


LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT PLANNING AND DESIGN GUIDE

Version 1.0

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CVC
CREDIT VALLEY CONSERVATION

TORONTO AND REGION Conservation
for The Living City

NOTICE

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LIST OF ACRONYMS AND ABBREVIATIONS

AEM	Adaptive environmental management
AASHTO	American Association of State Highway and Transportation Officials
ARC	Atlanta Regional Commission
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BAU	Business-as-usual
BC MWLAP	British Columbia Ministry of Water, Land and Air Protection
BMP	Best management practice
CA	Conservation authority
CEC	Cationic exchange capacity
CHMC	Canada Mortgage and Housing Corporation
cm	Centimetre
CRWMG	Credit River Water Management Guidelines
CSA	Canadian Standards Association
CWP	Center for Watershed Protection
CVC	Credit Valley Conservation
EIR	Environmental impact report
GVRD	Greater Vancouver Regional District
hr	Hour
HSG	Hydrologic soil group
ICPI	Interlocking Concrete Pavement Institute
IWMP	Integrated watershed monitoring program
L	Litre
LEED	Leadership in Energy and Environmental Design
LID	Low impact development
m	Metre
MDE	Maryland Department of the Environment
meq	Milliequivalents
MESP	Master environmental and servicing plan
mm	Millimetre
MPCA	Minnesota Pollution Control Agency
MTO	Ministry of Transportation of Ontario
N	Nitrogen
NAPA	National Asphalt Pavement Association
NCPTC	National Concrete Pavement Technology Center
NRC	National Research Council of Canada
NRMCA	National Ready Mix Concrete Association
OMAFRA	Ontario Ministry of Agriculture, Food, and Rural Affairs
OMMAH	Ontario Ministry of Municipal Affairs and Housing
OMNR	Ontario Ministry of Natural Resources
OMOE	Ontario Ministry of the Environment
OMOEE	Ontario Ministry of Environment and Energy
OPSS	Ontario Provincial Standard Specification
P	Phosphorus

PAH	Polycyclic aromatic hydrocarbons
PDEP	Pennsylvania Department of Environmental Protection
PVC	Polyvinyl chloride
PWD	Philadelphia Water Department
PWQO	Provincial Water Quality Objective
s	Second
SMPPD	Stormwater Management Practices Planning and Design
STEP	Sustainable Technologies Evaluation Program
SWM	Stormwater management
SWMP	Stormwater management practice
SWAMP	Stormwater Assessment Monitoring and Performance Program
TP	Total phosphorus
TRCA	Toronto and Region Conservation Authority
TSS	Total suspended solids
TWDB	Texas Water Development Board
UNHSC	University of New Hampshire Stormwater Center
U.S. EPA	United States Environmental Protection Agency
yr	Year

PREFACE

This document – the *Low Impact Development Stormwater Management Planning and Design Guide* – has been developed by Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA) as a tool to help developers, consultants, municipalities and landowners understand and implement sustainable stormwater planning and practices in the CVC and TRCA watersheds. The use of sustainable stormwater planning and practices will help ensure the continued health of the streams, rivers, lakes, fisheries and terrestrial habitats in our watersheds.

The guide is intended to provide engineers, ecologists and planners with up-to-date information and direction on landscape-based stormwater management planning and low impact development stormwater management practices such as rainwater harvesting, green roofs, bioretention, permeable pavement, soakaways and swales. The information contained in the guide will help practitioners adopt landscape-based stormwater management approaches, and will help select, design, construct and monitor more sustainable stormwater management practices.

This manual is not a stand-alone document. It is intended to augment the Ontario Ministry of the Environment's 2003 *Stormwater Management Planning and Design Manual*, which provides design criteria for "conventional" end-of-pipe stormwater management practices such as wet ponds and constructed wetlands. It is also a companion document to other stormwater related guidance documents prepared by CVC and TRCA. Amongst others, these include:

CVC

- Credit River Water Management Guidelines (CRWMG) (2007);
- Credit River Stormwater Management Criteria (currently under development; will be an appendix to the CRWMG;
- Geomorphic and Meander Belt Guidelines (an appendix to the CRWMG);
- Floodline Mapping Guidelines (an appendix to the CRWMG);
- Environmental Impact Report Terms of Reference (an appendix to the CRWMG);
- Technical Guidelines for Floodproofing, 1994 (an appendix to the CRWMG);
- Hydrologic/Hydraulic Modeling (an appendix to the CRWMG Guidelines);
- Guidelines for Hydrogeologic Studies (an appendix to the CRWMG);
- Headwater Assessment Guidelines (an appendix to the CRWMG).

TRCA

- Planning and Development Procedural Manual (2007);
- Stormwater Management Criteria (currently under development);
- Floodplain Management Guideline; and
- Stream Crossing Guidelines.

1.0 INTRODUCTION

1.1 About This Document

The *Low Impact Development Stormwater Management Planning and Design Guide* (*LID SWM Guide*) has been developed by Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA) as a tool to help developers, consultants, municipalities and landowners understand and implement more sustainable stormwater management planning and design practices in their watersheds. Many jurisdictions have defined the term low impact development. For this document, the following definition, adapted from the United States Environmental Protection Agency (U.S. EPA, 2007) will be used:

> Low impact development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

The *LID SWM Guide* provides information and direction to assist engineers, ecologists and planners with landscape-based stormwater management planning and the selection, design, construction and monitoring of sustainable stormwater management practices. The focus of this guide is on guidance regarding the planning and design of structural low impact development practices for stormwater management.

The practice of managing stormwater is continuing to evolve as the science of watershed management and understanding of our watersheds grow. Effective management of stormwater is critical to the continued health of our streams, rivers, lakes, fisheries and terrestrial habitats. CVC and TRCA believe that an improved understanding of the municipal and environmental planning process and the requirements for stormwater management will lead to improvements in management practices and an increasingly standardized and streamlined approach to addressing stormwater throughout the CVC and TRCA watersheds.

The *LID SWM Guide* is intended to augment the Ontario Ministry of the Environment (OMOE) Stormwater Management Planning and Design Manual (2003). The OMOE manual provides design criteria for “conventional” end-of-pipe stormwater management practices such as wet ponds and constructed wetlands but provides only limited information about lot level and conveyance controls. The OMOE manual does, however, emphasize the use of a “treatment train” approach to reduce the impacts of stormwater runoff. A treatment train approach – a combination of lot level, conveyance, and end-of-pipe stormwater management practices – is usually required to meet the multiple objectives of stormwater management, which include maintaining the hydrologic cycle, protecting water quality, and preventing increased erosion and flooding.

This *LID SWM Guide* focuses on a number of lot level and conveyance stormwater management practices that have been used extensively in Europe, the United States, British Columbia and at demonstration sites in Ontario. These practices have only recently been considered for broad application in Ontario as part of the treatment train approach. These low impact development practices include green roofs, bioretention, permeable pavement, soakaways, perforated pipe systems, enhanced grass swales, dry swales and rainwater harvesting. The *LID SWM Guide* recommends and supports the use of the treatment train approach for stormwater management. Accordingly, the reader is urged to refer to the OMOE manual (OMOE, 2003), as a guide for incorporating more traditional practices such as wet ponds and wetlands into the overall stormwater management planning and design process.

The *LID SWM Guide* is not intended to limit innovation or restrict the use of creative solutions for stormwater management. Indeed, the OMOE, CVC, TRCA and partner municipalities encourage the development of innovative designs and technologies.

1.2 History and Context

In 1993, the Ontario Ministry of the Environment and Energy and Ontario Ministry of Natural Resources released three policy documents that focused on integrating water resources management and urban planning:

- Water Management on a Watershed Basis: Implementing an Ecosystems Approach;
- Subwatershed Planning; and
- Integrating Water Management Objectives into Municipal Planning Documents.

These documents heralded a new approach to water management in Ontario. They emphasized the need for an increased focus on protecting the natural environment and the need to expand stormwater management practices to pay more attention to water quality and environmental concerns, in addition to addressing traditional water quantity concerns.

In 1994, the Ontario Ministry of Environment and Energy (OMOEE) released two practitioners’ guides to stormwater management planning:

- Stormwater Quality Best Management Practices; and
- Stormwater Management Practices Planning and Design (SMPPD) Manual.

The OMOEE SMPPD manual was intended to introduce practitioners to a broad range of stormwater management facilities that were designed to not only offset the effects of hydrologic changes of urban development on streams and rivers, but also address water quality and erosion impacts. The SMPPD manual also provided detailed guidance on how to design and build multi-purpose facilities and included sections on operations and maintenance, as well as environmental monitoring requirements.

In 2003, OMOE released a new Stormwater Management Planning and Design Manual, which significantly updated and expanded on the 1994 version. The 2003 manual:

- provided an overview of the impacts of urbanization on the hydrologic cycle and stream ecosystems;
- addressed the evolution of the watershed planning process and implications for the design process;
- incorporated water quantity, erosion control, water quality protection, and water balance principles into the selection and design of stormwater management practices (SWMPs);
- documented the performance of SWMPs that have been monitored;
- incorporated design considerations for SWMPs in cold climates;
- provided information on new “state of the art” SWMPs;
- addressed infill projects;
- updated operations and maintenance requirements;
- provided design examples for SWMPs;
- updated material related to planting strategies and the function of plant materials in SWMP design;
- provided examples of retrofitting SWMPs; and
- outlined integrated planning for stormwater management.

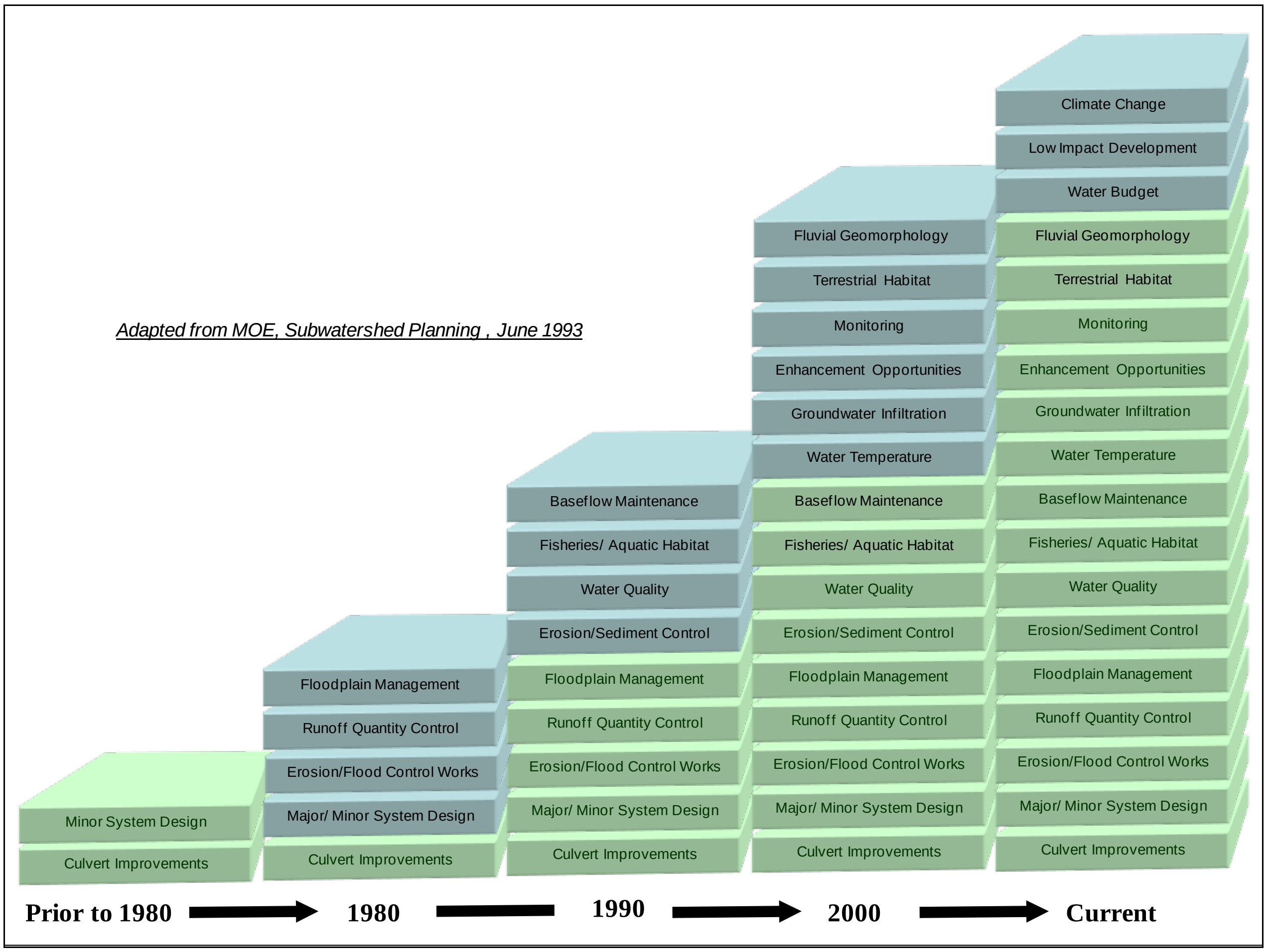
1.3 The Evolution of Stormwater Management

During the past three decades, the practice of stormwater management has evolved. In the mid 1970s, attempts to control runoff flow rates from urban developments were initiated. By the late 1980s, water quality became an additional focus and in the late 1990s, approaches to mitigate accelerated stream channel erosion were introduced. Lot level stormwater management approaches have been advocated in Ontario since 1995 (OMMAH, 1995), but widespread application has yet to occur. Today, with improvements in our understanding of watershed systems and the potential impacts urbanization can have on aquatic ecosystems, stormwater management addresses a broad suite of issues including fluvial geomorphology (stream channel forming processes), groundwater resources and the protection of aquatic and terrestrial habitats (Figure 1.2.1).

Municipalities, with the support of conservation authorities, review stormwater management facilities and plans designed to address this multitude of concerns. This has led to an increasing complexity in stormwater management planning and design including:

- increasingly complex stormwater management facilities and best management practices;
- the need to involve more inter-disciplinary expertise in studies to define environmental opportunities and constraints;
- expanding requirements for multi-purpose stormwater management facilities; and,
- increased emphasis on the treatment train approach and use of multiple types of controls to address environmental issues.

Figure 1.2.1 Evolution of stormwater management practice in Ontario



CVC and TRCA have been extensively involved in integrated watershed-wide environmental monitoring for many years. The results of this monitoring have shown that the environmental health of many watersheds continue to decline as urbanization increases. This environmental deterioration has taken place despite widespread compliance with provincial and conservation authority requirements for stormwater management planning and facility design. Conventional stormwater management, which focuses on controlling peak flow rate and the concentration of suspended solids, has failed to address the widespread and cumulative hydrologic modifications in watersheds that increase the volume of stormwater, increase the runoff rate, and cause excessive erosion and degradation of stream channels. Conventional stormwater management also fails to adequately treat other pollutants of concern, such as nutrients, pathogens and metals.[1]

CVC's recent Credit River Water Management Strategy Update concludes that continued use of what are currently considered "state of the art" stormwater management practices will lead to continued degradation of the watershed, jeopardizing the health of the Credit's world class fishery and other valued environmental resources (CVC, 2007b). To protect the health of the Credit River watershed, the updated water management strategy calls for an immediate shift to more proactive and innovative stormwater management systems that include low impact development practices. TRCA's Rouge River Watershed Plan (TRCA, 2007c), Humber River Watershed Plan (TRCA, 2008a) and Don River Watershed Plan (TRCA, 2009a) reach similar conclusions about the inability of conventional stormwater management practices to protect the health of rivers and the need for low impact development approaches. In addition, the Rouge River Watershed Plan concludes that widespread implementation of LID practices in new and existing developments could increase the resiliency of the watershed system to some anticipated impacts of climate change on baseflow and channel erosion (TRCA, 2007d).

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

[1] Gaffield, S.J., R.L Goo, L.A. Richards and R.J.Jackson. 2003. Public Health Effects of Inadequately Managed Stormwater Runoff. *American Journal of Public Health*. September 2003. Vol. 93. No. 9. pp. 1527-1533; Kok, S. and J.Shaw. 2005. Wet Weather Flow Management in the Great Lakes Areas of Concern. *Proceedings EWRI 2005*. Copyright ASCE 2005; Marsalek, J. 2002. Overview of urban stormwater impacts on receiving waters. P. 3-14. *Proceedings of the Urban Water Management: Science, Technology and Delivery. NATO Advanced Research Workshop*. Borovetz, Bulgaria; Marsalek, J., H.Y.F. Ng. 1989. Evaluation of pollution loadings from urban non-point sources, methodology and application. *J. Great Lakes Res.* 15(3) 444-451; Rohrer C.A., L.A. Roesner, B.P. Bledsoe. 2004. The Effect of Stormwater Controls on Sediment transport in Urban Streams. *Proceedings World Water Congress 2004*. Copyright ASCE 2004; Saravanapavan, T. M. Voorhees and A. Parker. 2005. Stormwater Evaluation for TMDLs and Implementation in Urban Northeast Watersheds. *Proceedings EWRI: Impacts of Global Climate Change*. Copyright ASCE 2005; US EPA. 1997. *Urbanization and Streams: Studies of Hydrologic Impacts.* Office of Water. Washington DC. EPA841-R-97-009; Schueler, T. 2000. *Nonpoint Sources of Pollution to the Great Lakes Basin*. Great Lakes Science Advisory Board. ISBN 1-894280-14-8. Feb 2000; Schueler, T. 2002. Comparative Pollutant Removal Capability of Stormwater Treatment Practices. *The Practice of Watershed Protection*. Vol. 64. pp. 371-376; Schueler, T. and D. Caraco. 2001. *Sources and control of pollutants in urban runoff*. International Joint Commission. Windsor Ontario; Schueler, T. and J. Galli. 1992. Environmental Impacts of Stormwater Ponds. In *Watershed Restoration Source Book*, ed. P.Kumble, T. Schueler, Washington, D.C..

Finally the 2003 OMOE Stormwater Management Planning and Design Manual, though reflective of current technology is rapidly becoming dated, since much of the material it reviewed dates from 1999. In the last five years, over 30 state-of-the-science stormwater management manuals and guidelines have been released in locations such as Maryland, Washington State, British Columbia, Minnesota, Pennsylvania and Oregon. The objective of maintaining predevelopment water balance, use of the treatment train approach and application of low impact development practices are all becoming common practice in these jurisdictions.

Two recent documents, one prepared by the City of Toronto and the other prepared by the Greater Vancouver Regional District summarize how the approach to stormwater management needs to change.

> Rainwater should be treated as a resource to nourish and enhance the City's environment. Management should begin where precipitation hits the ground according to the priority of source, conveyance, end-of-pipe and finally, stream restoration measures (City of Toronto, 2006).
>
> There is a need for a change in the philosophy of treating runoff from one of stormwater management to rainwater management (GVRD, 2005).

This is why CVC and TRCA commissioned the development of a stormwater management guide to provide guidance on the kind of cutting edge practices that are needed to protect the health of the CVC and TRCA watersheds. The *LID SWM Guide* draws on published research, literature and local studies to provide planning and design guidance that reflects regional policies, practices and climate. It provides information and guidance on the following:

- how to integrate stormwater management into the urban planning process;
- how to design, construct and maintain a range of LID stormwater management practices; and
- the kinds of environmental and performance monitoring that should be carried out.

Acknowledging that it will not always be possible to maintain the predevelopment water budget of a site, predicted increases in runoff from land development that cannot be mitigated through stormwater infiltration practices should be minimized through practices that either evapotranspire (*e.g.,* green roofs, bioretention), or harvest runoff for non-potable uses (*i.e.*, rainwater harvesting). In areas where development has already taken place, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall impacts of existing developments on receiving waters. LID practices can include:

- conservation site design strategies (*i.e.*, non-structural LID practices);

- infiltration practices;
- rainwater harvesting;
- runoff storage and evapotranspiration;
- runoff conveyance;
- filtration practices; and
- landscaping.

Studies show that implementing LID practices can have multiple positive environmental effects including:

- protection of downstream resources;
- abatement of pollution;
- recharge of groundwater;
- improvement of water quality;
- improvement of habitat;
- reduced downstream flooding and erosion;
- conservation of water and energy; and
- improved aesthetics in streams and rivers.

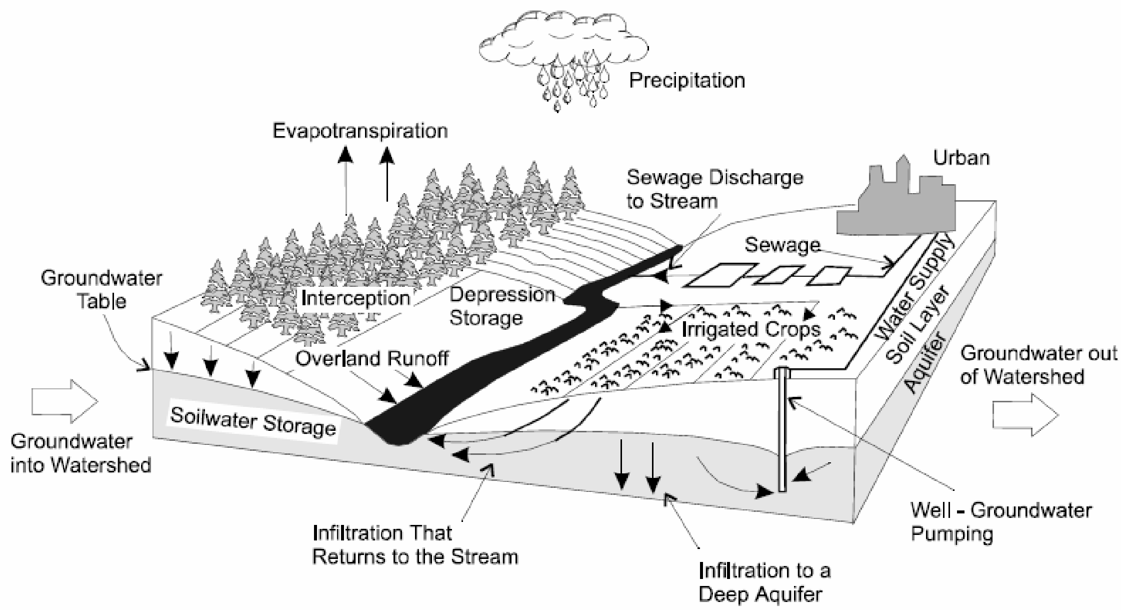
These combined benefits help to mitigate potential negative impacts of climate change on groundwater levels, risk of flooding and stream channel erosion.

1.4 The Impact of Urbanization

As indicated previously, early stormwater management plans developed in the 1980s focused on controlling water quantity, with the intent of ensuring that runoff from newly developed urban areas did not increase the potential for flooding downstream.

Figure 1.4.1 provides an illustration of the hydrologic cycle. When lands are urbanized, there are significant changes in the proportion of precipitation that infiltrates into the ground, evaporates back into the atmosphere and enters drainage features as surface runoff primarily as a result of clearing of vegetation and paving of the ground surface.

Figure 1.4.1; The hydrologic cycle



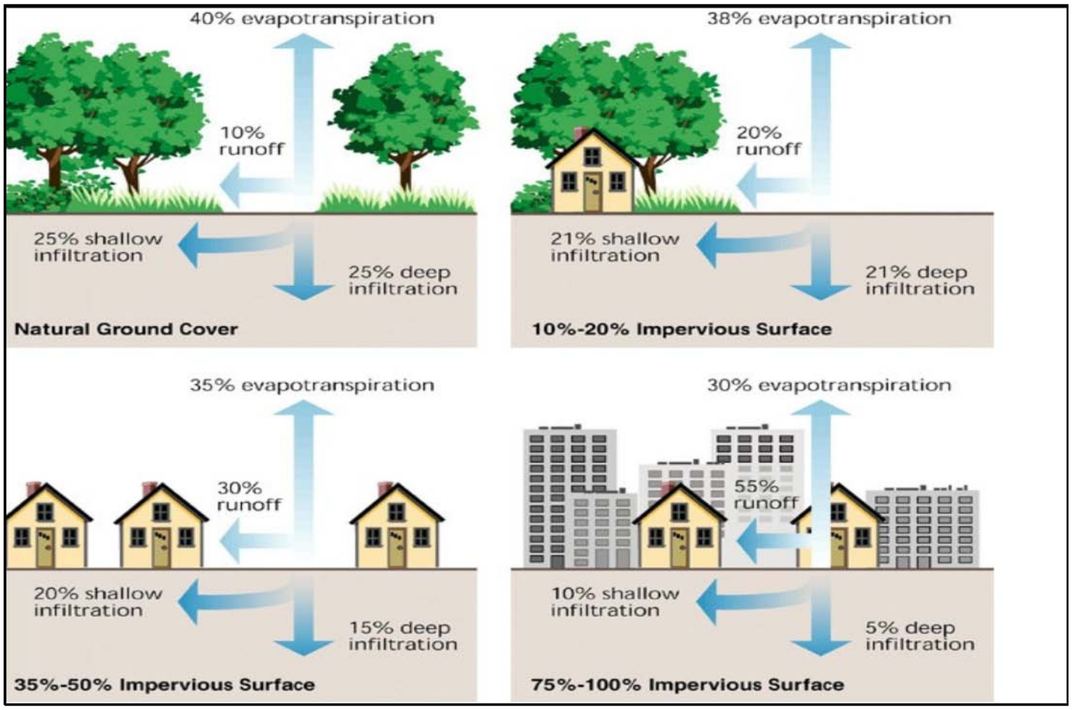
Source : After, M. L. Davis, D. A. Cornwell. **Introduction to Environmental Engineering**, 1991.

