impact Development Stormwater Management Planning and Design Guide [3] has developed specific guidelines for the treatment and use of stormwater for infiltration systems based on the quality of stormwater runoff generated from various urban sources. A summary of the risks for groundwater contamination from infiltration BMPs discussed in this guide is provided below:

Stormwater infiltration practices should:

- Not receive runoff from high traffic areas where large amounts of de-icing salts are applied (e.g., busy highways), nor from pollution hot spots (e.g., source areas where land uses or activities have the potential to generate highly contaminated runoff such as vehicle fuelling, servicing or demolition areas, outdoor storage or handling areas for hazardous materials and some heavy industry sites).
- Prioritize infiltration of runoff from source areas that are comparatively less contaminated such as roofs, low traffic roads and parking areas.
- Apply sedimentation pretreatment practices (e.g., oil and grit separators) before infiltration of road or parking area runoff.

Also included in this guide is a summary table of guidelines for appropriate stormwater BMPs according to stormwater source area and runoff characteristics (Table 3).

Systems Performance

Other research has been conducted on the general performance of stormwater BMPs. Summaries of a few recent studies are included. For example, the publication of a recent analysis indicated that infiltration-based LID technologies were more effective than storage-based BMPs for small storms, but storage-based BMPs were more effective for managing runoff from more intense storms ([34] Damodaram *et al.* 2010). These results suggest that a combination of infiltration and storage BMPs are needed to address all stormwater runoff from developed sites.

Transpiration rates have also been studied in different stormwater management systems. One study measured transpiration rates of urban trees in structural soil and found that transpiration rates were reduced under slow soil drainage conditions ([30] Bartens *et al.* 2009). Other work investigated the variability of green roof plant transpiration under water stressed conditions and found some evidence for decreased transpiration rates when plants were subjected to periodic water stress ([62] Voyde *et al.* 2010).

Table 3. Guidelines for appropriate stormwater BMPs based according to stormwater source area
From: Table 2.8.1 in Low Impact Development Stormwater Management Planning and Design Guide [3]

Stormwater Source Area	Runoff Characteristics	Opportunities	Principles
Foundation drains, slab underdrains, road or parking lot underdrains	Relatively clean, cool water.	Suitable for infiltration or direct discharge to receiving watercourses.	Should not be directed to stormwater management facility that receives road or parking lot runoff.
Roof drains, roof terrace area drains, overflow from green roofs	Moderately clean water, contaminants may include asphalt granules, low levels of hydrocarbons and metals from decomposition of roofing materials, animal droppings, natural organic matter and fall out from airborne pollutants, potentially warm water.	- Infiltration; - Filtration; - Harvesting with rain barrels or cisterns and use for non-potable purposes (*e.g.*, irrigation, toilet flushing) after pretreatment; - Attenuation and treatment in wet pond or wetland detention facility.	Runoff should be treated with a sedimentation and/or filtration practice prior to infiltration. Where possible, runoff should not be directed to end-of-pipe facilities to capitalize on potential for infiltration or harvesting. Flow moderation (quantity control) prior to discharge to receiving watercourse is required.
Low and medium traffic roads and parking lots, driveways, pedestrian plazas, walkways	Moderately clean water, contaminants may include low levels of sediment, de-icing salt constituents, hydrocarbons, metals and natural organic matter. Typically warm water.	- Infiltration after pretreatment; - Filtration after pre-treatment; - Harvesting with cisterns or permeable pavement reservoirs and use for outdoor non-potable purposes (*e.g.*, vehicle washing, irrigation) after pretreatment; - Attenuation and treatment in wet pond or wetland detention facility.	Runoff should be treated with a sedimentation and/or filtration practice prior to infiltration. Flow moderation (quantity control) prior to discharge to receiving watercourse is required. Water quality should be tested prior to use for non-potable purposes.
High traffic roads and parking lots	Potential for high levels of contamination with sediment, de-icing salt constituents hydrocarbons and metals. Typically warm water.	- Filtration after sedimentation pre-treatment; - Attenuation and treatment in wet pond or wetland detention facility; - Infiltration after pretreatment only where groundwater uses are limited.	Runoff should be treated with a sedimentation and/or filtration pretreatment practice prior to infiltration.
Pollution hot spots* such as vehicle fueling, servicing or demolition areas, outdoor storage and handling areas for hazardous materials, some heavy industry sites	Potential for high levels of contamination with sediment, de-icing salt constituents, hydrocarbons, metals, and other toxicants.	- Attenuation and treatment in wet pond, wetland or hybrid detention facility; - Potential requirement for sedimentation pretreatment; - Infiltration and harvesting practices not recommended.	Runoff from these sources should not be infiltrated or used for irrigation. Spill containment or mitigation devices recommended contingent on size of storage facilities.

* *Pollution hot spots* are areas where certain land uses or activities have the potential to generate highly contaminated runoff (*e.g.*, vehicle fuelling, service or demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites).

Relevant Manuals and Reports

Several pre-existing literature reviews and databases on studies that measured the volume reduction and pollutant removal benefits of stormwater BMPs were used in this literature review. Sources are listed in order of importance/relevance, with key references boxed. A description of each source, as reported by that source, is given below. Primary research papers on the impacts of recharge systems on soil and groundwater quality are listed in alphabetical order at the end of the literature review.

Runoff Reduction and Pollutant Removal

[12] The **2008 Center for Watershed Protection Technical Memorandum: The Runoff Reduction Method** contains an extensive literature review of studies measuring runoff reduction and pollutant removal efficiencies of stormwater BMPs, including low-impact development techniques. **Appendix B** summarizes runoff reduction results by BMP. **Appendix F** summarizes runoff reduction results by individual study, including study description, methodology, runoff reductions, pollutant reductions, and implications for design.

[13] The **Wright Water Engineers and Geosyntec Consultants 2011 International Stormwater Best Management Practices (BMP) Database Volume Reduction Technical Summary** contains data from 1,930 events and 47 studies passing primary and secondary screening that was analyzed for stormwater runoff volume reduction ([event inflow – event outflow]/event inflow).

[14] The **Wright Water Engineers and Geosyntec Consultants 2011 International Stormwater Best Management Practices (BMP) Database Pollutant Removal Technical Summary** contains data on event inflow and event outflow pollutant concentrations. A percent removal has been derived for the purpose of this literature review from International BMP Database reported mean inflow and outflow concentrations, but this value is not supported by the International BMP Database Project due to inconsistencies and biases associated with this metric (See reference 15 for more information).

[15] **Wright Water Engineers and Geosyntec Consultants 2007 Frequently Asked Questions Fact Sheet for the International Stormwater BMP Database**: **Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance?** is a paper that summarized key shortcomings associated with percent removal as a tool to assess BMP performance.

[1] The **2008 Minnesota Stormwater Manual** contains detailed design guidance for Low Impact Development and traditional stormwater BMPs in the context of Minnesota climate and regulations.

[3] The **Credit Valley Conservation/ Toronto and Region Conservation Authority (CVC/TRCA) 2010 Low Impact Development Planning and Design Guide** contains

detailed design guidance for Low Impact Development activities in the context of the Toronto climate and regulations.

[5] The **Charles River Watershed Association 2008 Low Impact Best Management Practice (BMP) Information Sheets** include summaries of other published estimates of pollutant removal efficiencies for various stormwater BMPs.

[16] The **2000 U.S. EPA Low-Impact Development (LID) Literature Review** was an early study on the availability and reliability of data to assess the effectiveness of Low Impact Development (LID) practices for controlling stormwater runoff volume and reducing pollutant loadings to receiving waters.

[17] The **2010 University of Minnesota Stormwater Treatment: Assessment and Maintenance** guidelines present case studies submitted by practitioners outlining monitoring and assessment results for various stormwater treatment practices.

[22] The **2005 MN DOT Report: The Cost and Effectiveness of Stormwater Management Practices** evaluated urban stormwater management practices for cost and effectiveness in removing suspended sediments and phosphorus.

Available in the Future:

[19] The **Online U.S. EPA Urban Stormwater BMP Performance Tool** has been developed to provide stormwater professionals with easy access to approximately 220 studies assessing the performance of over 275 BMPs. Additional studies will be added to this collection periodically. This Tool presents information previously compiled by the International Stormwater BMP Database and by the State of California in an easy to use search and sort format. In the future, EPA hopes to add more studies to this collection, particularly ones that evaluate the performance of "green infrastructure" or "Low Impact Development" BMPs.

Impacts on Soil and Groundwater Quality

[20] The Toronto Region and Conservation Authority (2009) **Review of the Science and Practice of Stormwater Infiltration in Cold Climates** is a literature review of infiltration based stormwater management, with particular emphasis on peer reviewed journal articles and published reports from jurisdictions with climate and soil conditions similar to Ontario, covering risks of groundwater contamination and cold climate performance monitoring.

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III. COST-BENEFIT

Introduction

One of the deciding factors in choosing stormwater BMPs is the cost per benefit. Unfortunately many benefits of stormwater BMPs have various values that are not easily monetized. These benefits include wildlife habitat, added beauty to a community, improved air quality, reduced thermal impacts, and restoration of natural features, such as wetlands, forest, natural drainage features, original topography, undisturbed soils, and open space. In this way, the true cost per benefit of a stormwater BMP is very difficult to quantify.

One measure of the cost per benefit of a stormwater BMP that is used is the total capital construction costs and annual operation and maintenance (O&M) costs averaged over the life of the BMP (whole life cycle cost). This extensive analysis is out of the scope for this literature review, but the reader is encouraged to check the 2009 Water Environment Research Foundation BMP and LID Whole Life Cost Model [24], an online standardized tool useful for estimating whole life costs for stormwater BMPs and LID practices in their projects.

Reported in this literature review are several publicly available reports that calculated capital and O&M costs for a range of stormwater BMPs. The draft report from the EPA: Achieving More Cost-Effective Stormwater Plans Using Low-Impact Development (LID) Strategies [25] contains the most up-to-date cost estimates for Low Impact Development BMPs, but cannot be reproduced until the final draft is published. The reader is encouraged to look for the final draft of this report in the future.

Main Findings

Cost estimates for stormwater BMPs are tightly linked to design capacity, estimated life expectancy of the BMP, and current costs of materials and land. As a result, caution must be used when comparing cost estimates from different reports and different years. Because no single report presents cost estimates for all of the volume reduction BMPs in this literature review, the data from each report is presented separately below and in Table 4 through Table 7. Historical costs were converted to 2012 dollars using the Historical Cost Index.

The 1991 Costs of Urban Nonpoint Source Water Pollution Control Measures compared capital and annual operating and maintenance costs for 5 BMPs: infiltration trench, infiltration basin, pervious pavement, grassed (dry) swale, and grassed filter strips (Table 4). Capital costs ranged from $12,000 to $118,000 per acre for infiltration basins and pervious pavement systems, and less than $10 to greater than $100 per lineal foot for infiltration trenches, swales and filter strips. Capital costs for pervious pavement were greater than infiltration basins, but the annual O&M costs were much less. Capital and O&M costs for filter strips and swales were much less than infiltration trenches.

The Charles River Watershed Association 2008 Installation and Maintenance Costs and Requirements Matrix presented capital and annual O&M costs for pervious pavement systems, rain garden (bioretention device), tree filter, vegetated swale, green roof, and rainwater harvesting cistern (Table 5). Capital costs ranged from $5 to $25 dollars per square foot for pervious pavement and pavers, rain gardens, vegetated swales, and green roofs, and less than

$1,000 to greater than $10,000 per tree box filter or rainwater harvesting cistern system. Annual O&M costs for pervious pavements and pavers, tree trenches, and rainwater harvesting cisterns ranged from $100 to $550 per year. Annual O&M costs for rain gardens and green roofs were similar to traditional landscaping costs.

The MN DOT 2005 Cost and Effectiveness of Stormwater Management Practices report compared capital and 20 year O&M costs (20-year life cycle cost) per volume of treated stormwater for a dry detention basin, infiltration trench, and bioinfiltration filter (Table 6). The 20-year life cycle cost per treated stormwater volume decreased as the amount of treated stormwater increased. In addition, the infiltration trench was the most expensive and the dry detention basin the least expensive.

The 2000 Economics of Low Impact Development Literature Review estimated the number of gallons of stormwater management per $1,000 invested for several Low Impact Development stormwater BMPs, including: green streets, street trees, green roofs, and rain barrels (Table 7). Green streets and street trees were able to manage the most gallons of stormwater per $1,000 invested, and green roofs were able to manage the least.

Reporting of costs relative to benefits has not been standardized nor adopted within stormwater studies. Comparison of costs across studies should be done with caution due to the multiple variables that impact costs, such as:

- What aspects of the project are included (for example is land cost included)?
- What is the relative performance of the BMP (and is it removing pollutants in its optimal design range)?
- Are O&M costs considered and if so, how they are calculated over time?

It should be noted that many costs are provided as simple costs per unit of BMP, which is separate from the removal benefits thus making the connection to benefit difficult. Ideally, costs could be calculated to give a cost ($) per unit area treated to a certain standard or per unit of pollutant removed. There are still some important nuances that should be considered when looking at cost effectiveness of a specific BMP. For example, is the overriding water treatment goal and/or site constraint such that certain BMPs must be used and do the BMPs need to be used outside of their optimal range to gain a higher level of needed treatment?

Table 4. Southwestern Wisconsin Regional Planning Commission Capital and Annual Operation and Maintenance Costs by BMP in 1991 and 2012 dollars ($)
(From the Costs of Urban Nonpoint Source Water Pollution Control Measures, 21)

BMP	Size/ Assumptions	Capital Costs		Annual O&M Costs	
		1991 dollars	2012 dollars	1991 dollars	2012 dollars
Infiltration Trench	3’ × 4’ × 100’	$24 - $74 per lineal foot	$48 - $147 per lineal foot	$285	$568
	6’ × 10’ × 100’	$71 - $167 per lineal foot	$141 - $333 per lineal foot	$615	$1,225
Infiltration Basin	3’ deep, 0.25 acre	$12,000 - $35,000	$24,000 - $70,000	$917	$1,827
	3’ deep, 1 acre	$38,000 - $107,000	$76,000 - $213,000	$2,468	$4,916

BMP	Size/ Assumptions	Capital Costs		Annual O&M Costs	
		1991 dollars	2012 dollars	1991 dollars	2012 dollars
Pervious Pavement	Asphalt	$40,000 per acre	$80,000 per acre		
	Pervious Pavement	$80,000 - $118,000 per acre	$159,000 - $235,000 per acre	$200 per acre	$400 per acre
Grassed Swale	1.5’ × 10’ × 1000’	$6,400 - $17,100	$12,700 - $34,100	$0.58 per lineal foot	$1.16 per lineal foot
	3’ × 21’ × 1000’	$12,900 - $33,400	$25,700 - $66,500	$0.75 per lineal foot	$1.49 per lineal foot
Grassed Filter Strips	25’ × 1000’	$9 - $23 per lineal foot	$18 - $46	$0.51 per lineal foot	$1.02 per lineal foot
	50’ × 1000’	$17 - $43 per lineal foot	$34 - $86	$0.91 per lineal foot	$1.81 per lineal foot
	100’ × 1000’	$32 - $82 per lineal foot	$64 - $163	$1.71 per lineal foot	$3.41 per lineal foot

Table 5. Charles River Watershed Association Capital and Annual Operation and Maintenance Costs by BMP in 2008 dollars ($)
(From the CRWA Installation and Maintenance Costs and Requirements Matrix C, 5)

BMP	Capital Costs		Annual O&M Costs	
	2008 dollars	2012 dollars	2008 dollars	2012 dollars
Pervious Pavement	$7 - $15 per square foot	$7 - $16 per square foot	$400 - $500	$427 - $534
Pervious Pavers	$8 - $12 per square foot	$9 - $13 per square foot	$400 - $500	$427 - $534
Bioretention (Rain Garden)	$10 - $12 per square foot	$11 - $13 per square foot	Similar to traditional landscaping	
Tree Filter	$8,000 - $10,000 per system $1,500 - $6,000 installation	$8,500 - $10,700 per system $1,600 - $6,400 installation	$100 - $500 per system	$107 - $534 per system
Vegetated Swale	~$7 per square foot	~$7.50 per square foot	$200	$214
Green Roof	$5 - $25 per square foot	$5 - $27 per square foot	$1,200 per year over lifetime of roof	$1,280 per year over lifetime of roof
Rainwater Harvesting Cistern	$600 - $13,000 depending on extent of accompanying plumbing system‡	$640 - $13,900	$550	$588

‡ No cistern sizing information reported by source

Table 6. Minnesota Department of Transportation 20-year life cycle costs based on treated water volume in 2005 dollars ($)
(From the MN DOT Cost and Effectiveness of Stormwater Management Practices, 22)

Capital costs + 20-year O&M costs, excluding land costs:		Treated Water Volume (ft^3)		
		3,000	10,000	30,000
Dry Detention Basin	2005 dollars	$22,000	$46,000	$91,000
	2012 dollars	$28,000	$58,500	$116,000
Infiltration Trench	2005 dollars	$84,000	$226,000	$554,000
	2012 dollars	$107,000	$287,500	$705,000
Bioinfiltration Filter	2005 dollars	$49,000	$122,000	$286,000
	2012 dollars	$62,000	$155,000	$364,000

Table 7. Gallons of stormwater managed per $1,000 invested (data from Plum and Seggos 2007) (From the Economics of Low Impact Development Literature Review, 23)

LID Stormwater Practice	Gallons of stormwater managed per $1,000 invested (2007 dollars)	Gallons of stormwater managed per $1,000 invested (2012 dollars)
Conventional storage tanks	2,400	2,110
Green Streets	14,800	13,010
Street Trees	13,170	11,580
Green Roofs	810	710
Rain Barrels	9,000	7,910

Relevant Manuals and Reports

Sources used to estimate the costs of volume reduction BMPs are listed below in order of importance/relevance, with a description of each source, as reported by that source. The two boxed sources at the end were not used in this literature review, but the reader is encouraged to utilize these tools in the future to estimate specific costs of volume reduction BMPs.

[21] The **1991 Southwestern Wisconsin Regional Planning Commission Technical Report: Costs of Urban Nonpoint Source Water Pollution Control Measures** provides guidance for estimating the capital and annual operation maintenance costs of urban nonpoint source control measures including: wet detention basins, infiltration trenches, infiltration basins, grassed swales, vegetated filter strips, pervious pavement, catch basin cleaning, and street sweeping.

[5] The **Charles River Watershed Association 2008 Low Impact Best Management Practice (BMP) Information Sheets** provide summaries of the current understanding of the benefits, performance, installation costs, maintenance needs and costs, and additional concerns regarding several Low Impact Development BMPs.

[22] The **2005 MN DOT Report: The Cost and Effectiveness of Stormwater Management Practices** evaluated urban stormwater management practices for cost and effectiveness in removing suspended sediments and phosphorus. Construction and annual operating and maintenance cost data was collected and analyzed for dry detention basins, wet basins, sand filters, constructed wetlands, bioretention filters, infiltration trenches, and swales using literature that reported on existing BMP sites across the United States.

[23] The **2007 ECONorthwest Economics of Low-Impact Development Literature Review** summarizes the literature that identifies and measures the economic costs and benefits of managing stormwater using LID, or that compares costs or benefits, or both, between LID and conventional controls.

Final report available soon:

[25] The **2011 EPA DRAFT Report: Achieving More Cost-Effective Stormwater Plans Using Low-Impact Development (LID) Strategies** presents four detailed comparative case studies that compare the established LID design to an alternative conventional design with respect to 1.) Stormwater Performance Assessment, 2.) Capital Cost Comparisons, 3.) Life Cycle Cost Assessments, and 4.) Cost-Effectiveness Comparisons. Four additional case studies are presented that compare capital costs only. The information presented in this draft report cannot be reproduced, please refer to the final draft when available.

Available online:

[24] The **2009 WERF BMP and LID Whole Life Cost Models** is an online tool to assist planners, developers, and engineers with estimating whole life costs for stormwater BMPs and LID practices.

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IV. MAINTENANCE

Introduction

The long term performance of BMPs is also reliant on proper operation and regular maintenance. High failure rates of stormwater infiltration practices from the 1980s have been attributed to inadequate buffer strips (i.e., pretreatment), infrequent inspections, and poor overall maintenance which resulted in sediment accumulation and clogging ([43] Lindsey *et al.* 1982). Therefore, it is highly recommended that site designers communicate how to maintain stormwater BMPs in an Operation & Maintenance (O&M) Manual. Owners and maintenance staff will be able to reference this manual, for example, when they have questions about sediment removal, valve operation, or capacity for future site expansion. Contents of an O&M manual could include: as-built plans, operating instructions for weirs and valves, vegetation list, vegetation maintenance schedule, and maintenance checklists.

Main Findings

Recommended maintenance activities and frequency for the non-structural volume reduction BMPs are listed in the following tables (Table 8 to Table 19). Where available, maintenance checklists are also included. BMPs that were source control and did not require maintenance were impervious surface reduction and soil amendments. For the other volume reduction BMPs, typical maintenance activities include:

1. Sediment and debris removal
2. Vegetative upkeep
3. Site erosion control
4. Mechanical system upkeep and repairs (if applicable)
5. Annual inspections for performance

In general, maintenance requirements tend to be greater in the first few years following construction to ensure proper establishment of vegetation. After vegetation is established, maintenance requirements are often less burdensome, but it depends on the amount of sediment and debris that accumulates and needs to be removed, the upkeep demand of plant species, the susceptibility of a site to erosion and degradation, and whether the BMP uses a mechanical system.

Source Control BMPs

Impervious Cover Reduction

Table 8. Vegetated landscaping recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 1,6]	Frequency
☐ Water plants. ☐ Re-mulch void areas. ☐ Treat diseased trees and shrubs. ☐ Prune and weed to maintain appearance.	As needed [1]
☐ Inspect soil and repair eroded areas. ☐ Remove litter and debris.	Monthly [6]
☐ Add additional mulch.	Annually [6]

Pervious Pavement Systems

Table 9. Pervious pavement recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 3]	Frequency
☐ Reservoir dewatering within 72 hours.	After major storms
☐ Inlet Structures: Drainage pipes and structures within or draining to the subsurface bedding beneath pervious pavement should be cleaned out on regular intervals.	As needed, frequent
☐ Grid pavers: Should be mowed regularly with grass clippings removed. May require periodic watering and fertilization to establish and maintain healthy vegetation.	As needed, frequent
☐ Drainage Areas: Impervious areas contributing to the pervious pavement should be regularly swept and kept clear of litter and debris. Flows from any landscaped areas should be diverted away from the pavement or be well stabilized with vegetation.	Semiannual
☐ Surface Sweeping: Sweeping should occur once or twice a year with a commercial vacuum sweeping unit to mitigate sediment accumulation and ensure continued porosity. Pervious pavement should not be washed with high pressure water systems or compressed air units, because they will push particles deeper into the pavement.	Annual to semiannual
☐ Inspection of pavement surface for deterioration.	Annually
☐ Heavy Vehicles: Trucks and other heavy vehicles can grind dirt into the porous surface and lead to clogging. These vehicles should be prevented from tracking or spilling dirt onto the pavement. Signage and training of facilities personnel is suggested.	Operation recommendation
☐ Construction and Hazardous Materials: Due to the potential for groundwater contamination, all construction or hazardous material carriers should be prohibited from entering a pervious pavement site.	Operation recommendation
☐ Winter Maintenance: No sand. Deicers used in moderation – pilot studies have found that pervious pavements require 75% less de-icing salt than convention pavement.	Operation recommendation

Downspout Disconnection

Table 10. Downspout disconnection recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 3]	Frequency
Maintain infiltration capacity of soil: ☐ Plant shrubs or trees along perimeter to prevent traffic. ☐ If ponding of water remains longer than 24 hours, dethatch and aerate, or if ponding still occurs, regrade or till to reverse compaction and/or add compost to improve soil moisture retention.	Annually

Green Roofs

Table 11. Green roof recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 3,5]	Frequency
☐ Leak detection. Electronic leak detection systems recommended.	After rain events [3]
☐ Watering based on actual soil moisture conditions as plants are designed to be drought tolerant.	As needed [3]
☐ Repair underlying roofing and waterproofing materials.	As needed [5]
☐ Monitor vegetation to ensure dense coverage.	Monthly in first 2 years, then biannual [3]
☐ Weeding to remove volunteer seedlings of trees and shrubs and debris removal. ☐ Keep overflow conveyance system clear.	Biannual [3]

Routing BMPs

Filter Strips and Level Spreaders

Table 12. Filter strip and level spreader recommended maintenance activities and frequency.