Definitions:
Overland runoff – water that travels over the ground surface to a channel
Streamflow – movement of water via channels
Groundwater flow – movement of water through the subsurface
Infiltration – penetration of water through the ground surface
Groundwater recharge – water that reaches saturated zone

Figure 1.4.2 illustrates the dramatic changes in the proportion of precipitation entering different flow pathways when land use changes from native vegetation to an urban landscape. In particular, there can be a 3 to 5 fold increase in the amount of runoff reaching streams, with a corresponding reduction in infiltration of water into the ground.

Not only is there a change in the total volume of stormwater runoff from urban areas, but the characteristics of the runoff change as shown in the Figure 1.4.3. For a given event, both the peak discharge (the peak rate of runoff) and the duration (the amount of time) that this higher peak flow occurs is increased in urban versus rural or forested watersheds (Figure 1.4.4).

Figure 1.4.2 The impact of conventional urbanization on the hydrologic cycle



Source: U.S. EPA, 2007

Figure 1.4.3 Flood hydrographs for urbanized and natural drainage basins

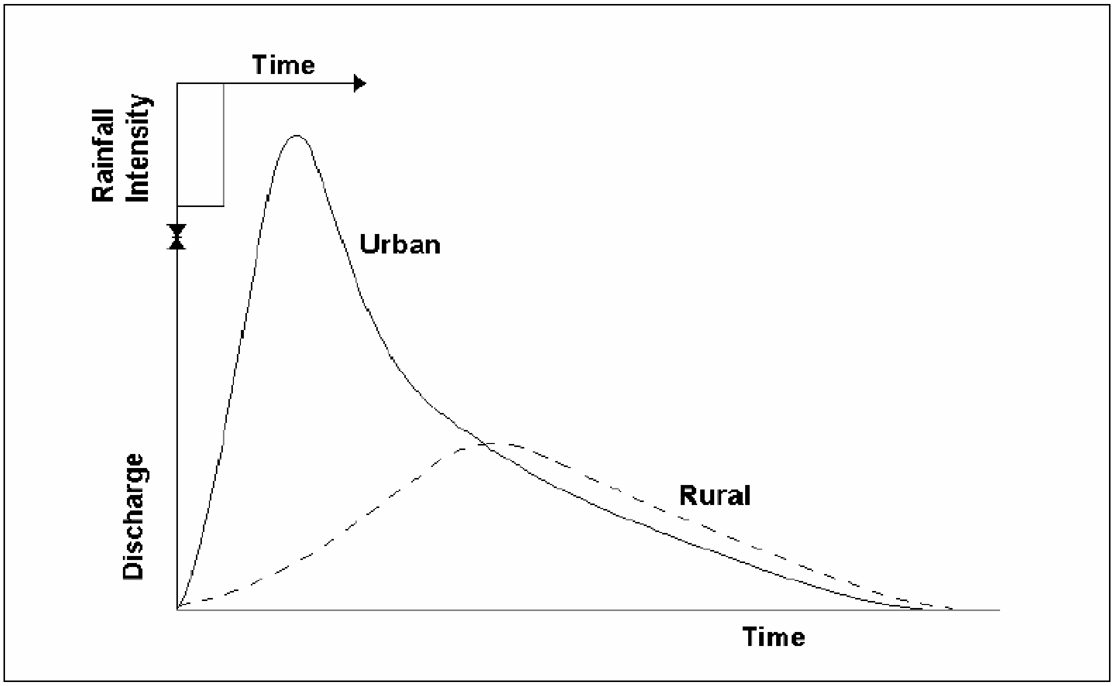
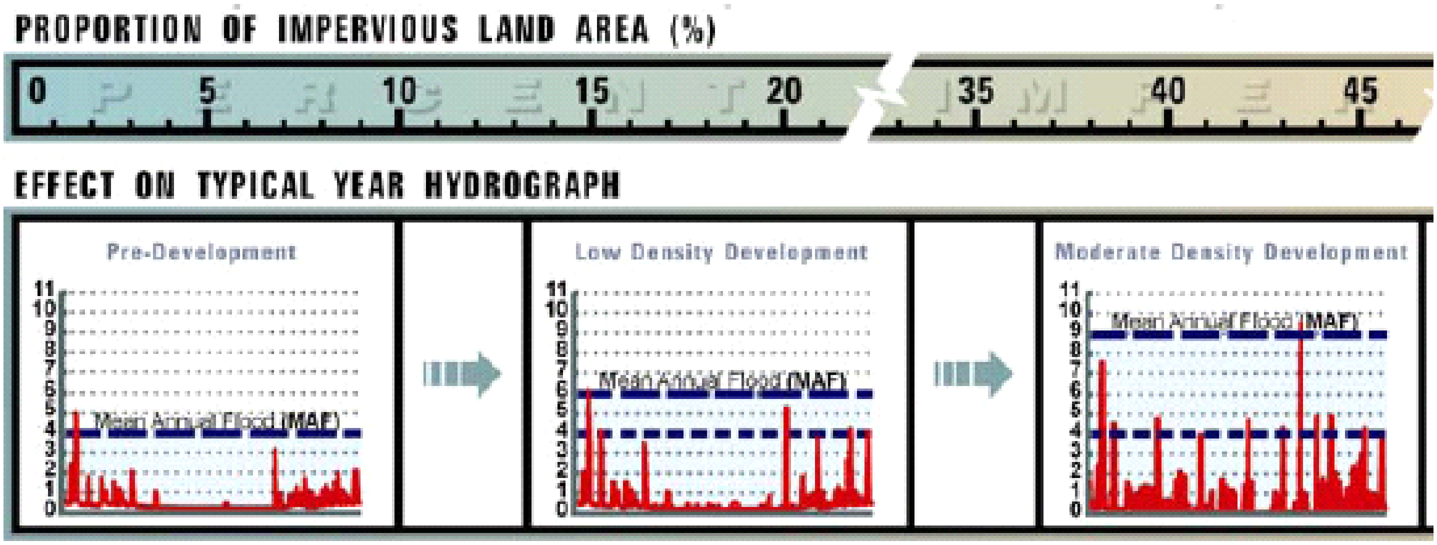


Figure 1.4.4 Changes in magnitude and frequency of peak flows as urbanization increases



Source: BC MWLAP, 2002

This means that not only is there an increase in potential for flooding downstream, but the hydrologic changes associated with increased imperviousness can cause other problems such as:

- alteration of stream flows;
- alteration of stream channels and associated aquatic habitat;
- increased erosion and sedimentation; and
- degraded water quality.

If effective stormwater management controls are not in place, increased imperviousness leads to a cascade of effects as shown in Table 1.4.1. Rivers in highly urbanized areas are sometimes referred to as “peaky” because they have too little flow under dry conditions, and too much flow (high volumes and high peak flows) when it rains. This leads to problems with flooding, erosion, water quality and alterations to stream channels and aquatic habitat.

Flooding and Stream Flows

While stormwater management ponds were originally used primarily to control the increase in peak flows from urbanization to address flooding concerns, it soon became apparent that both the peak flow and its duration needed to be controlled to address problems of erosion, sedimentation and habitat alteration. Since urban stormwater also carries a significant load of suspended sediments, nutrients and other contaminants, the amount of these materials entering a waterbody can be reduced simply by reducing the volume of stormwater reaching the waterbody. Thus controlling runoff volumes is part of the solution to addressing water quality impacts from urbanization.

Table 1.4.1 Ecosystem responses to urbanization

Results of Increased Imperviousness	Resulting Impacts					
	Flooding and Altered Stream Flows	Habitat Loss	Erosion and Sedimentation	Channel Widening	Streambed Alteration	Water Quality
Increased Flow Volume	✓	✓	✓	✓	✓	✓
Increased Peak Flow	✓	✓	✓	✓	✓	✓
Increased Peak Duration	✓	✓	✓	✓	✓	✓
Increased Stream Temperature		✓				✓
Decreased Base Flow	✓	✓				✓
Sediment Loading Changes	✓	✓	✓	✓	✓	✓

CVC's Credit River Water Management Strategy Update study showed that conventional stormwater best management practices have only limited benefits in restoring predevelopment runoff rates and represent only a small improvement over uncontrolled urban growth (Table 1.4.2; Figure 1.4.5). Only by implementing state of the science, treatment-train stormwater management technologies, did a significant reduction in runoff occur.

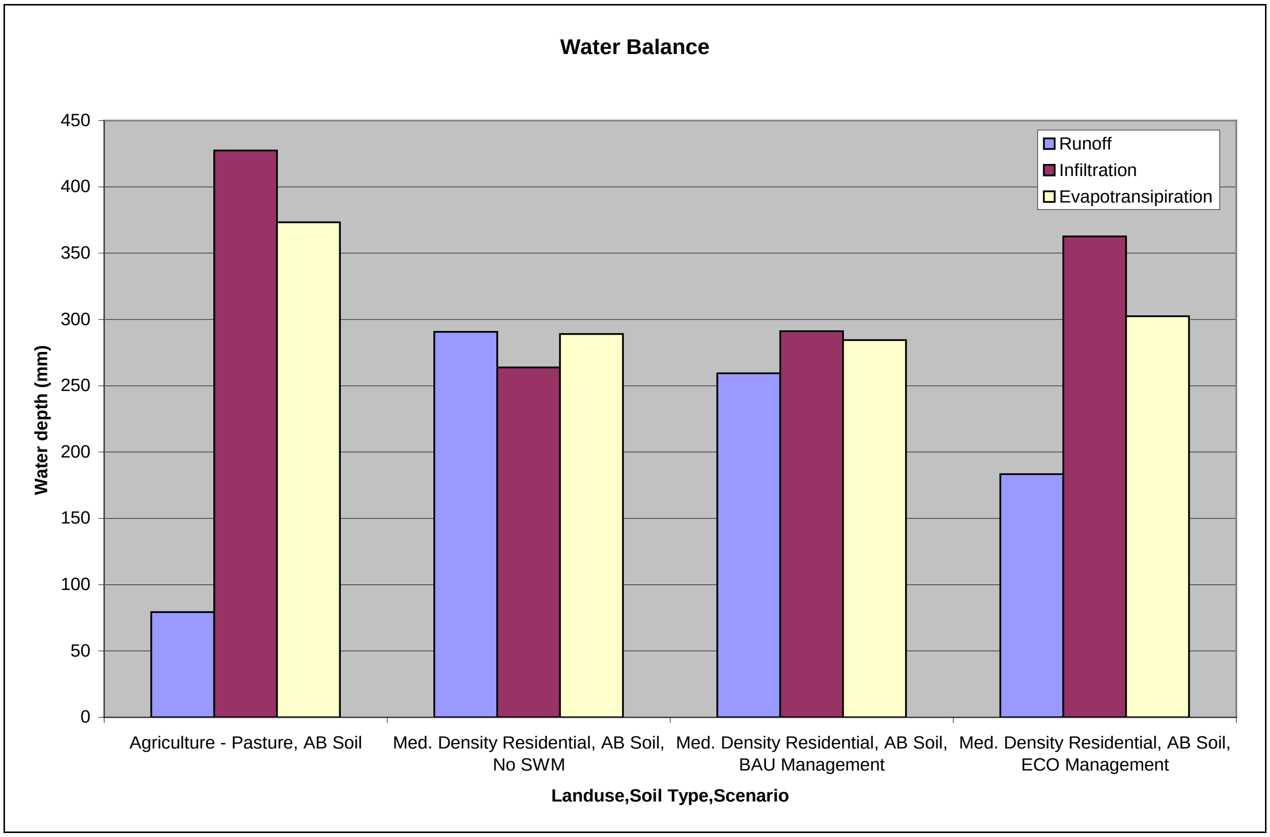
Table 1.4.2 Summary of water balance characteristics for different land uses, soil types and stormwater management strategies

Land Use	Soil Type	Scenario	Annual (mm)			
			Rainfall	Runoff	Infiltration	Evapo-transpiration
Agriculture - Pasture	Sandy Soils	Existing conditions	804	77	418	365
Medium Density Residential	Sandy Soils	No SWM*	804	291	264	289
Medium Density Residential	Sandy Soils	Business-as-usual management approach**	804	259	291	284
Medium Density Residential	Sandy Soils	"Ecotopia" management approach***	804	183	363	303

*SWM – Stormwater management;
** Business-as-usual (BAU) management approach assumes implementation of traditional stormwater management practices, such as detention ponds;
*** "Ecotopia" (ECO) management approach assumes implementation of a full treatment train of stormwater management practices, including lot level and conveyance controls and wetland treatment systems.

Source: CVC, 2007b

Figure 1.4.5 Comparison of runoff, infiltration and evapotranspiration rates for different stormwater management strategies



Source: CVC, 2007b

Erosion and Sedimentation

The changes in the water budget that accompany the urbanization of a watershed have a direct bearing on the morphology, stability and character of the receiving streams. These effects include:

- *Stream widening and bank erosion:* Stream channels enlarge to accommodate higher stormwater volumes and peak flows.

- *Streambed changes due to sedimentation:* Channel erosion and sediment loading from urban construction lead to deposition of fine material in streams covering coarser materials with mud, silt and sand.

- *Stream downcutting:* Another adjustment that occurs in response to flow increases is downcutting of the stream channel, which leads to a steepening of the stream profile or gradient, thus accelerating the erosion process.

- *Loss of riparian tree canopy:* The continued undercutting and failure of stream banks exposes tree roots that normally protect stream banks from erosion, leading to uprooting of trees that causes further weakening of the structural integrity of the stream banks

Many of these erosion and sedimentation effects are delayed until some time after the process of urbanization occurs. Stream channels can continue to enlarge and erode for decades after development occurs before they reach a new stable regime.

Water Quality

Urban stormwater is a source of a variety of pollutants including nutrients, contaminants, bacteria, and suspended sediment. Typical concentrations of these pollutants are shown in Table 1.4.3. Typical sources are listed in the Table 1.4.4.

In a recent review of the effectiveness of stormwater management practices, it was noted that one of the most effective ways of minimizing the potential for channel erosion, reduction in water quality loadings and degradation of aquatic habitat in the receiving channel downstream of an urban development is to minimize changes to runoff volume and discharge rate (Aquafor Beech Ltd., 2006). An equally important corollary to this statement is that a significant reduction in the delivery of pollutants from urban areas into receiving waters requires that sources of “clean” runoff are not contaminated or combined with polluted runoff.

Table 1.4.3 Comparison of urban stormwater runoff concentrations with provincial water quality objectives (PWQO)

Parameter	Units	PWQO	Observed Concentrations
Escherichia coli	CFU/100 mL	-	10,000 to 16 x 10^6
Total Suspended Solids (TSS)	mg/L	-	87 – 188
Total Phosphorus (TP)	mg/L	0.03 (interim)	0.3 – 0.7
Total Kjeldahl Nitrogen (TKN)	mg/L	-	1.9 – 3.0
Phenols	mg/L	0.001	0.014 – 0.019
Aluminum (Al)	mg/L	-	1.2 – 2.5
Iron (Fe)	mg/L	-	2.7 – 7.2
Lead (Pb)	mg/L	0.005 (interim)	0.038 – 0.055
Silver (Ag)	mg/L	0.0001	0.002 – 0.005
Copper (Cu)	mg/L	0.005	0.045 – 0.46
Nickel (Ni)	mg/L	0.025	0.009 – 0.016
Zinc (Zn)	mg/L	0.020 (interim)	0.14 – 0.26
Cadmium (Cd)	mg/L	0.0002	0.001 – 0.024

Source: Adapted from OMOE, 2003

Table 1.4.3 Major sources of common stormwater pollutants

Common Constituents	Major Sources Related to Urban Land Use
Sediment and Particulates	Construction, winter road sanding, vehicle emissions, pavement wear
Hydrocarbons (PAH's)	Spills, leaks, dumping, vehicle emissions, asphalt breakdown, wood preservatives
Pathogens (Bacteria, Viruses)	Illicit connection of septic systems to storm sewers, poor housekeeping (animal feces, bird feces from rooftops)
Chloride, Sodium, Calcium	De-icing salt applications
Cyanide	Anti-caking agent in de-icing salts and sand / salt mixtures
Nutrients (N, P)	Illicit connection of septic systems to storm sewers, detergents (car washing), lawn fertilizers
Cadmium	Tire wear, insecticides, wood preservatives
Zinc	Galvanized building materials, tire wear, motor oil, grease
Lead	Motor oil, lubricants, batteries, bearing wear, paint, vehicle exhaust
Copper	Wear of moving engine parts, metal plating, fungicides and insecticides
Manganese	Wear of moving engine parts
Nickel	Vehicle exhaust, lubricants, metal plating, wear of moving parts
Chromium	Metal plating, wear of moving parts
Iron	Steel structures, rusting automobile bodies
PCBs	Leaks from electrical transformers, spraying of highway right of ways, catalyst in tire construction

Source: Adapted from Burton and Pitt, 2002

Aquatic Habitats

Along with the alterations in hydrology, morphology and water quality that typically take place in a watershed as urbanization progresses, there can be a continued deterioration in the quality and quantity of aquatic habitat for fish and other forms of aquatic life. The impacts on habitat consist include:

- *Increased water temperature:* The combination of warmer runoff from impervious areas and SWM ponds, loss of riparian cover from erosion and reduction in groundwater infiltration can produce severely elevated temperatures in the receiving streams, which can contribute to reductions in dissolved oxygen and create conditions outside of the thermal tolerance limits for desirable fish species and other aquatic life.

- *Reduced groundwater levels and base flow conditions:* The loss of infiltration of rain adversely affects available groundwater resources, ultimately leading to a decline in stream baseflows, which can adversely affect instream habitat during periods when fish are most vulnerable to low flow conditions.

- *Degradation of habitat structure:* The negative effects on the quantity of aquatic habitats take several forms. Increased peak flows and velocities of flow can render some habitats unsuitable for fish; erosion and sedimentation can significantly alter valuable habitats and smother eggs.

- *Loss of channel structure:* As stream morphology degrades, the stream channel becomes straightened and the alternating sequence of pools and riffles is lost, reducing the diversity of habitats for fish.

- *Reduction in biodiversity*: Collectively the above effects will degrade the quality and reduce that variability of aquatic habitats leading to a corresponding reduction in the ability of the habitat to support the variety and abundance of aquatic life it once supported.

1.5 Legislative Framework

Conservation authorities (CAs) are directed by the *Conservation Authorities Act* to carry out a number of critical functions related to watershed planning and management. This includes preventing, eliminating, or reducing loss of life and property from flooding and erosion, and encouraging the protection and regeneration of natural systems. Under the *Conservation Authorities Act*, the powers of a CA include:

- to study and investigate the watershed and to determine a program whereby the natural resources of the watershed may be conserved, restored, developed and managed; and, to cause research to be done (Section 21); and
- to make regulations applicable in the area under its jurisdiction (Section 28).

Both TRCA and CVC administer their own individual regulations, which permit them to:

(a) prohibit, regulate or require the permission of the authority for straightening, changing, diverting or interfering in any way with the existing channel of a river, creek, stream or watercourse, or for changing or interfering in any way with a wetland;
(b) prohibit, regulate or require the permission of the authority for development, if in the opinion of the authority, the control of flooding, erosion, dynamic beaches or pollution or the conservation of land may be affected by the development.

Permit applications made under these regulations are assessed to determine if proposed works will affect the control of flooding, erosion, dynamic beaches, pollution or the conservation of land in accordance with the *Conservation Authorities Act*, and as guided by the two CAs' programs and policies. Both CAs have policies which implement their respective regulations and facilitate their role as commenting agencies under the *Planning Act* and the *Environmental Assessment Act* as described below.

Under the *Planning Act*, CAs are a prescribed agency, meaning they have the opportunity to comment on *Planning Act* applications circulated to them by their municipal partners. Municipalities are the approval authority for *Planning Act* applications and their decisions must be consistent with the provincial interest in planning expressed in the Ontario Ministry of Municipal Affairs and Housing (OMMAH) 2005 Provincial Policy Statement (PPS). Section 2.1 of the PPS provides direction for protecting natural heritage; Section 2.2 deals with water management; and Section 3.1 addresses the management of natural hazards and the need to direct development outside of hazardous areas. Because municipalities tend to have limited expertise with respect to Section 3.1, the Province entered into a memorandum of agreement (MOU) with Conservation Ontario, the umbrella organization that represents Ontario's 36 CAs, to delegate the responsibility of upholding the natural hazards section of the PPS to CAs. In this delegated role, CAs are responsible for representing the "Provincial Interest" on natural hazard matters where the Province is not involved.

Just as the Province recognized the expertise of conservation authorities, municipalities commonly rely on them for advice on natural heritage and water management. For regional municipalities, this relationship has been formalized through a series of MOUs with CVC and TRCA, while a mix of formal and informal agreements exist with local municipalities. Generally, these MOUs and agreements stipulate that the protection, restoration, and enhancement of the natural environment, and the safety of persons and property, is carried out in part through the review of, and preparation of comments on development applications, and that it is a shared responsibility of the municipality and the CA. Parameters for plan review and technical clearance are also established along with protocols for streamlining the planning process. Specific responsibilities typically include establishing requirements and conditions to determine the need for, and adequacy of, studies that assess impacts and propose mitigation measures related to surface and groundwater, natural features and functions.

As part of the overall planning process, CVC and TRCA are expected to review and comment on all environmental assessments (EAs) within their respective jurisdictions. Often, at the detailed design stage of infrastructure projects undergoing an EA process, a permit under a CA regulation is required.

In both their commenting roles under these two Acts, CVC and TRCA must also be aware of impacts to fish habitat, as both CAs have agreements with Fisheries and Oceans Canada to implement section 35(2) of the federal *Fisheries Act*, which states that no person shall carry on work that would cause the harmful alteration, destruction, or disruption of fish habitat.

The complexity of the planning and development process is apparent, so many of CVC's and TRCA's MOUs with their municipal partners recognize and secure the CA's expertise in water management, in order to help them "be consistent" with the water policies in Section 2.2 of the PPS. Section 2.2.1 states:

> Planning authorities shall protect, improve or restore the quality and quantity of water by: a) using the watershed as the ecologically meaningful scale for planning; b) minimizing potential negative impacts, including cross-jurisdictional and cross-watershed impacts; c) identifying

> surface water features, ground water features, hydrologic functions and natural heritage features and areas which are necessary for the ecological and hydrological integrity of the watershed; d) maintaining linkages and related functions among surface water features, ground water features, hydrologic functions and natural heritage features and areas; g) ensuring stormwater management practices minimize stormwater volumes and contaminant loads, and maintain or increase the extent of vegetative and pervious surfaces (OMMAH, 2005).

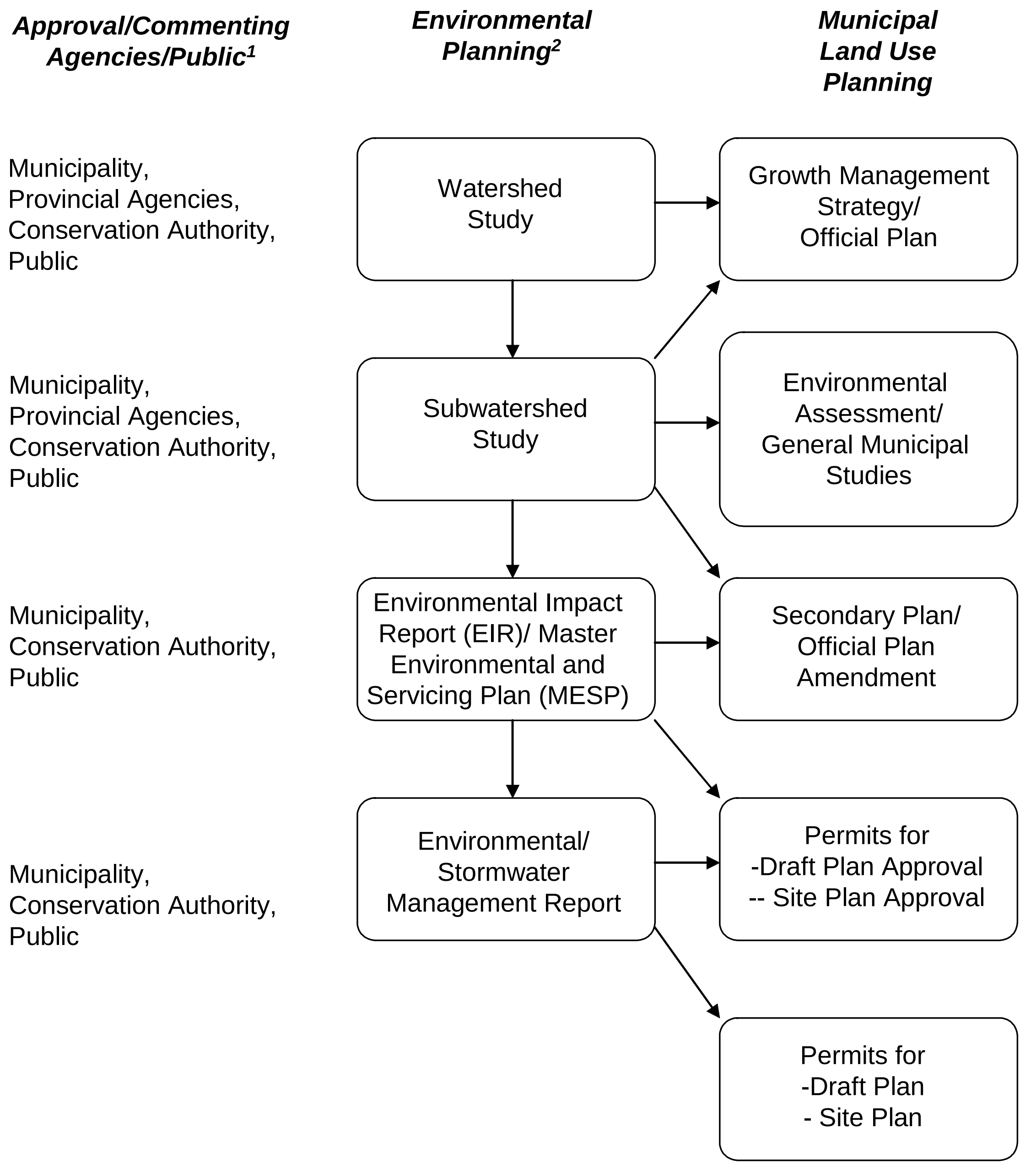
In CVC's and TRCA's role as advisors to our municipal partners on planning matters, and as ingrained in each agency's watershed management plans, the importance of achieving a post-development water balance that matches, as closely as possible, the pre-development water balance condition is emphasized. On sites that have been designed with conventional stormwater management, examination of post-development conditions has shown that natural features are not being sustained and natural hazards are being exacerbated. Therefore, the implementation of innovative stormwater management techniques is required to complement more traditional methods; these can include source and conveyance controls that infiltrate, re-use, or evapotranspirate run-off. This *Low Impact Development Stormwater Management Planning and Design Guide* outlines a host of these best management practices, collectively termed low impact development, which can be used to manage stormwater volume and protect the water resources and natural heritage systems over the long term. Accordingly, Section 2.2.2 of the PPS states that, "mitigative measures and/or alternative development approaches may be required in order to protect, improve or restore sensitive surface water features, sensitive ground water features, and their hydrologic functions" (OMMAH, 2005).