Maintenance Activity [From: 6]	Frequency
☐ Mow turf grass with low ground pressure equipment to a three- or four-inch height. Cut only when soil is dry to prevent tracking damage to vegetation, soil compaction, and flow concentrations.	Regular (frequent)
☐ Remove sediment and replant in areas of buildup. ☐ Limit fertilizer applications based on plant vigor and soil test results.	Regular (infrequent)
☐ Remove built-up sediment from pea gravel diaphragm/level spreader. ☐ Inspect for rills and gullies. Immediately fill rills and gullies with topsoil, install erosion control blanket and seed or sod. ☐ In areas without well-established vegetation, prepare soil and reseed or replace with alternative species. Install erosion control blanket.	Annual (Semiannual Year 1)
Inspection Checklist [From: 1]	**Frequency**
1. Debris Cleanout ☐ Contributing areas clean of litter and vegetative debris. ☐ Inlet and outlet clear. ☐ Filtration facility clean.	Monthly
2. Check Dams or Energy Dissipators ☐ No evidence of flow going around structures. ☐ No evidence of erosion at downstream toe.	Annual After Major Storms
3. Vegetation ☐ Minimum mowing depth not exceeded. ☐ Undesirable vegetation removed. ☐ No evidence of erosion.	Monthly
4. Dewatering ☐ Dewaters between storms within 48 hours.	Monthly
5. Sediment Deposition ☐ Clean of sediment. ☐ Winter accumulation of sand removed each spring. ☐ Contributing drainage area stabilized and free of erosion.	Annual
6. Outlet/Overflow Spillway ☐ Good condition, no need for repairs. ☐ No evidence of erosion. ☐ No evidence of blockage.	Annual

Dry Swales

Table 13. Dry swale recommended maintenance activities and frequency.

Maintenance Activity [From: 6]	Frequency
☐ Mow turf grass to 4 inches. ☐ Mow native grasses once a year early in spring – mowing in first year is critical to eliminate competition from annual weeds.	Frequent as needed
☐ Remove sediment buildup on the bottom of swale once it has accumulated to 25 percent of original design volume. ☐ Reseed as necessary to maintain dense vegetation. ☐ Fertilize rarely to avoid unnecessary export of nutrients, if necessary based on soil test, apply in cool spring or fall weather and with no phosphorus.	Infrequent as needed
☐ Ensure grass cover establishes – reseed. ☐ Remove excess sediment from pea gravel diaphragm ☐ Remove trash and debris.	Annual
Inspection Checklist [From: 1]	**Frequency**
1. Debris Cleanout ☐ Contributing areas clean of litter and vegetative debris. ☐ Inlet and outlet clear. ☐ Filtration facility clean.	Monthly
2. Check Dams or Energy Dissipators ☐ No evidence of flow going around structures. ☐ No evidence of erosion at downstream toe.	Annual After Major Storms
3. Vegetation ☐ Minimum mowing depth not exceeded. ☐ Undesirable vegetation removed. ☐ No evidence of erosion.	Monthly
4. Dewatering ☐ Dewaters between storms within 48 hours.	Monthly
5. Sediment Deposition ☐ Clean of sediment. ☐ Winter accumulation of sand removed each spring. ☐ Contributing drainage area stabilized and free of erosion.	Annual
6. Outlet/Overflow Spillway ☐ Good condition, no need for repairs. ☐ No evidence of erosion. ☐ No evidence of blockage.	Annual

Surface Treatment BMPs

Bioretention Devices

Table 14. Bioretention device recommended maintenance activities and frequency.

Maintenance Activity [From: 1,6]	**Frequency**
☐ Water as necessary during dry periods. Treat diseased trees and shrubs. Prune and weed to maintain appearance. Mow filter strip.	As needed after first growing season [1,6]
☐ Remove any sediment and debris build-up in pre-treatment areas. ☐ Remove as necessary build-up of road sand associated with spring melt period and replant areas that have been impacted by sand/salt build up.	Annually [1]
☐ Replace mulch over the entire area. ☐ Replace pea gravel diaphragm or filter fabric if warranted. ☐ Test soil for pH. Modify soil to main soil pH of 5.2 – 8.0.	2 to 3 years [1]
Inspection Checklist [From: 1]	**Frequency**
1. Debris Cleanout ☐ Contributing areas clean of litter and vegetative debris. ☐ No dumping of yard wastes into practice. ☐ Bioretention areas clean of litter and vegetative debris.	Monthly
2. Vegetation ☐ Plant height taller than design water depth. ☐ Undesirable vegetation removed. ☐ Grass height less than 6 inches. ☐ No evidence of erosion.	Monthly
3. Dewatering ☐ Dewaters between storms within 48 hours. ☐ No evidence of standing water.	Monthly
4. Check Dams/Energy Dissipators/Sumps ☐ No evidence of sediment buildup. ☐ Sumps should not be more than 50% full of sediment. ☐ No evidence of erosion at downstream toe of drop structure.	Annual After major storms
5. Outlet/Overflow Spillway ☐ Good condition, no need for repair. ☐ No evidence of erosion. ☐ No evidence of any blockages.	Annual After major storms
6. Sediment Deposition ☐ Pretreatment areas clean of sediments. ☐ Contributing drainage area stabilized and clear of erosion. ☐ Winter sand deposition evacuated every spring.	Annual
7. Integrity of Filter Bed ☐ Filter bed has not been blocked or filled inappropriately.	Annual

Tree Trenches

Table 15. Tree trench recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 5]	Frequency
☐ Inspect plants and structural components. ☐ Clean inflow and outflow mechanisms. ☐ Test mulch and soil for build-up of pollutants that may be harmful to the vegetation.	Periodic
☐ Replace mulch.	Biannual
☐ Complete replacement of filter.	25 years

Infiltration Basins

Table 16. Infiltration basin recommended maintenance activities and frequency.

Maintenance Activity [From: 1, 3, 6]	Frequency
☐ Clean out leaves, debris and accumulated sediment caught in pretreatment device, inlets and outlets.	Annually [3]
☐ Sediment removal should be performed when sediment is dry enough to crack and readily separate from the basin floor. Light equipment which will not compact the underlying soil, should be used to remove the top layer of sediment. The remaining soil should be tilled and re-vegetated as soon as possible.	As needed [6]
☐ Vegetation should be maintained to control weed growth and maintain the health of the vegetation in the basin. Weed once monthly during the first two growing seasons. After that, weeding two or three times per growing season.	Monthly to biannually [6]
☐ Disc or otherwise aerate basin bottom. De-thatch basin bottom.	Annually [1]
☐ Scrape basin bottom and remove sediment. Restore original cross-section and infiltration rate. Seed or sod to restore cover.	Every 5 years [1]
Inspection Checklist [From: 1]	**Frequency**
1. Debris Cleanout ☐ Contributing drainage area clear of litter and vegetative debris.	Monthly
2. Dewatering ☐ Basin dewaters between storms.	Monthly
3. Vegetation ☐ Minimum growing depth not exceeded. ☐ Undesirable vegetation removed. ☐ No evidence of erosion.	Monthly
4. Sediment Deposition of Basin ☐ Clean of sediment. ☐ Winter accumulation of sand removed each spring. ☐ Contributing drainage area stabilized and free of erosion.	Annual
5. Inlets ☐ Good condition. ☐ No evidence of erosion.	Annual
6. Outlet/Overflow Spillway ☐ Good condition, no need for repair. ☐ No evidence of erosion.	Annual

Subsurface Treatment BMPs

Below-ground Recharge Systems

Table 17. Below-ground recharge system recommended maintenance activities and frequency.

Maintenance Activity [From: 1]	Frequency
☐ Replace clogged pea gravel/topsoil and top surface filter fabric.	As needed
☐ Remove sediment and oil/grease from pre-treatment devices, as well as overflow structures. ☐ Mow grass filter strips should be mowed as necessary. Remove grass clippings. ☐ Repair undercut and eroded areas at inflow and outflow structures.	Monthly
☐ Remove trees that start to grow in the vicinity of the trench.	Semi-annual inspection
☐ Perform total rehabilitation of the trench to maintain design storage capacity. Excavate trench walls to expose clean soil.	Upon failure
Inspection Checklist [From: 1]	**Frequency**
1. Debris Cleanout ☐ Contributing drainage area clear of litter and vegetative debris. ☐ Trench surface and inlet area clean. ☐ Inflow pipes and overflow spillway clear.	Monthly
2. Dewatering ☐ Trench dewaters between storms.	Monthly
3. Sediment Traps or Forebays ☐ Evidence of trapping sediment. ☐ Greater than 50% of storage volume remaining.	Annual
4. Sediment Cleanout of Trench ☐ No evidence of sedimentation in gravel filter. ☐ Sediment accumulation doesn't yet require cleanout.	Annual
5. Inlets ☐ Good condition. ☐ No evidence of erosion.	Annual
6. Outlet/Overflow Spillway ☐ Good condition, no need for repair. ☐ No evidence of erosion.	Annual
7. Aggregate Repairs ☐ Surface of aggregate clean. ☐ Top layer of stone does not need replacement. ☐ Trench does not need rehabilitation.	Annual

Reuse BMPs

Rainwater Harvesting

Table 18. Rainwater harvesting recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 3]	Frequency
☐ Regular inspections.	Every 6 months (spring and fall)
☐ Keep leaf screens, eavestroughs and downspouts free of leaves and other debris. ☐ Check screens and patch holes or gaps. ☐ Clean and maintain first flush diverters and filters, especially those on drip irrigation systems. ☐ Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. ☐ Replace damaged components. ☐ Mosquito control: If screening is not sufficient to deter mosquitoes, vegetable oil can be used to smother larvae.	As needed

Stormwater Harvesting

Table 19. Stormwater harvesting recommended maintenance activities and frequency.

Maintenance and Inspection Activity [From: 7]	Frequency
☐ Inspect operation of the stormwater harvesting system to assure that the pump, flow meter, and filter system are operating properly and achieving desired flow volumes. ☐ Inspect operation of the irrigation system to assure that the pump, timer, distribution lines, and sprinkler heads are working properly.	Monthly and after major storm events
☐ Submit a maintenance log including the following: – Stormwater volume harvested using a flow meter specifying the day, time, and volume – Stormwater volume irrigated or otherwise used using a flow meter specifying the day, time, and volume used – Observations of the stormwater harvesting system operation, maintenance, and a list of parts that were replaced – Observations of the irrigation system operation, maintenance, and a list of parts that were replaced – Dates on which the stormwater harvesting and irrigation (or other use systems) were inspected and maintenance activities conducted	Every 2 years

Relevant Manuals

Because of the fundamental nature of maintenance, every stormwater manual includes some description of the required operation and maintenance for individual BMPs. Due to the large overlap in O&M requirements across sources, the maintenance recommendations in this literature were derived from one or two key references for each BMP, summarized below:

[1] The **2008 Minnesota Stormwater Manual** contains detailed design guidance for Low Impact Development and stormwater BMPs in the context of Minnesota climate and regulations.

[3] The **CVC/TRCA 2010 Low Impact Development Planning and Design Guide** contains detailed design guidance for Low Impact Development activities in the context of the Toronto climate and regulations. The CVC is noted for its progressive use of LID.

[5] The **Charles River Watershed Association 2008 Low Impact Best Management Practice (BMP) Information Sheets** provide summaries of the current understanding of the benefits, performance, installation costs, maintenance needs and costs, and additional concerns regarding several Low Impact Development BMPs. In addition, the CRWA developed three matrices to help municipal officials, developers and others with the selection of stormwater BMPs, including stormwater management goals, physical and site specific constraints and opportunities, and installation, operational, and maintenance costs and requirements.

[6] The **2001 Minnesota Urban Small Sites BMP Manual** provides information on tools and techniques to assist Twin Cities' municipalities and WMOs in guiding development and redevelopment. The manual includes detailed information on 40 BMPs that are aimed at managing stormwater pollution for small urban sites in a cold-climate setting.

V. DESIGN GUIDANCE

Introduction

Detailed design specifications can be found for each volume reduction BMP in Appendix A at the end of the literature review. The guidelines found in Appendix A were chosen from the source with the most current or extensive summary of BMPs with a focus on volume reduction that are in a cold climate. Only one or two guidelines were chosen for each BMP. Additional information can be found in the sources listed in Table 1.

Main Findings

There are a variety of proposed design guidances on BMPs. Some guidelines are technical in nature due to the physical settings where they are implemented. The fact sheets listed below are not detailed to the level of design drawings and specifications, but were chosen for their broad target audience and are a good overview of the BMP. Note: The information found in the guidelines listed below should be reviewed with the Wisconsin Conversation Standards for compliance with location specific regulations.

Source Control BMPs

Impervious Cover Reduction

- Pollution Prevention Fact Sheet: Reducing Impervious Surfaces [2]
- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Low Impact Development Site Design Strategies [3]

Soil Amendments/ Decompaction

- Pollution Prevention Fact Sheet: Volume Control Using Compost Materials/ Soil Amendments [2]

Pervious Pavement Systems

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Permeable Pavement [3]

Downspout Disconnection

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Downspout Disconnection [3]

Green Roofs

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Green Roof [3]

Routing BMPs

Level Spreaders and Filter Strips

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Vegetated Filter Strips [3]

Dry Swales

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Dry Swale [3]

Surface Treatment BMPs

Bioretention Devices

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Bioretention [3]

Tree Trenches

- Charles River Watershed Association Low Impact Best Management Practice Information Sheet: Stormwater Tree Pit [5]

Infiltration Basins

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Soakaways, Infiltration Trenches and Chambers [3]

Subsurface Treatment BMPs

Below-ground Recharge Systems

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Soakaways, Infiltration Trenches and Chambers [3]

Reuse BMPs

Rainwater (Stormwater) Harvesting

- CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Rainwater Harvesting [3]
- No fact sheets are available for stormwater reuse, but similar principles apply for stormwater reuse as rainwater reuse.

Relevant Manuals

Detailed design guidelines have been created for many states and municipalities. These guidelines are often summarized in shorter fact sheets to help choose appropriate stormwater BMPs for a given site. Over ten guides are listed in Section VII that are more commonly referred to in the upper Midwest area. The fact sheets included in the appendices at the end of this literature review were chosen from two sources and were chosen for being the most recent and comprehensive for volume reduction BMPs for cold climates.

[2] The pollution prevention fact sheets contained in the **EOR 2008 Guide on Utilizing Pollution Prevention Activities to Meet MS4 General Permit Requirements** provide communities regulated under the Minnesota Municipal Separate Storm Sewer Systems General Permit with basic tools and information that will lead to increased use of pollution prevention activities within stormwater pollution prevention programs and local stormwater programs. This reference contains information on the following BMPs:

- Reducing Impervious Surfaces
- Pervious Pavement Systems
- Volume Control Using Compost Materials/ Soil Amendments
- Green Roofs
- Rainwater Harvesting/ Stormwater Reuse & Rain Barrel Programs
- Urban Forestry & Stormwater Management
- Vegetated Swales & Buffer Strips

[3] The **CVC/TRCA 2010 Low Impact Development Planning and Design Guide** contains detailed design guidance for Low Impact Development activities in the context of the Toronto climate and regulations. The CVC is noted for its progressive use of LID. This reference contains information on the following BMPs:

- Low Impact Development Site Design Strategies
- Permeable Pavement
- Downspout Disconnection
- Soakaways, Infiltration Trenches and Chambers
- Vegetated Filter Strips
- Dry Swales
- Bioretention
- Green Roofs
- Rainwater Harvesting

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VI. SITE SUITABILITY

Introduction

Selecting the most appropriate volume control BMP is dependent on site conditions. Optimal site characteristics, including site topography, distance to water table, soil type, drainage area, and setbacks, were summarized by BMP in tables in the following section (Table 20 to Table 30). The site requirements reported in this literature review are not comprehensive but represent the broad range of requirements for each volume reduction BMP. Detailed site requirements can be found for each volume reduction BMP in the appendices at the end of the literature review and in the references listed in Table 1. Note: The information found in the guidelines listed below should be reviewed with the Wisconsin Conversation Standards for compliance with location specific regulations.

Main Findings

One major feature of the site is the slope of the drainage area. Slope can be a factor in BMP suitability due to the physical configuration of the BMP and that steeper slopes can create challenges to the design of the BMP. The ranges provided are guidelines. Designing outside the typical slope ranges can be accomplished, but more design effort will be needed accommodate that type of BMP. Dry swales and pervious pavements work well in low slope settings (1-3%), filter strips and bioretention devices can be used in slighter higher slopes (1-5%), green roofs can be built on roofs with slopes up to 10%, and infiltration basins can be built in sites with the greatest slopes (up to 15%).

Another important feature of the site is the distance to the seasonally high water table. As discussed in the previous section regarding groundwater quality, stormwater BMPs with high recharge capacity have the risk to degrade groundwater quality, especially at depths less than 5 feet. As a result, most BMPs require a separation from the bottom of the treatment system to the top of the seasonally high water table of at least 5 feet.

In order to properly function for stormwater volume reduction, stormwater BMPs without under drains must be constructed in soil with adequate infiltration rates. Pervious pavements, dry swales, infiltration systems, and bioretention devices perform best in Hydrologic Soil Groups A and B, or in soils amended to achieve an infiltration rate of at least 0.6 inches per hour and connected to a pervious layer. BMPs in less pervious soils can also be used, but under drains will be an important part of the design and volume reduction will be driven more by evaporation and transpiration than by recharge.

Other considerations include drainage areas relative to BMP surface area and other zoning or setback requirements. These vary considerably by BMP and are specific to local runoff characteristics and regulations. **The site suitability data presented in Tables 20 – 30 below were primarily drawn from the City of Toronto.** These site considerations should be viewed as a starting point for possible site considerations specific to the City of Fitchburg and Dane County.

Infiltration suitability
Contexts where infiltration practices should not be used ([38] Ferguson 1994):

- Soil as impervious as the roofs and pavements that will be placed upon it;
- Highly contaminated soils (e.g., toxic waste or saline deposits);
- Steep unstable slopes; and,
- Land in close proximity to water supply wells, septic tanks, basements or other sensitive structural foundations.

In these contexts, evaporation and harvesting are more appropriate management techniques ([20] TCRA 2009).

Source Control BMPs

Impervious Cover Reduction

Table 20. Impervious cover reduction site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Useful for steep topography
Water Table	N/A
Soil	N/A
Drainage Area	N/A
Setbacks	Residential street minimum width requirements. Front yard setback requirements. Area zoning ordinance requirements for outside roadway radii and right-of-ways.

Pervious Pavement Systems

Table 21. Pervious pavements site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	At least 1% and no greater than 5%
Water Table	Greater than 5 feet above seasonally high water table or top of bedrock elevation
Soil	Infiltration rate of native soils greater than 0.6 inches per hour. Systems located in native soils with an infiltration rate less than 0.6 inches per hour require a perforated pipe under drain
Drainage Area	Impervious area treated should not exceed 1.2 times the area of pervious pavement which receives the runoff
Setbacks	Located downslope from building foundations Recommended minimum setback of 12 feet If pavement does not receive runoff from other surfaces, no setback required

Downspout Disconnection

Table 22. Downspout disconnection site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Discharge to gradual slope (1 – 5 %) that conveys runoff away from the building.
Water Table	Disconnect only where minimum depth to the seasonally high water table is at least 5 feet below the surface
Soil	Infiltration rates adequate to prevent ponding water following rain events.
Drainage Area	N/A
Setbacks	N/A

Green Roofs

Table 23. Green roof site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	N/A
Water Table	N/A
Soil	N/A
Drainage Area	N/A
Setbacks	N/A
Other	Roofs with slopes up to 10%

Surface Treatment BMPs

Level Spreaders and Filter Strips

Table 24. Level spreader and filter strip site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Runoff from ground-level impervious surfaces that generate sheet flow. Flow path length across filter strip should be at least 15 feet with 1 to 5 % slope.
Water Table	Greater than 5 feet above seasonally high water table or top of bedrock elevation
Soil	All soil types. Heavily compacted soils should be tilled to a depth of 12 inches and amended with compost to achieve an organic content of 8 to 15% by weight or 30 to 40% by volume.
Drainage Area	Maximum flow path length across contributing impervious surfaces less than 100 feet.
Setbacks	N/A

Dry Swales

Table 25. Dry swale site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Longitudinal slopes ranging from 0.5 to 4%. On slopes steeper than 3%, check dams should be used.
Water Table	Greater than 5 feet above seasonally high water table or top of bedrock elevation
Soil	Hydrologic soil groups A and B are preferable, or located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 0.6 inches per hour, an underdrain is required.
Drainage Area	Typically treat drainage areas of two hectares or less. Typical ratios of impervious drainage area to swale surface area range from 5:1 to 15:1.
Setbacks	Facilities should be setback a minimum of twelve (12) feet from building foundations unless an impervious liner and underdrain is used.
Other	Proximity to underground utilities. Swale length between culverts should be 15 feet or greater.

Surface Treatment BMPs

Bioretention Cells

Table 26. Bioretention cell site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Contributing slopes should be between 1 to 5 %.
Water Table	The bottom of the system should be vertically separated by 5 feet from the seasonally high water table or top of bedrock elevation.
Soil	Hydrologic soil groups A and B are preferable, or located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 0.6 inches per hour, an underdrain is required.
Drainage Area	Typical contributing drainage areas are between 1000 square feet and 1 acre. The maximum recommended contributing drainage area is 2 acres. Typical ratios of impervious drainage area to swale surface area range from 5:1 to 15:1.
Setbacks	Facilities should be setback a minimum of twelve (12) feet from building foundations unless an impervious liner is used.
Other	Proximity to underground utilities and overhead wires (if trees are used)

Tree Trenches

Table 27. Tree trench site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	None given
Water Table	None given
Soil	None given
Drainage Area	Should not be placed at low points as they are not designed to collect large volumes of runoff.
Setbacks	None given
Other	Proximity to underground utilities and overhead wires.

Subsurface Treatment BMPs

Below-ground Recharge Systems

Table 28. Below-ground recharge system site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	Slopes less than 15%
Water Table	The bottom of the system should be vertically separated by 5 feet from the seasonally high water table or top of bedrock elevation.
Soil	Hydrologic soil groups A and B are preferable, or located in portions of the site with the highest native soil infiltration rates.
Drainage Area	Impervious drainage area to treatment system area ratio between 5:1 and 30:1 A maximum ratio of 10:1 is recommended for facilities receiving road or parking lot runoff
Setbacks	Facilities should be setback a minimum of twelve (12) feet from building foundations.
Other	Proximity to underground utilities.

Reuse BMPs

Rainwater Harvesting

Table 29. Rainwater harvesting and reuse site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	None given
Water Table	None given
Soil	All soils
Drainage Area	Variable
Setbacks	None given

Stormwater Harvesting

Table 30. Stormwater harvesting and reuse site considerations (adapted from: 3)

Site Characteristic	Considerations
Site Topography	None given
Water Table	None given
Soil	All soils
Drainage Area	Variable
Setbacks	None given

Relevant Manuals

Site suitability guidelines were drawn from the fact sheets included in the appendices at the end of this literature review, listed below. See Design Guidelines for rationale in choosing these two sources.

[2] The pollution prevention fact sheets contained in the **EOR 2008 Guide on Utilizing Pollution Prevention Activities to Meet MS4 General Permit Requirements** provide communities regulated under the Minnesota Municipal Separate Storm Sewer Systems General Permit with basic tools and information that will lead to increased use of pollution prevention activities within stormwater pollution prevention programs and local stormwater programs. This reference contains information on the following BMPs:

- Reducing Impervious Surfaces
- Pervious Pavement Systems
- Volume Control Using Compost Materials/ Soil Amendments
- Green Roofs
- Rainwater Harvesting/ Stormwater Reuse & Rain Barrel Programs
- Urban Forestry & Stormwater Management
- Vegetated Swales & Buffer Strips

[3] The **CVC/TRCA 2010 Low Impact Development Planning and Design Guide** contains detailed design guidance for Low Impact Development activities in the context of the Toronto climate and regulations. The CVC is noted for its progressive use of LID. This reference contains information on the following BMPs:

- Low Impact Development Site Design Strategies
- Permeable Pavement
- Downspout Disconnection
- Soakaways, Infiltration Trenches and Chambers
- Vegetated Filter Strips
- Dry Swales
- Bioretention
- Green Roofs
- Rainwater Harvesting

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VII. COLD CLIMATE SUITABILITY

Introduction

Stormwater managers in cold climates must recognize that runoff from snowmelt has characteristics different than those of rainfall runoff, and that BMP design criteria addressing only rainfall runoff might not work well during cold periods. This becomes a major problem because a substantial percentage of annual runoff volume and loading can come from snowmelt in years when snowfall is high. The heart of the problem with snowmelt runoff is that water volume in the form of snow and ice builds for several months and suddenly releases with the advent of warm weather in the spring or during short interim periods all winter long. The interim melts generally do not contribute a significant volume of runoff when compared to the large spring melt. Note that snowmelt peaks are substantially less than those from rainfall, but the total event volume of a snowmelt, although it occurs over a much longer period, can be substantially more. Ignoring the contribution of large spring melts to the annual runoff and pollution loading analysis could be a major omission in a watershed analysis.

The following section details cold climate conditions and associated design challenge for stormwater BMPs in cold climates, addresses the suitability of volume reduction BMPs in cold climates, and discusses design considerations and modifications necessary for proper operation of volume reduction BMPs in cold climates.

Main Findings

Cold Climate Challenges

The 1997 Stormwater BMP Design Supplement for Cold Climates identified the following cold climate conditions and associated BMP design challenges:

1. Cold Temperatures
    - Pipe freezing
    - Permanent pool ice-covered
    - Reduced biological activity
    - Reduced oxygen levels during ice cover
    - Reduced settling velocities
2. Deep Frost Line
    - Frost heaving
    - Reduced soil infiltration
    - Pipe freezing
3. Short Growing Season
    - Short time period to establish vegetation
    - Different plant species appropriate to cold climates than moderate climates
4. Significant Snowfall
    - High runoff volumes during snowmelt and rain-on-snow
    - High pollutant loads during spring melt
    - Other impacts of road salt/deicers
    - Snow management may affect BMP storage

Pollution Prevention

One major concern for the design of stormwater BMPs in cold climates is accommodating high pollutant loads during spring melt. Section 8 of the 1997 Stormwater BMP Design Supplement for Cold Climates discussed options for controlling pollution from sand and other abrasives, road deicers (commonly road salt, NaCl) and airport deicers. Three measures were proposed to reduce pollution from sand application:

1. use of a clean sand source,
2. street sweeping during and immediately after the spring runoff, and
3. operator training focusing on application of the minimum amount of sand necessary.

In addition, several changes were also proposed to reduce pollution from traditional deicing:

1. apply less salt,
2. apply alternate deicers,
3. use additives to reduce deicer application,
4. change the timing of application,
5. modify spreaders, and
6. implement salt storage regulations.

Recent Research

One cold climate concern for stormwater BMPs is that road salt runoff can mobilize heavy metals increasing the potential for ground and surface water contamination from infiltration BMPs. Results from infiltration experiments conducted at two highway infiltration pond sites in Washington indicated that sodium chloride resulted in the release of copper and lead. Using magnesium salt instead of sodium salt had less of an effect on lead and copper but had a much greater effect on the mobilization of cadmium. Releases of metals during or immediately following salt application produced concentrations that ranged from 50% to 1000% greater than the concentrations released from the control experiments ([47] Nelson *et al.* 2009).

Another cold climate concern is variability in seasonal performance of infiltration BMPs due to freezing temperatures. Variability in seasonal performance of infiltration BMPs has been related to temperature dependence of the viscosity of water ([37] Emerson and Traver 2008) and hydraulic conductivity of the soil ([31] Braga *et al.* 2007). Pervious asphalts in Sweden were found to have a 50% reduction in surface infiltration rates when temperatures decreased from 20°C to 0°C ([27] Bäckström and Bergstrom 2000). However, other studies suggest no reduction in performance during cold season months. A field study of a pervious-pavement system found minimal performance reduction from frozen media and attributed this to the well-drained nature of the pavement and underlying soil ([55] Roseen *et al.* 2012). They had also previously found that infiltration chambers perform optimally during the cold season when they are located well below the frost line ([54] Roseen *et al.* 2009). In addition, a multi-year study of pervious concrete over infiltration silt/sand beds showed that infiltration rates of the sand were lower during colder periods, but pollutant reduction to surface waters was greater than 90% due to infiltration to natural soils below the BMP ([40] Horst *et al.* 2011). Seasonal performance evaluations at the University of New Hampshire Stormwater Center field facility indicated that

LID designs have a high level of functionality during winter months and that frozen filter media do not reduce performance ([54] Roseen *et al.* 2009).

In a Minnesota study ([35] Davidson *et al.* 2008), experimental bioretention devices functioned for the majority of the winter season but infiltration stopped when air temperatures were well below freezing. They recommended the following design guidelines to optimize cold climate performance:

1. Use engineered soils devoid of silt or clay particles
2. Keep pool depths less than 1 foot deep that draw down to the frost line within 12 hours to minimize potential for freezing
3. Install an under drain system with a valve to permit operation as an infiltration or filtration system depending on conditions.

Cold Climate Suitability

The suitability of volume reduction BMPs with respect to the cold climate conditions is summarized in Table 31. A more detailed description of cold climate suitability and considerations for each volume reduction BMP is provided below. Specific design modifications for stormwater BMPs that address the design challenges listed above can be found in the 1997 Stormwater BMP Design Supplement for Cold Climates, the Minnesota Stormwater Manual, and the Low Impact Development Stormwater Management Planning and Design Guide.

Cold Climate Design Recommendations

(From the CVC/TRCA 2010 Low Impact Development Planning and Design Guide. Excerpts denoted by quotes and include cited references.)

Pervious Pavement Systems

"For cold climates, well-designed mixes can meet strength, permeability, and freeze-thaw resistance requirements. In addition, experience suggests that snow melts faster on a porous surface because of rapid drainage below the snow surface. Also, a well-draining surface will reduce the occurrence of black ice or frozen puddles ([32] Cahill Associates, 1993; [53] Roseen, 2007). Systems installed in the Greater Toronto Area have generally not suffered from heaving or slumping ([58] TRCA, 2008). Pervious pavement is typically designed to drain within 48 hours. If freezing should occur before the pavement structure has drained, then the large void spaces in the open graded aggregate base creates [an insulating] barrier to freeze-thaw. Pervious pavers have the added benefit of having enough flexibility to handle minor heaving without being damaged. Pervious pavement can be plowed, although raising the blade height 25 mm may be helpful to avoid catching pavers or scraping the rough surface of the pervious pavement. Sand should not be applied for winter traction on pervious pavement as this can quickly clog the system."

Green Roofs

"Green roofs are a feasible BMP for cold climates. Snow can protect the vegetation layer and once thawed, will percolate into the growing medium and is either absorbed or drained away just as it would during a rain event. No seasonal adjustments in operation are needed."

Level Spreaders and Filter Strips

Filter strips adjacent to roads and parking lots can act as a pervious snow storage area. Additional maintenance may be needed to remove accumulated sand and to replace vegetation damaged by road de-icing salts.

Bioretention Devices

"Performance studies show that bioretention effectively captures and treats runoff during winter months with average daily temperatures in the -5 to 10 ºC range ([59] Traver, 2005; [61] UNHSC, 2005, [54] Roseen *et al.*, 2009). Frost penetration of filter media varied from zero to 17 cm in studies at the University of New Hampshire ([53] Roseen, 2007). Year round monitoring of a bioswale in the Greater Toronto Area showed the facility continued to function during winter, with temperatures in the filter bed remaining above zero at a depth of 50 cm below the surface ([58] TRCA, 2008). While bioretention frequently accepts runoff containing high chloride concentrations, the dissolved chloride will pass through to the groundwater without treatment. Cold climate adaptation for bioretention designs include:

- extending the filter bed and underdrain pipe below the frost line,
- oversizing the underdrain to reduce the freezing potential, and
- selecting salt-tolerant vegetation.

Some bioretention design variants, such as stormwater planters and curb extensions, are new to cold climates and have not been monitored in winter conditions. Stormwater planters that are wholly above ground should be given special consideration, as the underdrain and other conveyance structures will be more susceptible to freezing."

Below-ground Recharge Systems

"Soakaways, infiltration trenches and chambers will continue to function during winter months if the inlet pipe and top of the facility is located below the local maximum frost penetration depth ([46] MTO, 2005)."

Rainwater Harvesting

"Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternatively, an outdoor system can be used seasonally." [3]

Table 31. Cold climate suitability of volume reduction stormwater BMPs
(From: Table 9.3 in the Minnesota Stormwater Manual)

	Volume Reduction BMP	Cold Climate Suitability	Notes
SOURCE CONTROL	**Impervious Surface Reduction**	Yes	Preserving pervious areas for meltwater to infiltrate is an effective way to control volume and to minimize mobilization of pollutants
	Soil Amendments	Yes	Enhancing soil permeability will increase recharge of meltwater
	Pervious Pavement Systems	Yes	Recent research has shown this approach to be successful in cold climates when properly installed and maintained, and when sanding is kept to a minimum
ROUTING	**Filter Strips**	Marginal	Vegetative filtering is reduced once vegetation dies back in fall; some physical filtering will occur if vegetation density and depth are sufficient
	Dry Swales	Yes	Routing meltwater over a pervious surface will yield some reduction in flow and improved water quality
SURFACE TREATMENT	**Bioretention Devices**	Yes-to-Marginal	These can provide needed storage during the cold season and for spring runoff events; vegetation will not be a factor during winter
	Tree Trenches	Marginal	These are designed for the growing season, but some do provide a sump area for runoff to collect and will infiltrate some of the volume
	Green Roofs	Yes	Recent research has shown that slow melting in the spring reduces the volume running off of roof surfaces
SUB-SURFACE TREATMENT	**Below-ground Recharge Systems**	Yes with Caution	Effective as long as the system is installed below the frostline to avoid ice build-up and designed, installed and maintained properly; caution applies to limitations on source area to avoid high concentrations of chloride and toxics
REUSE	**Rainwater Harvesting**	Yes with Caution	Capturing meltwater from a building can perform at higher levels and will reduce volume but ice build-up could be a problem unless collection occurs below frostline

Relevant Manuals and Reports

Three reports and many primary research papers were used to identify cold climate considerations for volume reduction BMPs. The Center for Watershed Protection 1997 Stormwater BMP Design Supplement for Cold Climates is the primary reference for design of traditional BMPs in cold climates. The Minnesota Stormwater Manual devotes a chapter to a detailed discussion regarding cold climate design challenges and recommended BMP considerations and modifications. The CVC/TRCA 2010 Low Impact Development Planning and Design Guide supplements these works with cold climate considerations of new BMPs.

[11] The **Center for Watershed Protection 1997 Stormwater BMP Design Supplement for Cold Climates** identifies cold climate design challenges, provides detailed guidance on design modifications for traditional stormwater BMPs in cold climates, and recommends pollution prevention techniques for cold climate unique pollutants, such as salt, sand, and de-icers.

[1] The **2008 Minnesota Stormwater Manual** contains detailed design guidance for Low Impact Development and stormwater BMPs in the context of Minnesota climate and regulations.

[3] The **CVC/TRCA 2010 Low Impact Development Planning and Design Guide** summarizes in detail cold climate considerations for Low Impact Development BMPs.

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Appendix A. Volume Reduction Best Management Practice Design Guides

The following design guides are included in a separate document:

Impervious Cover Reduction
Pollution Prevention Fact Sheet: Reducing Impervious Surfaces
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Low Impact Development Site Design Strategies

Soil Amendments/ Decompaction
Pollution Prevention Fact Sheet: Volume Control Using Compost Materials/ Soil Amendments

Pervious Pavement Systems
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Permeable Pavement

Downspout Disconnection
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Downspout Disconnection

Green Roofs
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Green Roof

Level Spreaders and Filter Strips
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Vegetated Filter Strips

Dry Swales
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Dry Swale

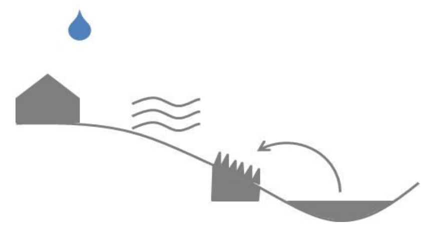
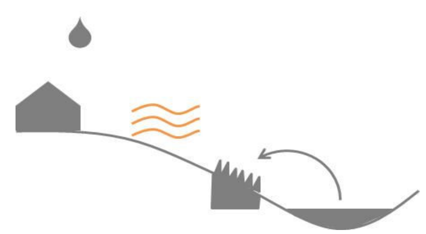
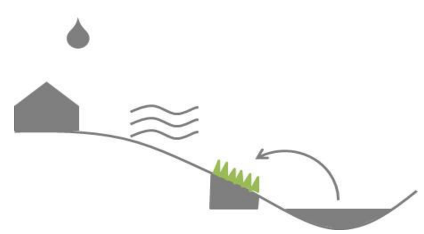
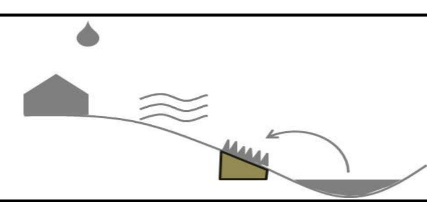
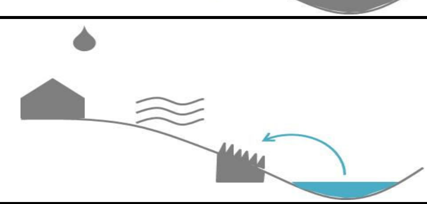
Bioretention Devices
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Bioretention

Tree Trenches
Charles River Watershed Association Low Impact Best Management Practice Information Sheet: Stormwater Tree Pit

Below-ground Recharge Systems
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Soakaways, Infiltration Trenches and Chambers

Rainwater (Stormwater) Harvesting
CVC/TRCA Low Impact Development Planning and Design Guide Fact Sheet: Rainwater Harvesting

Volume Reduction BMP Summary Matrix

	VOLUME REDUCTION BMP	LOCATION IN THE LANDSCAPE	HYDROLOGIC BENEFITS: INFILTRATION	HYDROLOGIC BENEFITS: EVAPO-TRANSPIRATION	HYDROLOGIC BENEFITS: RUNOFF VOLUME REDUCTION	SURFACE WATER POLLUTANT REMOVAL: TP	SURFACE WATER POLLUTANT REMOVAL: TN	SURFACE WATER POLLUTANT REMOVAL: TSS	SURFACE WATER POLLUTANT REMOVAL: Metals	GROUNDWATER CONTAMINATION RISK
SOURCE CONTROL	Impervious Cover Reduction		✔	✔	40%	30-55%	64%			
	Soil Amendments/ Decompaction		✔	✔	50-75%	50-75%	50-75%			
	Pervious Pavements		✔		45-85%	30-80%	60-80%		90%	💧
	Downspout Disconnection		✔	✔	25-50%	25-50%	25-50%			
	Green Roofs			✔	45-90%	highly variable	20-90%	70-90%	80%	
ROUTING	Level Spreaders		✓	✓	50-75%	50-75%	50-75%			
	Filter Strips		✓	✓	25-75%	30-80%	35%	75-90%	80%	
	Dry Swales		✓	✓	10-60%	15-75%	55-75%			
SURFACE TREATMENT	Bioretention Devices (without under drain)		✔	✔	65-85%	90%	90%		30-99%	💧
	Bioretention Devices (with underdrain)			✔	40-45%	55-65%	45-65%	85%	95%	
	Tree Trenches		✔	✔	variable	75%	70%	85%	80%	
	Infiltration Basins		✔	✔	50-90%	15-90%	60-90%			💧
SUBSURFACE TREATMENT	Below-ground Recharge Systems		✔		85%	50-80%	40-70%	70-90%	70-90%	💧
REUSE	Rainwater Harvesting				40%	40%	40%			
	Stormwater Harvesting		✓	✔	20-75%	45-95%				
NOTES			(With suitable soils) ✔ Primary Benefit ✓ Little Benefit		Reduction ranges represent variations in design and site conditions across multiple studies. As a result, comparisons between BMPs across different studies may not reflet true performance. Please refer to the individual references reported in Literature Review Table 2 for more information on how the volume and pollutant reductions were calculated.					💧= Pretreatment/siting restrictions needed to address groundwater contamination risk

Volume Reduction BMP Summary Matrix (continued)

	VOLUME REDUCTION BMP	MAINTENANCE: LIFESPAN	MAINTENANCE: REQUIREMENTS	SITE SUITABILITY: TOPOGRAPHY	SITE SUITABILITY: WATER TABLE	SITE SUITABILITY: SOIL TYPE	SITE SUITABILITY: DRAINAGE AREA: BMP AREA RATIO	SITE SUITABILITY: OTHER	OTHER CONSIDERATIONS: COLD CLIMATES	OTHER CONSIDERATIONS: CONTAMINATED SITES	OTHER CONSIDERATIONS: ULTRA URBAN
SOURCE CONTROL	Impervious Cover Reduction	> 30 years	L			All		☑; Zoning restrictions		M	L
	Soil Amendments/ Decompaction	> 30 years	L			All		☑		M	M
	Permeable Pavements	15-25 years	M	0-3%	≥ 5' separation	Infiltration ≥0.6 in/hr	1.2	☑	❄	L	H
	Downspout Disconnection	> 30 years	L	1-5%	≥ 5' separation	All		☑		L	L
	Green Roofs	Asphalt lifespan + 20 years	M	Roof slope <10%		All				H	H
ROUTING	Level Spreaders	10-20 years	L			All				M	L
	Filter Strips	> 30 years	L	1-5%	≥ 5' separation	All	< 100' wide	☑		H	H
	Dry Swales	> 30 years	M	0.5-3%	≥ 5' separation	A or B preferred	5 - 15 (< 2 ac)	☑		M	M
SURFACE TREATMENT	Bioretention Devices (without under drain)	> 20 years	M	1-5%	≥ 5' separation	A or B preferred	5 - 15 (0.5 - 2 ac)	Setback required	❄	L	H
	Bioretention Devices (with underdrain)	> 20 years	M			All	5 - 15 (0.5 - 2 ac)	Setback required	❄	H	H
	Tree Trenches	25 years	M			All		Utilities	❄❄	H	H
	Infiltration Basins	20-30 years	M	<15%	≥ 5' separation	A or B	5 - 30 (10 for roads)	☑, Setback required	❄	L	L
SUBSURFACE TREATMENT	Below-ground Recharge Systems	20-30 years	H	<15%	≥ 5' separation	A or B	5 - 30 (10 for roads)	Width≥Depth Setbacks required	❄	M	M
REUSE	Rainwater Harvesting	25 years	H			All			❄❄	H	H
	Stormwater Harvesting		H			All			❄❄	H	H
	NOTES	**Estimates from:** CRWA EOR	**Relative ranking:** **L** - Low **M** - Medium **H** - High	**Source:** CVC/TRCA 2010	**Source:** Dane County	**Soil Types** **A** **B**	**Source:** CVC/TRCA 2010	**Source:** CVC/TRCA 2010 ☑ public right-of-way suitable	❄ design mod. required ❄❄ reduced performance	**Suitability:** **L** - Low **M** - Medium **H** - High	**Suitability:** **L** - Low **M** - Medium **H** - High

Reducing Impervious Surfaces

Reducing stormwater runoff through the use of alternative design standards and ordinance development

Impervious areas such as road and parking pavement, building surfaces, and walkways/driveways significantly increase stormwater runoff volumes, which in turn causes flooding and streambank erosion. Impervious surfaces also facilitate the wash-off and transport of pollutants like oil, grease and sediment into downstream rivers, lakes and wetlands. This fact sheet identifies methods and design standards used to achieve a reduction in the total runoff volume from impervious surfaces and gives examples of municipal ordinances that foster the reduction of impervious surfaces.

Benefits / Pollution Reduction

Reduced imperviousness results in smaller stormwater discharges which enhances flood control, reduces erosion and increases infiltration. Any reduction in runoff volume translates into reduced pollutant loads to downstream waters. Reduced runoff can also reduce the size and cost of stormwater management systems. Increased greenspace can facilitate recreational and community activities that enhance the quality of life of residents/employees.

Program Development & Implementation

Managing the extent of impervious area of buildings, roads and parking pavements occurs through the site planning and design process. Example methods to reduce imperviousness include but are not limited to, narrower road sections, alternative road layouts, reduced application of sidewalks and on-street parking, cul-de-sac design, parking lot design, house setbacks, structure/building impervious area limits and driveway designs. These methods are a component of design methodologies such as low impact development, design with nature, sustainable development and conservation design, and could become a part of standard building codes.

Design for Reducing Imperviousness

This strategy relies on several techniques to reduce the total area of rooftops, parking lots, streets, sidewalks and other types of impervious cover created at a development site. The basic approach is to reduce each type of impervious cover by downsizing the required minimum geometry specified in current local codes, keeping in mind that there are minimum requirements that must be met for fire, snowplow and school bus operation.

Image Courtesy of Emmons & Olivier Resources, Inc.

Trees and vegetation in the landscape of a cul-de-sac.

Impervious area can also be effectively removed by routing runoff flow to an area that will absorb the water, such as a yard, swale or bioretention area. Below are several techniques that can be used to reduce imperviousness. The City of Inver Grove Heights, MN, has implemented several of these techniques in its ordinance for the Northwest Area.

Narrower streets

Many communities require residential streets that are much wider than needed to support travel lanes, on-street parking, and emergency access. Some communities currently require residential streets as wide as 32 to 40 feet, which provide two parking lanes and two moving lanes.

Local experience has shown that residential streets can have pavement widths as narrow as 22 to 26 feet, and still accommodate all access and parking needs (ITE, 1997). Even narrower access streets or shared driveways can be used when only a handful of homes are served. The City of Inver Grove Heights Northwest Area requires a 28 foot paved local public street in addition to a sidewalk or trail on one side of the street. Local private streets have a 24-foot width requirement. Narrower streets help reduce traffic speeds in residential neighborhoods which, in turn, improve pedestrian safety.

Local public works, police and fire departments might object to narrower streets. Referring to the documents in the Additional Resources section can help identify how to address some of their concerns.

Slimmer sidewalks

Many communities require sidewalks that are excessively wide or are located adjacent to the street where the pedestrians are at risk from vehicles. A better site design technique modifies the width and location of sidewalks to promote safer pedestrian mobility. Impervious cover is reduced when sidewalks are reduced in width and located away from the street. Sidewalks can also be disconnected so they drain to lawns or landscaping instead of the gutter and storm drain system, or they can be constructed with permeable concrete, asphalt or blocks.

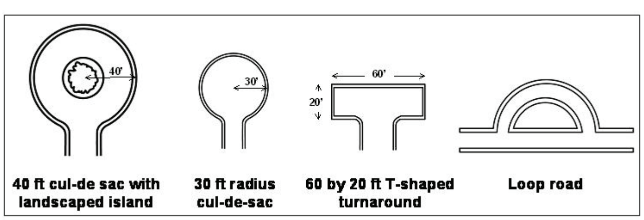
Sidewalk that drains to adjacent vegetation and provides common walkways linking pedestrian areas.

Smaller cul-de-sacs

Impervious cover can be reduced by minimizing the diameter of residential street cul-de-sacs and/or incorporating landscaped islands. Many communities require cul-de-sacs that have a greater diameter than needed to allow emergency and large vehicles to adequately turn around. Alternatives to the traditional 80 foot diameter cul-de-sac include 60 foot diameter cul-de-sacs, hammerhead turnarounds and loop roads. The Northwest Area zoning ordinance requires an outside roadway radius of 35 feet and a street property line (right-of-way) of 50 feet.

In addition, the inside of the turnaround can be landscaped as a bioretention area to further reduce impervious cover and improve stormwater treatment. Trees and vegetation planted in landscaped islands can be used to intercept rain water and treat stormwater runoff from surrounding pavement. Each of these alternative turnaround options produces a more attractive and safe environment for residents.