Innovative, non-traditional stormwater management needs to take place in not only areas of new development, but also in areas undergoing redevelopment. While development standards and practices have improved greatly since the earlier decades of urbanization, older developed areas have already taken their toll on watershed conditions. Impervious surfaces cover considerable portions of CVC and TRCA watersheds and a large proportion of these areas lack comprehensive stormwater control.

Therefore, in both development and redevelopment scenarios, a comprehensive outlook is necessary to effectively manage stormwater from a landscape perspective. This can be achieved by considering stormwater and LID as early in the planning process as possible, as further described in Chapter 2.

The general inter-relationship between the traditional municipal land use planning process and environmental (*i.e.*, watershed) planning is depicted in Figure 1.5.1. Ideally, this provides a hierarchy of plans that integrate environmental and municipal planning, and a process in which all relevant agencies provide input under their respective legislative mandates.

Figure 1.5.1 Relationship between municipal land use planning and environmental (watershed) planning processes



1. Approval/commenting agency/public involvement will vary from jurisdiction to jurisdiction
2. For a given jurisdictional area, one Environmental Planning component would generally be associated with one Municipal Land Use Planning component. Multiple arrows leading from the Environmental Planning component to the Municipal Land Use Planning component signify different approaches which are used in different jurisdictions.

Adapted from OMOE, 2003

1.6 Report Outline

Chapter 1 provides an overview of why the guide has been developed. It reviews the environmental impacts of urbanization and the current planning framework for stormwater management in Ontario.

Chapter 2 discusses how stormwater management facility planning and design can be better integrated into the development planning process, in particular, illustrating how better site design and identification of environmental opportunities and constraints early on in the process can lead to more effective stormwater management. The chapter also highlights the importance of planners, engineers, biologist, hydrogeologists and landscape architects working together to develop an overall plan.

Chapter 3 provides an introduction to low impact development, an overview of the LID design process and information to help practitioners select practices suitable to site specific conditions and stormwater source areas.

Chapter 4 describes ten structural low impact development practices for stormwater management. Guidance regarding site suitability, design, operation and maintenance is provided for each general type of practice.

Chapter 5 describes compliance, performance and environmental effects monitoring programs, as they relate to stormwater management systems.

Chapter 6 provides a master list of documents that have been referred to in this guide.

2.0 INTEGRATING STORMWATER MANAGEMENT INTO THE PLANNING PROCESS

2.1 Introduction

As the science of stormwater management has evolved, a variety of documents has been produced to assist and provide direction to practitioners in Ontario. These include documents such as the trilogy of watershed planning documents produced in 1993 (OMOEE & OMNR, 1993a; 1993b; 1993c), provincial stormwater management planning and design guidelines (OMOEE & OMNR, 1991, OMOEE, 1994; OMOE, 2003), and municipal stormwater management guidelines (City of Toronto, 2006). With the initiation of integrated watershed monitoring programs by CVC and TRCA early in this decade, information is becoming available to evaluate and track watershed health at scales that are informative to watershed managers, land use planners and stormwater management system designers. Information being generated by watershed monitoring programs and from recent regional scale studies of hydrogeology (*e.g.*, York Peel Durham Toronto Groundwater Management Project), terrestrial natural heritage (*e.g.*, CVC, 2004; TRCA, 2007e), and aquatic natural heritage (*e.g.*, CVC, 2002; OMNR & TRCA, 2005; TRCA, 2009b), has greatly improved our understanding of watershed system features, functions and linkages and the effectiveness of conventional management approaches to maintain watershed health. The latest generation of watershed planning studies has integrated this information into recommendations to improve conventional management approaches, which include integrating low impact development practices into stormwater management planning and design (Aquafor Beech Ltd., 2006; CVC, 2007b; TRCA, 2007c; TRCA, 2008a; TRCA, 2009a). Drawing on direction from stormwater management guidelines and recent watershed planning studies, guidance regarding study requirements at various stages in the development planning and review process has also been produced (*e.g.*, CVC, 2007a; TRCA, 2007b). Collectively, this body of knowledge provides:

- a rationale for considering watersheds as the natural and logical boundary for environmental and land use planning;

- direction with respect to the types of environmental studies that are required for development to take place and the range of expertise needed to be involved;

- evidence that current urban design and stormwater management approaches are not sustainable over the long term if watershed goals are to be realized, and, therefore, that a change in planning and design practices is required;

- a need to enhance stormwater management in existing urban areas;

- direction with respect to the diverse range of disciplines needed to effectively and successfully undertake an integrated planning and design approach; and

- recognition that new technologies such as the treatment train approach, low impact development (LID) principles and green building certification systems (*e.g.*, Leadership in Energy and Environmental Design - LEED, Green Globes) represent the next step in the evolution of stormwater management practice.

The primary objective of this chapter is to outline an approach to the planning and design of stormwater management systems and facilities that is focused on ensuring that infrastructure is fully integrated within both the urban fabric of the community and the functional landscape.

The chapter provides an overview of a landscape-based approach to stormwater management planning. This approach is founded on the principle that development form, servicing and stormwater management strategies should be defined by the biophysical, hydrological and ecological attributes of the environment and landscape in addition to other planning objectives (*e.g.*, land use, densities, transportation, and urban design).

This chapter also provides a brief overview of key steps in the recommended process for designing best management practices (BMPs) for stormwater management. More detailed discussion is provided in CVC's Credit River *Water Management Guidelines* (2007a) and TRCA's *Planning and Development Procedural Manual* (2007b).

Lastly, it provides examples of opportunities for integrating landscape-based stormwater management at various planning scales (*i.e.*, the community, neighbourhood and site scales) and stages in the process.

2.2 Environmental, Land Use and Stormwater Management Planning

Documents such as CVC's *Credit River Water Management Guidelines* (2007a) and TRCA's *Planning and Development Procedural Manual* (2007b) describe the types of environmental studies at the watershed, subwatershed and site scales that should be undertaken and submitted in support of development proposals. Each municipality tends to be unique with respect to how it carries out its municipal land use and environmental planning processes. It is therefore not possible to define a process that is applicable to all municipalities for all types of studies.

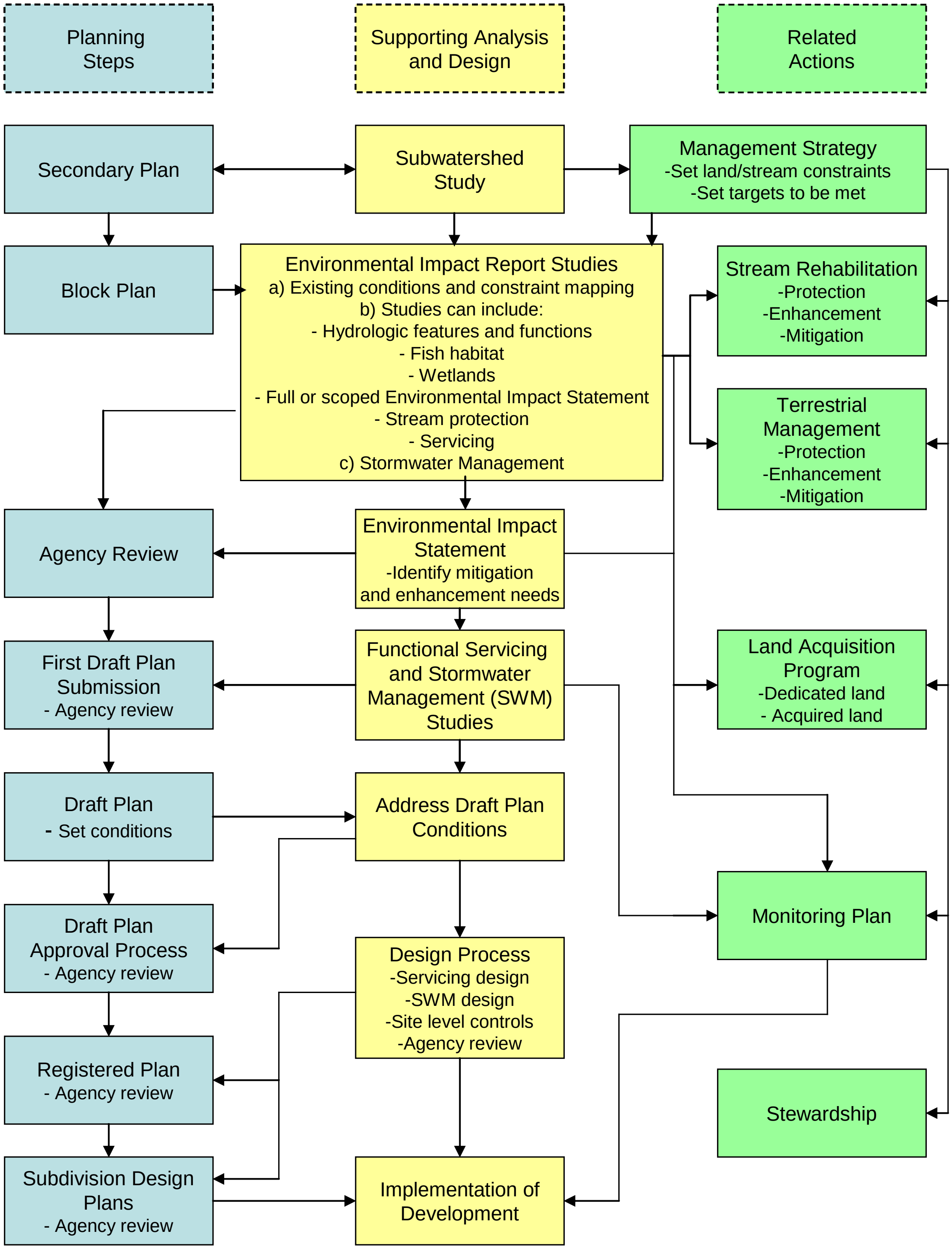
Figure 1.5.1, adapted from the 2003 OMOE Stormwater Management Planning and Design Manual illustrates the general inter-relationship between municipal land use planning and environmental (watershed) planning studies. Figure 1.5.1 includes the agencies that are typically involved in the review of documents at each phase in the land use planning and development proposal review processes. Figure 2.2.1 illustrates the relationship between the major land use planning stages, requirements for supporting analysis and design, and related actions such as stream rehabilitation, management of terrestrial habitats, land acquisition and monitoring.

This section of the *LID SWM Guide* illustrates how landscape-based stormwater management planning can take place at various scales and land use planning stages. This is summarized in Table 2.2.1.

Table 2.2.1 Summary of stormwater management planning at key scales and land use planning stages

Scale	Planning Stage	Description
Watershed plans	Master Plans Growth Plan Official Plan	Major themes and objectives for the municipality's future growth are established, and challenges and opportunities for growth are identified, such as municipal policy direction for innovative SWM approaches and other climate change initiatives.
Community/ Subwatershed	Secondary Plan	Major elements of the natural heritage system are identified including terrestrial, aquatic and water resources (hydrology, hydrogeology, fluvial geomorphology, etc.). Stormwater management objectives for surface and groundwater resources. Future drainage boundaries, locations of stormwater management facilities and watercourse realignments are established.
	Block Plan	The location of lots, roads, parks and open space blocks, natural heritage features and buffers, and stormwater management facilities are defined. A full range of opportunities to achieve stormwater management objectives are identified, establishing a template for the more detailed resolution of the design of stormwater management facilities at subsequent stages in the planning and design process.
Neighbourhood	Draft Plan of Subdivision/ Functional Servicing Plan	Conceptual design is carried out for stormwater management facilities. Consideration must be given to how stormwater management objectives can be achieved and how these objectives influence the location and configuration of each of the components listed above
	Registered Plan	Detailed design is carried out for stormwater management facilities.
Site	Site Plan	Site-specific opportunities are identified to integrate stormwater management facilities into all of the components of a development including landscaped areas, parking lots, roof tops and subsurface infrastructure. Solutions must be considered in the context of the overall stormwater management strategy for the block or secondary plan area to ensure that functional requirements are achieved
Site	CA Permits and other approvals	Detailed design of SWM for the site

Figure 2.2.1 Example of relationship between major land use planning stages, supporting environmental analysis and design, and related actions[1]



[1] This figure provides a general description of various land use planning stages which may not always take place in this order and may not be limited to only these steps and studies. Requirements noted are not an exhaustive list. Guidance regarding required supporting analysis and design should be obtained from the relevant approval authorities which will be specific to the context of the proposed development.

2.3 Overview of Landscape-based Stormwater Management Planning

This section of the *LID SWM Guide* is focused on promoting an approach to the planning and design of stormwater management systems and facilities that ensures that infrastructure is fully integrated into the urban fabric of the community while protecting natural heritage features and functions. This landscape-based approach to stormwater management planning is founded on the principle that development form, servicing and stormwater management strategies should be defined by the biophysical, hydrological and ecological attributes of the landscape.

Landscape-based stormwater management planning is founded on an understanding of the interrelated functions of the natural and hydrological features that comprise the landscape. This approach has regard for the environmental context of a specific site or sub-catchment within the matrix of the larger landscape, subwatershed and watershed, including features, functions and systems that are situated beyond the limits of the site. The landscape-based approach to stormwater management planning also recognizes the importance of temporal, seasonal and microclimatic factors on ecological function. The ultimate goal of a landscape-based approach to stormwater management planning is to maintain the ecological integrity of healthy sites, subwatersheds and watersheds, or enhance it where predevelopment conditions are degraded. The application of this approach to stormwater management planning requires a comprehensive understanding of natural and hydrologic features and functions, including the following:

- biophysical, hydrological, hydrogeological and natural heritage features;
- the interrelated functions of these features;
- modifying factors (such as climate); and
- temporal factors (such as seasonal changes, life cycles and successional processes).

The landscape-based approach to stormwater management planning and design is also founded on recognition of the value of land, both as a commodity and as the fundamental basis of a sustainable ecosystem. The approach is focused on utilizing land efficiently and where possible overlaying more than one function on any given piece of land. This requires a commitment to innovation in the design process, which facilitates exploring opportunities to integrate stormwater management infrastructure within the streets, lots, parks and other components of a proposed development.

To be successful, the landscape-based approach to stormwater management planning must be implemented at successive stages and scales within the overall planning process, beginning at the watershed scale and proceeding through the community or subwatershed, neighbourhood and site scales and associated planning stages. At each stage in the process, a multi-disciplinary team should identify opportunities to integrate facilities into the landscape. These can be built upon and resolved in further detail at subsequent stages in the planning process. Flexibility in the stormwater management planning and design process is important to allow for innovative thinking and problem solving. The product of this process will be a comprehensive and effective stormwater management strategy that is comprised of a suite of practices that are fully integrated into the landscape of a proposed development.

2.4 Landscape-based SWM Planning and Design Principles

The landscape-based stormwater management planning approach is founded on the following principles:

- Stormwater is a resource.

- Stormwater management facilities and practices (*i.e.*, lot level, conveyance and end-of-pipe practices) should be fully integrated within their physical, social and ecological contexts.

- The planning of stormwater management facilities should be an integral component of the overall land use and environmental planning process. It should begin at the watershed scale to ensure that opportunities to achieve a full range of community and environmental objectives and targets are realized, along with the primary stormwater management objective and targets.

- The design process should be focused on maximizing the benefits that can be achieved as a product of the implementation of stormwater management facilities, including the protection and enhancement of existing natural heritage resources and the provision of recreational and interpretive opportunities.

- Since developable land is a valuable and limited resource, integration of stormwater management facilities with other land uses is desirable (*e.g.*, within road right-of-ways, below parking areas, sports fields or landscaped areas).

- Stormwater management facilities should be situated and configured to ensure that they are integral components of the community and regional open space system, as well as to contribute to the quality of urban design of the community.

- Stormwater management planning should consider the maintenance requirements of facilities and aim to minimize them.

- A range of innovative techniques should be used to enhance facility performance, minimize maintenance requirements, ensure longevity and address public safety issues in addition to other functional and pragmatic considerations.

- Integration of stormwater management facilities into the landscape should take place at a range of scales. However, proposed solutions should be supported by strategies to ensure that long-term functional requirements are achieved when facilities are proposed on private lands.

- Whenever possible, public education and interpretation of the important function of stormwater management facilities should be an integral component of the management strategy for the community.

These principles provide the foundation for exploring innovative design solutions that integrate stormwater management facilities into the landscape. The landscape-based approach to stormwater management planning recognizes that some facilities take up significant space in the community and therefore are key components of the visual landscape and open space system.

2.5 Integrated Design Process

The landscape in the CVC and TRCA watersheds is comprised of a diverse assemblage of natural and cultural heritage elements integrated within a complex, functional system. The influence of hydrology on the function of the individual components of the system and the system as a whole is profound. The viability of vegetation communities, aquatic and terrestrial habitats and other key natural and cultural features within the landscape is directly influenced by hydrology. Modifications to the hydrologic regime result in alterations to stormwater runoff patterns and water quality. These changes can compromise the long-term sustainability of aquatic and terrestrial natural heritage features and functions within the landscape. The complexity of the system dictates that any planning process that changes the landscape to create a new community, development or site-specific initiative, and the stormwater management system related to the development, must have regard for all of the interrelated features and functions that sustain the landscape.

The most effective way to achieve sustainable solutions is to use a design process that dissects the landscape into its component parts, and then assesses and understands the function of each part and its influence on the others and the whole. Although the primary goal of the stormwater management design process is the appropriate treatment of runoff to control the quantity and ensure the quality of stormwater discharge, an understanding of the influences of runoff on all of the various features and interrelated functions within the landscape is fundamental to the success of the design process. The integrated design process is an effective means to ensure that complementary environmental, social and practical objectives are achieved in the development and design of stormwater management strategies.

To be fully effective, the integrated design process requires the involvement of a range of disciplines including professionals from the fields of:

- engineering;
- landscape architecture;
- terrestrial and aquatic sciences;
- geosciences (hydrogeology, fluvial geomorphology); and
- planning.

Additional expertise may be required, depending on the characteristics of the study area, to ensure the planning and design decisions are made on the basis of a comprehensive understanding of the features, functions and regional influences of the landscape and the implications of the proposed development. The process also requires that a comprehensive understanding of watershed management and natural heritage system objectives and targets relevant to the site be gained early on in the planning and design phase of the project. It is also important that the design process has regard for the long-term implications of development on the environment as well as recognition of the anthropogenic influences that have contributed to the present state of the landscape, with the objective of identifying opportunities for restoration and enhancement. The involvement of a multi-disciplinary team is essential during the design process, to ensure that objectives identified at the conceptual planning stage are achieved in the detailed design. Although the specific contribution of each discipline may vary during the design process, it is important that all disciplines be involved in the review of design solutions at key milestones to ensure that the full range of objectives remains attainable as the process moves forward.

The integrated design process is comprised of four progressive steps which are described below:

1. Establish objectives
2. Identify targets
3. Define techniques
4. Design development

Step 1: Establish Objectives

It is necessary to establish a full range of environmental, social and functional objectives to guide the planning and design process of a new development, regardless of scale. Objectives should be established based on a detailed understanding of the environment characteristics of the site and its larger contexts. Watershed and subwatershed studies provide contextual information, objectives and targets for watershed management that inform land use planning and stormwater management planning and design at both the neighbourhood and site scales. Municipal and conservation authority stormwater management guidelines and criteria documents provide specific objectives and targets for stormwater management design. While objectives for stormwater management are a subset of the complete suite of design objectives to address a full range of development considerations, it is important that they be considered as a first step in the design process.

Step 2: Identify Targets

In addition to specific stormwater management targets, a full range of targets should be established related to other design objectives. These may include targets relating to development density, land use mix, transportation systems and natural heritage systems that address ecological, social, functional, economic and practical considerations. Targets related to operations and maintenance should also be established for each component of a development to ensure that solutions proposed will remain practical, affordable and operational over the long-term.

Step 3: Define Techniques

Once site and project-specific objectives and targets are established, the range of stormwater management techniques required to achieve these targets is generated. This will include techniques that go beyond those that relate specifically to servicing or stormwater management. For example, techniques such as tree preservation and enhancement of natural cover may relate more to natural heritage objectives, but can also be effective stormwater management practices. Similarly there are techniques that can be implemented related to road network configuration and design, grading, built form and land use patterns that can contribute to the efficiency and effectiveness of a stormwater management strategy for a development. For this reason it is essential that a multi-disciplinary team be involved in the process of defining techniques to ensure that all opportunities are identified and considered as well as to catalyze the development of innovative, integrated solutions.

Step 4: Development Design

In this step stormwater management techniques are integrated and refined to generate site-specific design solutions and implementation strategies. Development design should be executed as a collaborative process involving the multi-disciplinary team. A workshop or charette can be effective forums for refining design solutions efficiently while ensuring that the interests of all disciplines are addressed. As the development design phase proceeds, the solutions proposed should be evaluated with respect to the objectives and targets established in the initial stages of the design process.

The underlying goal of the integrated design process is to ensure that the fullest range of opportunities to achieve stormwater management objectives are identified and capitalized on, as well as to ensure that designs are resolved to achieve maximum benefits that consider all development related factors, even at the finest level of detail.