Image Adapted from Center for Watershed Protection. 1997.



Turnaround options for residential streets.

Smaller parking lots

In many communities, parking lots are over-sized and under-designed. Local parking and landscaping codes can be modified to allow the following techniques to be applied within parking lots:

- Minimize standard stall dimensions for regular spaces
- Provide compact car spaces
- Use pervious pavement (asphalt, concrete, pavers, sand amendments, vegetation) particularly for light-use or overflow parking
- Incorporate efficient, narrow parking lanes
- Reduce minimum parking demand ratios for certain land uses
- Treat the parking demand ratio as a maximum limit
- Create hydraulically designed stormwater “islands” or landscaping areas to treat runoff using bioretention, filter strips or other practices
- Encourage shared parking arrangements with adjacent land uses
- Enable owners/developers to provide proof of parking for required number of parking spaces while constructing only those that the owner/developer demonstrates are necessary

The Inver Grove Heights Northwest Area ordinance encourages joint parking arrangements and requires multi-family and mixed-use development to provide 50 percent of total parking underground, under the principal structure or as tuck-under parking. In addition, the ordinance includes incentives for pervious parking if more than the minimum parking requirement is desired.

Parking lot landscaping makes the lot more attractive to customers, and promotes safety for both vehicles and pedestrians. In addition, trees and other landscaping help screen adjacent land uses, shade people and cars, reduce summertime temperatures, improve air quality and bird habitat, reduce runoff volume and improve water quality.

Shorter Driveways

Most local codes contain front yard setback requirements that dictate driveway length. In many communities, front yard setbacks for certain residential zoning categories may extend 50 or 100 feet or even longer, which increases driveway length well beyond what is needed for adequate parking and access to the garage. Shorter setbacks reduce the length and impervious cover for individual driveways. The Northwest Area of Inver Grove Heights, MN, allows a 20 foot setback. In addition, driveway widths can be reduced and more permeable driveway surfaces can be allowed such as porous pavers, porous asphalt or porous concrete. Another way to reduce impervious cover is to allow shared driveways that provide street access for more than a single home. The Northwest Area zoning ordinance allows and encourages shared driveways.

Reduced Imperviousness Development Rules

Development rules are frequently in conflict with alternate design standards that limit the amount of impervious surface associated with a development. Development rules can refer to subdivision codes, zoning regulations, parking and street standards and other local ordinances that regulate development. Section 515.80 Subd. 39 of the City of Inver Grove Heights City Code is a good example of an ordinance facilitating reduced imperviousness (see Additional Resources).

The Center for Watershed Protection (see Additional Resources) recommends the following four step process to adapt local development rules to more closely conform to reduced imperviousness principles and related conservation design principles.

Step 1

Identify the development rules in your MS4. Locate all MS4 rules that have a potential impact on the way land is developed. Consider zoning ordinances, subdivision codes, street standards, covenants, fire codes and standards, parking requirements, building regulations/standards, stormwater management ordinances, buffer or floodplain regulations and environmental regulations.

Step 2

See how the rules stack up to the development principles of interest. Rate development rules on a scale of 1 to 10 (or similar) for how favorably they compare with the reduced imperviousness techniques giving a higher score for more favorable comparisons. If out of the maximum points possible, 80 percent or less are received, consider a systematic reform of imperviousness development rules.

Step 3

Consider which development rules might be changed. Given the difficulty and effort in changing development rules, prioritize proposed changes. Consider all the factors that contribute to established development rules. A low rate from Step 2 does not necessarily imply the rule should be or can be changed. In prioritizing, consider how changes will impact development costs, liability, property values, public safety and any other elements.

Step 4

Start a local roundtable process. Utilize a consensus process such as a local site planning roundtable to proceed with the desired development rule changes. The process allows for systematic review of existing rules and determination of whether or not changes can or should be made. Ultimately, the roundtable will come to agreement on the changes to be made to codes, engineering standards, guidelines, regulations and ordinances. Include key players in the roundtable, especially those agencies or personnel with authority for development review. Consider planning agencies/commissions, public works department, road/highway department, developers, fire officials, health department, land use lawyers, real estate brokers, chamber of commerce, elected officials, residents/land owners, stormwater management authority and any other potential stakeholders. In addition, consider utilizing an outside facilitator to guide and structure the roundtable process.

Maintenance Considerations

Narrower roads, sidewalks and cul-de-sacs, smaller parking lots and shorter driveways reduce maintenance needs, but the nature of the maintenance requirements is no different than that for existing features. Among others, these will include repair of failed structure or surface, periodic sweeping to remove accumulated debris, cleanout of sump manholes, and inspection of drainage paths to make sure structures are operable. There are a variety of pervious pavements with respective maintenance needs that compare to those of impervious pavements but may require annual vacuum cleaning. Pervious pavements can reduce winter maintenance needs including less salting, plowing and sanding due to the textured and porous nature of the pavement.

Typical Cost

Reducing imperviousness surfaces reduce maintenance and construction costs. In addition, reduced imperviousness reduces the size and cost of both the stormwater conveyance system and stormwater management practices. Additional resources may be required at the planning stages until familiarity with the design concepts and standards are established. The adoption of new ordinances requires an investment in training for the plan reviewer, the consultant, and possibly the public. MS4s must also consider the cost of enforcement, including staff and equipment requirements.

LOW IMPACT DEVELOPMENT SITE DESIGN STRATEGIES

CVC/TRCA LOW IMPACT DEVELOPMENT PLANNING AND DESIGN GUIDE - FACT SHEET

PRESERVING IMPORTANT HYDROLOGIC FEATURES AND FUNCTION

There are many features in the natural landscape that provide the important hydrologic functions of retention, detention, infiltration, and filtering of stormwater. These features include, but are not limited to; highly permeable soils, pocket wetlands, significant small (headwater) drainage features, riparian buffers, floodplains, undisturbed natural vegetation, and tree clusters. All areas of hydrologic importance should be delineated at the earliest stage in the development planning process.

STRATEGIES

1. ***Buffers provide filtration, infiltration, flood management, and bank stability benefits.*** Unlike stormwater ponds and other structural infrastructure, buffers are essentially a no capital cost and low maintenance form of "green" infrastructure. The benefits of buffers diminish when slopes are greater than 25%; therefore steep slopes should not be counted as buffer.
2. ***Preserve areas of undisturbed soil and vegetation cover.*** Typical construction practices, such as topsoil stripping and stockpiling, and site grading and compaction by construction equipment, can considerably reduce the infiltration capacity (and treatment capacity) of soils. During construction, natural heritage features and locations where stormwater infiltration practices will be constructed should be delineated and not subject to construction equipment or other vehicular traffic, nor stockpiling of topsoil.
3. ***Avoid development on permeable soils.*** Highly permeable soils (i.e., hydrologic soil groups A and B) function as important groundwater recharge areas. To the greatest extent possible, these areas should be preserved in an undisturbed condition or set aside for stormwater infiltration practices. Where avoiding development on permeable soils is not possible, stormwater management should focus on mitigation of reduced groundwater recharge through application of stormwater infiltration practices.
4. ***Preserve existing trees and, where possible, tree clusters.*** Mature stands of deciduous trees will intercept 10 to 20% of annual precipitation falling on them, and a stand of evergreens will intercept 15 to 40%. Preserving mature trees will provide immediate benefits in new developments, whereas newly planted trees will take 10 years or more to provide equivalent benefits. Tree clusters can be incorporated into parking lot interiors or perimeters, private lawns, open space areas, road buffers, and median strips. An uncompacted soil volume of 15 to 28 m3 is recommended to achieve a healthy mature tree with a long lifespan.

SITING AND LAYOUT OF DEVELOPMENT

The location and configuration of elements, such as streets, sidewalks, driveways, and buildings, within the framework of the natural heritage system provides many opportunities to reduce stormwater runoff.

STRATEGIES

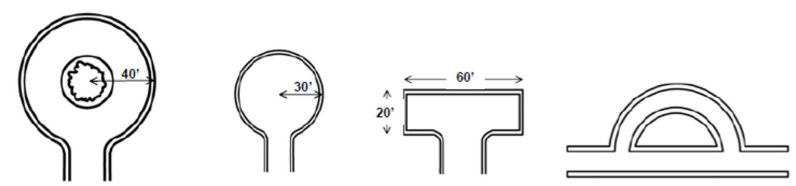
5. ***Fit the design to the terrain.*** Using the terrain and natural drainage as a design element will reduce the amount of clearing and grading required and the extent of necessary underground drainage infrastructure. This helps to preserve predevelopment drainage boundaries.
6. ***Use open space or clustered development.*** Clustering development increases the development density in less sensitive areas of the site while leaving the rest of the site as protected community open space. Some features of open space or clustered development are smaller lots, shared driveways, and shared parking. Clustered development also reduces the amount of impervious surfaces and stormwater runoff to be managed, reduces pressure on buffer areas, reduces the construction footprint, and provides more area and options for stormwater controls.
7. ***Use innovative street network designs.*** Certain roadway network designs (e.g., loops, cul-de-sacs, fused grids) create less impervious area than others. These layouts by themselves may not achieve the many goals of urban design. However, used in a hybrid form together or with other street patterns, they can meet multiple urban design objectives and reduce the necessary street area, thereby reducing the amount of impervious surfaces and stormwater runoff to be managed.
8. ***Reduce roadway setbacks and lot frontages.*** The lengths of setbacks and frontages are a determinant for the area of pavement, street, driveways, and walkways, needed to service a development. Municipal zoning regulations for setbacks and frontages have been found to be a significant influence on the production of stormwater runoff.

REDUCING IMPERVIOUS AREA

Many of the strategies described previously are primarily for the purpose of reducing impervious area on a macro scale. The following strategies provide examples of how to reduce impervious area on a micro or lot level scale.

STRATEGIES

9. ***Reduce street width.*** Streets constitute the largest percentage of impervious area and contribute proportionally to the urban runoff. Streets widths are sized for the free flow of traffic and movements of large emergency vehicles. In many cases, such as low density residential, these widths are oversized for the typical function of the street. Amending urban design standards to allow alternative, narrower street widths might be appropriate in some situations. There are a variety of ways to accommodate emergency vehicle movements and traffic flow on narrower streets, including alternative street parking configurations, vehicle pullout space, connected street networks, prohibiting parking near intersections, and reinforced turf or gravel edges.
10. ***Reduce building footprints.*** Reduce the building footprint by using taller multi-story buildings and taking advantage of opportunities to consolidate services into the same space.
11. ***Reduce parking footprints.*** Excess parking not only results in greater stormwater impacts and greater stormwater management costs but also adds unnecessary construction and maintenance costs and uses space that could be used for a revenue generating purpose.
    - Keep the number of parking spaces to the minimum required. Parking ratio requirements are often set to meet the highest hourly parking demand during the peak season. The parking space requirement should instead consider an average parking demand and other factors influencing demand like access to mass transit.
    - Take advantage of opportunities for shared parking. For example, businesses with daytime parking peaks can be paired with evening parking peaks, such as offices and a theatre, or land uses with weekday peak demand can be paired with weekend peak demand land uses, such as a school and church.
    - Reductions in impervious surface can also be found in the geometry of the parking lot. One way aisles when paired with angled parking will require less space than a two way aisle. Other reductions can be found in using unpaved end-of-stall overhangs, setting aside smaller stalls for compact vehicles, and configuring or overlapping common areas like fire lanes, collectors, loading, and drop off areas.
    - More costly approaches to reducing the parking footprint include parking structures or underground parking.
12. ***Consider alternative cul-de-sac designs.*** Using alternatives to the standard 15 metre radius cul-de-sac can further reduce the impervious area required to service each dwelling. Ways to reduce the impervious areas of cul-de-sacs include a landscaped or bioretention centre island, T-shaped turnaround, or by using a loop road instead.
13. ***Eliminate unnecessary sidewalks and driveways.*** A flexible design standard for sidewalks is recommended to allow for unnecessary sidewalks to be eliminated. Sidewalks that are not needed for pedestrian circulation or connectivity should be removed. Often sidewalks are only necessary on one side of the street. Driveway impervious area can be reduced through the use of shared driveways or alley accessed garages



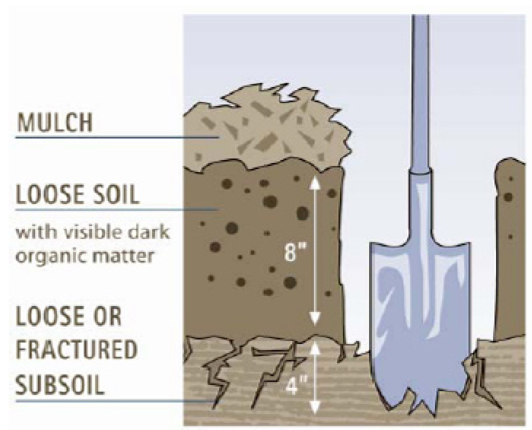
40 ft cul-de sac with landscaped island | 30 ft radius cul-de-sac | 60 by 20 ft T-shaped turnaround | Loop road

Source: CWP, 1998

	Square grid (Miletus, Houston, Portland, etc.)	Oblong grid (most cities with a grid)	Oblong grid 2 (some cities or in certain areas)	Loops (Subdivisions – 1950 to now)	Culs-de-sac (Radburn – 1932 to now)
Percentage of area for streets	36.0%	35.0%	31.4%	27.4%	23.7%
Percentage of buildable area	64.0%	65.0%	68.6%	72.6%	76.3%

Source: CMHC, 2002

Soil Amendment Guidelines



Soil amendment sizing criteria:

impervious area / soil area = 1
- use 100 mm compost, till to 300 - 450 mm depth

impervious area / soil area = 2
- use 200 mm compost, till to 300 - 450 mm depth

impervious area / soil area = 3
- use 300 mm compost, till to 450 - 600 mm depth

Compost should consist of well-aged (at least one year) leaf compost. Amended soil should have an organic content of 8-15% by weight or 30-40% by volume.

Source: Soils for Salmon, 2005

Open Drainage Applied in a Medium Density Neighbourhood

Source: U.S. EPA

USING NATURAL DRAINAGE SYSTEMS

Rather than collect and move stormwater rapidly to a centralized location for detention and treatment, the goal of these strategies is to take advantage of undisturbed vegetated areas and natural drainage patterns (e.g., small headwater drainage features). These strategies will extend runoff flow paths and slow down flow to allow soils and vegetation to treat and retain it. Using natural systems or green infrastructure is often more cost effective than traditional drainage systems, and they provide more ancillary benefits.

STRATEGIES

14. ***"Disconnect" impervious areas.*** Roof leaders or downspouts, parking lots, driveways, sidewalks, and patios should be disconnected from the storm sewer and directed towards stabilized pervious areas as sheet flow where possible. In cases of concentrated flow, the flow can be broken up with level spreaders or flow dissipating riprap. With the proper treatment, the landscaped areas of a site can accept runoff from impervious areas. Deep tilling or soil aeration is recommended for topsoil that has been replaced or compacted by construction equipment. Soil amendments can be applied to hydrologic soil group C and D soils to encourage runoff absorption. Use deep rooting vegetation in landscaped areas when possible which will maintain and possibly improve soil infiltration rate over time:
    - ***Undisturbed densely vegetated areas and buffers*** - A hydrologist and/or ecologist should be consulted before designing a site to drain to sensitive natural heritage features like pocket wetlands.
    - ***Landscaped and disturbed areas*** - With the proper treatment, the landscaped areas of the site can accept runoff from impervious areas. Deep tilling or soil aeration is recommended for topsoil that has been replaced or compacted by construction equipment. Soil amendments can be applied to hydrologic soil group C and D soils to encourage runoff absorption. Use deep rooting vegetation in landscaped areas when possible which will maintain and possibly improve the infiltration rates over time.
15. ***Preserve or create micro-topography.*** Undisturbed lands have a micro-topography of dips, hummocks and mounds which slow and retain runoff. Site grading smoothes out these topographic features. Micro-topography can be restored in areas of ornamental landscaping or naturalization.
16. ***Extend drainage flow paths.*** Slowing down flows and lengthening flow paths allow more opportunities for stormwater to be filtered and infiltrated. Extending the travel time can also delay and lower peak flows. Where suitable, flows should be conveyed using vegetated open channels (e.g., enhanced grass swales).

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 3.2 OF THE CVC/TRCA LID SWM GUIDE

Volume Control Using Compost Materials / Soil Amendments

Soil amendment techniques, standards and ordinances

Land development including landscaping practices damage soil structure and function by removing or compacting topsoil. These practices can impact water resources by decreasing infiltration, increasing erosion, impairing fish habitat, and increasing the need for permanent stormwater management.

These practices also create chemically dependent landscapes which are difficult and expensive to maintain and contribute to polluted runoff. Soil compaction also reduces the water retention capacity of soil which requires additional irrigation and increased public water supply demand. This fact sheet provides guidance on soil amendment practices and implementation of soil amendment standards and ordinances.

Benefits / Pollution Reduction

Compost, an organic material, absorbs and infiltrates rainwater, reduces flooding and soil erosion and filters out pollutants typically associated with stormwater runoff. Compost also stores water and nutrients for plants to use during drought conditions, promoting healthy plants and better looking lawns that require less irrigation, pesticides and fertilizers. In addition, healthy amended soils that require less irrigation reduce municipal water demand.

Program Development & Implementation

Programs developed to provide volume control through soil amendments may include MS4 standards and/or ordinances. Soil amendment guidelines as well as guidelines for standards and ordinance development are identified below. The program is ultimately dependent upon several factors including the MS4's available resources, extent of development and/or redevelopment opportunities, and character of its soil and stormwater runoff.

Awareness Campaigns

Awareness campaigns inform the public, public employees, businesses, property owners, and elected officials of the negative effects of soil compaction and the benefits of soil amendments. Efforts can also contribute to generating acceptance of a new ordinance and encouraging individuals and organizations to implement soil amendments on a voluntary basis.

Brochures
Develop informative brochures, and guidance for specific audiences such as developers, businesses, homeowners and local development permitting authorities.

Signage at MS4 installations
Locate signage at parks and government buildings identifying compost-amended sites and the associated functions and benefits.

Workshops and seminars
Workshops and seminars can be used to provide the technical assistance that developers, city staff and consultants will need in order to meet a new soil amendment ordinance.


Unrestricted flickr ® Image

Compost delivery to a project site.

Soil Amendment Application Guidelines

Design variants are summarized below to provide guidance appropriate for implementing soil amendments within various site constraints and conditions. A good design approach will likely apply a combination of techniques at a single site based on the local conditions. There are soil and compost calculator worksheets in the Additional Resources section.

General guidance

Unless soils are native and can be left undisturbed, the following guidance applies to techniques implemented:

- Minimum final soil depth of 8 inches
- Avoiding plowing or tilling within drip line of trees
- Soil pH testing, and if necessary, adjusting proposed suite of plants

Undisturbed native soil

Areas of the site that do not need to be disturbed should be identified to protect areas of native vegetation. Fence off these areas to protect them from compaction during the construction phase.

Amend existing soil in-place

Where the soil has been compacted or the organic layer (e.g. forest duff or upper soil horizon) removed, the simplest way to restore soil quality is to rototill compost into the existing soil. Apply a 2.5-inch deep layer of compost to the existing soil. Rototill compost into the soil to a depth of at least 8 inches. Tilling to this depth will require repeated passes with a large machine, such as a tractor-mounted or heavy rear-tine rototiller.

Unrestricted flickr ® Image

Rototilling compost into the soil.

Import topsoil mix

Where subsoil is too rocky, compacted or poorly drained to amend effectively, a topsoil mix with 8-13 percent soil organic matter can be imported and placed on the surface. The topsoil mix should contain 30-40 percent compost by volume and clean sand or sandy soil to promote adequate drainage. The soil depth should be 8 inches and the pH suitable for proposed plants. Ask topsoil suppliers for test results of their product to verify the material contains the desired organic matter content and pH. For best results, plow or till compacted subsoil at least 2 inches deep before applying topsoil mix and/or rototill some of the newly applied topsoil into the subsoil.

Native soil

Sites that contain original, undisturbed native soils (most often applicable to forested land) may be stockpiled and reapplied without compost amendments after grading or other construction disturbances are completed. Remove forest duff layer and topsoil and stockpile separately prior to grading. Cover soil and duff piles with woven weed barrier (available from nursery supply stores) that sheds moisture yet allows air flow. Reapply topsoil to landscape areas to a minimum 8-inch depth after grading and other disturbances are completed. For best results, plow or till compacted subsoil at least 2 inches deep before replacing stockpiled topsoil, and/or rototill some of the replaced topsoil into the subsoil. Apply a 2-inch layer of stockpiled duff as mulch after planting.

Disturbed soil

Stockpile topsoil, reapply and amend in place. This design variant is only applicable to sites where the soil is not the original, undisturbed native soil. Topsoil and forest duff excavated for structures and paved areas or removed before site grading can be stockpiled and reapplied after grading and amended.

Remove soil and stockpile prior to grading. Cover soil with woven weed barrier (available from nursery supply stores) that sheds moisture yet allows air flow. Reapply stockpiled soil to landscape areas to a minimum 8-inch depth after grading and other disturbances are completed. In some cases, purchasing additional topsoil will be needed to achieve the 8-inch depth. Plow or till compacted subsoil at least 2 inches deep before replacing stockpiled soil, and/or rototill some of the replaced soil into the subsoil. Apply a layer of compost to the reapplied soil at a depth of 2.5 inches. Rototill compost into the soil to a depth of at least 8 inches. Tilling to this depth will require repeated passes with a large machine, such as a tractor or heavy rear-tine rototiller.

Scarification

The Minnesota Stormwater Manual recommends plowing or tilling (scarifying) compacted subsoil more than the 2 inches recommended in the above applications. For high-traffic areas, the recommended depth of scarification is 10 inches. For all other areas within the construction limits, the recommended depth of scarification is four inches.

Planting areas vs. turf areas

The Minnesota Stormwater Manual recommends a greater depth of compost, 3 inches, for planting areas than for turf areas which may be adequately amended with only 1.75 inches of compost. In all cases, the recommended minimum depth of the resulting topsoil layer with the incorporated compost is 8 inches.

Compost Specifications

When purchasing compost to be incorporated into the soil as a volume control soil amendment, look for specifications presented in the following table, adapted from Table 1 of Chapter 12-3 Runoff Volume Minimization of the Minnesota Stormwater Manual.

Parameter	Parameter Definition	Range
Source material/ Nutrient content	Typically biosolids/animal manure, source separated compostable materials or sorted yard wastes	Nitrogen: 0.5 – 3 Phosphorus: 0.5 – 1.5 Potassium: 0.5 – 1
Maturity	Level of completeness of the composting process	Seed emergence and seed vigor = minimum 80% relative to positive control
Stability	Biological activity in the composted material	CO_2 evolution rate: < 8 milligrams CO_2-C per grams organic matter per day
pH	Acidity/alkalinity	5.5 – 8.5
Soluble salts	The amount of soluble ions in a solution of compost and water	Varies widely according to source materials for compost, but should be < 10 deciSiemen per meter (millimhos per centimeter)
Organic matter	The amount of carbon-based materials	30-65% dry weight basis
Particle size	Size of particles	Pass through 1-inch screen or less
Biological contaminants	Pathogens (disease causing organisms) and weed seeds	Meet or exceed US EPA Class A standards, 40 CFR Section 503.32(2) levels
Physical contaminants	Man-made materials (like pieces of plastic or glass) that do not compose, also called 'inerts'	< 1% dry weight basis
Trace metals	Elements that can be toxic to humans, animals or plants	Meet or exceed standards for Class I compost set in Minn.R. 7035.2836, Subp. 6, (A)

Soil Amendment Ordinances

Introduce regulations whereby property owners and developers are required to provide soil amendments to any development or redevelopment site. King County, Washington, may have been the first local government to institute a clearing and grading ordinance that includes soil amendment requirements. The ordinance was first introduced in 2005 and was updated in December 2008. It serves as a good starting point for an MS4 ordinance.

"The topsoil layer shall be a minimum of eight inches thick, unless the applicant demonstrates that a different thickness will provide conditions equivalent to the soil moisture-holding capacity native to the site. The topsoil layer shall have an organic matter content of between five to ten percent dry weight and a pH suitable for the proposed landscape plants. When feasible, subsoils below the topsoil layer should be scarified at least four inches with some incorporation of the upper material to avoid stratified layers. Compost used to achieve the required soil organic matter content must meet the definition of "composted materials" in WAC 173-350-220."

Rice Creek Watershed District water quality and volume control rules are designed to account for loss of infiltration due to soil compaction during construction. As an incentive for soil amendments, the water quality and volume control benefits of compost amended soils are given credit in the rules. The District provides a corresponding soil amendment guidelines worksheet for permit applicants.

Monitoring and Assessment

The MS4 could engage in documenting the effectiveness of its soil amendment standards by conducting monitoring to see what water quality and other benefits are accomplished. Findings could provide feedback for standards/ordinance revisions.

Maintenance Considerations

Compost amended sites are maintained no differently than sites that have not been amended. However, less watering and fertilizer may be required, as well as less runoff management.

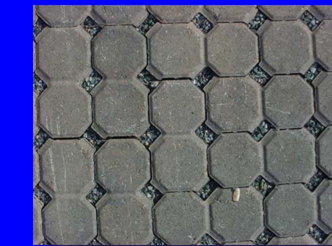
Typical Cost

Amending with compost is often the most economical way to uncompact and bring soils up to the desired soil organic matter content. On sites with the original, undisturbed, native soil and where space permits, stockpiling and reapplying topsoil may be less costly. Importing topsoil usually costs more than amending existing soil, although it may be easier where subsoil conditions make cultivation difficult. Reductions in the need for irrigation and fertilizer can provide payback for up front costs in the range of 2 to 7 years. Implementation of amended soils can also result in a cost savings due to reduced detention ponding requirements.

The adoption of a soil amendment ordinance requires an investment in training for the plan reviewer, the consultant, and possibly the public. MS4s must also consider the cost of enforcement, including staff and equipment requirements. Awareness campaign costs are determined by the type of materials produced and the method of distribution selected. Signs at city buffer installations may initially have a higher cost than printed materials, but can serve as a more effective tool for increasing public understanding.

PERMEABLE PAVEMENT

CVC/TRCA LOW IMPACT DEVELOPMENT PLANNING AND DESIGN GUIDE - FACT SHEET



GENERAL DESCRIPTION

Permeable pavements, an alternative to traditional impervious pavement, allow stormwater to drain through them and into a stone reservoir where it is infiltrated into the underlying native soil or temporarily detained. They can be used for low traffic roads, parking lots, driveways, pedestrian plazas and walkways. Permeable pavement is ideal for sites with limited space for other surface stormwater BMPs. Examples of permeable pavement types include:

- permeable interlocking concrete pavers (i.e., block pavers);
- plastic or concrete grid systems (i.e., grid pavers);
- pervious concrete; and
- porous asphalt.

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

DESIGN GUIDANCE

GEOMETRY & SITE LAYOUT

Permeable pavement systems can be used for entire parking lot areas or driveways or can be designed to receive runoff from adjacent impervious pavement. For example, the parking spaces of a parking lot or road can be permeable pavers while the drive lanes are impervious asphalt. In general, the impervious area should not exceed 1.2 times the area of the permeable pavement which receives the runoff (GVRD, 2005).

PRE-TREATMENT

In most permeable pavement designs, the pavement bedding layer acts as pretreatment to the stone reservoir below. Periodic vacuum sweeping and preventative measures like not storing snow or other materials on the pavement are critical to prevent clogging. An optional pretreatment element can be a pea gravel choking layer above the coarse gravel storage reservoir.

CONVEYANCE AND OVERFLOW

All designs require an overflow outlet connected to a storm sewer with capacity to convey larger storms. One option is to set storm drain inlets slightly above the surface elevation of the pavement, which allows for temporary shallow ponding above the surface. Another design option is an overflow edge, which is a gravel trench along the downgradient edge of the pavement surface that drains to the stone reservoir below.

Pavements designed for full infiltration, where native soil infiltration rate is 15 mm/hr or greater, do not require incorporation of a perforated pipe underdrain. Pavements designed for partial infiltration, where native soil infiltration rate is less than 15 mm/hr, should incorporate a perforated pipe underdrain placed near the top of the granular stone reservoir. Partial infiltration designs can also include a flow restrictor assembly on the underdrain to optimize infiltration with desired drawdown time between storm events.

MONITORING WELLS

A capped vertical standpipe consisting of an anchored 100 to 150 mm diameter perforated pipe with a lockable cap installed to the bottom of the facility is recommended for monitoring the length of time required to fully drain the facility between storms.

STONE RESERVOIR

The stone reservoir must be designed to meet both runoff storage and structural support requirements. Clean washed stone is recommended as any fines in the aggregate material will migrate to the bottom and may prematurely clog the native soil. The bottom of the reservoir should be flat so that runoff will be able to infiltrate evenly through the entire surface. If the system is not designed for infiltration, the bottom should be sloped at 1 to 5% toward the underdrain.

GEOTEXTILE

A non-woven needle punched, or woven monofilament geotextile fabric should be installed between the stone reservoir and native soil to maintain separation.

EDGE RESTRAINTS

Pavers must abut tightly against the restraints to prevent rotation under load and any consequent spreading of joints. The restraints must be able to withstand the impact of temperature changes, vehicular traffic and snow removal equipment. Metal or plastic stripping is acceptable in some cases, but concrete edges are preferred. Concrete edge restraints should be supported on a minimum base of 150 mm of aggregate.

LANDSCAPING

Adjacent landscaping areas should drain away from permeable pavement to prevent sediments from running onto the surface. Urban trees also benefit from being surrounded by permeable pavement rather than impervious cover, because their roots receive more air and water.

OPERATION AND MAINTENANCE

Annual inspections of permeable pavement should be conducted in the spring to ensure continued infiltration performance. Check for deterioration and whether water is draining between storms. The pavement reservoir should drain completely within 72 hours of the end of the storm event. The following maintenance procedures and preventative measures should be incorporated into a maintenance plan:

Surface Sweeping: Sweeping should occur once or twice a year with a commercial vacuum sweeping unit. Permeable pavement should not be washed with high pressure water systems or compressed air units.

Inlet Structures: Drainage pipes and structures within or draining to the subsurface bedding beneath permeable pavement should be cleaned out on regular intervals.

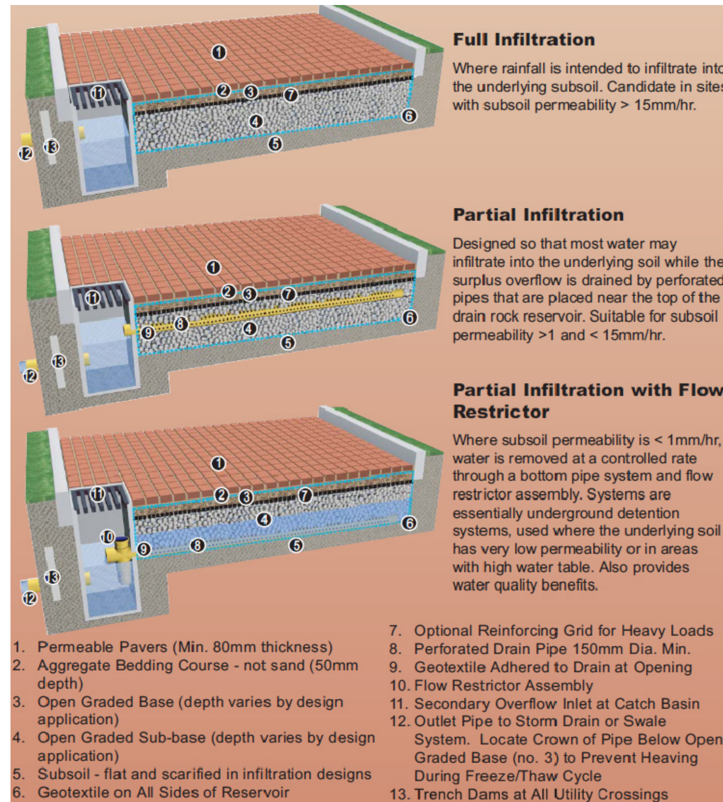
Heavy Vehicles: Trucks and other heavy vehicles should be prevented from tracking or spilling dirt onto the permeable pavement.

Construction and Hazardous Materials: Due to the potential for groundwater contamination, all construction or hazardous material carriers should be prohibited from entering a permeable pavement site.

Drainage Areas: Impervious areas contributing to the permeable pavement should be regularly swept and kept clear of litter and debris. Flows from any landscaped areas should be diverted away from thepavement or be well stabilized with vegetation.

Grid Pavers: Grid paver systems that have been planted with grass should be mowed regularly with the clippings removed. Grassed grid pavers may require periodic watering and fertilization to establish and maintain healthy vegetation.

Winter Maintenance: Sand should not be spread on permeable pavement as it can quickly lead to clogging. Deicers should only be used in moderation and only when needed. Pilot studies have found that permeable pavement requires 75% less de-icing salt than conventional pavement over the course of a typical winter season. Permeable pavement is plowed for snow removal like any other pavement. Plowed snow piles should not be stored on permeable pavement systems.



Source: GVRD

ABILTY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Permeable pavement with no underdrain	Yes	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate
Permeable pavement with underdrain	Moderate - based on native soil infiltration rates and storage beneath the underdrain	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate
Permeable pavement with underdrain and liner	No - some volume reduction occurs through evapotranspiration	Moderate - limited filtering and settling of sediments	Partial - based on available storage volume and soil infiltration rate

GENERAL SPECIFICATIONS

Material	Specification	Quantity
Pervious Concrete	• NO4-RG-S7 mix with air entrainment proven to have the best freeze-thaw durability after 300 freeze-thaw cycles. • 28 day compressive strength = 5.5 to 20 MPa • Void ratio = 14% - 31% • Permeability = 900 to 21,500 mm/hr	Thickness will range from 100mm - 150 mm depending on the expected loads
Porous Asphalt	• Open-graded asphalt mix with a minimum of 16% air voids • Polymers can be added to provide additional strength for heavy loads • The University of New Hampshire Stormwater Center has detailed design specifications for porous asphalt on their webpage: http://www.unh.edu/erg/cstev/pubs_specs_info	Thickness will range from 50 mm to 100 mm depending on the expected loads.
Permeable Pavers	• Permeable pavers should conform to manufacturer specifications. • ASTM No. 8 (5 mm dia.) crushed aggregate is recommended for fill material in the paver openings. For narrow joints between interlocking shapes, a smaller sized aggregate may be used (Smith, 2006). • Pavers shall meet the minimum material and physical properties set forth in CAN 3-A231.2, Standard Specification for Precast Concrete Pavers. • Pigment in concrete pavers shall conform to ASTM C 979. • Maximum allowable breakage of product is 5%.	For vehicular applications, the minimum paver thickness is 80 mm and for pedestrian applications is 60 mm. Joint widths should be no greater than 15 mm for pedestrian applications.
Stone Reservoir	All aggregates should meet the following criteria: • Maximum wash loss of 0.5% • Minimum durability index of 35 • Maximum abrasion of 10% for 100 revolutions and maximum of 50% for 500 revolutions <u>Granular Subbase</u> The granular subbase material shall consist of granular material graded in accordance with ASTM D 2940. Material should be clear crushed 50 mm diameter stone with void space ratio of 0.4. <u>Granular Base</u> The granular base material shall be crushed stone conforming to ASTM C 33 No 57. Material should be clear crushed 20 mm diameter stone. <u>Bedding</u> The granular bedding material shall be graded in accordance with the requirements of ASTM C 33 No 8. The typical bedding thickness is between 40 mm and 75 mm. Material should be 5 mm diameter stone or as determined by the Design Engineer (Smith, 2006).	See BMP Sizing section for aggregate bed depth and multiply by application are to get total volume.
Geotextile	Material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. Primary considerations are: • Suitable apparent opening size (AOS) for non-woven fabrics, or percent open area (POA) for woven fabrics, to maintain water flow even with sediment and microbial film build-up; • Maximum forces that will be exerted on the fabric (i.e., what tensile, tear and puncture strength ratings are required?); • Load bearing ratio of the underlying native soil (i.e., is geotextile needed to prevent downward migration of aggregate into the native soil?); • Texture (i.e., grain size distribution) of the overlying aggregate material; and • Permeability of the native soil. For further guidance see CVC/TRCA LID SWM Planning and Design Guide, Table 4.7.3.	Between stone reservoir and native soil.
Underdrain (optional)	• HDPE or equivalent material, continuously perforated with smooth interior and a minimum inside diameter of 100 mm. • Perforations in pipes should be 10 mm in diameter. • A standpipe from the underdrain to the pavement surface can be used for monitoring and maintenance of the underdrain. The top of the standpipe should be covered with a screw cap and a vandal-proof lock.	Pipes should terminate 0.3 m short from the sides of the base.

SITE CONSIDERATIONS

Wellhead Protection

Permeable pavement should not be used for road or parking surfaces within two (2) year time-of-travel wellhead protection areas.

Site Topography

Permeable pavement surface should be at least 1% and no greater than 5%.

Water Table

The base of permeable pavement stone reservoir should be at least one (1) metre above the seasonally high water table or top of bedrock elevation.

Soil

Systems located in native soils with an infiltration rate of less than 15 mm/hr (i.e., hydraulic conductivity of less than 1x10-6 cm/s) require a perforated pipe underdrain. Native soil infiltration rate at the proposed location and depth should be confirmed through measurement of hydraulic conductivity under field saturated conditions.

Drainage Area & Runoff Volume

In general, the impervious area treated should not exceed 1.2 times the area of permeable pavement which receives the runoff.

Setback from Buildings

Should be located downslope from building foundations. If the pavement does not receive runoff from other surfaces, no setback is required. If the pavement receives runoff from other surfaces a minimum setback of four (4) metres downgradient is recommended.

Pollution Hot Spot Runoff

To protect groundwater from possible contamination, runoff from pollution hot spots should not be treated by permeable pavement.

CONSTRUCTION CONSIDERATIONS

SEDIMENT CONTROL

The treatment area should be fully protected during construction so that no sediment reaches the permeable pavement system. Construction traffic should be blocked from the permeable pavement and its drainage areas once the pavement has been installed.

BASE CONSTRUCTION

In parking lots, the stone aggregate should be placed in 100 mm to 150 mm lifts and compacted with a minimum 9,070 kg (10 ton) steel drum roller.

WEATHER

Porous asphalt and pervious concrete will not properly pour and set in extremely high and low temperatures.

PAVEMENT PLACEMENT

Properly installed permeable pavement requires trained and experienced producers and construction contractors.

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.7 OF THE CVC/TRCA LID SWM GUIDE

DOWNSPOUT DISCONNECTION

CVC/TRCA LOW IMPACT DEVELOPMENT PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

Simple downspout disconnection involves directing flow from roof downspouts to a pervious area that drains away from the building. This prevents stormwater from directly entering the storm sewer system or flowing across a "connected" impervious surface, such as a driveway, that drains to a storm sewer. Simple downspout disconnection requires a minimum flow path length across the pervious area of 5 metres.





DESIGN GUIDANCE

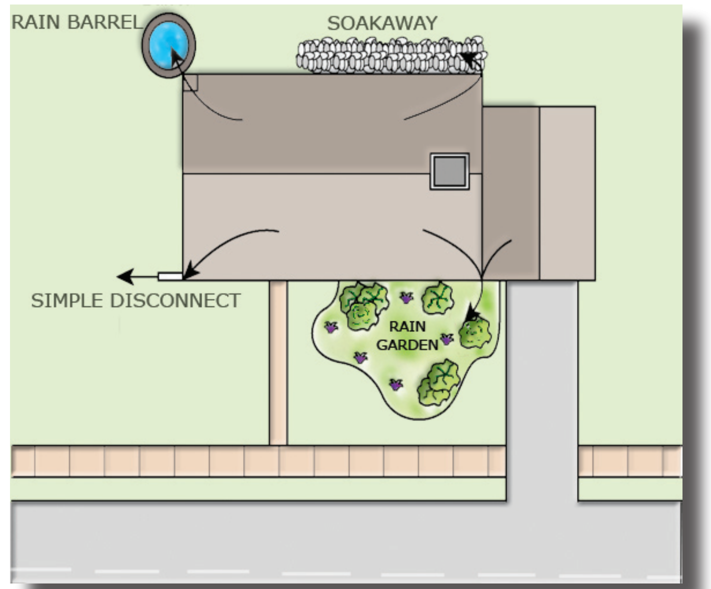
Roof downspout disconnections should meet the following criteria:

- Pervious areas used for downspout disconnection should be graded to have a slope of between 1 to 5%;
- Pervious areas should slope away from the building;
- The flow path length across the pervious area should be 5 metres or greater;
- The infiltration rate of soils in the pervious area should be 15 mm/hr or greater (i.e., hydraulic conductivity of 1x10-6 cm/s or greater);
- If infiltration rate of the soil in the pervious area is less than 15 mm/hr, it should be tilled to a depth of 300 mm and amended with compost to achieve a ratio of 8 to 15% organic content by weight or 30 to 40% by volume;
- If the flow path length across the pervious area is less than 5 metres and the soils are hydrologic soil group C or D, roof runoff should be directed to another LID practice (e.g., rainwater harvesting system, bioretention area, swale, soakaway, perforated pipe system);
- The total roof area contributing drainage to any single downspout discharge location should not exceed 100 square metres; and,
- A level spreading device (e.g., pea gravel diaphragm) or energy dissipating device (e.g., splash pad) should be placed at the downspout discharge location to distribute runoff as evenly as possible over the pervious area.

APPLICATIONS

There are many options for keeping roof runoff out of the storm sewer system. Some of the options are as follows:

- Simple roof downspout disconnection to a pervious area or vegetated filter strip, where sufficient flow path length across the pervious area and suitable soil conditions exist;
- Roof downspout disconnection to a pervious area or vegetated filter strip that has been tilled and amended with compost to improve soil infiltration rate and moisture storage capacity;
- Directing roof runoff to an enhanced grass swale, dry swale, bioretention area, soakaway or perforated pipe system;
- Directing roof runoff to a rainwater harvesting system (e.g., rain barrel or cistern) with overflow to a pervious area, vegetated filter strip, swale, bioretention area, soakaway or permeable pavement.



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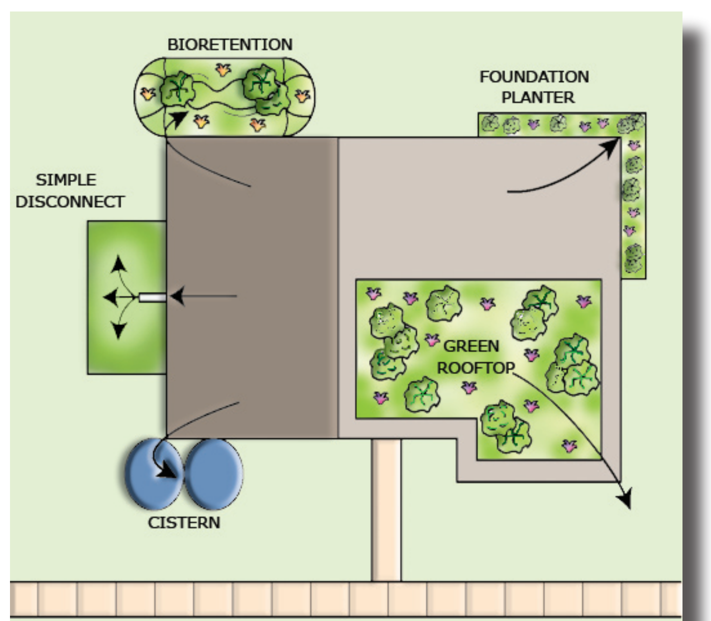


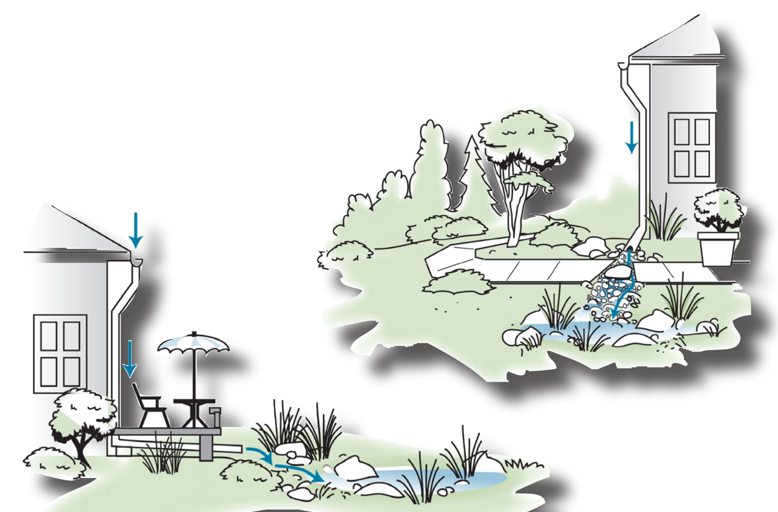
COMMERCIAL

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benfit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Downspout Disconnection	Partial - depends on soil infiltration rate and length of flow path over the pervious area	Partial - depends on soil infiltration rate and length of flow path over the pervious area	Partial - depends on combination with other practices

Downspout disconnection is primarily a practice used to help achieve water balance benefits, although it can also contribute to water quality improvement. Very limited research has been conducted on the runoff reduction benefits of downspout disconnection, so initial estimates are drawn from research on filter strips, which operate in a similar manner. The research indicates that runoff reduction is a function of soil type, slope, vegetative cover and filtering distance. A conservative runoff reduction rate is 25% for hydrologic soil group (HSG) C and D soils and 50% for HSG A and B soils.* These values apply to disconnections that meet the feasibility criteria outlined in this section, and do not include any further runoff reduction due to the use of compost amendments along the filter path.

*Hydrologic soil group (HSG) classifications are based on the ability of the soil to transmit water. Soil groups are ranked from A to D. Group A soils are sandy, loamy sand, or sandy loam types. Group B soils are silt loam or loam types, Group C soils are sandy clay loam types. Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay types



OVERVIEW

SITE CONSIDERATIONS

Site Topography
Disconnected downspouts should discharge to a gradual slope that conveys runoff away from the building. The slope should be between 1% and 5%. Grading should discourage flow from reconnecting with adjacent impervious surfaces.

Water Table
Roof downspouts should only be disconnected where the minimum depth to the seasonally high water table is at least one (1) metre below the surface.

Pollution Hot Spot Runoff
Downspout disconnection can be used where land uses or activities at ground-level have the potential to generate highly contaminated runoff (e.g., vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites) as long as the roof runoff is kept separate from runoff from ground-level impervious surfaces.

COMMON CONCERNS

- **ON PRIVATE PROPERTY**
  Property owners or managers will need to be educated on its function and maintenance needs, and may be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer could be used to encourage property owners or managers to maintain existing practices.
- **STANDING WATER AND PONDING**
  Downspout disconnection is not intended to pond water, so any standing water should be infiltrated or evaporated within 24 hours of the end of each runoff event. If ponding for longer than 24 hours occurs, mitigation actions noted under Operation and Maintenance should be undertaken.

CONSTRUCTION CONSIDERATIONS

SOIL DISTURBANCE AND COMPACTION
Only vehicular traffic necessary for construction should be allowed on the pervious areas to which roof downspouts will be discharged. If vehicle traffic is unavoidable, then the pervious area should be tilled to a depth of 300 mm to loosen the compacted soil.

EROSION AND SEDIMENT CONTROL
If possible, construction runoff should be directed away from the proposed downspout discharge location. After the contributing drainage area and the downspout discharge location are stabilized and vegetated, erosion and sediment control structures can be removed.

OPERATION AND MAINTENANCE

Maintenance of disconnected downspouts will generally be no different than for lawns or landscaped areas. A maintenance agreement with property owners or managers may be required to ensure that downspouts remain disconnected and the pervious area remains pervious. For long-term efficacy, the pervious area should be protected from compaction. One method is to plant shrubs or trees along the perimeter of the pervious area to prevent traffic. On commercial sites, the pervious area should not be an area with high foot traffic. If ponding of water for longer than 24 hours occurs, the pervious area should be dethatched and aerated. If ponding persists, regrading or tilling to reverse compaction and/or addition of compost to improve soil moisture retention may be required.