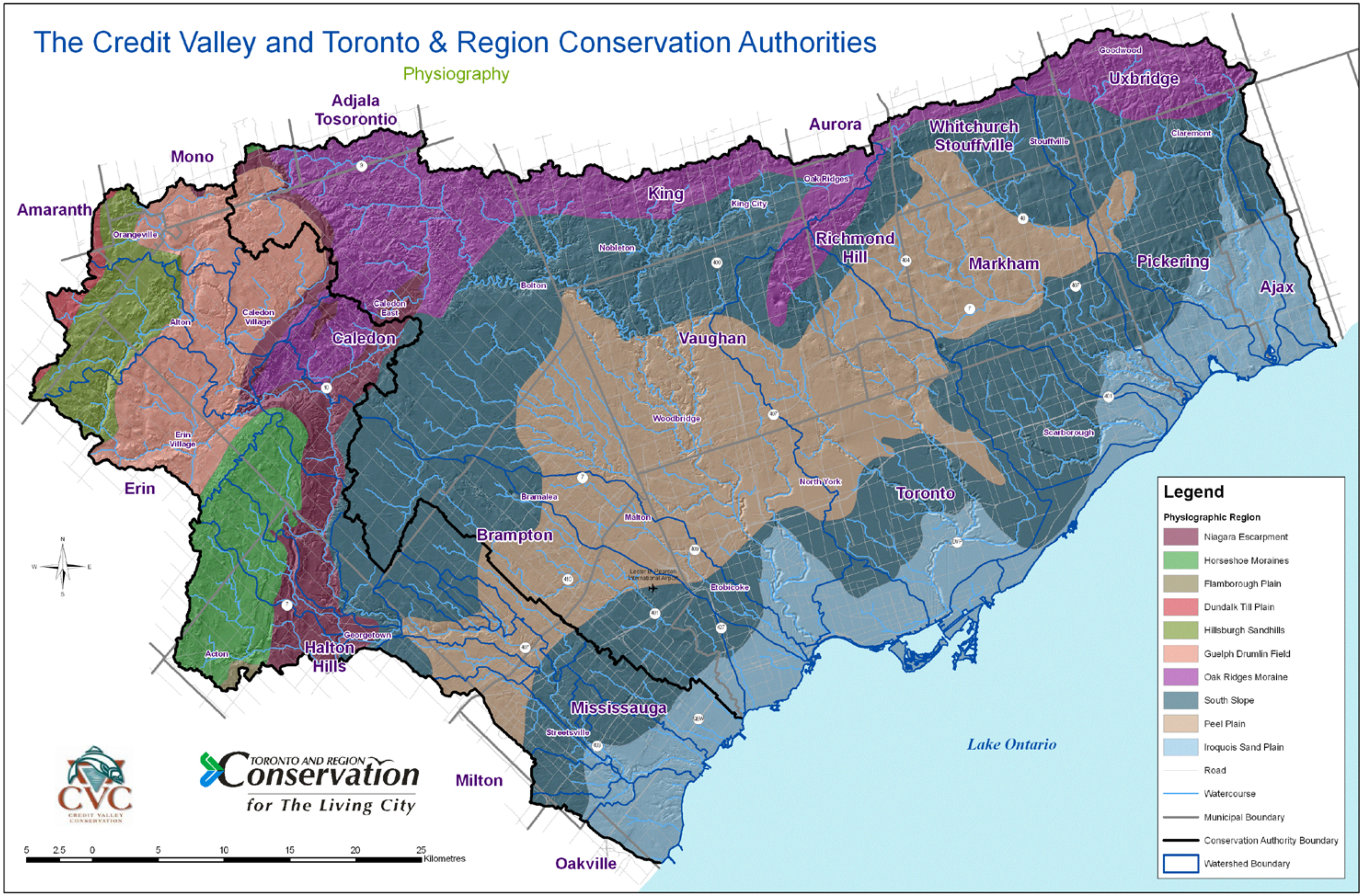
2.6 Opportunities Afforded by Landscape and Context

An understanding of the landscape and regional context of a development site provides inspiration and direction for the design of stormwater management systems that are functionally effective, efficient and complementary to the environment and the community of which they are a part. At the broad scale, planners can identify the basic strategies to address stormwater management objectives. For example, as illustrated in Figure 2.6.1, the underlying pervious soil stratigraphy associated with physiographic regions like the Lake Iroquois Sand Plain and the Oak Ridges Moraine, signals the potential to develop a stormwater strategy based primarily on infiltration practices. In contrast, sites located on the more impervious clay-based soils of the South Slope and Peel Plain may require the designer to explore strategies that employ a combination of attenuation, filtration, harvesting, evapotranspiration and infiltration practices to achieve stormwater management objectives. Stormwater management opportunities afforded by the physiographic, biophysical and ecological characteristics of the landscape can be identified and capitalized upon when sites are examined with consideration of regional landscape and watershed scale contexts.

The watershed planning approach ensures that important natural features and ecological functions and other factors that contribute to the sustainability of the regional ecosystem are identified. Watershed and subwatershed plans provide the foundation for developing a stormwater management strategy that capitalizes on the opportunities afforded by context, while respecting and responding to the elements that are fundamental to ensuring the long-term sustainability of the regional landscape.

The following section describes components of the regional landscape and the cues that they provide for designing more sustainable stormwater management strategies. Information and management recommendations regarding these components are typically provided in watershed and subwatershed plans which help to inform planning at more detailed scales of study.

Figure 2.6.1 Physiographic regions in the CVC and TRCA jurisdictions



2.6.1 Physiography and Landform

The physiography of a proposed development site is a key determinant in the process of formulating stormwater management strategies (Figure 2.6.1). In simplistic terms, physiographic characteristics such as topography and the characteristics of the soils and geology underlying the site dictate the potential to implement stormwater management strategies that employ infiltration as the primary solution. Similarly, other hydrogeologic characteristics such as depth to water table or depth to bedrock profoundly influence the feasibility of using various types of stormwater management facilities (also see section 2.6.5).

Landform also has a strong influence on the potential to implement various types of stormwater management techniques. Landform provides insight on how to design facilities such as ponds and wetlands so that they are well integrated into the landscape. Landform also dictates flow patterns, runoff velocities and discharge rates. As a general principle, development plans and stormwater management strategies should respect existing landform characteristics including maintaining predevelopment drainage divides and catchment area discharge points as closely as possible.

2.6.2 Ecological Context

The development of stormwater management practices (SWMPs), which include lot level, conveyance and end-of-pipe facilities, but in particular, detention ponds and wetlands, typically requires significant alteration of the landscape, not only in terms of physical change, but also with respect to ecosystem function. Beyond simply managing the quality and controlling the rate of discharge of runoff, ponds and wetlands can affect the function of the landscape of which they are a part. Consequently, stormwater management strategies need to be developed in consideration of their context not only with respect to the physical landscape, but also related to the function of the subwatershed ecosystem. The degree to which positive influences can be realized is determined by factors relating to the selection, siting and design of facilities.

Stormwater management practices represent opportunities in the urban environment to protect, enhance or complement existing wildlife habitat features and functions. These opportunities are typically associated with linear corridors that ultimately connect with the natural drainage system of the local landscape unit. Connecting SWMPs to neighbouring natural areas can enrich wildlife habitat in the adjacent natural areas due to increased patch size or the provision of enhanced buffers. However, it is important to note that SWMPs are functional components of the servicing infrastructure of a development and as such, require periodic maintenance and management to ensure their optimal function. Furthermore, SWMPs are designed to remove contaminants from stormwater and as such, should not be considered natural habitat features.

While complementing wildlife habitat functions may be desirable in many circumstances, there are also situations in which wildlife use of these facilities should be deterred. This can include:

- where excessive numbers of animals are attracted and populations approach nuisance levels;
- where flocking birds need to be controlled in the low altitude vicinity of airport flight paths; and,
- where facilities are associated with or integrated into certain kinds of public park or open space areas.

2.6.3 Natural Heritage and Open Space Systems

The configuration of the natural heritage and open space systems presents opportunities to integrate stormwater management facilities into the landscape to improve connectivity, enhance the integrity of core habitat areas, and provide a spectrum of environmental benefits that extend well beyond the limits of the stormwater management facility. An understanding of the key attributes and deficiencies of the existing natural heritage system (both terrestrial and aquatic systems) is essential as a basis for the development of stormwater management strategies, to ensure that important features and functions are not compromised while identifying opportunities for enhancement.

The configuration of the open space system within a development presents opportunities to complement its size, function and connectivity through strategically locating SWMPs. SWMPs can be designed to complement the open space system by increasing its breadth, providing gateway points and view corridors and accommodating uses that further enhance the function of parks and open spaces within the community. It also presents opportunities to integrate SWMPs within parks and open spaces that could enhance the performance of the overall stormwater management system while conserving developable land. Parks, sports fields, pedestrian plazas, walkways and other open spaces that form the public realm of a community can be strategically situated to accommodate SWMPs without compromising their utility or function. Integrating SWMPs into public spaces reduces the developable portion of a site that is used for stormwater management purposes.

2.6.4 Soils

The characteristics of soils within a site are key factors in designing stormwater management systems. A soil profile comprised predominantly of high permeability soils affords the opportunity to apply stormwater management strategies that employ infiltration as the primary treatment process. In contrast, in areas where soil permeability is low, the opportunities to use infiltration-based SWMPs may be limited, requiring the exploration of strategies that employ filtration, harvesting, evapotranspiration and detention as the primary treatment processes. The suitability of the surface soil to support healthy, dense vegetation cover is also an important consideration in the design of specific SWMPs that rely on vegetation as a functional element (*e.g.*, bioretention, swales, vegetated filter strips).

2.6.5 Hydrogeology

Developing stormwater management plans requires an understanding of the depth to water table, depth to bedrock, native soil infiltration rates, estimated annual groundwater recharge rates, locations of significant groundwater recharge and discharge, groundwater flow patterns and the characteristics of the aquifers and aquitards that underlay the area. Shallow groundwater or bedrock conditions may present challenges with respect to the location, design and function of ponds and infiltration facilities. Of paramount concern is the potential for contamination of groundwater resources through the introduction of pollutants from stormwater into the groundwater system. In many areas within the jurisdictions of TRCA and CVC, residents still rely on groundwater for their potable water supply and so the protection of groundwater quality in these areas is of critical importance. Another important consideration is the potential to deplete groundwater resources (*i.e.*, lowering of groundwater levels in aquifers) as a consequence of unmitigated impacts on recharge from impervious cover.

2.7 Benefits of the Treatment Train Approach

Effective stormwater management strategies employ a treatment train approach that combines a suite of lot level, conveyance and end-of-pipe controls to treat runoff efficiently and effectively. At the present time, reliance on larger end-of-pipe detention pond facilities as the primary component of a stormwater management strategy is the norm. This compromises opportunities to implement low impact development practices that enhance the performance of stormwater management systems and provide ecological sustainability benefits. Treatment train stormwater management strategies that integrate a full range of facility types have the potential to achieve a broader range of benefits including:

- maintaining and enhancing shallow groundwater levels and interflow patterns;
- maintaining predevelopment drainage divides and catchment discharge points;
- moderating run off velocities and discharge rates;
- improving water quality;
- enhancing evapotranspiration;
- maintaining soil moisture regimes to support the viability of vegetation communities; and
- maintaining surface and groundwater supplies to support existing wetland, riparian and aquatic habitats.

Chapter 4 of this guide describes low impact development stormwater practices that can be applied as part of a treatment train approach to achieve this broader range of benefits.

2.8 Importance of the Runoff Source Area

With respect to water quality, all urban stormwater runoff is not equal. The types and levels of contaminants in runoff vary depending on the characteristics of the source area. For example, source areas like roads or parking lots are subject to vehicular traffic and application of sand and de-icing salt during winter, making them significant sources of such contaminants as sediment, de-icing salt constituents (*e.g.*, sodium and chloride), petroleum hydrocarbons and heavy metals. In contrast, roofs are only subject to atmospheric deposition of contaminants and are not subject to vehicular traffic, nor the spreading of sand and de-icing salt. Roof runoff typically contains much lower levels of petroleum hydrocarbons and heavy metals than road runoff, particularly in residential areas, and is generally suitable for infiltration. Contaminant levels in runoff from low and medium traffic roads and parking lots, pedestrian plazas and walkways are typically lower than from highways or high traffic parking lots and can represent opportunities to minimize runoff through the application of permeable pavement or other infiltration practices. Certain types of source areas, referred to here as “pollution hot spots”, have a high potential to generate contaminated runoff due to the human activities and contaminant sources typically present, such as vehicle fuelling, service or demolition areas, outdoor storage and handling areas for hazardous materials and some types of manufacturing or heavy industry. Such differences in runoff contamination potential have implications on the types of treatment practices that are suitable and on opportunities for rainwater harvesting and the use of permeable pavements.

It is important that stormwater management plans be developed with consideration of the different types of runoff source areas that will be present, and recognition of source areas with low to moderate contamination potential that represent opportunities for rainwater harvesting, permeable pavement and other stormwater infiltration practices. Furthermore, it is vital to ensure that relatively clean runoff is not mixed with lesser quality runoff from surfaces that are subject to higher levels of contamination, rendering it less suitable for infiltration or harvesting. Table 2.8.1 provides descriptions of some general types of source areas, contaminant types and levels typically present in runoff and suggestions for suitable treatment practices and principles for their application.

Table 2.8.1 Types of stormwater source areas, typical runoff characteristics and opportunities for treatment and use

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).

2.9 Landscape-Based Stormwater Management Opportunities

Landscape-based stormwater management strategies can be applied at various scales ranging from the community scale (*e.g.*, Secondary Plan or Block Plan stages), neighbourhood scale (*e.g.*, Draft Plan of Subdivision or Registered Plan stages) to the site scale. The most effective strategies are developed at larger scales and subsequently refined at progressively more detailed scales in the planning and design process. Stormwater management opportunities identified at the larger scales provide the basis for an overall stormwater management strategy that functions as a system of integrated facilities applied at the subdivision or site scales. In addition, the recent focus on intensification within existing urban areas dictates the need to identify opportunities to retrofit stormwater management practices into existing developments and service infrastructure contexts. Creative problem solving will be required to achieve stormwater management objectives within these constrained sites.

Throughout the full range of scales, there is a need to consider landscape and the elements of urban development as a cohesive unit in order to identify the most effective set of solutions for a particular site. Components of urban development such as built form, roads and services present opportunities to achieve stormwater quality and quantity control objectives through innovative design. For built form, alternatives include the incorporation of green roofs, permeable pavement, and rainwater harvesting systems. With respect to roads, options include reduced on-street parking, innovative road network designs (*e.g.*, fused grid road network; CMHC, 2007), the installation of permeable pavement, the use of swales, vegetated filter strips and bioretention areas in boulevards or the integration of perforated pipe systems beneath the road bed. The application of these alternatives can help reduce reliance on end-of-pipe facilities by reducing the quantity of impervious cover in a development and treating stormwater closer to where it is generated. Opportunities that can be applied at scales ranging from large scale to site specific are discussed in the following sections.

2.9.1 Opportunities at the Community Scale

At the community scale (*e.g.*, Secondary and Block Plan stages), the exploration of stormwater management solutions should be focused on a thorough understanding of the physical and ecological characteristics of the landscape. The properties of the native soils, groundwater depth and flow patterns, topography and the assemblage of natural heritage features within and adjacent to the limits of the site provide the fundamental basis for the exploration of landscape-based stormwater management strategies. Characteristics of the landscape can have a profound influence on stormwater management objectives and therefore the environmental inventory phase of the community design process needs to be sufficiently detailed. In addition to inventories of natural heritage features and functions that would typically be addressed within an Environmental Impact Report (EIR) or Master Environmental Servicing Plan (MESP), a landscape-based approach to stormwater management planning requires understanding the following additional parameters:

- small headwater drainage features and their contributing catchment areas; and
- groundwater recharge rates, flow patterns and discharge areas.

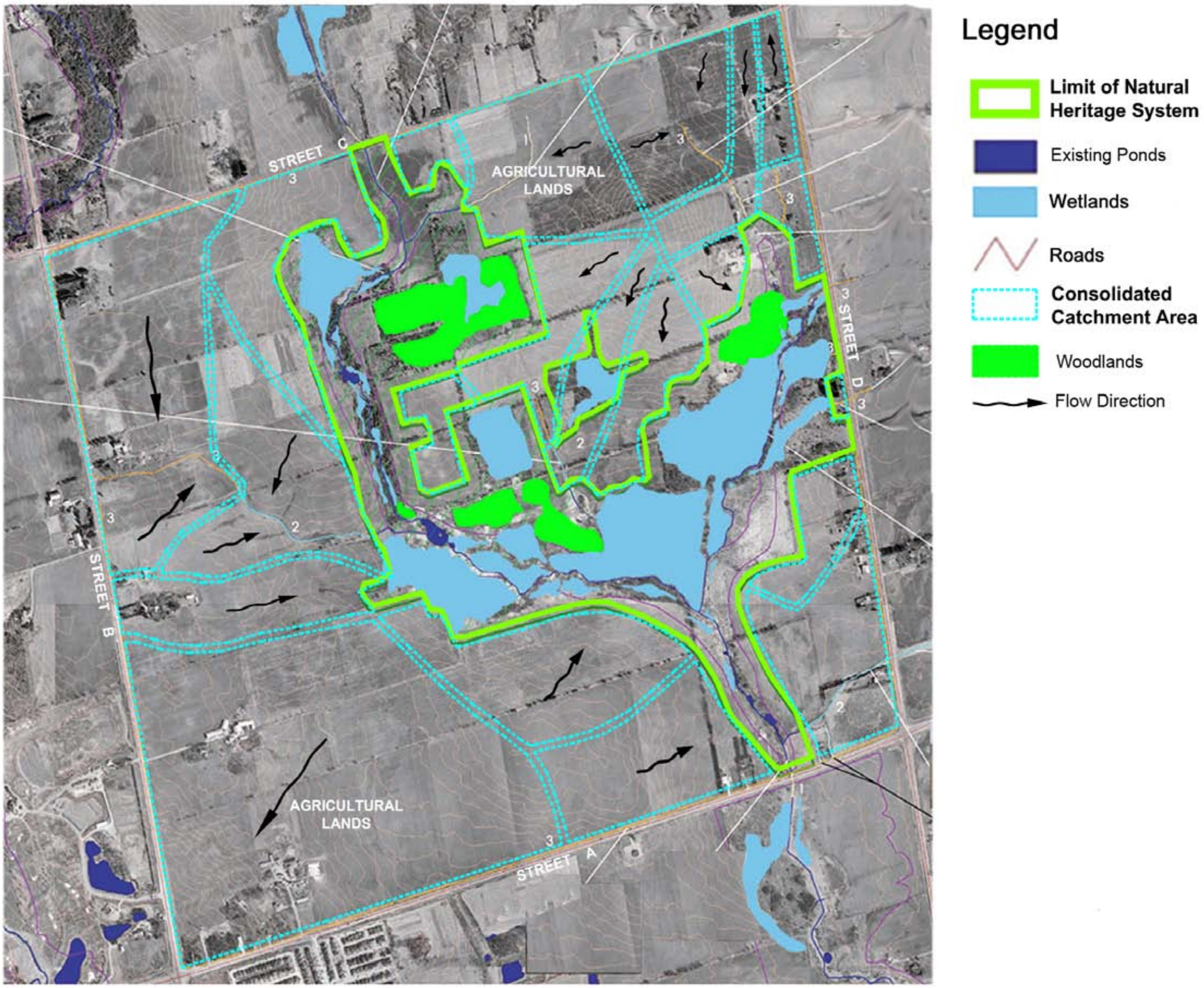
As an initial step in the planning process, opportunities to conserve natural heritage features (*i.e.*, green infrastructure) should be identified and features that contribute to the ecological integrity of the landscape should be incorporated into the overall development scheme (e.g., Figure 2.9.1). Natural features should be considered for preservation not only because of their ecological value and habitat function, but also in consideration of their contribution to evapotranspiring and infiltrating stormwater. Enhancement of the urban tree canopy and extent of forest cover in urban/urbanizing subwatersheds is an effective stormwater management strategy (TRCA, 2007c, TRCA, 2007d; TRCA 2008a). Preservation of existing natural heritage features can complement the function of SWMPs as part of a comprehensive stormwater management strategy.

New developments and communities are designed in consideration of a full range of environmental, transportation, social, practical and functional objectives to optimize their function, marketability and long term sustainability. It is important that stormwater management objectives be considered in the process of planning each of these components. For example, as mentioned in section 2.6.1, maintaining predevelopment drainage divides and catchment discharge points as closely as possible should be an objective that is considered. One means of achieving this is to align major roads to follow the divides between sub-catchment areas and local roads to follow overland flow directions. Open space components within a community plan should be situated, where possible, near the downstream limit of the sub-catchment area in order to optimize the potential to integrate stormwater management facilities within the open space system.

A suggested process for identifying landscape-based stormwater management opportunities at the community scale (*e.g.*, Secondary Plan or Block Plan stage) is comprised of the following steps:

1. Use available information from regional, watershed and subwatershed scale studies to develop an understanding of the environmental contexts in which the site is located and the watershed management objectives and targets (*e.g.*, stormwater management, natural heritage system and aquatic community objectives/targets) relevant to the site.
2. Undertake a comprehensive inventory of the biophysical, ecological and hydrological characteristics of the site.
3. Identify existing terrestrial and aquatic natural heritage features and functions that require protection as the basis for a natural heritage system.
4. Identify opportunities to enhance features, connectivity and functional integrity of the natural heritage system.
5. Identify soil and hydrogeologic conditions that are well-suited for stormwater infiltration practices.
6. Identify patterns of shallow groundwater flow and locations of discharge to receiving watercourses or wetlands within or adjacent to the limits of the site.
7. Identify strategic and desirable locations for stormwater management practices (SWMPs) and the nature and function of facilities (*e.g.*, attenuation, infiltration, filtration, evapotranspiration, harvesting, etc.).
8. Identify a long list of opportunities to integrate desirable SWMPs into components of the community or built form.
9. Explore a full range of design options for the community that can achieve stormwater management objectives in conjunction with other community design objectives.
10. Develop the community design plan.
11. Resolve the design of the stormwater management strategy including defining the SWMPs to be incorporated into the design of specific components of the development and establish specific design and performance criteria for each practice.

Figure 2.9.1 Block plan – catchment area and natural heritage system delineation as the basis for an integrated stormwater management strategy



Block Plan – Catchment Area and Natural Heritage System Delineation as the Basis for an Integrated SWM Strategy.

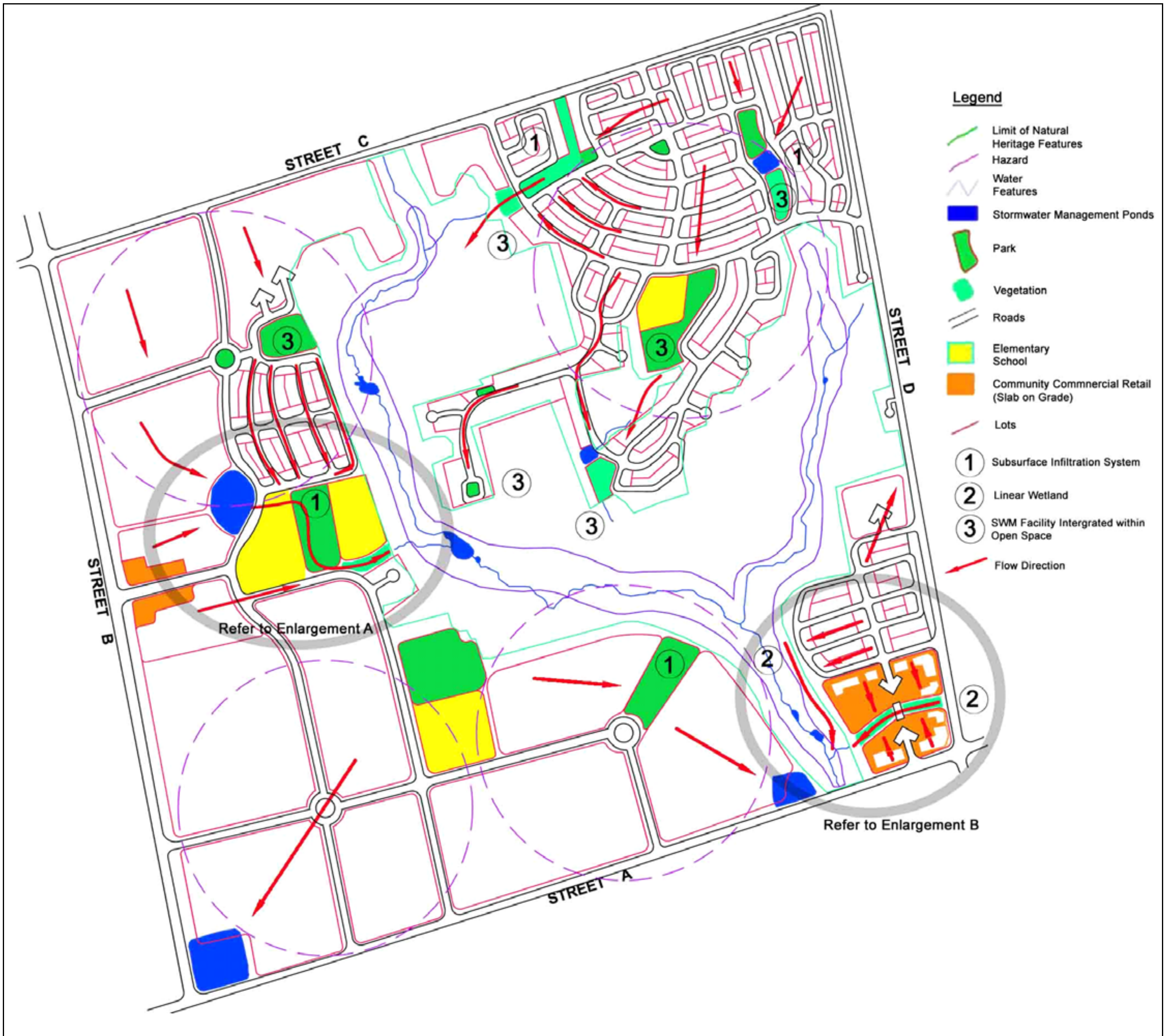
Source: Schollen and Company Inc. *et al.* 2006, Markham Small Streams Study

This process differs from traditional development planning and design processes in the following ways:

- detailed environmental inventory information regarding small drainage features and groundwater recharge, flow directions and discharge areas is required early in the process;
- where possible, configuration of the major road network and development blocks is defined by sub-catchment boundaries within the site;
- where possible, configuration of the local road network follows overland flow directions;
- open space corridors are located along important drainage features;
- where possible, parks are located at the downstream end of sub-catchments that contribute runoff to important drainage features to provide opportunities for integration of SWMPs;
- where underlying soils and geology are conducive, infiltration practices are a major component of the stormwater management system;
- surface conveyance systems (*e.g.*, grassed swales) are considered, where feasible; and
- consideration is given to alternative built forms where topographic or hydrogeologic constraints exist.

It is at the community scale that the full range of opportunities to achieve stormwater management objectives is identified. This establishes a template for more detailed resolution of the site specific design of SWMPs at subsequent stages in the planning and design process. To be fully effective, it is important at this early stage to explore the broadest range of SWMPs in order to ensure that opportunities are not missed prior to embarking on more detailed planning stages. Figures 2.9.2 to 2.9.4 illustrate the theoretical community design plan that would result from application of the landscape-based stormwater management planning process described above.