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.3 OF THE CVC/TRCA LID SWM GUIDE

GENERAL DESCRIPTION

Green roofs, also known as "living roofs" or "rooftop gardens", consist of a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof. Green roofs are touted for their benefits to cities, as they improve energy efficiency, reduce urban heat island effects, and create greenspace for passive recreation or aesthetic enjoyment. They are also attractive for their water quality, water balance, and peak flow control benefits. The green roof acts like a lawn or meadow by storing rainwater in the growing medium and ponding areas. Excess rainfall enters underdrains and overflow points and is conveyed in the building drainage system. After the storm, a large portion of the stored water is evapotranspired by the plants, evaporates or slowly drains away.

There are two types of green roofs: intensive and extensive. Intensive green roofs contain greater than 15 cm depth of growing medium, can be planted with deeply rooted plants and are designed to handle pedestrian traffic. Extensive green roofs consist of a thinner growing medium layer (15 cm depth or less) with herbaceous vegetative cover. Guidance here focuses on extensive green roofs.

DESIGN GUIDANCE

ROOF STRUCTURE

The load bearing capacity of the roof structure must be sufficient to support the soil and plants of the green roof assembly, as well as the live load associated with maintenance staff accessing the roof. A green roof assembly weighing more than 80 kg per square metre, when saturated, requires consultation with a structural engineer. Green roofs may be installed on roofs with slopes up to 10%. As a fire resistance measure, non-vegetative materials, such as stone or pavers should be installed around all roof openings and at the base of all walls that contain openings.

WATERPROOFING SYSTEM

The first layer above the roof surface is a waterproofing membrane. Two common waterproofing techniques are monolithic and thermoplastic sheet membranes. Another option is a liquid-applied inverted roofing membrane assembly system in which the insulation is placed over the waterproofing, which adheres to the roof structure. An additional protective layer is generally placed on top of the membrane followed by a physical or chemical root barrier. Once the waterproofing system has been installed it should be fully tested prior to construction of the drainage system. Electronic leak detection systems should also be installed at this time if desired.

DRAINAGE LAYER

The drainage system includes a porous drainage layer and a geosynthetic filter mat to prevent fine growing medium particles from clogging the porous media. The drainage layer can be made up of gravels or recycled-polyethylene materials that are capable of water retention and efficient drainage. The depth of the drainage layer depends on the load bearing capacity of the roof structure and the stormwater retention requirements. The porosity of the drainage layer should be greater than or equal to 25%.

CONVEYANCE AND OVERFLOW

Once the porous media is saturated, all runoff (infiltrate or overland flow) should be directed to a traditional roof storm drain system. Landscaping style catch basins should be installed with the elevation raised to the desired ponding elevation. Alternately, roof drain flow restrictors can be used. Excess runoff can be directed through roof leaders to another stormwater BMP such as a rain barrel, soakaway, bioretention area, swale or simply drain to a pervious area.

GROWING MEDIUM

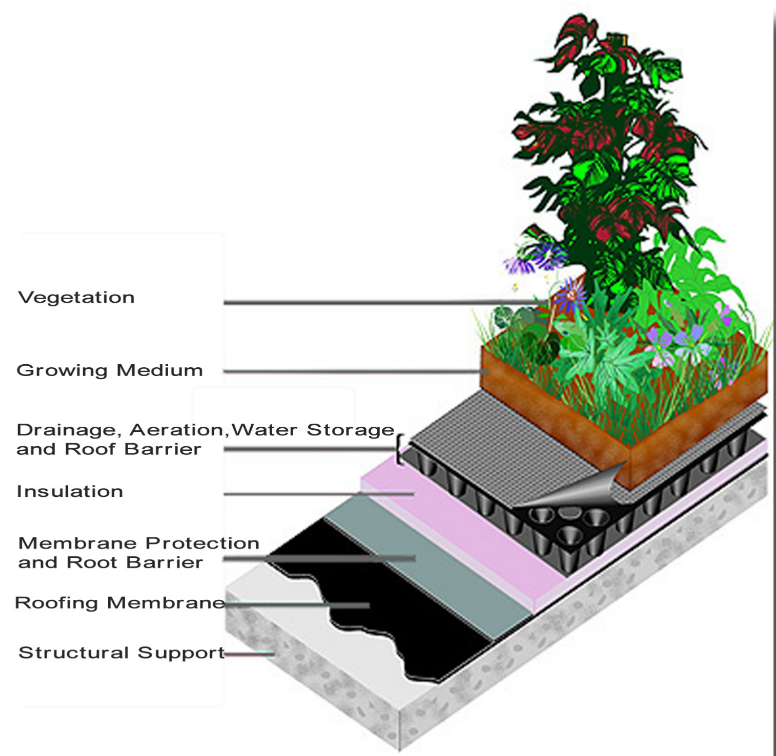
The growing medium is usually a mixture of sand, gravel, crushed brick, compost, or organic matter combined with soil. The medium ranges between 40 and 150 mm in depth and increases the roof load by 80 to 170 kg per square metre when fully saturated. The sensitivity of the receiving water to which the green roof ultimately drains should be taken into consideration when selecting the growing medium mix. Green roof growing media with less compost in the mix will leach less nitrogen and phosphorus. Low nutrient growing media also promotes the dominance of stress-tolerant native plants. Fertilizer applied to the growing medium during production and the period during which vegetation is becoming established should be coated controlled release fertilizer to reduce the risk of damage to vegetation and leaching of nutrients into overflowing runoff. Fertilizer applications should not exceed 5 g of nitrogen per square metre.

MODULAR SYSTEMS

Modular systems are trays of vegetation in a growing medium that are prepared and grown off-site and placed on the roof for complete coverage. There are also pre-cultivated vegetation blankets that are grown in flexible growing media structures, allowing them to be rolled out onto the green roof assembly. The advantage of these systems is that they can be removed for maintenance.

Green Rooftops are composed of:

- A roof structure capable of supporting the weight of a green roof system;
- A waterproofing system designed to protect the building and roof structure;
- A drainage layer that consists of a porous medium capable of water storage for plant uptake;
- A geosynthetic layer to prevent fine soil media from clogging the porous media;
- Soil with appropriate characteristics to support selected green roof plants;
- Plants with appropriate tolerance for harsh rooftop conditions and shallow rooting depths.



GREEN ROOF LAYERS
(Source: Great Lakes Water Institute)

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Green Rooftops	Yes	Yes	Yes

GENERAL SPECIFICATIONS

ASTM International released the following Green Roof standards in 2005:

- E2396-05 Standard Test Method for Saturated Water Permeability of Granular Drainage Media;
- E2397-05 Standard Determination of Dead Loads and Live Loads associated with Green Roof Systems;
- E2398-05 Standard test method for water capture and media retention of geocomposite drain layers for green roof systems;
- E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems; and
- E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems.

Although the Ontario Building Code (2006) does not specifically address the construction of green roofs, requirements from the Building Code Act and Division B may apply to components of the construction. Further requirements from sections 2.4 and 2.11 of the 1997 Ontario Fire Code also require consideration.

COMMON CONCERNS

WATER DAMAGE TO ROOF

While failure of waterproofing elements may present a risk of water damage, a warranty can ensure that any damage to the waterproofing system will be repaired. Leak detection systems can also be installed to minimize or prevent water damage.

VEGETATION MAINTENANCE

Extreme weather conditions can have an impact on plant survival. Appropriate plant selection will help to ensure plant survival during weather extremes. Irrigation during the first year may be necessary in order to establish vegetation. Vegetation maintenance costs decrease substantially after the first two years.

COLD CLIMATE

Green roofs are a feasible BMP for cold climates. Snow can protect the vegetation layer and once thawed, will percolate into the growing medium and is either absorbed or drained away just as it would during a rain event. No seasonal adjustments in operation are needed.

COST

An analysis to determine cost effectiveness for a given site should include the roof lifespan, energy savings, stormwater management requirements, aesthetics, market value, tax and other municipal incentives. It is estimated that green roofs can extend the life of a roof structure by as long as 20 years by reducing exposure of the materials to sun and precipitation. They can also reduce energy demand by as much as 75% .

ON PRIVATE PROPERTY

Property owners or managers will need to be educated on their routine operation and maintenance needs, understand the long-term maintenance plan, and may be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer could be used to encourage property owners or managers to maintain existing practices.

CONSTRUCTION CONSIDERATIONS

An experienced professional green roof installer should install the green roof. The installer must work with the construction contractor to ensure that the waterproofing membrane installed is appropriate for use under a green roof assembly. Conventional green roof assemblies should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Green roofs can be purchased as complete systems from specialized suppliers who distribute all the assembly components, including the waterproofing membrane. Alternatively, a green roof designer can design a customized green roof and specify suppliers for each component of the system.

OPERATION AND MAINTENANCE

- Green roof maintenance is typically greatest in the first two years as plants are becoming established. Vegetation should be monitored to ensure dense coverage. A warranty on the vegetation should be included in the construction contract.
- Regular operation of a green roof includes irrigation and leak detection. Watering should be based on actual soil moisture conditions as plants are designed to be drought tolerant. Electronic leak detection is recommended. This system, also used with traditional roofs, must be installed prior to the green roof.
- Ongoing maintenance should occur at least twice per year and should include weeding to remove volunteer seedlings of trees and shrubs and debris removal. In particular, the overflow conveyance system should be kept clear.

SITE CONSIDERATIONS

Roof Slope
Green roofs may be installed on roofs with slopes up to 10%.

Drainage Area & Runoff Volume
Green roofs are designed to capture precipitation falling directly onto the roof surface. They are not designed to receive runoff diverted from other source areas.

Structural Requirements
Load bearing capacity of the building structure and selected roof deck need to be sufficient to support the weight of the soil, vegetation and accumulated water or snow, and may also need to support pedestrians, concrete pavers, etc.

CVC/TRCA LOW IMPACT DEVELOPMENT
PLANNING AND DESIGN GUIDE - FACT SHEET

GREEN ROOFS

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.2 OF THE CVC/TRCA LID SWM GUIDE

VEGETATED FILTER STRIPS

CVC/TRCA LOW IMPACT DEVELOPMENT PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

Vegetated filter strips (a.k.a. buffer strips and grassed filter strips) are gently sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious areas. They slow runoff velocity and filter out suspended sediment and associated pollutants, and provide some infiltration into underlying soils. Originally used as an agricultural treatment practice, filter strips have evolved into an urban SWM practice. Vegetation may be comprised of a variety of trees, shrubs and native plants to add aesthetic value as well as water quality benefits. With proper design and maintenance, filter strips can provide relatively high pollutant removal benefits. Maintaining sheet flow into the filter strip through the use of a level spreading device (e.g., pea gravel diaphragm) is essential. Using vegetated filter strips as pretreatment practices to other best management practices is highly recommended. They also provide a convenient area for snow storage and treatment, and are particularly valuable due to their capacity for snowmelt infiltration.

DESIGN GUIDANCE

GEOMETRY AND SITE LAYOUT

The maximum contributing flow path length across adjacent impervious surfaces should not exceed 25 metres. The impervious surfaces draining to a filter strip should not have slopes greater than 3%.

The filter strip should have a flow path length of at least five (5) metres to provide substantial water quality benefits; however, some pollutant removal benefits are realized with three (3) metres of flow path length.

PRETREATMENT

A pea gravel diaphragm at the top of the slope is recommended to act as a pretreatment device and level spreader to maintain sheet flow into the filter strip.

CONVEYANCE AND OVERFLOW

Level spreaders are recommended to ensure runoff draining into the filter strip does so as sheet flow (e.g., pea gravel diaphragms, concrete curbs with cutouts). When filter strip slopes are greater than 5%, a series of level spreaders should be used to help maintain sheet flow.

When designed as a stand alone water quality BMP (i.e., not pretreatment to another BMP) the vegetated filter strip should be designed with a pervious berm at the toe of the slope for shallow ponding of runoff. The berm should be 150 to 300 millimetres in height above the bottom of the depression and should contain a perforated pipe underdrain connected to the storm sewer. The volume ponded behind the berm should be equal to the water quality storage requirement. During larger storms, runoff overtops the berm and flows directly into a storm sewer inlet.

SOIL AMENDMENTS

If soils on the filter strip site are highly compacted, or of such low fertility that vegetation cannot become established, they should be tilled to a depth of 300 mm and amended with compost to achieve an organic content of 8 to 15% by weight or 30 to 40% by volume.

OPERATION AND MAINTENANCE

Generally, routine maintenance will be the same as for any other landscaped area; weeding, pruning, and litter removal. Regular watering may be required during the first two years until vegetation is established. Routine inspection is very important to ensure that dense vegetation cover is maintained and inflowing runoff does not become concentrated and short circuit the practice. Vehicles should not be parked or driven on filter strips. For routine mowing of grassed filter strips, the lightest possible mowing equipment should be used to prevent soil compaction.

For the first two years following construction the filter strip should be inspected at least quarterly and after every major storm event (> 25 mm). Subsequently, inspections should be conducted in the spring and fall of each year and after major storm events. Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.

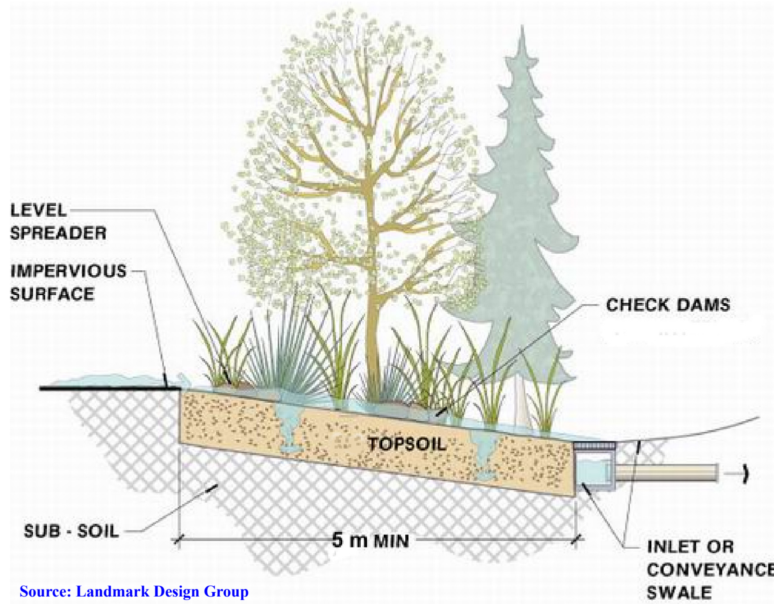
Trash and debris should be removed from pretreatment devices and the filter strip surface at least twice annually. Other maintenance activities include weeding, replacing dead vegetation, repairing eroded areas, dethatching and aerating as needed. Remove accumulated sediment on the filter strip surface when dry and exceeding 25 mm depth


Source: Trinkaus Engineering


Source: Wisconsin Department of Natural Resources

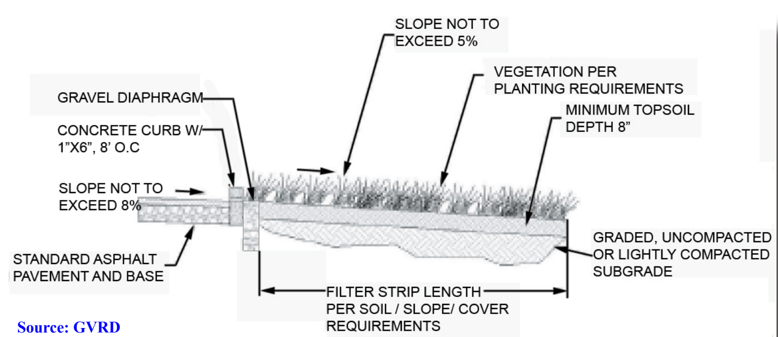

Source: Wisconsin Department of Natural Resources


Source: Washington State Department of Transportation

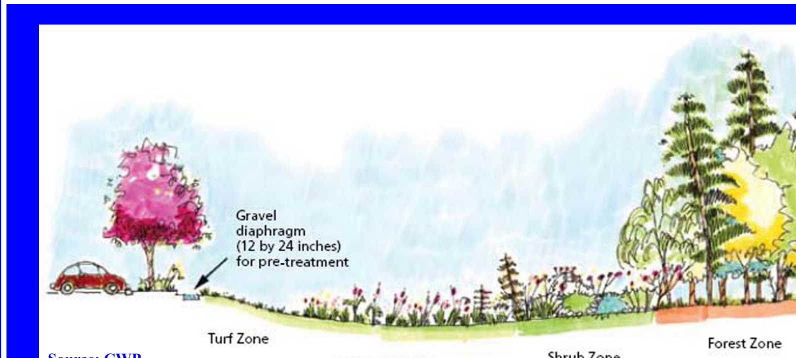


Source: Landmark Design Group

VEGETATED FILTER STRIPS



Source: GVRD



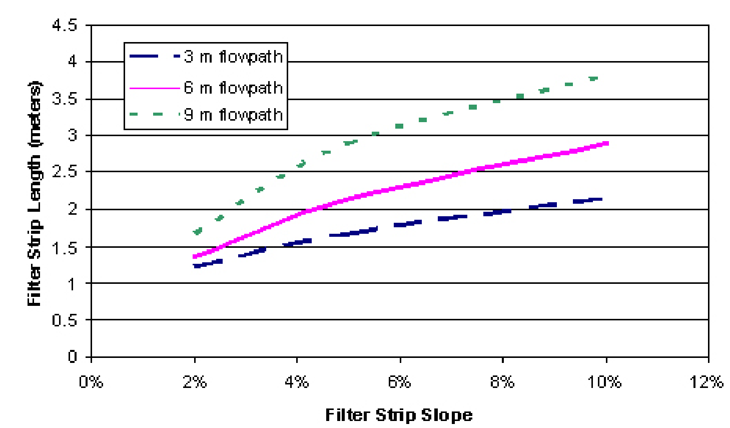
Source: CWP

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Vegetated Filter Strips	Partial - depends on soil infiltration rate	Partial - depends on soil infiltration rate and flow path length	Partial - depends on soil infiltration rate

GENERAL SPECIFICATIONS

Material	Specification	Quantity
Gravel Diaphragm	Washed 3 to 10 mm diameter stone	Diaphragm should be a minimum of 300 mm wide and 600 mm deep (MDE, 2000).
Gravel/ Earthen Berm	Berm should be composed of sand (35 to 60%), silt (30 to 55%), and gravel (10 to 25%) (MDE, 2000) Gravel should be 15 to 25 mm in diameter.	N/A



Source: Pennsylvania Department of Environmental Protection

CONSTRUCTION CONSIDERATIONS

Soil Disturbance and Compaction

The limits of disturbance should be clearly shown on all construction drawings. Before site work begins, areas for filter strips should be clearly marked and protected by acceptable signage and silt fencing. Only vehicular traffic used for construction should be allowed within three metres of the filter strip.

Erosion and Sediment Control

Construction runoff should be directed away from the proposed filter strip site. If used for sediment control during construction, it should be regraded and revegetated after construction is finished.

SITE CONSIDERATIONS

Available Space

The flow path length across the vegetated filter strip should be at least 5 metres to provide substantial water quality benefits. Vegetated filter strips incorporated as pretreatment to another BMP may be designed with shorter flow path lengths.

Site Topography

Filter strips are best used to treat runoff from ground-level impervious surfaces that generate sheet flow (e.g., roads and parking areas). The recommended filter strip slope is between 1 to 5%.

Flow Path Length Across Impermeable Surface

The maximum flow path length across the contributing impermeable surface should be less than 25 metres.

Soil

Filter strips are a suitable practice on all soil types. If soils are highly compacted, or of such low fertility that vegetation cannot become established, they should be tilled to a depth of 300 mm and amended with compost to achieve an organic content of 8 to 15% by weight or 30 to 40% by volume.

Pollution Hot Spot Runoff

To protect groundwater from possible contamination, source areas where land uses or human activities have the potential to generate highly contaminated runoff (e.g., vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites) should not be treated by vegetated filter strips.

Water table

Filter strips should only be used where depth to the seasonally high water table is at least one (1) metre below the ground surface.

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

DRY SWALES

CVC/TRCA LOW IMPACT DEVELOPMENT
PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

A dry swale can be thought of as an enhanced grass swale that incorporates an engineered filter media bed and optional perforated pipe underdrain or a bioretention cell configured as a linear open channel. They can also be referred to as infiltration swales or bio-swales. Dry swales are similar to enhanced grass swales in terms of the design of their surface geometry, slope, check dams and pretreatment devices. They are similar to bioretention cells in terms of the design of the filter media bed, gravel storage layer and optional underdrain. In general, they are open channels designed to convey, treat and attenuate stormwater runoff. Vegetation or aggregate material on the surface of the swale slows the runoff water to allow sedimentation, filtration through the root zone and engineered soil bed, evapotranspiration, and infiltration into the underlying native soil.

DESIGN GUIDANCE

GEOMETRY AND SITE LAYOUT

- SHAPE: A parabolic shape is preferable for aesthetic, maintenance and hydraulic reasons. However, design may be simplified with a trapezoidal cross-section as long as the engineered soil (filter media) bed boundaries lay in the flat bottom areas. Swale length between culverts should be 5 metres or greater.
- BOTTOM WIDTH: For the trapezoidal cross section, the bottom width should be between 0.75 and 2 metres. When greater widths are desired, bioretention cell designs should be used.
- SIDE SLOPES: Should be no steeper than 3:1 for maintenance considerations (mowing). Flatter slopes are encouraged where adequate space is available to provide pretreatment for sheet flows entering the swale.
- LONGITUDINAL SLOPE: Should be as gradual as possible to permit the temporary ponding of the water quality storage requirement. Should be designed with longitudinal slopes generally ranging from 0.5 to 4%, and no greater than 6%. On slopes steeper than 3%, check dams should be used. Check dam spacing should be based on the slope and desired ponding volume. They should be spaced far enough apart to allow access for maintenance equipment (e.g., mowers).

PRE-TREATMENT

Pretreatment prevents premature clogging by capturing coarse sediments before they reach the filter bed. Where runoff source areas produce little sediment, such as roofs, dry swales can function effectively without pretreatment. To treat parking area or road runoff, a two-cell design that incorporates a forebay is recommended. Pretreatment practices that may be feasible, depending on conveyance method and availability of space include:

- SEDIMENTATION FOREBAY (TWO-CELL DESIGN): Forebay ponding volume should account for 25% of the water quality storage requirement and be designed with a 2:1 length to width ratio.
- VEGETATED FILTER STRIP (SHEET FLOW): Should ideally be a minimum of three (3) metres in width. If smaller strips are used, more frequent maintenance of the filter bed can be anticipated.
- GRAVEL DIAPHRAGM (SHEET FLOW): A small trench filled with pea gravel, which is perpendicular to the flow path between the edge of the pavement and the dry swale will promote settling out of sediment and maintain sheet flow into the facility. A drop of 50-150 mm into the gravel diaphragm can be used to dissipate energy and promote settling.
- RIP RAP AND/OR DENSE VEGETATION (CHANNEL FLOW): Suitable for small dry swales with drainage areas less than 100 square metres.

GRAVEL STORAGE LAYER

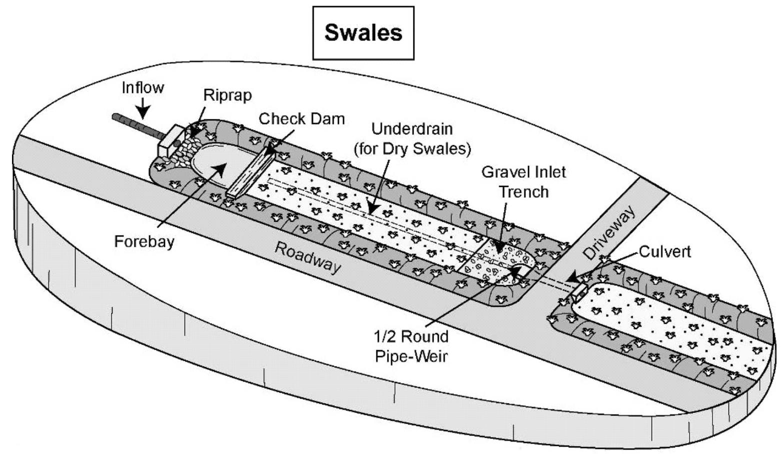
- DEPTH: Should be a minimum of 300 mm deep and sized to provide the required storage volume. Granular material should be 50 mm diameter clear stone.
- PEA GRAVEL CHOKING LAYER: A 100 mm deep layer of pea gravel (3 to 10 mm diameter clear stone) should be placed on top of the coarse gravel storage layer as a choking layer separating it from the overlying filter media bed.

FILTER MEDIA

- COMPOSITION: To ensure a consistent and homogeneous bed, filter media should come pre-mixed from an approved vendor.
- DEPTH: Recommended depth is between 1.0 and 1.25 m. However in constrained applications, pollutant removal benefits may be achieved in beds as shallow as 500 mm. If trees are to be included in the design, bed depth must be at least 1.0 m.
- MULCH: A 75 mm layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth and pretreats runoff before it reaches the filter bed.

UNDERDRAIN

- Only needed where native soil infiltration rate is less than 15 mm/hr (hydraulic conductivity of less than 1x10-6 cm/s).
- Should consist of a perforated pipe embedded in the coarse gravel storage layer at least 100 mm above the bottom.
- A strip of geotextile filter fabric placed between the filter media and pea gravel choking layer over the perforated pipe is optional to help prevent fine soil particles from entering the underdrain.
- A vertical standpipe connected to the underdrain at the furthest downstream end of the swale can be used as a cleanout and monitoring well.



ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Dry swale with no underdrain or full infiltration	Yes	Yes - size for water quality storage requirement	Partial - based on available storage volume and soil infiltration rate
Dry swale with underdrain or partial infiltration	Partial - based on available storage volume beneath the underdrain and soil infiltration rate	Yes - size for water quality storage requirement	Partial - based on available storage volume beneath the underdrain and soil infiltration rate
Dry swale with underdrain and impermeable liner or no infiltration	Partial - some volume reduction through evapotranspiration	Yes - size for water quality storage requirement	Partial - some volume reduction through evapotranspiration

OPERATION AND MAINTENANCE

Dry swales require routine inspection and maintenance of the landscaping as well as periodic inspection for less frequent maintenance needs or remedial maintenance. Generally, routine maintenance will be the same as for any other landscaped area; weeding, pruning, and litter removal. Regular watering may be required during the first two years until vegetation is established.

For the first two years following construction the facility should be inspected at least quarterly and after every major storm event (> 25 mm). Subsequently, inspections should be conducted in the spring and fall of each year and after major storm events. Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.

Trash and debris should be removed from pretreatment devices, the dry swale surface and inlet and outlets at least twice annually. Other maintenance activities include reapplying mulch, pruning, weeding replacing dead vegetation and repairing eroded areas as needed. Remove accumulated sediment on the dry swale surface when dry and exceeding 25 mm depth.

CONVEYANCE AND OVERFLOW

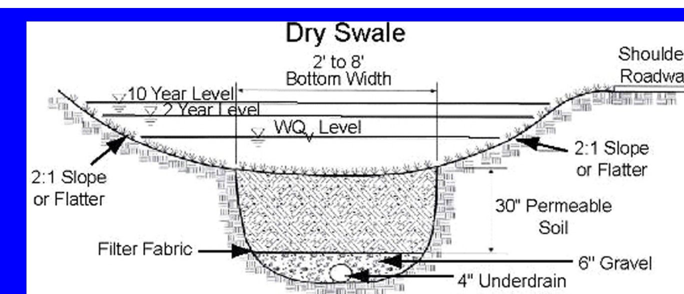
Should be designed for a maximum velocity of 0.5 m/s or less for a 4 hour 25 mm Chicago storm event. The swale should also convey the locally required design storm (usually the 10 year storm) at non-erosive velocities with freeboard provided above the required design storm water level.

MONITORING WELLS

A capped vertical standpipe consisting of an anchored 100 to 150 millimetre diameter perforated pipe with a lockable cap installed to the bottom of the facility at the furthest downgradient end is recommended for monitoring the length of time required to fully drain the facility between storms.

GENERAL SPECIFICATIONS

Material	Specification	Quantity
Filter Media Composition	Filter Media Soil Mixture to contain: • 85 to 88% sand • 8 to 12% soil fines • 3 to 5% organic matter (leaf compost) Other Criteria: • Phosphorus soil test index (P-Index) value between 10 to 30 ppm • Cationic exchange capacity (CEC) greater than 10 meq/100 g • Free of stones, stumps, roots and other large debris • pH between 5.5 to 7.5 • Infiltration rate greater than 25 mm/hr.	Volumetric computation based on surface area and depth used in design computations
Geotextile	Material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. For further guidance see CVC/TRCA LID SWM Planning and Design Guide, Table 4.9.4.	Strip over the perforated pipe underdrain (if present) between the filter media bed and gravel storage layer (stone reservoir).
Gravel	Washed 50 mm diameter clear stone with void space ratio of 0.4 should be used to surround the underdrain.	Volumetric computation based on depth.
Underdrain (optional)	Perforated HDPE or equivalent material, minimum 100 mm dia., 200 mm dia. recommended. Set pipe invert at least 100 mm above bottom of the gravel layer.	• Perforated pipe for length of dry swale. • Non-perforated pipe to connect with storm drain system. • One or more caps. • T's for underdrain
Check Dams	• Should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete and underlain with filter fabric. • Wood used should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.	Computation of check dam material needed based on surface area and depth used in design computations
Mulch or Matting	• Shredded hardwood bark mulch • Where flow velocities dictate, use erosion and sediment control matting - coconut fiber or equivalent.	Mulch - A 75 mm layer on the surface of the filter bed. Matting - based on filter bed area.



SITE CONSIDERATIONS

Available Space
Footprints are 5 to 15% of their contributing drainage area. Swale length between culverts should be 5m or greater.

Site Topography
Longitudinal slopes ranging from 0.5 to 4%. On slopes steeper than 3%, check dams should be used.

Drainage Area and Runoff Volume to Site
Typically treat drainage areas of two hectares or less. Typical ratios of impervious drainage area to treatment facility area range from 5:1 to 15:1.

Soil
Dry swales can be located over any soil type, but hydrologic soil group A and B soils are best for achieving water balance benefits. Facilities should be located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than 1x10-6 cm/s) an underdrain is required. Native soil infiltration rate at the proposed facility location and depth should be confirmed through measurement of hydraulic conductivity under field saturated conditions.

Wellhead Protection
Facilities receiving road or parking lot runoff should not be located within two (2) year time-of-travel wellhead protection areas.

Water Table
The bottom of the swale should be separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre to prevent groundwater contamination.

Pollution Hot Spot Runoff
To protect groundwater from possible contamination, runoff from pollution hot spots should not be treated dry swales designed for full or partial infiltration. Facilities designed with an impermeable liner (filtration only facilities) can be used to treat runoff from pollution hot spots.

Setback from Buildings
Should be set back four (4) metres from building foundations unless an impermeable liner and underdrain system is used.

Proximity to Underground Utilities
Designers should consult local utility design guidance for the horizontal and vertical clearance between storm drains, ditches, and surface water bodies.

CONSTRUCTION CONSIDERATIONS

Ideally, dry swale sites should remain outside the limit of disturbance until construction of the swale begins to prevent soil compaction by heavy equipment. Dry swale locations should never be used as the site of sediment basins during construction, as the concentration of fines will prevent post-construction infiltration. To prevent clogging, stormwater should be diverted away from the practice until the drainage area is fully stabilized.

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.9 OF THE CVC/TRCA LID SWM GUIDE

BIORETENTION

CVC/TRCA LOW IMPACT DEVELOPMENT
PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

As a stormwater filter and infiltration practice, bioretention temporarily stores, treats and infiltrates runoff. Depending on native soil infiltration rate and physical constraints, the system may be designed without an underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for filtration only (i.e., a biofilter). The primary component of the practice is the filter bed which is a mixture of sand, fines and organic material. Other elements include a mulch ground cover and plants adapted to the conditions of a stormwater practice. Bioretention is designed to capture small storm events or the water quality storage requirement. An overflow or bypass is necessary to pass large storm event flows. Bioretention can be adapted to fit into many different development contexts and provide a convenient area for snow storage and treatment.

Source: Minnesota Businesses for Clean Water

Source: City of Portland

DESIGN GUIDANCE

SOIL CHARACTERISTICS

Bioretention can be constructed over any soil type, but hydrologic soil group A and B are best for achieving water balance goals. If possible, bioretention should be sited in the areas of the development with the highest native soil infiltration rates. Bioretention in soils with infiltration rates less than 15 mm/hr will require an underdrain. Designers should verify the native soil infiltration rate at the proposed location and depth through measurement of hydraulic conductivity under field saturated conditions.

GEOMETRY & SITE LAYOUT

Key geometry and site layout factors include:

- The minimum footprint of the filter bed area is based on the drainage area. Typical drainage areas to bioretention are between 100 m2 to 0.5 hectares. The maximum recommended drainage area is 0.8 hectares. Typical ratios of impervious drainage area to treatment facility area range from 5:1 to 15:1.
- Bioretention can be configured to fit into many locations and shapes. However, cells that are narrow may concentrate flow as it spreads throughout the cell and result in erosion.
- The filter bed surface should be level to encourage stormwater to spread out evenly over the surface.

PRE-TREATMENT

Pretreatment prevents premature clogging by capturing coarse sediment particles before they reach the filter bed. Where the runoff source area produces little sediment, such as roofs, bioretention can function effectively without pretreatment. To treat parking area or road runoff, a two-cell design that incorporates a forebay is recommended. Pretreatment practices that may be feasible, depending on the method of conveyance and the availability of space include:

- *Two-cell design (channel flow):* Forebay ponding volume should account for 25% of the water quality storage requirement and be designed with a 2:1 length to width ratio.
- *Vegetated filter strip (sheet flow):* Should be a minimum of three (3) metres in width. If smaller strips are used, more frequent maintenance of the filter bed can be anticipated.
- *Gravel diaphragm (sheet flow):* A small trench filled with pea gravel, which is perpendicular to the flow path between the edge of the pavement and the bioretention practice will promote settling out of sediment and maintain sheet flow into the facility. A drop of 50-150 mm into the gravel diaphragm can be used to dissipate energy and promote settling.
- *Rip rap and/or dense vegetation (channel flow):* Suitable for small bioretention cells with drainage areas less than 100 square metres.

GRAVEL STORAGE LAYER

- DEPTH: Should be a minimum of 300 mm deep and sized to provide the required storage volume. Granular material should be 50 mm diameter clear stone.
- PEA GRAVEL CHOKING LAYER: A 100 mm deep layer of pea gravel (3 to 10 mm diameter clear stone) should be placed on top of the coarse gravel storage layer as a choking layer separating it from the overlying filter media bed.

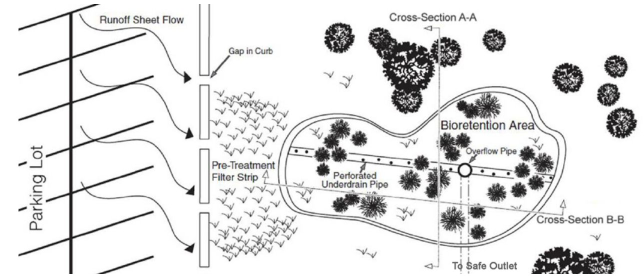
FILTER MEDIA

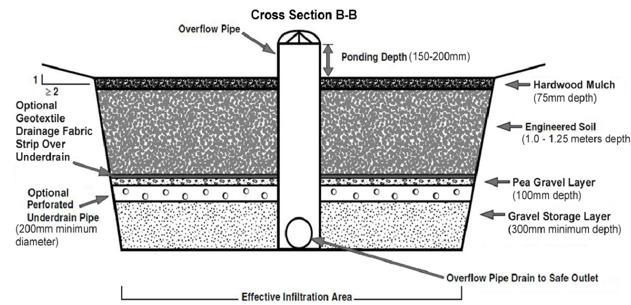
- COMPOSITION: To ensure a consistent and homogeneous bed, filter media should come pre-mixed from an approved vendor.
- DEPTH: Recommended depth is between 1.0 and 1.25 m. However in constrained applications, pollutant removal benefits may be achieved in beds as shallow as 500 mm. If trees are to be included in the design, bed depth must be at least 1.0 m.
- MULCH: A 75 mm layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth and pretreats runoff before it reaches the filter bed.

CONVEYANCE AND OVERFLOW

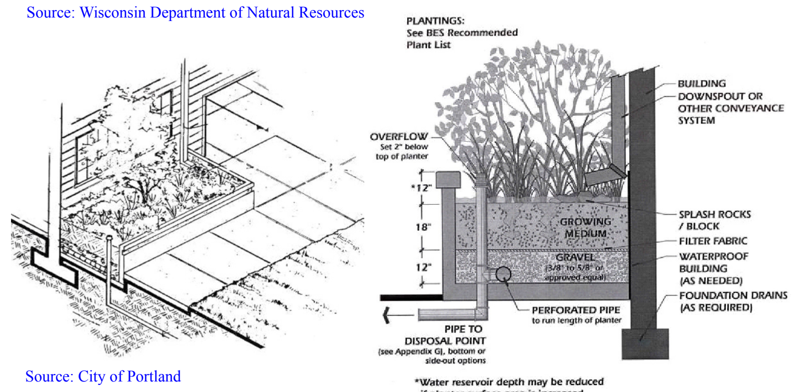
Bioretention can be designed to be inline or offline from the drainage system. Inline bioretention accepts all flow from a drainage area and conveys larger event flows through an overflow outlet. Overflow structures must be sized to safely convey larger storm events out of the facility. The invert of the overflow should be placed at the maximum water surface elevation of the bioretention area, which is typically 150-250 mm above the filter bed surface.

Offline bioretention practices use flow splitters or bypass channels that only allow the required water quality storage volume to enter the facility. This may be achieved with a pipe, weir, or curb opening sized for the target flow, but in conjunction, create a bypass channel so that higher flows do not pass over the surface of the filter bed. Using a weir or curb opening minimizes clogging and reduces maintenance frequency.





Source: Wisconsin Department of Natural Resources



Source: City of Portland

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefits
Bioretention with no underdrain	Yes	Yes - size for water quality storage requirement	Partial - based on available storage volume and infiltration rates
Bioretention with underdrain	Partial - based on available storage volume beneath the underdrain and soil infiltration rate	Yes - size for water quality storage requirement	Partial - based on available storage volume beneath the underdrain and soil infiltration rate
Bioretention with underdrain and impermeable liner	Partial - some volume reduction through evapotranspiration	Yes - size for water quality storage requirement	Partial - some volume reduction through evapotranspiration

UNDERDRAIN

- Only needed where native soil infiltration rate is less than 15 mm/hr (hydraulic conductivity of less than 1×10^{-6} cm/s).
- Should consist of a perforated pipe embedded in the coarse gravel storage layer at least 100 mm above the bottom.
- A strip of geotextile filter fabric placed between the filter media and pea gravel choking layer over the perforated pipe is optional to help prevent fine soil particles from entering the underdrain.
- A vertical standpipe connected to the underdrain can be used as a cleanout and monitoring well.

MONITORING WELLS

A capped vertical stand pipe consisting of an anchored 100 to 150 mm diameter perforated pipe with a lockable cap installed to the bottom of the facility is recommended for monitoring drainage time between storms.

GENERAL SPECIFICATIONS

Material	Specification	Quantity
Filter Media Composition	Filter Media Soil Mixture to contain: • 85 to 88% sand • 8 to 12% soil fines • 3 to 5% organic matter (leaf compost) Other Criteria: • Phosphorus soil test index (P-Index) value between 10 to 30 ppm • Cationic exchange capacity (CEC) greater than 10 meq/100 g • Free of stones, stumps, roots and other large debris • pH between 5.5 to 7.5 • Infiltration rate greater than 25 mm/hr	Recommended depth is between 1.0 and 1.25 metres.
Mulch Layer	Shredded hardwood bark mulch	A 75 mm layer on the surface of the filter bed
Geotextile	Material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. For further guidance see CVC/TRCA LID SWM Planning and Design Guide, Table 4.5.5.	Strip over the perforated pipe underdrain (if present) between the filter media bed and gravel storage layer (stone reservoir)
Gravel	Washed 50 mm diameter clear stone should be used to surround the underdrain and for the gravel storage layer Washed 3 to 10 mm diameter clear stone should be used for pea gravel choking layer.	Volume based on dimensions, assuming a void space ratio of 0.4.
Underdrain	Perforated HDPE or equivalent, minimum 100 mm diameter, 200 mm recommended.	• Perforated pipe for length of cell. • Non-perforated pipe as needed to connect with storm drain system. • One or more caps. • T's for underdrain configuration

CONSTRUCTION CONSIDERATIONS

Ideally, bioretention sites should remain outside the limit of disturbance until construction of the bioretention begins to prevent soil compaction by heavy equipment. Locations should not be used as sediment basins during construction, as the concentration of fines will prevent post-construction infiltration. To prevent sediment from clogging the surface of a bioretention cell, stormwater should be diverted away from the bioretention until the drainage area is fully stabilized.

For further guidance regarding key steps during construction, see the CVC/TRCA LID SWM Planning and Design Guide, Section 4.5.2 - Construction Considerations)

OPERATION AND MAINTENANCE

Bioretention requires routine inspection and maintenance of the landscaping as well as periodic inspection for less frequent maintenance needs or remedial maintenance. Generally, routine maintenance will be the same as for any other landscaped area; weeding, pruning, and litter removal. Regular watering may be required during the first two years until vegetation is established.

For the first two years following construction the facility should be inspected at least quarterly and after every major storm event (> 25 mm). Subsequently, inspections should be conducted in the spring and fall of each year and after major storm events. Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.

Trash and debris should be removed from pretreatment devices, the bioretention area surface and inlet and outlets at least twice annually. Other maintenance activities include reapplying mulch, pruning, weeding replacing dead vegetation and repairing eroded areas as needed. Remove accumulated sediment on the bioretention area surface when dry and exceeding 25 mm depth.

SITE CONSIDERATIONS

Wellhead Protection
Facilities receiving road or parking lot runoff should not be located within two (2) year time-of-travel wellhead protection areas.

Available Space
Reserve open areas of about 10 to 20% of the size of the contributing drainage area.

Site Topography
Contributing slopes should be between 1 to 5%. The surface of the filter bed should be flat to allow flow to spread out. A stepped multi-cell design can also be used.

Available Head
If an underdrain is used, then 1 to 1.5 metres elevation difference is needed between the inflow point and the downstream storm drain invert.

Water Table
A minimum of one (1) metre separating the seasonally high water table or top of bedrock elevation and the bottom of the practice is necessary.

Soils
Bioretention can be located over any soil type, but hydrologic soil group A and B soils are best for achieving water balance benefits. Facilities should be located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than 1×10^{-6} cm/s) an underdrain is required. Native soil infiltration rate at the proposed facility location and depth should be confirmed through measurement of hydraulic conductivity under field saturated conditions.

Drainage Area & Runoff Volume
Typical contributing drainage areas are between 100 m2 to 0.5 hectares. The maximum recommended contributing drainage area is 0.8 hectares. Typical ratios of impervious drainage area to treatment facility area range from 5:1 to 15:1.

Pollution Hot Spot Runoff
To protect groundwater from possible contamination, runoff from pollution hot spots should not be treated by bioretention facilities designed for full or partial infiltration. Facilities designed with an impermeable liner (filtration only facilities) can be used to treat runoff from pollution hot spots.

Proximity to Underground Utilities
Designers should consult local utility design guidance for the horizontal and vertical clearances required between storm drains, ditches, and surface water bodies.

Overhead Wires
Check whether the future tree canopy height in the bioretention area will interfere with existing overhead phone and power lines.

Setback from Buildings
If an impermeable liner is used, no setback is needed. If not, a four (4) metre setback from building foundations should be applied.

TORONTO AND REGION Conservation for The Living City

CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.5 OF THE CVC/TRCA LID SWM GUIDE

Stormwater Tree Pit

Alternative Names: Tree Box, Tree Box Filter, Street Tree Well

BENEFITS

Overall

- Reduces stormwater runoff volume, flow rate and temperature
- Increases groundwater infiltration and recharge
- Provides some local flood control
- Treats stormwater runoff
- Improves quality of local surface waterways
- Improves aesthetic appeal of streets and neighborhoods
- Provides wildlife habitat
- Provides shade to nearby buildings to reduce energy costs
- Requires limited space
- Simple to install
- Available in multiple sizes

Volume Attenuation/Flow Reduction

Stormwater tree pits generally capture and treat stormwater runoff from small, frequently-occurring storms but are not designed to capture runoff from large storms or extended periods of rainfall.

Pollutant Removal

Stormwater tree pits have proven to be effective at reducing some of the pollutants of most concern in the Charles River watershed:

- Total Suspended Solids: 85%
- Total Phosphorus: 74%
- Total Nitrogen: 68%
- Metals: 82%[4]

INSTALLATION COST

$8,000 – $10,000, to purchase one prefabricated system including filter material, plants and possibly some maintenance

$1500 – $6000 installation[3, 4, 6]

DESCRIPTION

Stormwater tree pits consist of an underground structure and above ground plantings which collect and treat stormwater using bioretention. Bioretention systems collect and filter stormwater through layers of mulch, soil and plant root systems, where pollutants such as bacteria, nitrogen, phosphorus, heavy metals, oil and grease are retained, degraded and absorbed. Treated stormwater is then infiltrated into the ground or, if infiltration is not appropriate, discharged into a traditional stormwater drainage system. Numerous prefabricated tree pit structures are commercially available. These typically include a ready-made concrete box containing an appropriate soil mixture and may also include plantings, usually one tree or a few small shrubs. Although underground they differ, above ground stormwater tree pits closely resemble traditional street trees and are perfect for urban streets where space is limited. Ideally, stormwater tree pits are employed in conjunction with other stormwater best management practices.

MAINTENANCE

Needs and Frequency

- Periodic inspection of plants and structural components
- Periodic cleaning of inflow and outflow mechanisms
- Periodic testing of mulch and soil for build-up of pollutants that may be harmful to the vegetation
- Biannual replacement of mulch

Cost

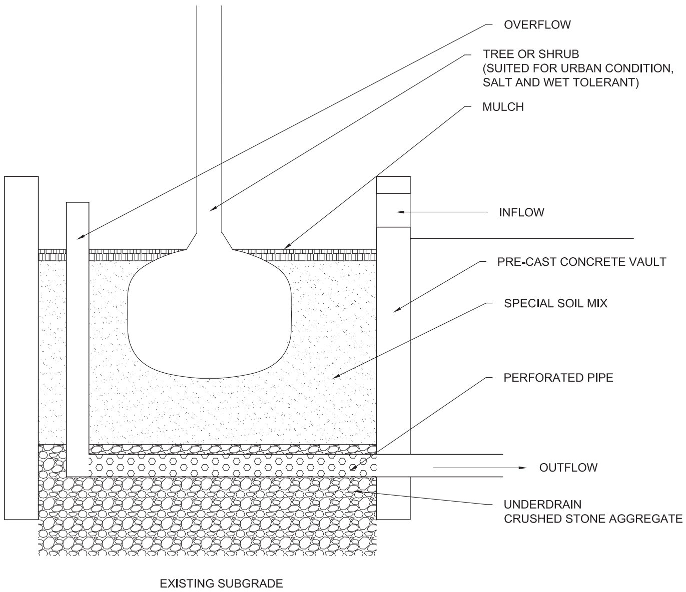
$100 – $500 annually/stormwater tree pit

Many proprietors of prefabricated systems will offer annual maintenance plans which can cost up to $500/year, however, if maintenance is performed by the stormwater tree pit owner it can usually be done more economically.[4]

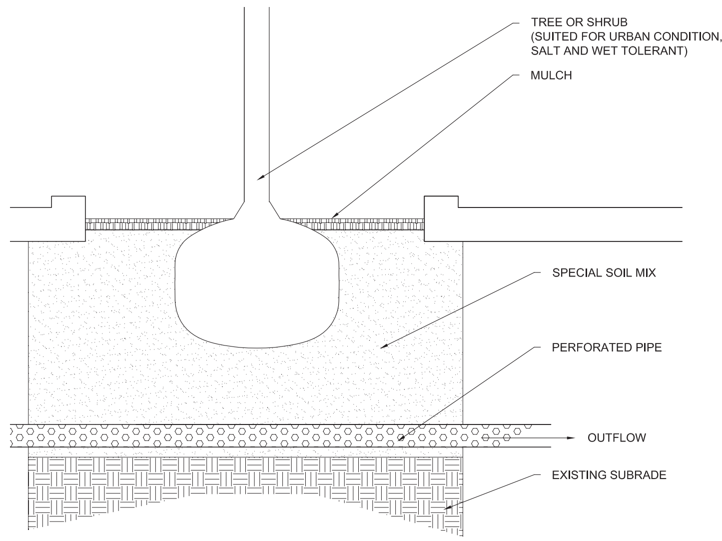
Other

Stormwater tree pits have an average lifespan of 25 years, although vegetation may need to be replaced more frequently.[4]

SCHEMATICS



Adapted from:
Low Impact Development Technologies
for Stormwater Management
http://www.unh.edu/erg/cstev/Presentations/index.htm
Accessed 01/22/2008



Adapted from:
Urban Horticultural Institute, New York
http://www.hort.cornell.edu/uhi/outreach/csc/article.html
Accessed 06/16/08

EXAMPLE PROJECTS

Town of Milton
Milton, MA
Tree pits are being installed upgradient of traditional stormwater catch basins to capture and treat stormwater runoff before it enters the stormwater drainage system.[5]

City of Portland
Portland, OR
Stormwater tree pits are being utilized in retrofits of narrow city streets to collect and treat stormwater.