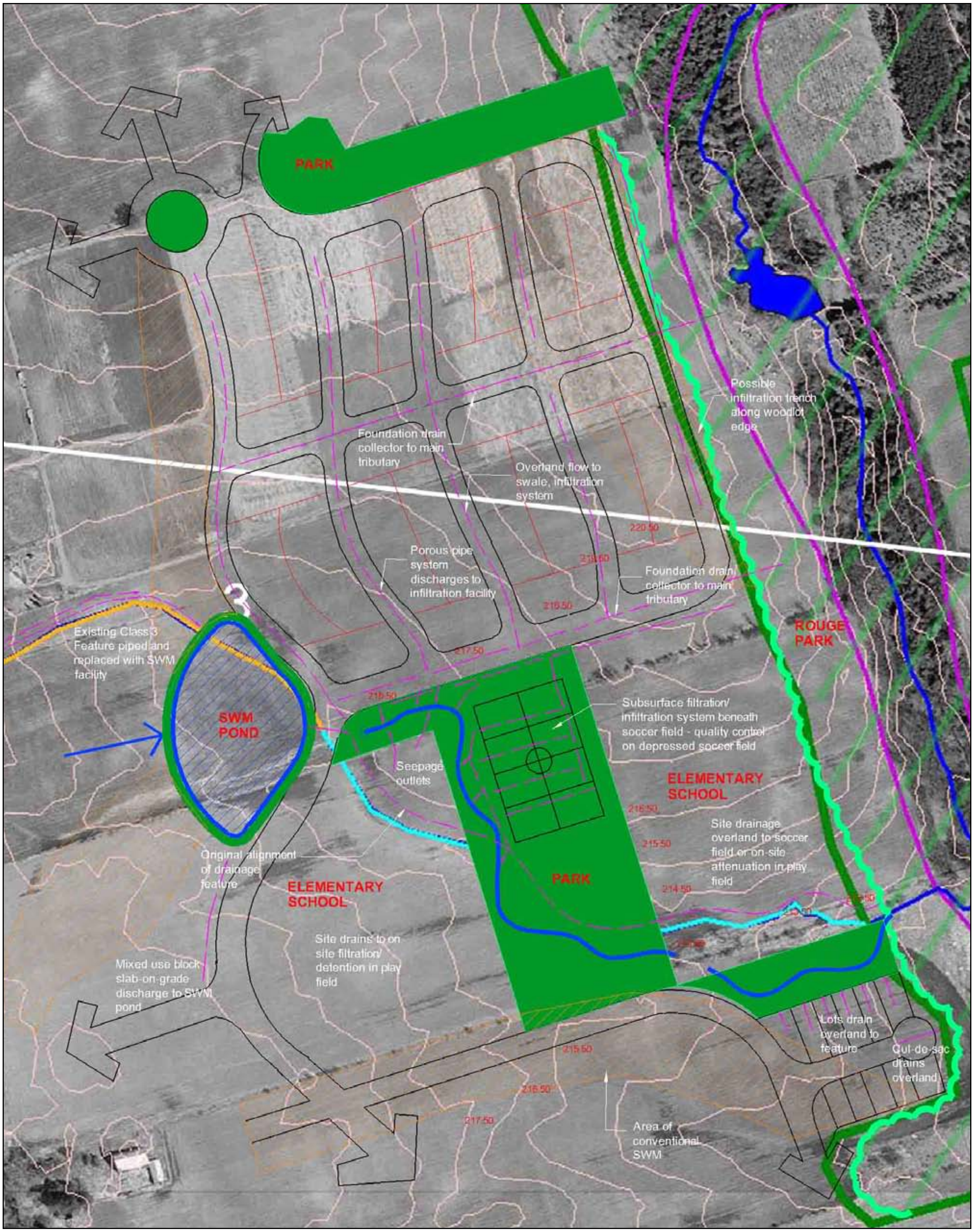
Figure 2.9.2 Stormwater management integrated within a theoretical community plan



Stormwater Management Integrated within Theoretical Community Plan

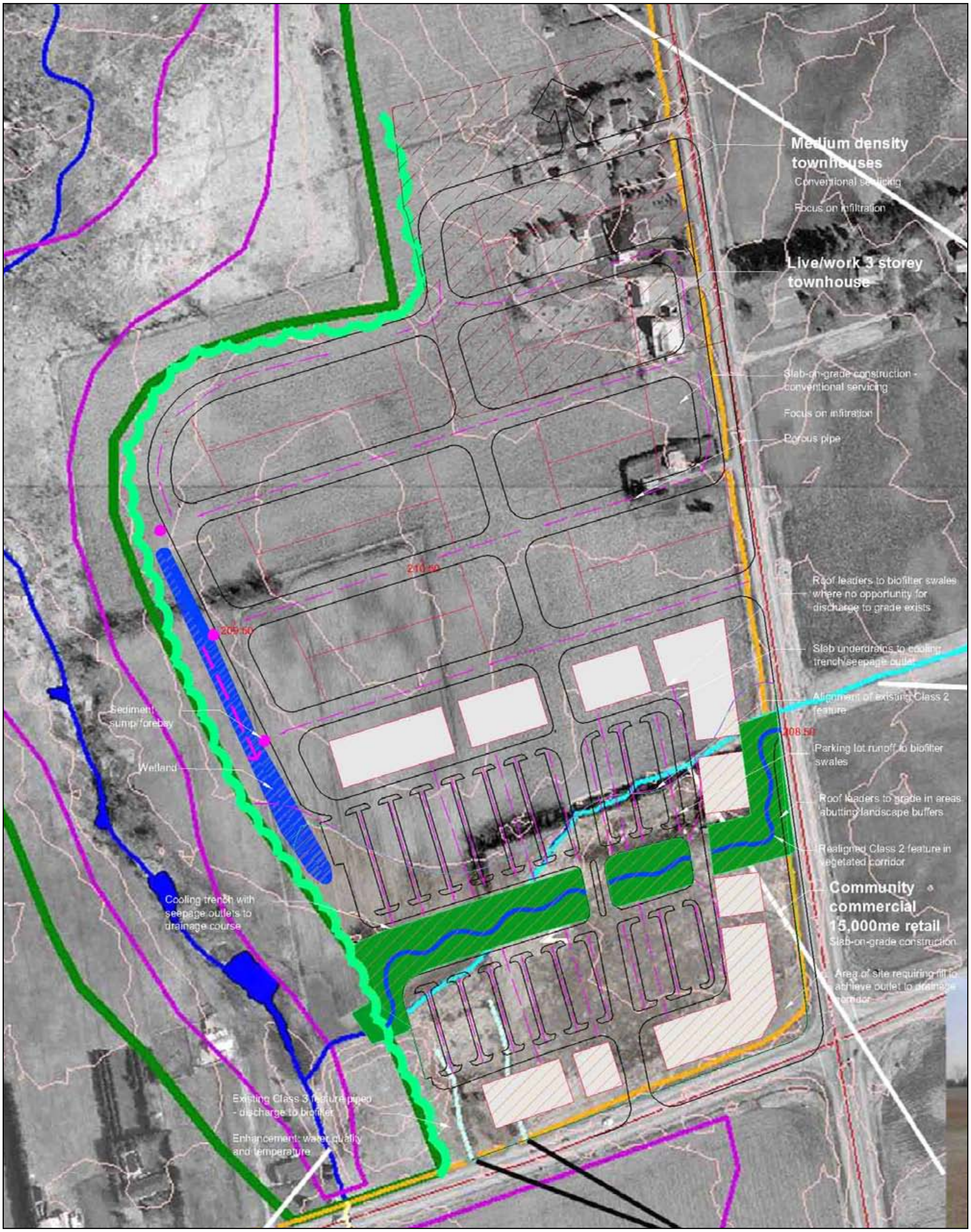
Source: Schollen and Company Inc. *et al.* 2006, Markham Small Streams Study

Figure 2.9.3 Demonstration plan – residential and institutional sub-catchment



Source: Schollen and Company Inc. *et al.* 2006, Markham Small Streams Study

Figure 2.9.4 Demonstration plan – commercial and mixed use sub-catchment



Source: Schollen and Company Inc. *et al.* 2006, Markham Small Streams Study

2.9.2 Opportunities at the Neighbourhood Scale

At the neighbourhood scale (*e.g.*, Draft Plan of Subdivision stage), the location of lots, roads, parks and open space blocks, natural heritage features and buffers and SWMPs are defined. Consequently, it is important at this stage in the planning process to consider how stormwater management objectives can be achieved and how these objectives might influence the location and configuration of each of the components listed above. At the neighbourhood scale, there are opportunities to achieve stormwater management objectives:

- in road rights-of-way;
- in parks and open spaces; and
- at the lot level.

Road Right-of-Way Opportunities

The road network comprises a significant component of a Draft Plan of Subdivision with its configuration typically designed to address transportation, transit and servicing objectives alone. However, the road network also represents potential opportunities for low impact development (LID) practices that can help to minimize and treat runoff and achieve stormwater management objectives. Such opportunities include:

- incorporating SWMPs such as bioretention areas, soakways or permeable pavement into boulevards, parking lanes, cul-de-sac islands and roundabouts, and perforated pipe conveyance systems below the road bed;

- minimize impervious surfaces through innovative road network design (*e.g.*, fused grid road network; CMHC, 2007) and by designing low traffic roads with only one lane of parking, sidewalks on only one side, and/or infiltration island cul-de-sacs or roundabouts.

Parks, Recreation and Open Space Opportunities

Parks, recreation areas (*e.g.*, sports fields) and open spaces present the potential to integrate SWMPs as amenities within the landscape. However, it is important that the integration of SWMPs within the public amenity space does not compromise its utility or function.

Integrating SWMPs within parks and open spaces provides opportunities to:

- construct infiltration or filtration facilities beneath sports fields, picnic areas, parking lots, playgrounds, trails and walkways;
- incorporate bioretention, vegetated filter strips and swales into open spaces as components of the landscaping plan;
- integrate SWMPs as water feature amenities within a park; and
- incorporate infiltration facilities within buffers adjacent to natural heritage features where the function and ecological integrity of the feature would not be compromised.

Lot Level Controls

At the neighbourhood scale (*e.g.*, Draft Plan of Subdivision stage), opportunities for a full range of lot level controls should also be considered. Lot level stormwater management facilities can be designed to be aesthetically attractive landscaping areas at the surface (*e.g.*, rain gardens/bioretention areas, green roofs, vegetated filter strips), or subsurface practices located below parking areas, roads, walkways, plazas, parks or sports fields that are not visible and take up no footprint at the surface.

However, unlike conveyance and end-of-pipe controls that typically become property of the municipality and are operated and maintained as public infrastructure, operation and maintenance of lot level controls on private property are the responsibilities of the individual property owners, managers or management organizations. To ensure that their functions are maintained over the lifespan of the facility, legal agreements regarding their long term operation and maintenance will need to be established, and training provided on their function and inspection and maintenance requirements.

As integrated components of the overall stormwater management strategy developed at the Draft Plan of Subdivision stage, the feasibility and long term viability of lot level controls need to be confirmed at the outset in consultation with the municipality to ensure that the strategy proposed can be implemented and will remain effective. The successful application of lot level controls requires both the commitment of the municipality and the establishment of agreements between the developer, municipality and property owner. Strategies to achieve this include:

- placing easements over the areas within which the infrastructure is located in favour of the municipality to allow for periodic inspection and maintenance of the facility should the owner or manager fail to do so;

- placing outlet control structures (*e.g.*, an orifice control on a bioretention system outlet) on municipal property outside the limit of the private land holding to allow for inspection, operation and maintenance by municipal personnel;

- requiring the submission of performance monitoring reports for review by the municipality or conservation authority;

- requiring a legal agreement to ensure that the system remains fully operational and is properly maintained;

- requiring the owner to pay the present value LID maintenance cost for the service life of the development into a municipal maintenance fund; and

- implementing an annual storm sewer user fee as part of municipal property tax or water bills based on the quantity of impervious cover that drains directly to a storm sewer (*i.e.*, does not first drain to a pervious area or LID practice) as an incentive for property owners to maintain existing LID practices and retrofit new practices on their properties where possible.

Implementation of a property owner/manager education program that is focused on ensuring operation and maintenance of lot level controls is also critical to realize consistent benefits over the long-term. A property owner/manager education program should be comprised of the following:

- *Pre-Sales Information Package:* This information package should be provided to prospective buyers and made available as a display in the sales office. The package should describe the lot level control to be implemented, its operation and the basic maintenance requirements. It is important that this information package also stipulate clearly that the lot level control is not to be altered.

- *Purchase Agreement Package:* This information package should form part of the agreement to purchase the property and should describe the system and any maintenance requirements as well, to encourage homeowners to maintain the installation. It is important that this document be focused on encouraging the maintenance of lot level initiatives. This information package should also be attached to the purchase agreement of subsequent property owners in the event that the property is resold in the future.

- *Property Owner's Guide:* A user-friendly property owner's guide should be distributed to residents after they move in. The guide should be simple and informative and should provide a basic description of the lot level control, its function and any maintenance requirements.

- *Newsletter:* In some communities, periodic newsletters are circulated informing homeowners of the activities which are occurring in their community. Information regarding the function of lot level controls should be included in the newsletter on a periodic basis. This approach serves to remind homeowners about the need to ensure that the function of the installation should be maintained.

Implementation of lot level controls can effectively reduce reliance on end-of-pipe facilities and result in a stormwater management strategy that is more beneficial to the environment than conventional end-of-pipe based solutions. Other incentives for implementing lot level controls include reduced costs for the construction of end-of-pipe facilities and potential reductions in the amount of land needed for SWMPs. Legal agreements and training regarding long term operation and maintenance of lot level controls on private property will be required, in order to allow reductions in the required size of downstream end-of-pipe controls as compensation for implementing lot level controls upstream. In evaluating the viability of this approach on a particular site, stormwater management system designers will need to quantitatively estimate the performance of upstream SWMPs in order to rationalize a requested reduction in size of an end-of-pipe facility and must get approval from regulatory agencies.

The following sections describe different types of lot level stormwater management controls that should be considered at the neighbourhood scale (*e.g.*, Draft Plan of Subdivision stage).

Depression Storage

Directing drainage from roof downspouts to shallow depressed areas in front, rear and side-yard areas is a simple technique to store and infiltrate runoff where possible. Depression storage areas can be located in low areas, planted as gardens or situated beneath decks. Typically, depression storage areas are small and have limited capacity and limited duration of retention in order to address property owner concerns relating to insects, damage to structures and inconvenience of ponded water on their property. Although their individual effectiveness is limited by their size, cumulatively depression storage areas can provide significant benefits in a stormwater management system.

Depression storage and other stormwater infiltration practices are particularly effective in areas with high soil permeability. Stormwater directed to depression storage and other infiltration practices should be from relatively clean sources including roof leaders and walkways, rather than surfaces prone to the accumulation of sand, oil and grit, to ensure the long-term function of the facility. Infiltration practices should not be proposed in areas where the water table is shallow or where there is the potential for stormwater with high contaminant concentrations. Care must be taken on properties where potable water sources are groundwater based to ensure that infiltration practices will not impair the quality of groundwater in underlying aquifers for use as drinking water. Depression storage and infiltration practices should be designed with an overflow outlet to ensure that positive drainage away from the basement of the building is achieved in the event that the function of the installation is compromised, or its capacity is exceeded.

Bioretention Areas

Bioretention areas are shallow excavated surface depressions containing mulch and a prepared soil mix and planted with specially selected native vegetation that captures and treats runoff (see section 4.5 for detailed design guidance). During storms, runoff ponds in the depression and gradually filters through the mulch, prepared soil mix and root zone. The filtered runoff can either infiltrate into the native soil or be collected in a perforated underdrain and discharged to the storm sewer system. They remove pollutants from runoff through filtration in the soil and uptake by plant roots and can help to reduce runoff volume through evapotranspiration and full or partial infiltration. They can also provide wildlife habitat and enhance local aesthetics.

Bioretention areas can be integrated into a range of landscape areas including medians and cul-de-sac islands, parking lot medians and boulevards. A variety of planting and landscape treatments can be employed to integrate them into the character of the landscape. Biofilters are a design variation that feature an impermeable liner and underdrain due to site constraints and are typically applied as pretreatment to another stormwater control although they can be effective as stand alone filtration facilities.

Rain Gardens

A variation on depression storage and bioretention areas, the rain garden is a deliberately designed landscape, with specific plant species and soil media to receive and detain, infiltrate and filter runoff discharged from roof leaders (see section 4.5 for detailed design guidance). Rain gardens are effective in both new and retrofit situations and can be designed to complement the landscape of most properties. The rain garden is constructed on a base of granular material with plant material selected for its rooting characteristics and tolerance of varying soil moisture conditions. The drainage area of the roof plane contributing to the downspout determines the size of the garden.

As with depression storage, rain garden installations are effective in areas where soil permeability is high. In addition, provision must be made to facilitate positive drainage away from the rain garden in the event storm flows exceed capacity. Although rain gardens were initially conceived for implementation on private residential lots under retrofit situations, they are also applicable to larger commercial, industrial, institutional and condominium developments as components of a treatment train stormwater management strategy.

Soakaways

Soakaways, which can also be referred to as infiltration trenches, galleries or chambers, are constructed below grade and therefore take up little or no space at the surface (see section 4.4 for detailed design guidance). Such facilities can be installed below a broad range of land uses including residential yards, parking areas, walkways, pedestrian plazas, parks and sports fields. The following are examples of approaches that can be employed to integrate soakaways into the landscape:

- Linear soakaways or infiltration trenches can be designed for installation beneath granular surfaced trail systems. Runoff from the adjacent development can be directed to the infiltration trench, while the trail network enhances the connectivity of the open space network within the community.

- In new communities that have been designed based upon the principles of new urbanism, soakaways can be incorporated into the rear laneways. Runoff from the roof areas of adjacent garages and residences is directed to the soakaway. Soakaways can also be retrofitted below rear laneways (*e.g.*, City of Chicago Green Alleys program).

- Soakaways can be constructed beneath decks, lawns and driveways of residential properties.

Permeable Pavement

Permeable pavement is a variation on traditional pavement design that utilizes pervious paving material underlain by a uniformly graded stone reservoir (see section 4.5 for detailed design guidance). The pavement surface may consist of permeable asphalt, permeable concrete, permeable interlocking concrete pavers, concrete grid pavers and plastic grid pavers. Openings in permeable interlocking concrete pavers, concrete grid pavers and plastic grid pavers are typically filled with pea gravel, sand or top soil and grass. Permeable pavements prevent the generation of runoff by allowing precipitation falling on the surface to infiltrate into the stone reservoir and, where suitable conditions exist, into the underlying soil. They are most appropriately applied in low to medium traffic areas (*e.g.*, residential roads, low traffic parking lots, driveways, walkways, plazas, playgrounds, boat ramps etc.) that typically receive low levels of contaminants. In addition to the stormwater management benefits, permeable pavements can be more aesthetically attractive than conventional, impermeable pavements.

Vegetated Filter Strips

Gently sloping, densely vegetated areas that are designed to treat runoff as sheet flow from adjacent impervious surfaces (see section 4.6 for detailed design guidance). Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Filter strips may be comprised of a variety of trees, shrubs, and native vegetation to add aesthetic value as well as water quality benefits. They are best suited to treating runoff from roads and highways, roof downspouts and low traffic parking lots. They are also ideal as pretreatment to another lot level or conveyance practice. Filter strips also provide a convenient area for snow storage and treatment.

Conveyance Controls

Opportunities to incorporate conveyance controls also need to be considered at the neighbourhood scale (*e.g.*, Draft Plan of Subdivision stage). Conveyance controls include grassed swales and perforated pipe systems (*i.e.*, exfiltration systems), which treat and infiltrate runoff while it is being transported from individual lots to a treatment facility and ultimately, to the receiving watercourse or water body. Where suitable conditions exist, they can be used instead of conventional storm sewer pipes.

Conveyance controls are typically situated within road rights-of-way or on other public property and are operated and maintained as part of municipal infrastructure. However, their operation and maintenance requirements differ from conventional stormwater conveyance infrastructure. To ensure the facilities are properly maintained over their expected lifespan, municipal staff will need to be provided training on their function, inspection and maintenance requirements.

The following sections describe different types of conveyance controls that should be considered at the neighbourhood scale (*e.g.* Draft Plan of Subdivision stage).

Grass Swales

Grass swales are vegetated, open channels designed to convey, treat and attenuate runoff. Design variations include simple grass channels, enhanced grass swales (see section 4.8 for detailed design guidance), and dry swales or bioswales (see section 4.9 for detailed design guidance). Vegetation in the swale slows the water to allow sedimentation, filtration through the soil matrix and root zone, and infiltration into the underlying native soil, where suitable conditions exist. They are well suited for treating highway or residential road runoff because they are linear practices but may not be well suited to high density urban areas because they require a relatively large area of pervious surfaces. Swales can also be used as snow storage areas.

Perforated Pipe Systems

A stormwater conveyance system that features pipe that is perforated along its length and installed in a granular bedding which allows infiltration of water into the native soil through the pipe wall as it is conveyed (see section 4.10 for detailed design guidance). They can also be referred to as pervious pipes, percolation drainage systems or exfiltration systems. Design variations can also include catchbasins that are connected to granular stone reservoirs by pervious pipes or where the catchbasin sumps are perforated, allowing runoff to gradually infiltrate into the native soil. They are best suited to treat drainage from low to medium traffic areas with relatively flat or gentle slope.

2.9.3 Opportunities at the Site Scale

At the site scale (*e.g.*, Site Plan stage), both the detailed configuration of built form and landscape are resolved, presenting a range of opportunities to design stormwater management controls as integral components of the development site. At this scale, there are opportunities to integrate stormwater management practices (SWMPs) into all of the components of a development including landscaped areas, parking areas, roof tops and subsurface infrastructure. Figures 2.9.5 and 2.9.6 illustrate examples of how SWMPs can be fully integrated into the design of the site. Facility designs must be considered in the context of the overall stormwater management strategy developed at the neighbourhood scale to ensure that watershed management objectives, targets and functional requirements are achieved. Legal agreements, incentives and/or property owner education materials may be needed to ensure long term operation and maintenance of stormwater management practices implemented at the lot level (see Section 2.9.2 - Lot Level Controls for further guidance).

Potential opportunities to integrate SWMPs at the site level stage in the planning process include:

- harvesting of rainwater from rooftops for non-potable uses (*e.g.*, irrigation, toilet flushing) using rain barrels or cisterns;
- installation of green roofs;
- drainage of runoff from rooftops to pervious or depression storage areas;
- integration of soakaways (*e.g.*, infiltration trenches or chambers) below landscaped areas, parking areas, parks, sports fields, etc.;
- incorporation of bioretention areas, rain gardens, biofilters or constructed wetlands into the landscape design for the site;
- use of permeable pavement in low and medium traffic areas;
- incorporation of bioretention areas, vegetated filter strips, and swales to intercept and treat parking lot and road runoff;
- incorporation of woodland restoration in upstream areas to reduce runoff rates;
- integration of detention ponds and wetlands as large aesthetic and recreational features within the landscape.

Figure 2.9.5 Institutional building – integrated stormwater management and landscaping plan

Source: Thunder Bay Regional Health Centre Model Study

Figure 2.9.6 Integrated stormwater management and landscaping plan for a school

Source: Bill Crothers Secondary School, Town of Markham.

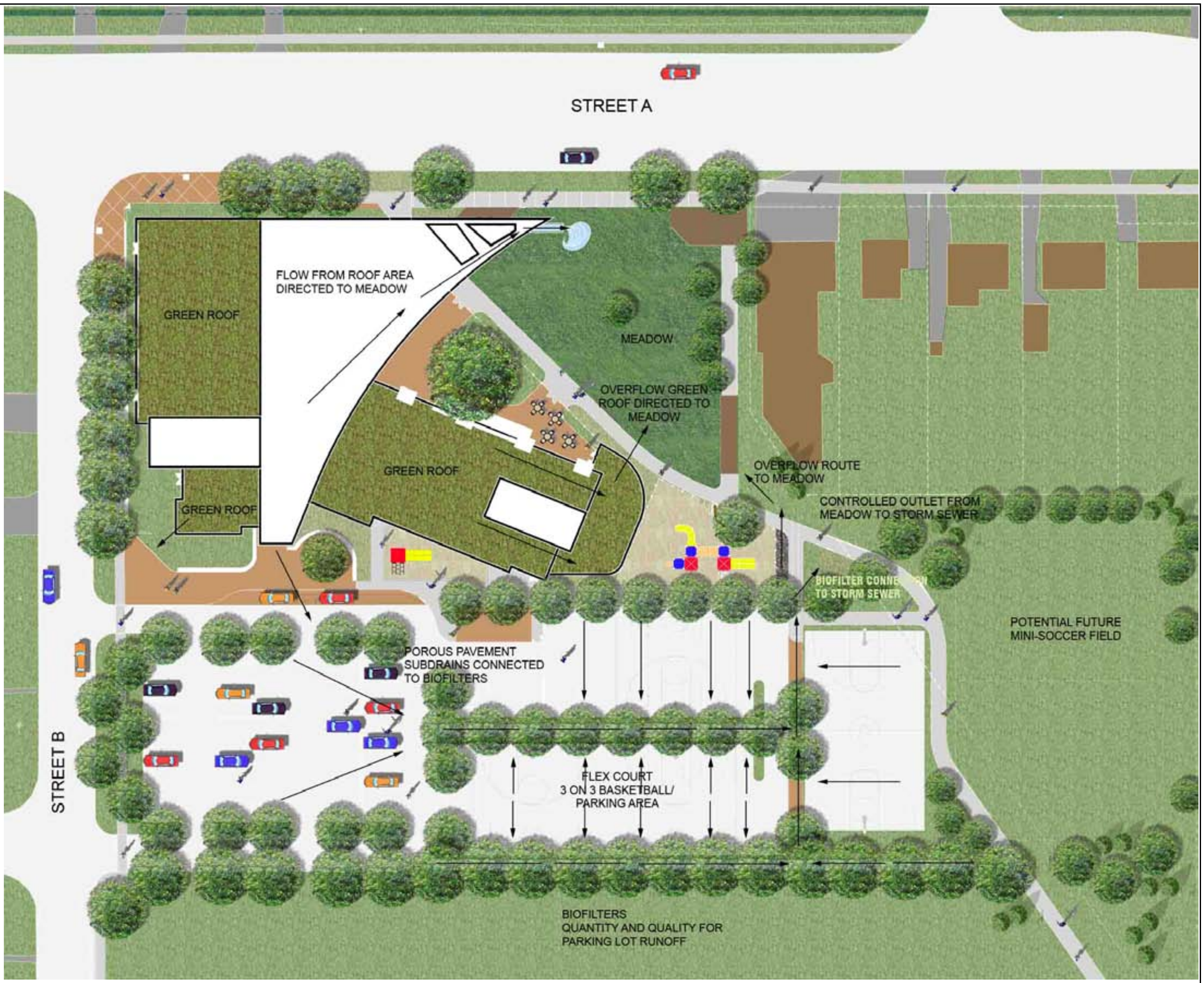
2.9.4 Infill and Redevelopment Opportunities

Infill and redevelopment present the most complex challenges with respect to integrating landscape-based solutions for stormwater management. This is because:

- sites are typically constrained with respect to the extent of potential open space available;
- there is typically limited flexibility to manipulate topography since grades around the perimeter of the site are fixed;
- service infrastructure around the site, including stormwater conveyance systems are typically fixed in terms of location, depth and capacity; and
- the presence of other service infrastructure beneath and around the site may limit potential excavation depths and opportunities for infiltration.