ADDITIONAL CONCERNS OR UNKNOWNS

- Stormwater tree pits should not be placed at a low point as they are not designed to collected large volumes of runoff.
- Stormwater tree pits should be used in conjunction with other systems, such as upgradient of a traditional catch basin or other stormwater best management practice (BMP).

SOURCES

[1]Center for Watershed Protection. (2007, August). Urban Stormwater Retrofit Practices Appendices. Urban Subwatershed Restoration Manual Series.

[2]Coffman, L. and T. Siviter. Filterra® by Americast. An Advanced Sustainable Stormwater Treatment System.

[3]Cooke, I. (2007). Neponset River Watershed Association. Personal Communication.

[4]Low Impact Development Center (LIDC). (2005, November). Tree Box Filters. Low Impact Development for Big Box Retailers. Available at: http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf.

[5]The Neponset River Watershed Association. (2007). NepRWA's Current Projects. Neponset.org. http://www.neponset.org/CurrentProjects.htm.

[6]Roy, S. (2007). GeoSyntec. Personal Communication. 2007.

SOAKAWAYS, INFILTRATION TRENCHES AND CHAMBERS

CVC/TRCA LOW IMPACT DEVELOPMENT PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

Soakaways are rectangular or circular excavations lined with geotextile fabric and filled with clean granular stone or other void forming material that receive runoff from a perforated pipe inlet and allow it to infiltrate into the native soil. They typically service individual lots and receive only roof and walkway runoff but can also be designed to receive overflows from rainwater harvesting systems. Soakaways can also be referred to as infiltration galleries, dry wells or soakaway pits.

Infiltration trenches are rectangular trenches lined with geotextile fabric and filled with clean granular stone or other void forming material. Like soakaways, they typically service an individual lot and receive only roof and walkway runoff. This design variation on soakaways is well suited to sites where available space for infiltration is limited to narrow strips of land between buildings or properties, or along road rights-of-way. They can also be referred to as infiltration galleries or linear soakaways.

Infiltration chambers are another design variation on soakaways. They include a range of proprietary manufactured modular structures installed underground, typically under parking or landscaped areas that create large void spaces for temporary storage of stormwater, allowing it to infiltrate into the underlying native soil. Structures typically have open bottoms, perforated side walls and optional underlying granular stone reservoirs. They can be installed individually or in series in trench or bed configurations. They can infiltrate roof, walkway, parking lot and road runoff with adequate pretreatment. Due to the large volume of underground void space they create in comparison to a soakaway of the same dimensions, and the modular nature of their design, they are well suited to sites where available space for other types of BMPs is limited, or where it is desirable for the facility to have little or no surface footprint (e.g., high density development contexts). They can also be referred to as infiltration tanks.

DESIGN GUIDANCE

MONITORING WELLS

Capped vertical non-perforated pipes are recommended to the inlet and outlet pipes to provide a means of inspecting and flushing them out as part of routine maintenance. A capped vertical standpipe consisting of an anchored 100 to 150 mm diameter perforated pipe with a lockable cap installed to the bottom of the facility is also recommended for monitoring the length of time required to fully drain the facility between storms. Manholes and inspection ports should be installed in infiltration chambers to provide access for monitoring and maintenance activities.

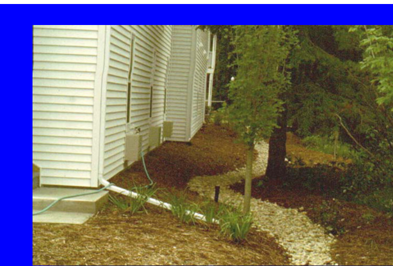
PRE-TREATMENT

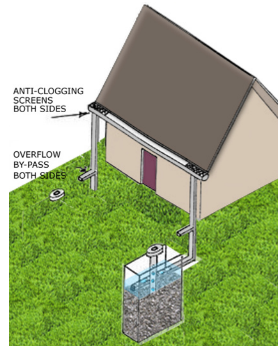
It is important to prevent sediment and debris from entering infiltration facilities because they could contribute to clogging and failure of the system. The following pretreatment devices are options:

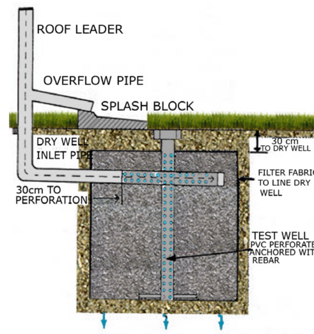
- Leaf screens: Leaf screens are mesh screens installed either on the building eavestroughs or roof downspouts and are used to remove leaves and other large debris from roof runoff.
- In-ground devices: Devices placed between a conveyance pipe and the facility (e.g., oil and grit separators, sedimentation chamber or goss traps), that can be designed to remove both large and fine particulate from runoff. A number of proprietary stormwater filter designs are available
- Vegetated filter strips or grass swales: Road and parking lot runoff can be pretreated with vegetated filter strips or grass swales prior to entering the infiltration practice

FILTER MEDIA

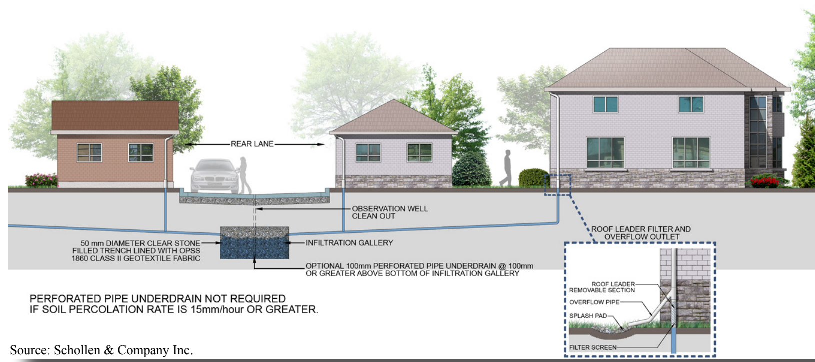
- Stone reservoir: Soakaways and infiltration trenches should be filled with uniformly-graded, washed stone that provides 30 to 40% void space. Granular material should be 50 mm clear stone
- Geotextile: A non-woven needle punched, or woven monofilament geotextile fabric should be installed around the stone reservoir of soakaways and infiltration trenches with a minimum overlap at the top of 300 mm. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. Specification of geotextile fabrics should consider the apparent opening size (AOS) for non-woven fabrics, or percent open area (POA) for woven fabrics, which affect the long term ability to maintain water flow. Other factors that need consideration include maximum forces to be exerted on the fabric, and the load bearing ratio, texture (i.e., grain size distribution) and permeability of the native soil in which they will be installed.







DRY WELL SYSTEM



INFILTRATION TRENCH BELOW A LANEWAY

INFILTRATION CHAMBER SYSTEM UNDER A PARKING LOT

GEOMETRY AND SITE LAYOUT

Soakaways and infiltration chambers can be designed in a variety of shapes, while infiltration trenches are typically rectangular excavations with a bottom width generally between 600 and 2400 mm. Facilities should have level or nearly level bed bottoms.

CONVEYANCE AND OVERFLOW

Inlet pipes to soakaways and infiltration trenches are typically perforated pipe connected to a standard non-perforated pipe or eavestrough that conveys runoff from the source area to the facility. The inlet and overflow outlet to the facility should be installed below the maximum frost penetration depth to prevent freezing. The overflow outlet can simply be the perforated pipe inlet that backs up when the facility is at capacity and discharges to a splash pad and pervious area at grade or can be a pipe that is at the top of the gravel layer and is connected to a storm sewer. Outlet pipes must have capacity equal to or greater than the inlet.

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Soakaways, Infiltration Trenches and Chambers	Yes	Yes	Partial, depends on soil infiltration rate

CONSTRUCTION CONSIDERATIONS

SOIL DISTURBANCE AND COMPACTION: Before site work begins, locations of facilities should be clearly marked. Only vehicular traffic used for construction of the infiltration facility should be allowed close to the facility location.

EROSION AND SEDIMENT CONTROL: Infiltration practices should never serve as a sediment control device during construction. Construction runoff should be directed away from the proposed facility location. After the site is vegetated, erosion and sediment control structures can be removed.

COMMON CONCERNS

RISK OF GROUNDWATER CONTAMINATION

Most pollutants in urban runoff are well retained by infiltration practices and soils and therefore, have a low to moderate potential for groundwater contamination. To minimize risk of groundwater contamination the following management approaches are recommended:

- infiltration practices should not receive runoff from high traffic areas where large amounts of de-icing salts are applied (e.g., busy highways), nor from pollution hot spots;
- prioritize infiltration of runoff from source areas that are comparatively less contaminated such as roofs, low traffic roads and parking areas; and,
- apply sedimentation pretreatment practices (e.g., oil and grit separators) before infiltration of road or parking area runoff.

RISK OF SOIL CONTAMINATION

Available evidence from monitoring studies indicates that small distributed stormwater infiltration practices do not contaminate underlying soils, even after 10 years of operation.

ON PRIVATE PROPERTY

Property owners or managers will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer could be used to encourage property owners or managers to maintain existing practices. Alternatively, infiltration practices could be located in an expanded road right-of-way or "stormwater easement" so that municipal staff can access the facility in the event it fails to function properly.

WINTER OPERATION

Soakaways, infiltration trenches and chambers will continue to function during winter months if the inlet pipe and top of the facility is located below the local maximum frost penetration depth.

OPERATION AND MAINTENANCE

Maintenance typically consists of cleaning out leaves, debris and accumulated sediment caught in pretreatment devices, inlets and outlets annually or as needed. Inspection via an monitoring well should be performed to ensure the facility drains within the maximum acceptable length of time (typically 72 hours) at least annually and following every major storm event (>25 mm). If the time required to fully drain exceeds 72 hours, drain via pumping and clean out the perforated pipe underdrain, if present. If slow drainage persists, the system may need removal and replacement of granular material and/or geotextile fabric.

SITE CONSIDERATIONS

Wellhead Protection

Facilities receiving road or parking lot runoff should not be located within two (2) year time-of-travel wellhead protection areas.

Site Topography

Facilities cannot be located on natural slopes greater than 15%.

Water Table

The bottom of the facility should be vertically separated by one (1) metre from the seasonally high water table or top of bedrock elevation.

Soil

Soakaways, infiltration trenches and chambers can be constructed over any soil type, but hydrologic soil group A or B soils are best for achieving water balance and channel erosion control objectives. If possible, facilities should be located in portions of the site with the highest native soil infiltration rates. Designers should verify the soil infiltration rate at the proposed location and depth through field measurement of hydraulic conductivity under field saturated conditions.

Drainage Area

Typically are designed with an impervious drainage area to treatment facility area ratio of between 5:1 and 20:1. A maximum ratio of 10:1 is recommended for facilities receiving road or parking lot runoff.

Pollution Hot Spot Runoff

To protect groundwater from possible contamination, runoff from pollution hot spots should not be treated by soakaways, infiltration trenches or chambers.

Setback from Buildings

Facilities should be setback a minimum of four (4) metres from building foundations.

Proximity to Underground Utilities

Local utility design guidance should be consulted to define the horizontal and vertical offsets. Generally, requirements for underground utilities passing near the practice will be no different than for utilities in other pervious areas. However, the designer should consider the need for long term maintenance when locating infiltration facilities near other underground utilities.

TORONTO AND REGION Conservation for The Living City

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FOR FURTHER DETAILS SEE SECTION 4.4 OF THE CVC/TRCA LID SWM GUIDE

RAINWATER HARVESTING

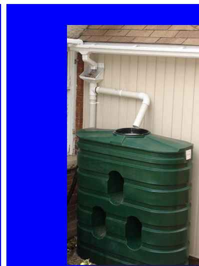
CVC/TRCA LOW IMPACT DEVELOPMENT
PLANNING AND DESIGN GUIDE - FACT SHEET

GENERAL DESCRIPTION

Rainwater harvesting is the process of intercepting, conveying and storing rainfall for future use. The rain that falls upon a catchment surface, such as a roof, is collected and conveyed into a storage tank. Storage tanks range in size from rain barrels for residential land uses (typically 190 to 400 litres in size), to large cisterns for industrial, commercial and institutional land uses. A typical pre-fabricated cistern can range from 750 to 40,000 litres in size.

With minimal pretreatment (e.g., gravity filtration or first-flush diversion), the captured rainwater can be used for outdoor non-potable water uses such as irrigation and pressure washing, or in the building to flush toilets or urinals. It is estimated that these applications alone can reduce household municipal water consumption by up to 55%. The capture and use of rainwater can, in turn, significantly reduce stormwater runoff volume and pollutant load. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also help reduce demand on municipal treated water supplies. This helps to delay expansion of treatment and distribution systems, conserve energy used for pumping and treating water and lower consumer water bills.



DESIGN GUIDANCE

CATCHMENT AREA

The catchment area is simply the surface from which rainfall is collected. Generally, roofs are the catchment area, although rainwater from low traffic parking lots and walkways, may be suitable for some non-potable uses (e.g., outdoor washing). The quality of the harvested water will vary according to the type of catchment area and material from which it is constructed. Water harvested from parking lots, walkways and certain types of roofs, such as asphalt shingle, tar and gravel, and wood shingle roofs, should only be used for irrigation or toilet flushing due to potential for contamination with toxic compounds.

COLLECTION AND CONVEYANCE SYSTEM

The collection and conveyance system consists of the eavestroughs, downspouts and pipes that channel runoff into the storage tank. Eavestroughs and downspouts should be designed with screens to prevent large debris from entering the storage tank. For dual use cisterns (used year-round for both outdoor and indoor uses), the conveyance pipe leading to the cistern should be buried at a depth no less than the local maximum frost penetration depth and have a minimum 1% slope. If this is not possible, conveyance pipes should either be located in a heated indoor environment (e.g., garage, basement) or be insulated or equipped with heat tracing to prevent freezing. All connections between downspouts, conveyance pipes and the storage tank must prevent entry of small animals or insects into the storage tank.

PRE-TREATMENT

Pretreatment is needed to remove debris, dust, leaves, and other debris that accumulates on roofs and prevents clogging within the rainwater harvesting system. For dual use cisterns that supply water for irrigation and toilet flushing only, filtration or first-flush diversion pretreatment is recommended. To prevent ice accumulation and damage during winter, first-flush diverters or in-ground filters should be in a temperature controlled environment, buried below the local frost penetration depth, insulated or equipped with heat tracing.

STORAGE TANKS

The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. The required size of storage tank is dictated by several variables: rainfall and snowfall frequencies and totals, the intended use of the harvested water, the catchment surface area, aesthetics, and budget. In the Greater Toronto Area, an initial target for sizing the storage tank could be the predicted rainwater usage over a 10 to 12 day period.

DISTRIBUTION SYSTEM

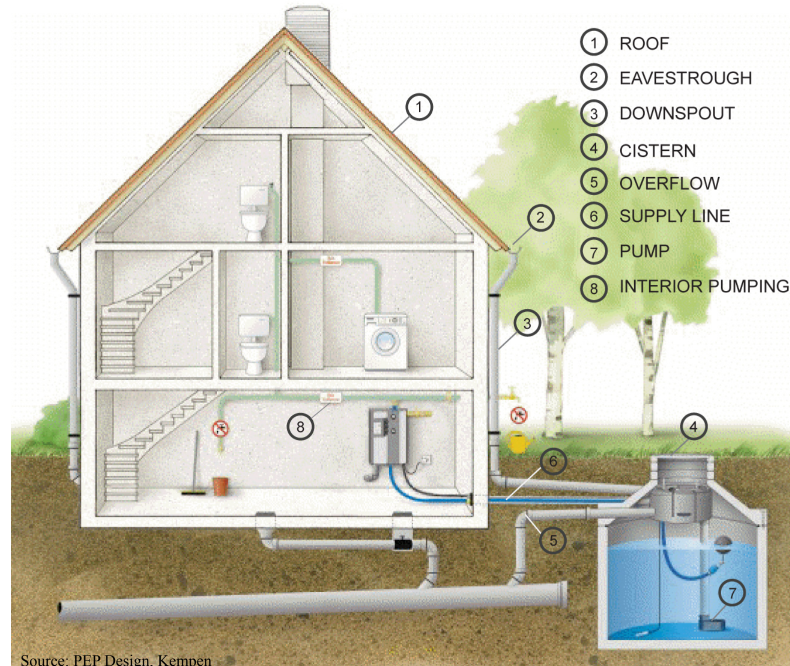
Most distribution systems are gravity fed or operated using pumps to convey harvested rainwater from the storage tank to its final destination. Typical outdoor systems use gravity to feed hoses via a tap and spigot. For underground cisterns, a water pump is needed. Indoor systems usually require a pump, pressure tank, back-up water supply line and backflow preventer. The typical pump and pressure tank arrangement consists of a multistage centrifugal pump, which draws water out of the storage tank into the pressure tank, where it is stored for distribution.

OVERFLOW SYSTEM

An overflow system must be included in the design. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s). The overflow system may consist of a conveyance pipe from the top of the cistern to a pervious area down gradient of the storage tank, where suitable grading exists. The overflow discharge location should be designed as simple downspout disconnection to a pervious area, vegetated filter strip, or grass swale. The overflow conveyance pipe should be screened to prevent small animals and insects from entering. Where site grading does not permit overflow discharge to a pervious area, the conveyance pipe may either be indirectly connected to a storm sewer (discharge to an impervious area connected to a storm sewer inlet) or directly connected to a storm sewer with incorporation of a backflow preventer.

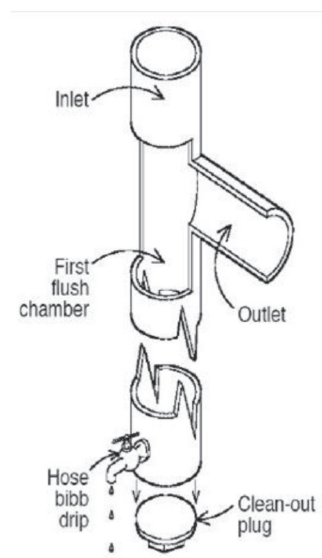
ACCESS AND MAINTENANCE

For underground cisterns, a standard size manhole opening should be provided for maintenance purposes. This access point should be secured with a lock to prevent unwanted access.

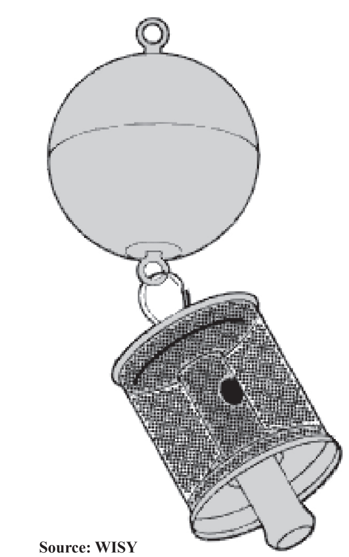


Source: PEP Design, Kempen

OVERVIEW



FIRST FLUSH DIVERTER



Source: WISY

FLOATING SUCTION FILTER

ABILITY TO MEET SWM OBJECTIVES

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Rainwater Harvesting	Yes - magnitude depends on water usage	Yes - size for the water quality storage requirement	Partial - can be used in series with other practices

GENERAL SPECIFICATIONS

Component	Specification	Quantity
Eavestroughs and Downspouts	Materials commonly used for eavestroughs and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead should not be used as solder as rainwater can dissolve the lead and contaminate the water supply.	Length of eavestroughs and downspouts is determined by the size and layout of the catchment and the location of the storage tanks.
Pretreatment	At least one of the following: • leaf and mosquito screens (1 mm mesh size); • first-flush diverter; • in-ground filter; • in-tank filter. Large tanks (10 m3 or larger) should have a settling compartment for removal of sediments.	1 per inlet to the collection system
Storage Tanks	• Materials used to construct storage tanks should be structurally sound. • Tanks should be installed in locations where native soils or building structures can support the load associated with the volume of stored water. • Storage tanks should be water tight and sealed using a water safe, non-toxic substance. • Tanks should be opaque to prevent the growth of algae • Previously used containers to be converted to rainwater storage tanks should be fit for potable water or food-grade products. • Cisterns above- or below ground must have a lockable opening of at least 450 mm diameter.	The size of the cistern(s) is determined during the design calculations.

Note: This table does not address indoor systems or pumps.

OPERATION AND MAINTENANCE

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. All rainwater harvesting system components should undergo regular inspections every six months during the spring and fall seasons to keep leaf screens, eavestroughs and downspouts free of leaves and other debris; check screens and patch holes or gaps; clean and maintain first flush diverters and filters, especially those on drip irrigation systems; inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots; and replace damaged system components as needed.

MOSQUITO CONTROL

If screening is not sufficient to deter mosquitoes, vegetable oil can be used to smother larvae. Alternatively mosquito dunks or pellets containing larvicide can be used.

WINTER OPERATION

Rainwater harvesting systems have a number of components that can be affected by freezing winter temperatures. For above-ground systems, winter-time operation may not be possible. Prior to the onset of freezing temperatures, above-ground systems should be disconnected and drained. For below-ground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

SITE CONSIDERATIONS

Available Space
Storage tanks can be placed underground, indoors, on roofs, or adjacent to buildings depending on intended uses of the rainwater.

Site Topography
Influences the placement of the storage tank and design of the distribution and overflow systems.

Soil
Underground cisterns should be placed on or in native, rather than fill soil.

Head
Rain barrels or above ground cisterns with gravity distribution systems should be sited up-gradient from landscaping areas to which rainwater is to be applied.

Pollution Hot Spot Runoff
Can be an effective BMP for roof runoff from sites where land uses or activities at ground level have the potential to generate highly contaminated runoff.

Winter Operation
Can be used throughout the winter if tanks are located below the local frost penetration depth or indoors.

Underground Utilities
Presence of underground utilities may constrain the location of underground storage tanks.

Plumbing Code
Code allows the use of harvested rainwater for toilet and urinal flushing, but systems require installation of backflow prevention devices.

Standing Water and Mosquitoes
If improperly managed, tanks can create habitat suitable for mosquito breeding, so screens should be placed on inlets and outlets to prevent entry.

Child Safety
Above and below ground cisterns with openings large enough for children to enter must have lockable covers.

Setback
Tanks should be water tight to avoid ponding or saturation of soils within 4 metres of building foundations.

Vehicle Loading
Underground tanks should be sited in areas without vehicular traffic.

Drawdown Between Storms
A suggested target for sizing the storage tank to ensure drawdown between storms is the predicted rainwater demand over a 10 to 12 day period.

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CVC CREDIT VALLEY CONSERVATION

FOR FURTHER DETAILS SEE SECTION 4.1 OF THE CVC/TRCA LID SWM GUIDE