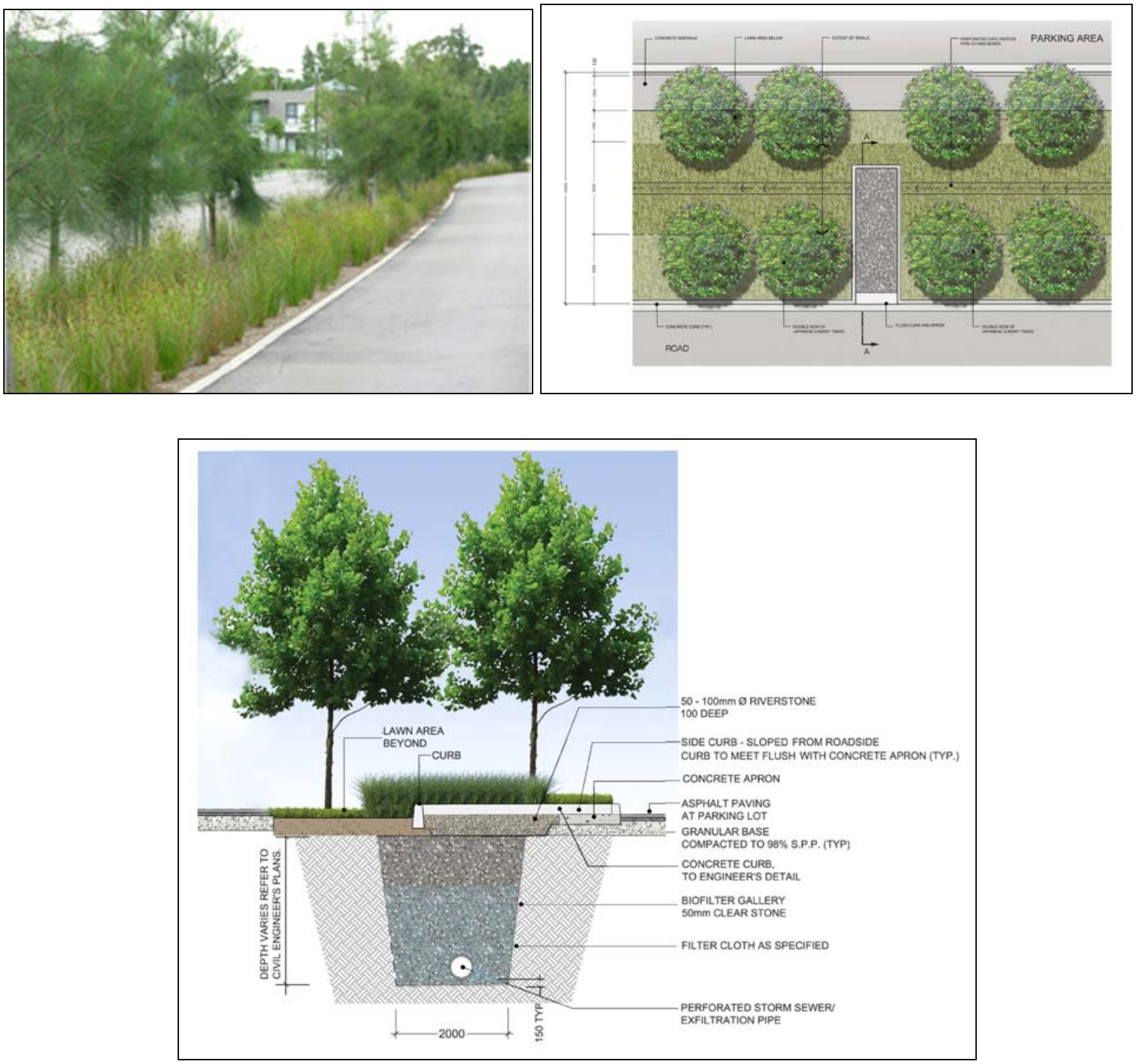
As a result, the exploration of stormwater management solutions for infill and redevelopment sites requires a high level of imagination, ingenuity and creativity. Figures 2.9.7 to 2.9.9 illustrate examples of SWMPs that can be incorporated into infill and redevelopment contexts.

Figure 2.9.7 Landscape-based stormwater management strategy – infill site



Landscape Based Stormwater Management Strategy – Infill Site

Figure 2.9.8 Examples of integrated SWM practices in infill and redevelopment sites



Source:, Schollen & Company Inc.

The opportunity for incorporating stormwater management facilities into infill and redevelopment sites needs to consider context and the limits of both landscape and built form. Stormwater management opportunities that should be explored for infill and retrofit developments include:

- roof top storage;
- green roofs;
- rainwater harvesting;
- bioretention areas;
- biofilters;

- grassed swales;
- permeable pavement;
- rain gardens;
- stormwater planters and fountains;
- depression storage;
- soakaways;
- constructed wetlands; and
- enhanced urban tree canopy.

Details regarding the application and design of these stormwater management techniques are discussed in Chapter 4.

Figure 2.9.9 More examples of SWM in infill and redevelopment sites

Durham College / UOIT – Linear SWM Wetland, Oshawa, Ontario – Schollen & Company Inc.

Biofilters – Edithvale Community Centre (Source: Schollen & Company Inc.)

3.0 LOW IMPACT DEVELOPMENT PRACTICES

3.1 Principles of Low Impact Development

As noted previously, in Ontario a treatment train approach to stormwater management, that utilizes a combination of lot level, conveyance and end-of-pipe practices, is advocated for new and infill development to maintain the hydrologic cycle, protect water quality and prevent erosion and flooding (OMOE, 2003). Low impact development (LID) practices can be an integral part of a treatment train approach to stormwater management. This section of the *LID SWM Guide* focuses on low impact development practices that have only recently been accepted and applied in Ontario as part of the treatment train approach. These practices include innovative site design strategies that minimize runoff (*i.e.*, nonstructural LID practices). They also include distributed, small scale lot level and conveyance practices (*i.e.*, structural LID practices) such as rainwater harvesting, green roofs, soakaways, bioretention, vegetated filter strips, permeable pavement, perforated pipe systems, and swales. Acknowledging that end-of-pipe facilities are also an integral part of the treatment train approach, the reader is urged to refer to the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003) for direction on incorporating practices such as wet detention ponds and wetlands into the overall planning and design for stormwater management.

A variety of terms have been used to describe the overall design philosophy of managing runoff as close to the source as possible. Low impact development is the term used here but it can be alternately referred to as, better site design, sustainable urban drainage systems, water sensitive urban design, or stormwater source controls. All of these approaches attempt to reproduce the predevelopment hydrologic regime through innovative site design and distributed engineering techniques aimed at infiltrating, filtering, evaporating, harvesting and detaining runoff, as well as preventing pollution. Key principles for low impact development design can be summarized as follows:

1. **Use existing natural systems as the integrating framework for planning**
   - Consider regional and watershed scale contexts, objectives and targets;
   - Look for stormwater management opportunities and constraints at watershed/subwatershed and neighbourhood scales;
   - Identify and protect environmentally sensitive resources;
   - see Chapter 2 for further guidance on the landscape-based approach to stormwater management planning and design.

2. **Focus on runoff prevention**
   - Minimize impervious cover through innovative site design strategies and application of permeable pavement;
   - Incorporate green roofs and rainwater harvesting systems in building designs;
   - Drain roofs to pervious areas with amended topsoil or stormwater infiltration practices;
   - Preserve existing trees and design landscaping to create urban tree canopies.

3. **Treat stormwater as close to the source area as possible**
   - Utilize decentralized lot level and conveyance stormwater management practices as part of the treatment train approach;
   - Flatten slopes, lengthen overland flow paths, and maximize sheet flow;
   - Maintain natural flow paths by utilizing open drainage (*e.g.*, swales).

4. **Create multifunctional landscapes**
   - Integrate stormwater management facilities into other elements of the development to conserve developable land;
   - Utilize facilities that provide filtration, peak flow attenuation, infiltration and water conservation benefits;
   - Design landscaping to reduce runoff, urban heat island effect and enhance site aesthetics.

5. **Educate and maintain**
   - Provide adequate training and funding for municipalities to monitor and maintain lot level and conveyance stormwater management practices on public property;
   - Teach property owners, managers and their consultants how to monitor and maintain lot level stormwater management practices on private property;
   - Establish legal agreements to ensure long-term operation and maintenance.

Typical LID designs incorporate more than one type of practice or technique to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from impervious surfaces, remove curbs and install grassed swales in common areas. Each LID practice incrementally reduces the volume of stormwater as it moves from the source area to the receiving waterbody. In doing so, LID practices are applied to meet stormwater management targets for water quality, channel erosion control and water balance. Although LID practices are not intended to meet stormwater management targets for flood control, they do provide some benefit in this regard.

LID practices, applied together with conventional end-of-pipe facilities, can provide better runoff and pollutant load reduction, be more cost effective, have lower maintenance burdens, and be more protective of aquatic habitat during extreme storms than end-of-pipe facilities alone. Several practices may be needed to achieve the required storage volume. The precise type and number of LID practices depends on several factors including land use, soils, geology, groundwater levels, groundwater uses, and the sensitivity of the receiving waterbody.

It should also be noted that LID practices may be beneficial in order to meet objectives other than those for stormwater management. For example, the City of Toronto, City of Mississauga and Town of Caledon have developed green development standards in which a variety of LID practices can help meet objectives relating to energy and water conservation, reduced use of materials and reduction of the urban heat island effect

(City of Toronto, 2007b; City of Mississauga, 2009; Town of Caledon, 2009). Furthermore, a recent housing development in Guelph (Reid Homes, 2007) and Halton Hills (Meadows in the Glen, 2009) have incorporated a variety of practices including rainwater harvesting, bioretention, enhanced grass swales and permeable pavement in order to meet green building certification requirements.

The following section provides guidance regarding innovative site design (*i.e.*, non-structural) strategies. The remainder of this chapter focuses on factors to be considered in the process of selecting and designing structural LID practices for stormwater management.

3.2 Low Impact Development Site Design Strategies

Increases in the quantity, rate, and frequency of runoff can be linked to two root causes: the conversion of undeveloped or agricultural land cover to urban uses, and the application of storm sewer systems. The goal of LID site design strategies is to minimize these two sources of hydrologic impacts. Avoiding downstream impacts through non-structural, innovative site design methods is more economical, operationally efficient, and aesthetically pleasing than concentrating all stormwater management efforts on treating and controlling runoff downstream. Therefore, site designers should exhaust all opportunities for non-structural methods to prevent runoff from being generated before determining how to mitigate the land cover change and storm sewer impacts through structural LID practices and detention ponds.

Sixteen (16) LID site design strategies can be grouped into four themes: Preserving important hydrologic features and functions; siting and layout of development; reducing impervious area; and using natural drainage systems. The strategies need to be considered together as they all overlap and relate to each other. For example, preserving a natural channel will impact the layout of the site, and the layout of the site determines the extent of impervious area and optimal locations of structural SWMPs.

3.2.1 Preserving Important Hydrologic Features and Functions

As discussed in Chapter 2, 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. These features act as sponges and can sometimes be used to buffer the hydrologic impacts created by neighbouring development. They preserve the natural character of the site and in many cases improve the aesthetics and value of the developed property.

All areas of hydrologic importance should be delineated at the earliest stage in the development planning process. Once these areas have been mapped, they can guide the layout of the site.

Strategies

1. **Preserve stream buffers, including along intermittent and ephemeral channels.** 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 infrastructure. In general, the literature recommends stream buffers for pollutant removal and support of aquatic and terrestrial riparian habitat (Wenger, 1999). The benefits of buffers diminish when slopes are greater than 25%; therefore steep slopes should not be counted as buffer (Schueler, 1995).

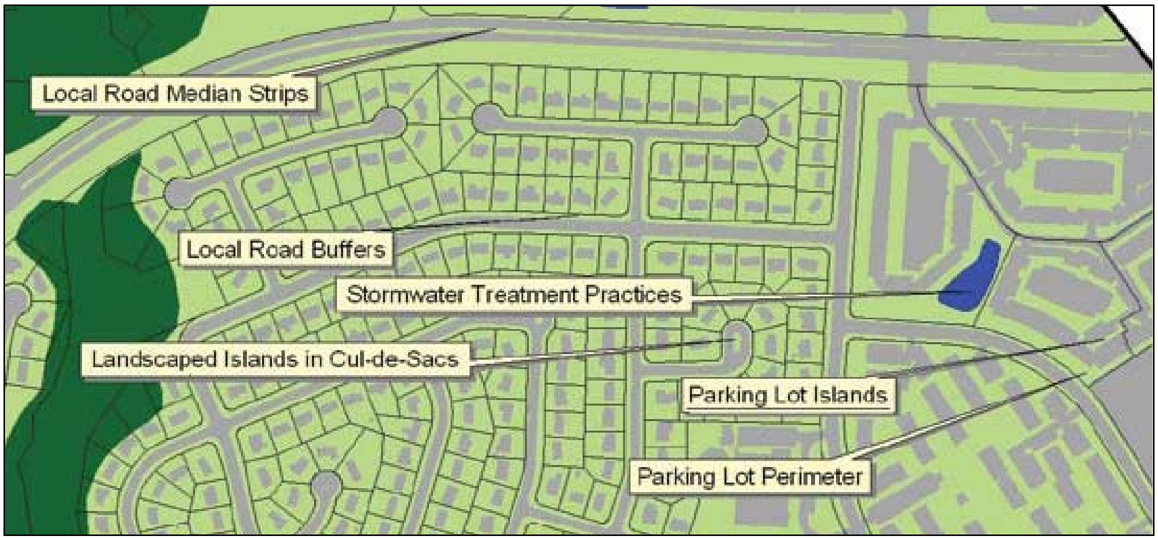
2. **Preserve areas of undisturbed soil and vegetation cover.** Typical construction practices, such as topsoil stripping and stockpiling, and site grading and compaction by construction equipment, can considerably reduce the infiltration capacity (and treatment capacity) of soils. In some instances, the bulk density of construction compacted soils is similar to values for impermeable surfaces. Native undisturbed soils have a structure that takes many, if not hundreds of years, to develop. The structure is created by the growth and decay of plant roots, earthworm, and insect activity. In addition to destroying the structure during topsoil stripping and stockpiling, biological activity in the soil is greatly diminished. The shallow rooted turf of lawns and landscaped areas will not provide the same stormwater benefits as the agricultural and native vegetation that it replaces. During construction, natural heritage features and locations where infiltration-based SWMPs 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. Compacting or paving over these areas will have significant hydrologic impacts. To the greatest extent possible, these areas should be preserved in an undisturbed condition or set aside for stormwater infiltration practices. On sites with a variety of soil types, impervious land cover should be concentrated in areas with the least permeable soils and underlying geology. 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% (Cappiella, 2005). Depending on understory vegetation, soils and topography, tree clusters may only produce surface runoff for major flood event storms. 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 development in many ways, including parking lot interiors or perimeters, private lawns, common open space areas, road buffers, and median

strips (Figure 3.2.1). Any areas of reforestation or new urban tree plantings need an uncompacted soil volume that allows the root systems to get air and water. An uncompacted soil volume of 15 to 28 cubic metres is recommended to achieve a healthy mature tree with a long lifespan (Casey Trees, 2008).

Figure 3.2.1. Development sites offer a number of locations for tree clusters



Source: Cappiella *et al.,* 2006

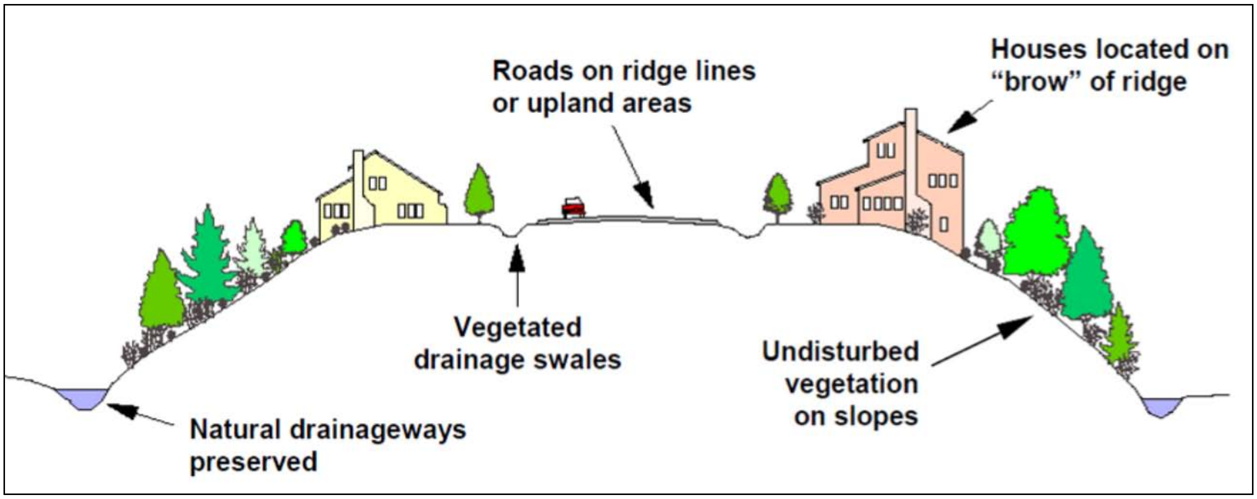
3.2.2 Siting and Layout of Development

The site layout is determined in part by the opportunities and constraints of the natural heritage system. 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. The goals of the site layout are to provide a functional and livable urban form while minimizing environmental impact. The techniques below highlight some of the ways in which site layouts can minimize their hydrologic impacts and preserve natural drainage patterns.

Strategies

5. **Fit the design to the terrain.** Using the terrain and natural drainage as a design element is an integral part to creating a hydrologically functional landscape (Prince George's County, 1999). Fitting development to the terrain will reduce the amount of clearing and grading required and the extent of necessary underground drainage infrastructure. This helps to preserve predevelopment drainage boundaries which helps to maintain distribution of flows. Generally, siting development in upland areas will take advantage of lowland areas for conveyance, storage, and treatment (Figure 3.2.2).

Figure 3.2.2. Site development in upland areas

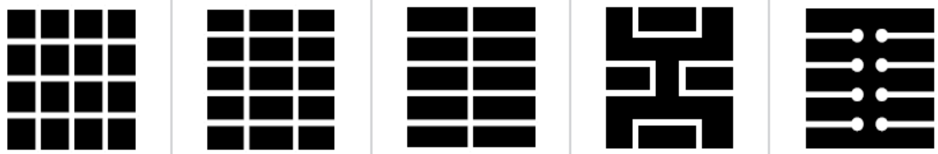


6. **Use open space or clustered development.** Clustering development increases the development density in less sensitive areas of the site while leaving the rest of the site as protected community open space. The open space can be undisturbed natural area or actively used recreational space. Features that often characterize open space or clustered development are smaller lots, higher density of structures in one area of a site, shared driveways, and shared parking. From a stormwater perspective, clustered development reduces the amount of impervious surface, reduces pressure on buffer areas, reduces the construction footprint, and provides more area and options for stormwater controls including LID practices (CWP, 1998).

7. **Use innovative street network designs.** Certain roadway network designs create less impervious area than others. Figure 3.2.3 from the Canadian Mortgage and Housing Corporation (2002) demonstrates that loop and cul-de-sac street patterns require less area for streets. 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 (CMHC, 2002). A study comparing different road network designs for a hypothetical community showed a fused grid pattern can reduce impervious cover by 4.3% compared to a traditional neighbourhood design (CMHC, 2007).

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. A study of residential parcels in Madison, Wisconsin found that reducing setbacks by 3 m and frontages by 5.5 m resulted in a 14% reduction of stormwater runoff (Stone and Bullen, 2006).

Figure 3.2.3 Comparison of buildable and street areas among 5 typical street patterns



	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

3.2.3 Reducing the Impervious Area:

Unnecessary hardscape can be found all around urban areas from paved but unused traffic and parking lot islands to rarely used overflow parking. 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. Individually, these reductions in impervious area may seem small but they can add up to substantial decreases in runoff and infrastructure costs.

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 (U.S. EPA, 2007).

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. A single story design converted to a two- storey structure with the same floor space will eliminate 50% of the building footprint impervious area.

11. **Reduce parking footprints.** Parking footprints can be reduced in several ways. Excess parking not only results in greater stormwater impacts and greater

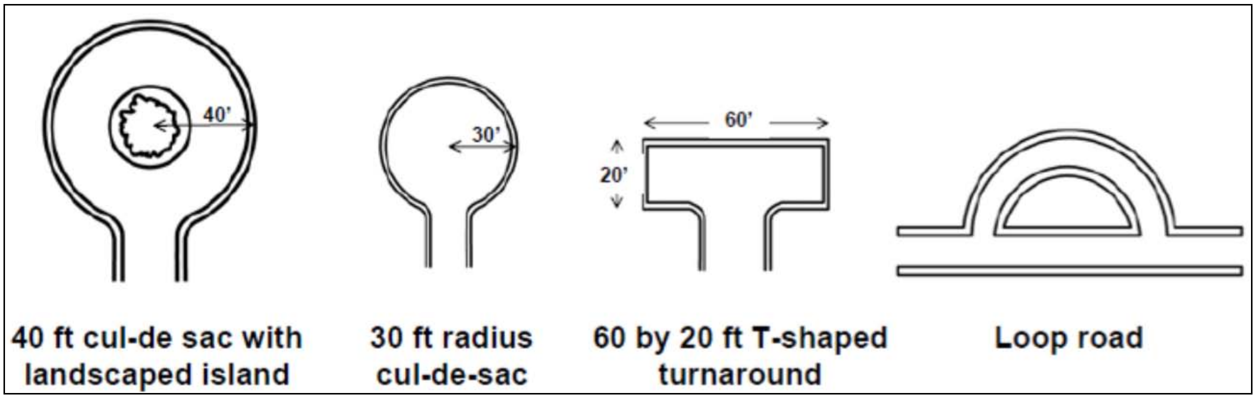
stormwater management costs but also adds unnecessary construction and maintenance costs and uses space that could be used for a revenue generating purpose.

- 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 alternatives cul-de-sacs.** Using alternatives to the standard 15 metre radius cul-de-sac can further reduce the impervious area required to service each dwelling (Figure 3.2.4). 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.** Sidewalks are an essential part of the transportation, recreation, safety, and character of a community. 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 (CWP, 1998).

Figure 3.2.4 Reduced impervious area alternative cul-de-sac designs



Source: CWP, 1998

3.2.4 Using Natural Drainage Systems

The use of natural drainage picks up where stormwater leaves impervious areas. 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 to provide communities with environmental services is often more cost effective than traditional drainage systems, and they provide more ancillary benefits.

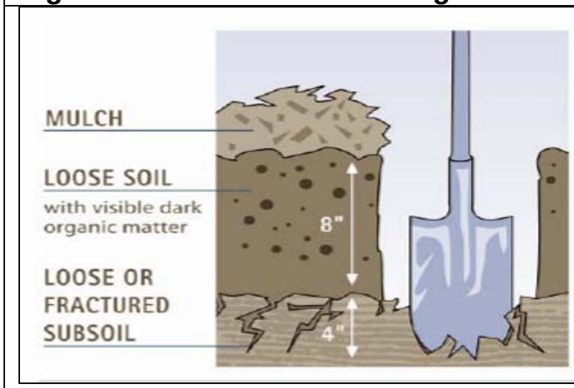
Strategies

14 **"Disconnect" impervious areas.** Impervious areas have varying degrees of hydrologic impact depending on their connection to the receiving waterbody. For example, impervious areas such as parking lots that drain directly to a concrete gutter and storm sewer will have a much greater impact than parking lots graded to drain to densely vegetated pervious areas. Roof leaders or downspouts, parking lots, driveways, sidewalks, and patios should be disconnected from the storm sewer and directed towards stabilized pervious areas where possible (see sections 4.3 – Downspout Disconnection and 4.6 – Vegetated Filter Strips for further design guidance). Opportunities for directing impervious surface runoff to pervious areas are first considered during the site layout stage. Sheet flow should be encouraged from all impervious surfaces draining to pervious areas. In cases of concentrated flow, the flow can be broken up with level spreaders or flow dissipating riprap. Use the following guidance for the pervious runoff receiving areas:

- *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. Former agricultural lands tend to develop a "hardpan" or compacted layer 0.5-1 meter below the soil surface from repeated plowings and farm equipment. Breaking up the hardpan may improve infiltration rates. Soil amendments can be applied to hydrologic soil group (HSG) C and D soils to encourage runoff absorption. See Figure 3.2.5 for guidance. Use deep rooting vegetation in landscaped areas when possible which will maintain and possibly improve the infiltration rates over time.

Figure 3.2.5. 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

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. Any depressed areas should drain within 48 hours, or they may provide breeding habitat for mosquitoes.

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 (see sections 4.8 – Enhanced Grass Swale and 4.9 – Dry Swale).

Figure 3.2.6. Open drainage applied in a medium density neighbourhood

Source: Seattle Public Utilities

3.2.5 LID Site Design Strategy Resources

Better Site Design: A Handbook for Changing Development Rules in Your Community, Center for Watershed Protection (1998)
http://www.cwp.org/Resource_Library/Better_Site_Design/#pwp

Low Impact Development Design Strategies: An Integrated Design Approach, U.S. EPA and Prince George's County, MD (1999)
http://www.epa.gov/owow/nps/lid/lidnatl.pdf

Pennsylvannia Department of Environmental Protection (PDEP). 2006. Pennsylvannia Stormwater Best Management Practices Manual. Harrisburg, PA. See Chapter 5: Non-structural BMPs.
http://www.portal.state.pa.us/portal/server.pt/community/best_management_practices_manual/10631.

3.3 Adapting Structural Low Impact Development Practices for Southern Ontario Conditions

Design guidance for the structural LID practices presented in chapter 4 was carefully adapted with consideration of the climate and predominant soil conditions in southern Ontario and of ultra urban development contexts that are particularly relevant to the Ontario Places To Grow legislation. Research and experience on LID practices from elsewhere in North America was evaluated to ensure that practices could be:

- adapted to withstand cold weather conditions in the region, withstand freeze-thaw conditions, and where possible treat the quality of snowmelt runoff;
- easily combined together to progressively reduce runoff volumes as a treatment train;
- feasible in the context of the more intense development and lot sizes that occur in the metropolitan areas that provide relatively little open space to locate practices;
- designed to collectively achieve target water balance and water quality storage volume requirements, contribute to stream channel erosion control, and reduce the size and cost of downstream conveyance and detention facilities;
- useful for reducing runoff volumes, even on sites with clayey soils with low infiltration rates;
- fit unobtrusively into open space and landscaping, and in some instances, provide amenity values;
- located within a stormwater easement, public right of way or conservation easement where they would be accessible for regular maintenance;

- applied in the context of new development, infill, redevelopment or retrofit projects; and

- evaluated to ensure the aggregate lifecycle cost for installation and maintenance of LID practices is equal to or less than the cost of constructing conventional stormwater conveyance and pond systems.

3.4 The Low Impact Development Design Process

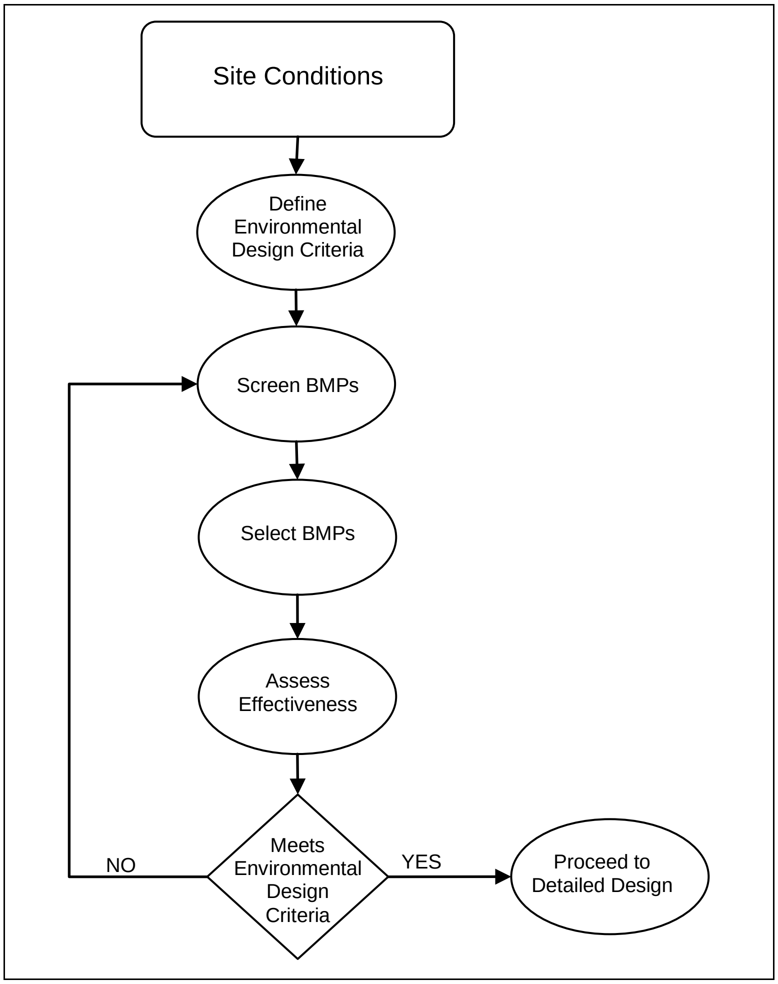
The ultimate goal of LID is to maintain natural or predevelopment hydrologic conditions, including minimizing the volume of runoff produced at the site (*i.e.*, neighbourhood, subdivision or individual lot). Runoff reduction is defined as the total runoff volume reduced through urban tree canopy interception, evaporation, rainwater harvesting, and engineered infiltration and evapotranspiration stormwater best management practices.

As described in chapter 2, the LID design process begins with a landscape-based approach to planning. The approach involves understanding regional and watershed-scale contexts, management objectives and targets relevant to the site. Where watershed or subwatershed scale studies or management plans are available, information and guidance they provide should be drawn upon. In the absence of a watershed plan, a subwatershed study may be required to establish the regional environmental context. Opportunities for LID practices are identified at the neighbourhood or subwatershed scales and refined at more detailed scales and planning stages. Inventories of the natural resources and drainage features present on the site are used as the integrating framework for stormwater management system planning.

Complete definition of pre-development site conditions is essential prior to screening of potential stormwater BMPs. The designer should prepare maps describing site conditions, to ensure that all environmental features and functions that need consideration in accordance with provincial, municipal and conservation authority development regulations are identified. This includes watercourses and small drainage features, floodplains, important recharge areas, steep slopes, wetlands, natural heritage conservation areas and significant wildlife habitats. In addition, information regarding native soil types, infiltration capacity and depth to water table must be determined. Using these conditions and the site design techniques described in Section 3.2, the natural heritage system, development footprint and constraints for stormwater BMPs can be established.

Once the site conditions are established, the designer evaluates the potential to apply a combination of best management practices (BMPs) to meet the environmental management criteria relevant to the site. Best management practices include the LID practices described in this guide and conventional end-of-pipe practices like wet and dry detention ponds and constructed wetlands. The general process for selecting the appropriate suite of best management practices (BMPs) is illustrated in Figure 3.4.1. Further description of each of the four steps is provided below.

Figure 3.4.1: Process for selecting a suite of best management practices



Step 1: Define Environmental Design Criteria

A detailed description of the design criteria that need to be defined is provided in the respective CVC and TRCA Stormwater Management Criteria documents. The criteria are required in order to:

- preserve groundwater and baseflow characteristics;
- prevent undesirable and costly geomorphic changes in the watercourse;
- prevent any increases in flood risk potential;
- protect water quality; and ultimately,
- maintain an appropriate diversity of aquatic life and opportunities for human uses

The design criteria required to protect, enhance or restore the environmental resources can be grouped under the following five categories.

- Flood Protection;
- Water Quality;
- Erosion Control;
- Recharge; and
- Natural Heritage Systems

Step 2: Screen Potential Best Management Practices

A number of factors need to be considered when screening the suitability of a given location within a development site for application of stormwater BMPs. Table 3.4.1 summarizes site constraints associated with some general types of structural LID practices for stormwater management that should be considered. Further details regarding each general type of LID practice can be found in section 4. Further information regarding constraints to the design of various end-of-pipe BMPs can be found in the Ontario Ministry of the Environment *Stormwater Management Planning and Design Manual* (2003). The use of LID BMPs should be considered first to meet the design criteria before the use of end-of-pipe BMPs.

Step 3: Selection of Suite of Best Management Practices

In order to assess if the selected suite of BMPs effectively meet the design criteria either computer models or simple spreadsheet models should be used. Model selection will be based on the size and type of development. A wide range of simple to complex computer models such as Visual OTTHYMO, SWMM, SWMMHYNO, HSP-F and QUALHYMO are available.

Step 4: Assessing the Effectiveness of the Selected Suite of Best Management Practices

Once the suite of best management practices have been selected and the models have been run, a comparison of the results and the environmental design criteria can be made. An iterative approach, which involves adjusting the size or adding/deleting BMPs should be used until the environmental design criteria are met. The project can then proceed to the detailed design stage.

Table 3.4.1 Comparison of site constraints for a range of structural LID SWM practices

LID Stormwater Management Practice	Depth to high water table or bedrock[1] (m)	Typical Ratio of Impervious Drainage Area to Treatment Facility Area	Native Soil Infiltration Rate (mm/hr)[3]	Head[4] (m)	Space[5] %	Slope[6] %	Pollution Hot Spots[7]	Set backs[8]
Rain barrel	Not applicable	[5 to 50 m^2][2]	Not applicable	1	0	NA	Yes	None
Cistern	1	[50 to 3000 m^2][2]	Not applicable	1 to 2	0 to 1	NA	Yes	U, T
Green roof	Not applicable	1:1	Not applicable	0	0	0	Yes	None
Roof downspout disconnection	Not applicable	[5 to 100 m^2][2]	Amend if < 15 mm/hr[9]	0.5	5 to 20	1 to 5	Yes	B
Soakaway, infiltration trench or chamber	1	5:1 to 20:1	Not a constraint	1 to 2	0 to 1	< 15%	No	B, U, T, W
Bioretention	1	5:1 to 15:1	Underdrain required if < 15 mm/hr	1 to 2	5 to 10	0 to 2	No	B, U, W
Biofilter (filtration only Bioretention design)	Not applicable	5:1	Not applicable	1 to 2	2 to 5	0 to 2	Yes	B, T
Vegetated filter strip	1	5:1	Amend if < 15 mm/hr[9]	0 to 1	15 to 20	1 to 5	No	None
Permeable pavement	1	1:1 to 1.2:1	Underdrain required if < 15 mm/hr	0.5 to 1	0	1 to 5	No	U, W
Enhanced grass swale	1	5:1 to 10:1	Not applicable	1 to 3	5 to 15	0.5 to 6	No	B, U
Dry swale	1	5:1 to 15:1	Underdrain required if < 15 mm/hr	1 to 3	5 to 10	0.5 to 6	No	B, U, W
Perforated pipe system	1	5:1 to 10:1	Not a constraint	1 to 3	0	< 15%	No	B, U, T, W

Notes:
1. Minimum depth between the base of the facility and the elevation of the seasonally high water table or top of bedrock.
2 Values for rain barrels, cisterns and roof downspout disconnection represent typical ranges for impervious drainage area treated.
3. Infiltration rate estimates based on measurements of hydraulic conductivity under field saturated conditions at the proposed location and depth of the practice.
4. Vertical distance between the inlet and outlet of the LID practice.
5. Percent of open pervious land on the site that is required for the LID practice.
6. Slope at the LID practice location.
7. Suitable in pollution hot spots or runoff source areas where land uses or activities have the potential to generate highly contaminated runoff (*e.g.*, vehicle fueling, servicing or demolition areas, outdoor storage or handling areas for hazardous materials and some heavy industry sites).
8. Setback codes: B = Building foundation; U = Underground utilities; T = Trees; W = drinking water wellhead protection areas.
9. Native soils should be tilled and amended with compost to improve infiltration rate, moisture retention capacity and fertility.

3.5 Costs and Benefits of Low Impact Development Approaches

The United States Environmental Protection Agency (U.S. EPA) examined the costs of LID approaches in *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices,* released in December 2007. The report summarized 17 case studies of developments in the United States and Canada that included low impact development approaches for managing stormwater. The case studies included a variety of different land uses and dealt with both greenfield and redevelopment scenarios. Table 3.6.1 summarizes findings from some of the projects that were reviewed along with a comparison of conventional development costs versus low impact development costs.

Some of the key findings from this study were:

- In 12 of the case studies, total capital cost savings ranged from 15 to 80 percent when LID methods were used. In one study, LID costs were higher than conventional stormwater management costs.

- The study focused on the cost savings and cost reductions that are achievable through the use of LID practices. It should also be noted that communities and/or developers can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, faster home sales, improved habitat, aesthetic amenities and improved quality of life. The study did not monetize and consider these values in performing the cost calculations, it was noted that these economic benefits are real and significant.

- More research is needed to quantitatively estimate and compare full life cycle costs of municipal infrastructure for conventionally designed developments versus LID designs (including long term operation, maintenance and eventual replacement).

Table 3.5.1 Summary of cost comparisons between conventional and LID approaches

Projects[1]	Conventional Development Cost	LID Cost	Cost Difference[2]	Percent Difference[2]
2nd Avenue SEA Street, Seattle, Washington	$868,803	$651,548	$217,255	25%
Auburn Hills, southwestern Wisconsin	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall, Bellingham, Washington,	$27,600	$5,600	$22,000	80%
Bloedel Donovan Park, Bellingham, Washington	$52,800	$12,800	$40,000	76%
Gap Creek, Sherwood, Arkansas	$4,620,600	$3,942,100	$678,500	15%
Garden Valley, Pierce County, Washington	$324,400	$260,700	$63,700	20%
Kensington Estates, Pierce County, Washington	$765,700	$1,502,900	-$737,200	-96%
Laurel Springs, Jackson, Wisconsin	$1,654,021	$1,149,552	$504,469	30%
Mill Creek, Kane County, Illinois[3]	$12,510	$9,099	$3,411	27%
Prairie Glen, Germantown, Wisconsin	$1,004,848	$599,536	$405,312	40%
Somerset, Prince George's County, Maryland	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus, Naperville, Illinois	$3,162,160	$2,700,650	$461,510	15%

Source: U.S. EPA (2007).

Notes:

1. While additional projects were part of the U.S. EPA review, available information does not allow comparison of costs between conventional and LID approaches.
2. Negative values denote increased cost for the LID design over conventional development costs.
3. Mill Creek costs are reported on a per-lot basis.

4.0 DESIGN OF STRUCTURAL LOW IMPACT DEVELOPMENT PRACTICES FOR STORMWATER MANAGEMENT

This chapter of the guide contains overviews, design templates, maintenance requirements and cost estimates for the following structural LID practices for stormwater management:

4.1 Rainwater harvesting;
4.2 Green roofs;
4.3 Roof downspout disconnection;
4.4 Soakaways, infiltration trenches and chambers;
4.5 Bioretention;
4.6 Vegetated filter strips;
4.7 Permeable pavement;
4.8 Enhanced grass swales;
4.9 Dry swales; and
4.10 Perforated pipe systems.

The overviews for each LID practice cover the following:

- Description of practice;
- Common concerns;
- Physical suitability and constraints; and
- Typical performance.

The design templates provide the following:

- Applications;
- Typical details;
- Design guidance;
- BMP sizing;
- Design resources;
- Design and material specifications; and
- Construction considerations and sequencing.

Recommended maintenance practices for each LID practice, together with base construction costs are provided where information is available. It should be noted that several of the practices as described in this guide have only been implemented for a few years. Construction, operation and maintenance costs will therefore need to be updated as these practices become more commonplace in Ontario.

4.1 Rainwater Harvesting

4.1.1 Overview

Description
Rainwater harvesting is the process of intercepting, conveying and storing rainfall for future use. Harvesting rainwater for domestic purposes has been practiced in rural Ontario for well over a century. Interest in adapting this practice to urban areas is increasing as it provides the combined benefits of conserving potable water and reducing stormwater runoff. When harvested rainwater is used to irrigate landscaped areas, the water is either evapotranspired by vegetation or infiltrated into the soil, thereby helping to maintain predevelopment water balance.

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 or commercial land uses (Figure 4.1.1). 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% (Reid Homes, 2007). 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 water resources (such as groundwater aquifers and reservoirs) from which municipal water supplies are drawn. By reducing demand on water resources, rainwater harvesting can result in significant cost savings due to:

- delayed expansion of municipal water treatment and distribution systems;
- lowered energy use for pumping and treating water; and
- lowered consumer water bills

There are two options for the design and operation of rainwater harvesting systems:

1) Some systems are designed for both outdoor and indoor uses (*i.e.*, dual use systems) with usage continuing throughout the year. In cold climate regions, such as southern Ontario, cisterns for year-round usage must be located underground below the local frost penetration depth, or indoors in a temperature controlled environment to prevent freezing.

2) Other systems are designed for outdoor water usage only, where water demand varies seasonally. Rain barrels or cisterns for seasonal, outdoor water uses can

be located above-ground or underground, acknowledging that they need to be decommissioned annually, prior to the onset of freezing temperatures.

Figure 4.1.1 Various types of rainwater storage tanks

Clockwise from top left: typical plastic rain barrel; cast in place concrete cistern integrated within a parking garage (Source: TRCA); above-ground plastic cistern; underground pre-cast concrete cistern (Source: University of Guelph)

Common Concerns

Some common concerns associated with rainwater harvesting that must be addressed during design include:

- *Winter Operation:* 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.

- *Plumbing Codes:* The 2006 Ontario Building Code explicitly allows the use of harvested rainwater for toilet and urinal flushing (See Section 7.1.5.3 of the Code). Canadian Standards Association has standards B.128.1 and B.128.2 that address the design, installation, maintenance and field testing of non-potable water systems. Systems using harvested rainwater indoors are required to have backflow preventers to keep non-potable harvested water separate from watermains carrying potable water. CSA-B64.10 provides guidance for the selection and installation of backflow prevention devices. Additionally, pipes carrying rainwater must be labeled as non-potable.

- *Standing Water and Mosquitoes:* Rainwater harvesting systems, if improperly managed, can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on inlets and overflow outlets to prevent mosquitoes and other insects from entering the system. If screening is not sufficient to deter mosquitoes, dunks containing larvicide can be added to storage tanks when harvested water is intended for irrigation only.

- *Child Safety:* Above grade home cisterns with openings large enough for children to enter the tank must have lockable covers. For underground cisterns, manholes should be secured to prevent unwanted access.

- *Drawdown Between Storms:* The extent to which cisterns reduce runoff and peak flows depends on use of the captured rainwater between storms, so that capacity exists to capture a portion of the next storm. Water demand estimations should be submitted for review along with other stormwater management system design documents.

- *On Private Property*: If a rainwater harvesting system is installed on private lots, 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

Physical Suitability and Constraints
A number of site-specific features influence how rainwater harvesting systems are designed. Some of the key considerations include:

- *Available Space:* Space limitations are rarely a concern with rainwater harvesting if considered during building design and site layout. Storage tanks can be placed underground, indoors, on roofs, or adjacent to buildings depending on intended uses of the rainwater. Designers must work with architects to site the tanks.

- *Site Topography:* Site topography influences the placement of storage tanks and the design of the rainwater conveyance and overflow systems. Locating storage tanks in low areas of the site will likely increase the volume of rainwater that can be stored for later use, but will increase the amount of pumping needed to distribute the harvested rainwater. Conversely, placing storage tanks at higher elevations will likely reduce the volume of rainwater that can be stored due to structural limitations on the weight of captured rainwater that can be stored, but will also reduce the amount of pumping needed for distribution or eliminate it altogether.

- *Available Head:* The needed head depends on intended use of the water. For residential landscaping uses, the rain barrel or cistern should be sited up-gradient of the landscaping areas or on a raised stand. Gravity-fed operations may also be used for indoor residential uses, such as laundry, that do not require high water pressure. For larger-scale landscaping operations, locating a cistern on the roof or uppermost floor may be the most cost efficient way to provide water pressure.

- *Soils:* Cisterns should be placed on or in native, rather than fill, soils. If placement on fill slopes is necessary, a geotechnical analysis is needed. Underground tanks and the pipes conveying rainwater to and from them, including overflow systems, should either be located below the local frost penetration depth (MTO, 2005), or insulated to prevent freezing during winter

- *Pollution Hot Spot Runoff:* Rainwater harvesting systems can be an effective stormwater BMP for roof runoff at sites 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).

- *Setbacks from Buildings:* Rainwater harvesting system overflow devices should be designed to avoid causing ponding or soil saturation within three (3) metres of building foundations. Storage tanks must be watertight to prevent water damage when placed near building foundations.

- *Proximity to Underground Utilities:* The presence of underground utilities (*e.g.*, water supply pipes, sanitary sewers, natural gas pipes, cable conduits, etc.), may constrain the location of underground rainwater storage tanks.

- *Vehicle Loading:* Underground cisterns should be placed in areas without vehicular traffic. Tanks under roadways, parking lots, or driveways must be designed for the live loads from heavy trucks, a requirement that could significantly increase construction costs.

Typical Performance

The ability of rainwater harvesting systems to help meet stormwater management objectives is summarized in Table 4.1.1. Except in retrofit situations, rainwater harvesting will not be a stand-alone BMP. It is part of a treatment train that will likely include practices such as vegetated filter strips and grass channels in addition to detention for stream channel erosion control requirements.

Table 4.1.1 Ability of rainwater harvesting systems 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

Water Balance

Harvested rainwater that is used for watering landscaping meets the objectives of the water balance requirement, as these flows are infiltrated or evapotranspired after storage. On a larger scale, where groundwater is the primary source of water, the reduced demand on wells within the watershed will add to the water balance benefits of rainwater harvesting. Any reduction in runoff volume achieved by rainwater harvesting will be a benefit to receiving waters with regard to mitigation of increases in stream channel erosion rates, but full mitigation will likely require rainwater harvesting to be applied in series with other LID practices.

Limited research has been conducted to evaluate the runoff reduction capacity of rain tanks and cisterns, particularly in cold climates (Table 4.1.2). Modeling research indicates that their runoff reduction capacity is limited by tank capacity, the length of time between storm events, and rainwater usage. Estimating the runoff reduction for an individual facility requires simulation modeling of rainfall and water usage. A rainwater harvesting system design tool spreadsheet has been developed for Ontario that can estimate runoff reduction, based on input of local climate data, catchment and storage tank dimensions and assumptions regarding typical water use patterns (University of Guelph and TRCA, 2009). The tool can also be used to estimate overall system cost.

Table 4.1.2 Volumetric runoff reduction by rainwater cisterns

LID Practice	Location	Runoff Reduction	Reference
Dual Use Cisterns[1]	Guelph, Ontario	89%	Farahbakhsh *et al.* (2009)
Dual Use Cisterns[1]	Toronto, Ontario	23 to 46%	TRCA (2010)
Dual Use Cisterns[1]	Australia	60 to 90%	Hardy *et al.* (2004)
Dual Use Cisterns[1]	Australia	40 to 45%	Coombes and Kuczera (2003)
Dual Use Cisterns[1]	New Zealand	35 to 40%	Kettle *et al.* (2004)
Runoff Reduction Estimate[2]		**40%**	

Notes:
1. Dual use cisterns provide a year-round supply of water for both indoor and outdoor uses.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval agencies.

Water Quality – Pollutant Removal Capacity

The pollutant removal capacity of rainwater harvesting systems stems from their ability to reduce the volume of stormwater runoff being generated from a site, thereby reducing pollutant load to receiving waters. During small to medium sized storm events a rainwater harvesting system with sufficient available storage capacity could capture 100% of the runoff from a catchment surface, thereby reducing the pollutant load from the surface to zero. The pollutant removal capacity of rainwater harvesting systems is directly proportional to the amount of runoff that is captured. Theoretically, if 100% of runoff is captured and used, no stormwater pollution from the catchment surface will be conveyed downstream. In applications where rainwater is harvested for use in commercial or industrial properties, runoff volume reductions in the order of 40 to 45% have been observed over the period of monitoring (Coombes and Kuczera, 2003; TRCA, 2008c).

Peak Flow Control

The storage and diversion capability of rainwater harvesting systems not only reduces runoff volume and pollutant load, but also peak discharge rates downstream. However, if cisterns are being implemented to meet peak flow control requirements, in addition to water conservation/runoff volume reduction benefits, they require additional design considerations. Depending on anticipated water usage rates, an outflow control may need to be incorporated. The outflow control would function like the outlet of a stormwater detention pond, to provide temporary detention and gradual release of incoming runoff during medium to large sized storm events, while still providing a reservoir of water in the cistern that can be drawn upon. Peak flow reductions of up to 90% are possible with large rainwater harvesting systems (Coombes, 2002).

Other Benefits to the Watershed

- Economic Benefits: Since outdoor residential irrigation can account for up to 40% of domestic water consumption in the hot summer months, rainwater harvesting can conserve water and reduce the demand on the municipal water system (LID Center, 2003b). Rainwater harvesting can reduce individual consumers' utility bills, but also represents a larger cost savings. Increased population drives the need for additional water supply infrastructure, including expansion of existing water treatment plants or construction of new ones. Rainwater harvesting, similar to water conservation efforts, reduces the demand for potable water. In particular, peak demand, driven by summertime outdoor watering, is reduced. It also reduces municipal costs associated with treating and pumping potable water to end users.

4.1.2 Design Template

Applications

Rainwater harvesting systems can be applied on most residential, commercial, industrial or institutional roofs where rainwater can be captured, stored, and used. They are particularly useful on infill and redevelopment sites that have little room for other stormwater BMPs. Rainwater harvesting systems can be installed underground, indoors, on the ground next to a building or on the roof. In the Greater Toronto Area, dual use rainwater cisterns are usually located underground, in temperature controlled parking areas or in basements to prevent freezing during cold weather.

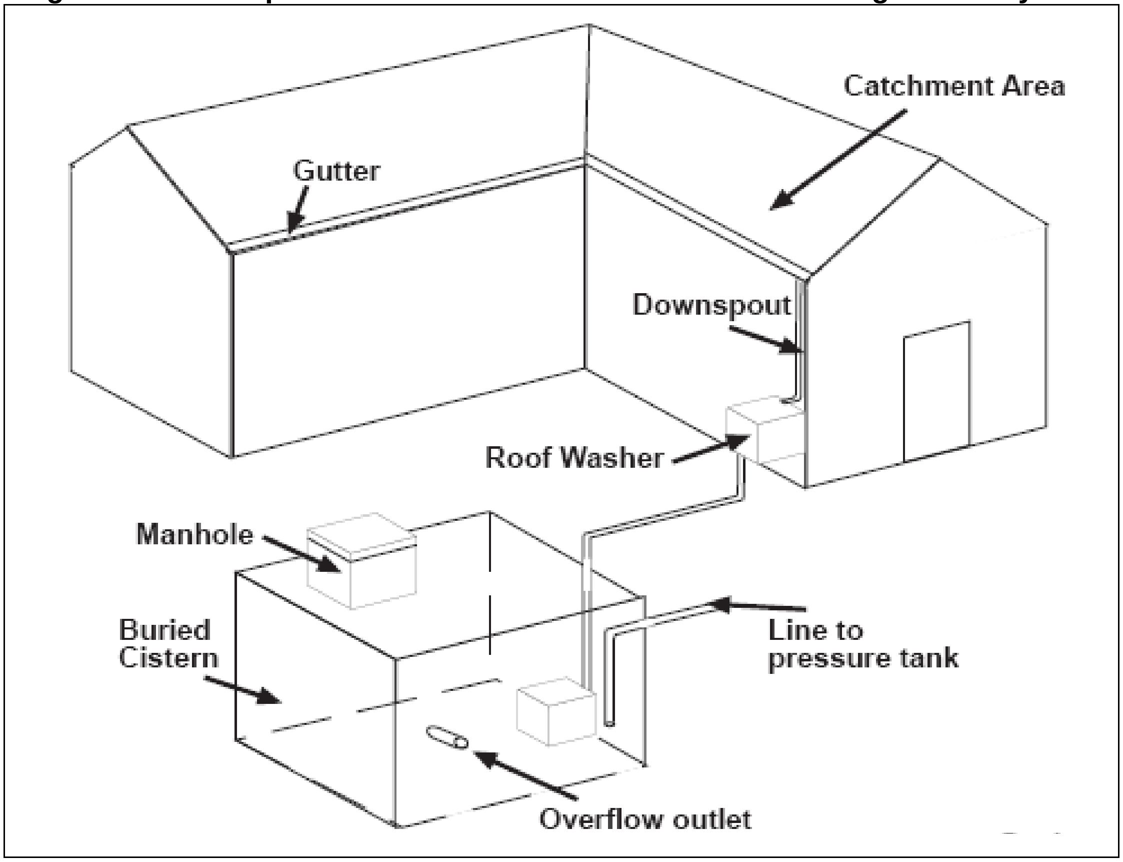
Rainwater that is captured and stored can be used to meet both outdoor and indoor non-potable water uses. Outdoors, harvested rainwater can be used for residential lawn and garden watering, commercial and institutional landscaping irrigation, decorative fountains, or other non-potable uses such as vehicle washing, building washing and fire fighting.

Typically, indoor uses of harvested rainwater are for non-potable purposes only. Toilet flushing is the most common large-scale indoor use of harvested rainwater. Laundry washing is another common residential water use with potential to utilize harvested rainwater, as it does not require potable water nor high water pressure. Separate plumbing, pumps, pressure tanks, and backflow preventers are necessary for indoor use of harvested water. Back-up water supply system arrangements,that can be drawn upon when the cistern runs dry, are also necessary for indoor uses.

Typical Details

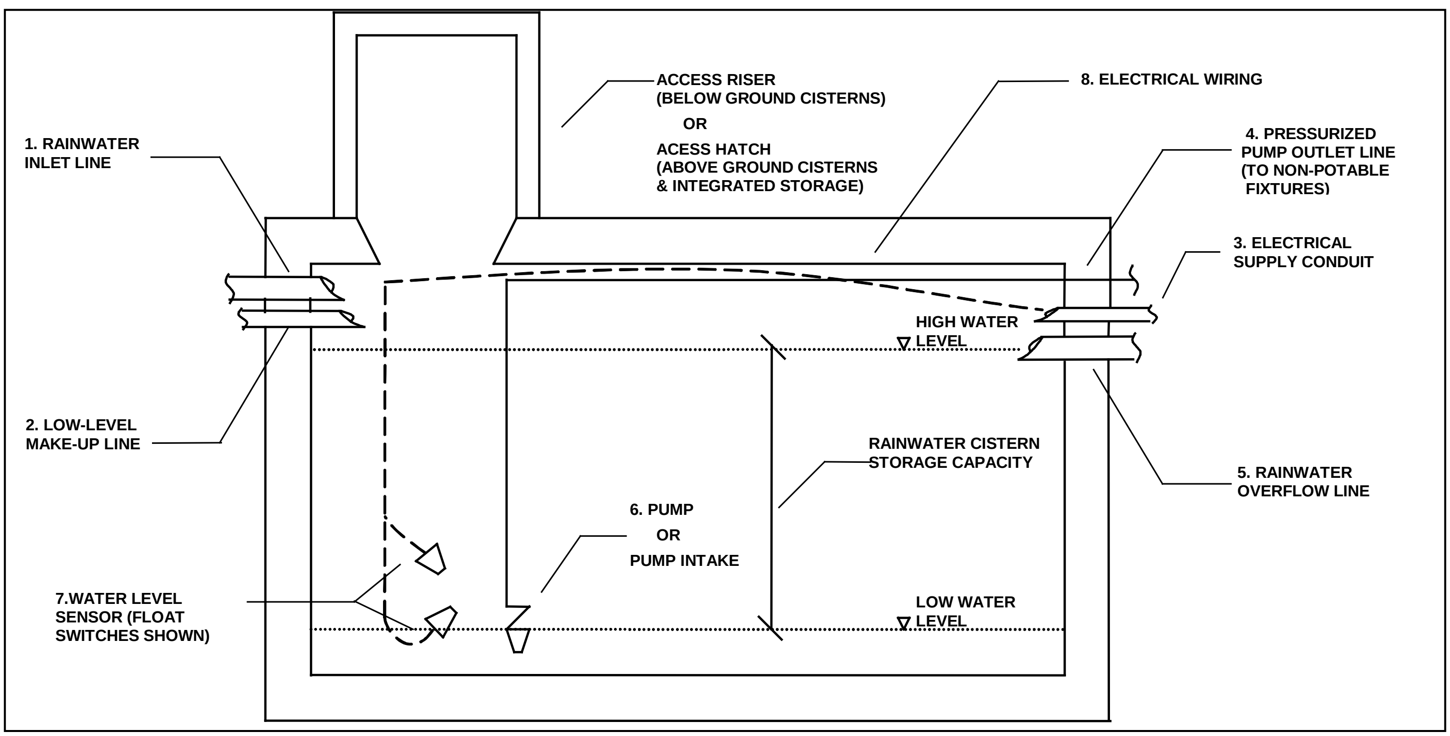
A typical residential rainwater harvesting cistern system is illustrated in Figure 4.1.2. A schematic of a dual use cistern is provided in Figure 4.1.3. Examples of common pretreatment devices are shown in Figure 4.1.4.

Figure 4.1.2 Components of a residential rainwater harvesting cistern system



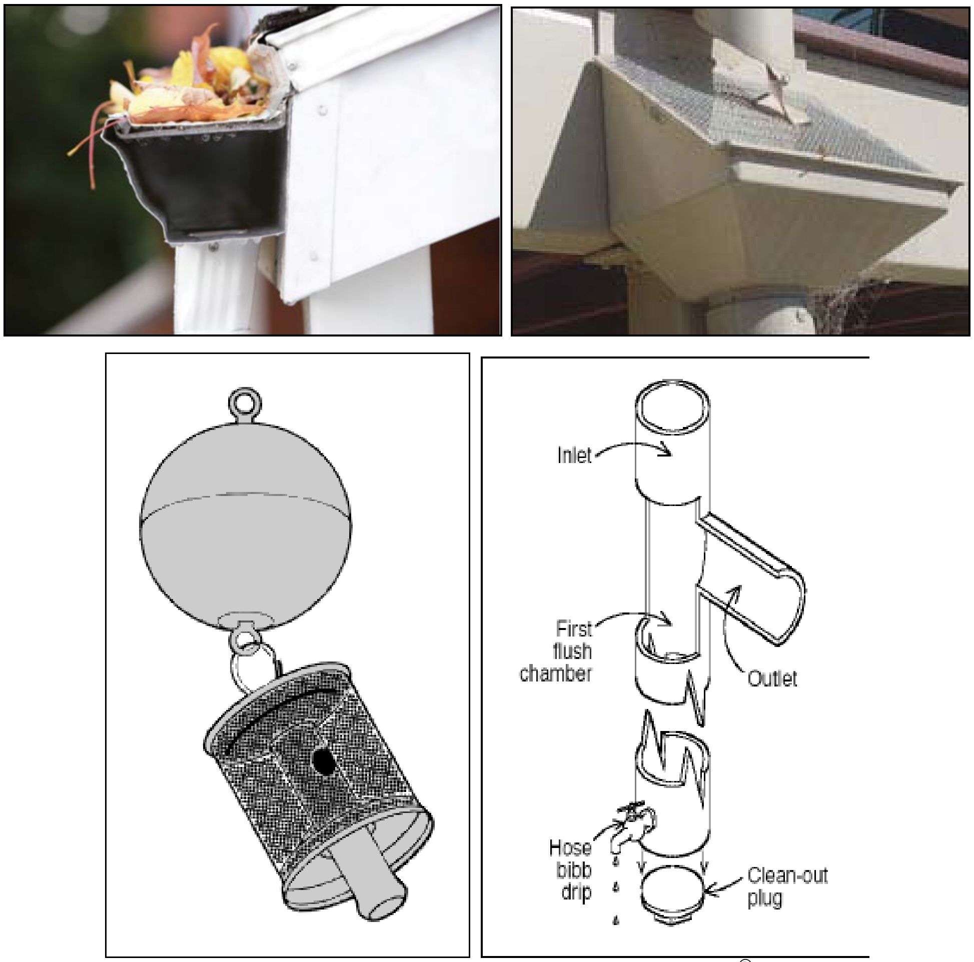
Source: Rupp, 1998

Figure 4.1.3 Schematic of a typical underground rainwater harvesting cistern



Source: University of Guelph, 2010

Figure 4.1.4 Examples of common pretreatment devices



Clockwise from top left: Leaf screens on eavestrough (Leaf Eater®, © Rainwater Harvesting Ltd.) and downspout (Fixa-Tech®, © Alu-Rex Inc.), First-flush diverter (Source: TWDB); Floating suction filter (© WISY)

Design Guidance

As shown in Figure 4.1.2, there are six components of a rainwater harvesting system:

- Catchment area;
- Collection and conveyance system (*e.g.* eavestroughs, downspouts, pipes);
- Pretreatment system (*e.g.*, filters and first-flush diverters);
- Storage tank (*e.g.*, rain barrels or cisterns);
- Distribution system; and
- Overflow system.

Guidance regarding the design of each of these components is provided below. For further detail, refer to, *Ontario Guidelines for Residential Rainwater Harvesting Systems* (University of Guelph, 2010). The University of Guelph and Toronto and Region Conservation Authority have also partnered to develop a *Rainwater Harvesting System Design Tool* to assist system designers in estimating rainwater capture, usage and overall system cost and optimizing benefits (University of Guelph and TRCA, 2009; download the tool from www.sustainabletechnologies.ca).

Catchment Area

The catchment area is simply the surface from which rainfall is collected. Generally, roofs are used as the catchment surface for a rainwater harvesting system, although rainwater harvested from other source areas, such as 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 source area and material from which the catchment area 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 landscape irrigation or toilet flushing due to potential for contamination with toxic compounds. To minimize contamination of roof catchment areas with natural debris it is recommended that overhanging tree branches be trimmed back.

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 as they would for a building without a rainwater harvesting system with the addition of screens to prevent large debris from entering the storage tank (also see Pretreatment). When sizing eavestroughs and downspouts, designers should design the conveyance system in a way that minimizes the frequency of overflow events. For a residential collection system, less detail may be needed. For dual use rainwater 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 (MTO, 2005) and have a minimum 1% slope (University of Guelph, 2010). 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.

Pretreatment

Pretreatment is needed to remove debris, dust, leaves, and other debris that accumulates on roofs and prevents clogging within the rainwater harvesting system. Different levels of pretreatment should be provided, depending on what the harvested water will be used for. Pretreatment devices should be easily accessible for inspection and maintenance. 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 freezing damage during periods of cold weather, first-flush diverter pretreatment devices should be either installed in a temperature controlled indoor environment, buried below the local frost penetration depth (MTO, 2005) or be insulated or equipped with heat tracing. If none of these measures can be taken, it may be necessary to disconnect the device from the conveyance system prior to the onset of freezing temperatures. Additional information about some common pretreatment devices is provided below.

- *Eavestrough or Downspout Filters:* Filters designed to remove leaves and other large debris from roof runoff such as leaf screens. Screen-type filters must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent runoff from flowing into the storage tanks. Built-up debris can also harbor bacterial growth (TWDB, 2005).

- *First Flush Diverters:* First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove large debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and animal droppings. Simple first flush diverters require gradual release drains or active management to drain the first flush water volume following each runoff event and regular cleaning to ensure they do not become clogged. First-flush diverters should be sized according to the desired amount of runoff to divert from the storage tank, typically 0.5 to 1.5 mm over the catchment area (University of Guelph, 2010).

- *In-ground Filters*: Filters placed between a conveyance pipe and an underground storage tank, designed to remove both large and fine particulate from harvested rainwater. A number of proprietary designs are available (*e.g.*, 3P Technik, GRAF, Rainharvesting Systems, WISY). Like leaf screens, they require regular cleaning to ensure they do not become clogged.

- *In-tank Filters*: Filters installed on the intake pipe within the storage tank (*e.g.*, floating suction filters). Like leaf screens, they require regular inspection to ensure they do not become clogged.

Storage Tank

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, a suggested starting point for sizing the storage tank would be based on the predicted rainwater usage (*e.g.*, toilet flushing and outdoor uses) over a 10 to 12 day period. Further details with respect to sizing of the tanks, such as a continuous simulation approach, are discussed later in this section under “BMP Sizing”.

Designers can roughly estimate the capacity required in the storage tanks by multiplying the rainfall depth of the design storm by the footprint of the catchment area. Cistern capacities range from 750 to 40,000 litres (CWP, 2007b). Typical cisterns for residential use are approximately 5,000 litres. Cisterns may be ordered from a manufacturer or can be constructed on site from a variety of materials including fiberglass, polypropylene, wood, metal and concrete. Above-ground tanks are often plastic while integrated tanks are usually cast-in-place concrete. Underground tanks may be concrete or plastic. All cisterns should be sealed using a water safe, non-toxic substance.

Regardless of the type of storage tank used, they should be opaque or otherwise protected from direct sunlight to inhibit algae growth and screened to discourage mosquito breeding and reproduction. Tanks should be accessible for cleaning, inspection, and maintenance. Underground rainwater cisterns should be installed so that the top of the tank is below the local frost penetration depth (MTO, 2005).

The location, size and configuration of a cistern on a given site depend upon several factors which need to be weighed to arrive at an optimum design (University of Guelph, 2010):

1. Whether the cistern can be integrated within the building or installed underground;
2. Accessibility for construction and maintenance;
3. Desired storage capacity;
4. Site grading;
5. Proximity constraints (*e.g.*, proximity to catchment area, overflow discharge location, control components of pump and pressure system, building foundations, underground utilities, trees).

Storage tank volume should be designed to achieve an optimal balance between meeting water demand, achieving stormwater management objectives and controlling the overall cost of the system. The volume of dead storage below the intake to the distribution system and an air gap at the top of the tank should be considered in selecting the storage tank capacity (Coombes, 2004). For gravity-fed systems a minimum of 150 mm of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications. To determine the optimum storage tank capacity, two methods are available (University of Guelph, 2010):

Rainwater Harvesting System Design Tool – a spreadsheet based computer program that uses information on geographic location, catchment area, and rainwater demand to determine an optimal cistern capacity and estimate overall system cost (University of Guelph and TRCA, 2009; to download the tool go to www.sustainabletechnologies.ca).

Rainwater Cistern Sizing Tables – Tables of optimal rainwater cistern capacities have been generated using the Rainwater Harvesting System Design Tool for a number of cities (*e.g.*, Table 4.1.3) given a variety of roof catchment areas and rainwater demand assumptions (University of Guelph and TRCA, 2009).

On sites where a rainwater harvesting system is being installed to manage runoff rates (*i.e.*, erosion control objectives), the storage tank can be sized to collect a specified portion of runoff from a storm event, resulting in a tank that is larger than needed to meet water conservation objectives alone. When used in conjunction with an appropriately designed outflow control the rainwater storage tank could provide temporary detention and controlled release of stormwater in order to achieve peak flow targets for erosion control.

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 uses use gravity to feed hoses via a tap and spigot. For underground cisterns or large sites, a water pump is needed. This can be a typical pump for distributing non-pressurized water for landscaping applications.

Indoor rainwater harvesting 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 and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump kicks on and supplies additional water to the distribution system. Many indoor systems also have a back-up municipal water supply line feeding into them (*i.e.*, “make-up” line) to provide a means of topping up the cistern with potable water when rainwater levels in the cistern fall below a specified level. A backflow preventer is required on “make-up lines” to prevent harvested rainwater from backing up into potable water supply lines. An alternative design switches fixtures connected to the cistern to municipal supply until additional rain or snowmelt fills the tank.

Overflow System

An overflow system must be included in the design in the event that multiple storms occur in succession and fill rainwater storage. 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 downgradient 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. When discharging overflows to a pervious area, the conveyance pipe should be screened to prevent small animals and insects from entering the pipe.

Where site conditions do not permit overflow discharge to a pervious area, the conveyance pipe may need to be indirectly connected to a storm sewer. An indirect connection to a storm sewer can be created by:

1. Overflowing from the inlet line (*e.g.*, roof downspout) to a pervious or impervious area that drains to a storm sewer;
2. Overflowing to a tile drain;
3. Overflowing via overland flow to a sewer grate.

Overflow conveyance pipes can also be directly connected to a storm sewer with incorporation of a backflow preventer (*i.e.*, backwater check valve) to prevent contamination of stored rainwater in the event that the storm sewer backs up during intense storm events. Alternatively, where suitable site conditions exist, the overflow conveyance pipe can be connected to a soakaway that overflows to a storm sewer with a backflow preventer.

Other Design Aspects

- Access and Maintenance Features: 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. A drain plug or cleanout sump, also draining to a pervious area, should be installed to allow the system to be completely emptied if needed.

Other Resources

Several other manuals that provide useful design guidance for rainwater harvesting are:

Canadian Standards Association publications
http://www.csa-intl.org/onlinestore/

Portland Stormwater Management Manual
http://www.portlandonline.com/bes/index.cfm?c=dfbcc

Rainwater Harvesting Systems for Montana
http://www.montana.edu/wwwpb/pubs/mt9707.html

Texas Rainwater Harvesting Manual
http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf

Tucson, AZ Water Harvesting Guidance Manual
http://dot.ci.tucson.az.us/stormwater/downloads/2006WaterHarvesting.pdf

University of Guelph. 2010. *Ontario Guidelines for Residential Rainwater Harvesting Systems*. Guelph, ON.

University of Guelph and Toronto and Region Conservation Authority (TRCA). 2010. *Rainwater Harvesting System Design Tool.* www.sustainabletechnologies.ca

Water Sensitive Planning Guide for the Sydney Region: Practice Note 4 - Rainwater Tanks. http://www.wsud.org/planning.htm

BMP Sizing

Rainwater harvesting systems should be designed by optimizing the size of the storage tank based on the size of the catchment area, estimated rainwater demand and cost. In the Greater Toronto Area, this can be done through application of the Rainwater Harvesting System Design Tool (spreadsheet) developed by the University of Guelph and TRCA (2009), or rainwater storage tank sizing tables generated by the spreadsheet tool (*e.g.*, Table 4.1.3). Figure 4.1.5 illustrates some input and output information from the Rainwater Harvesting System Design Tool.

Table 4.1.3: Recommended rainwater storage tank capacities for various catchment areas and water demands for systems in Toronto

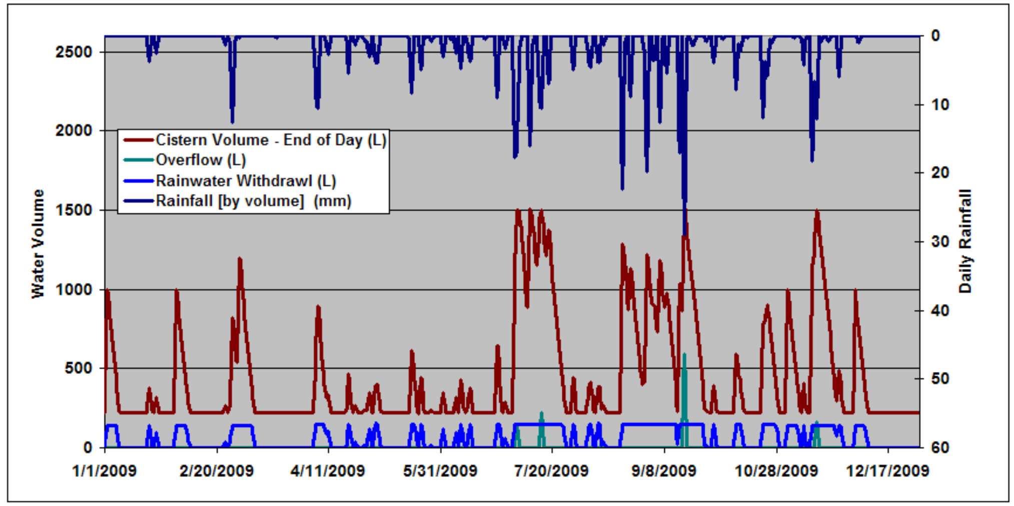
Rainwater Demand (Litres per day)	Optimum Rainwater Storage Tank Capacity (L)																		
	Roof Catchment Area (m²)																		
	50	100	150	200	250	300	350	400	450	500	600	700	800	900	1,000	1,500	2,000	2,500	3,000
50	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	5,000	5,000	5,000	5,000	5,000
100	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	5,000	5,000	5,000	5,000	5,000
150	2,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	5,000	5,000	5,000	5,000	5,000
200	2,000	5,000	5,000	5,000	5,000	5,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	5,000	5,000	5,000	5,000	5,000
250	2,000	5,000	5,000	7,500	5,000	5,000	5,000	5,000	5,000	5,000	5,000	4,000	4,000	4,000	5,000	5,000	5,000	5,000	5,000
300	2,000	5,000	5,000	7,500	7,500	7,500	7,500	7,500	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
350	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
400	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	5,000	5,000	5,000	5,000
450	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
500	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
600	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	7,500	7,500	7,500	7,500	7,500	7,500
700	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	10,000	10,000	7,500
800	-	5,000	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
900	-	-	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
1,000	-	-	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
1,500	-	-	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	15,000	15,000	15,000
2,000	-	-	5,000	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	15,000	15,000	15,000
2,500	-	-	-	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	15,000	15,000	15,000
3,000	-	-	-	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	10,000	10,000	10,000	10,000	10,000	15,000	15,000	15,000

Recommended rainwater storage tank capacities generated using the Rainwater Harvesting System Design Tool (University of Guelph and TRCA, 2009) assuming:

1. Historical rainfall for the City of Toronto (median annual rainfall 678 mm);
2. Optimum cistern is defined as a cistern providing at least a 2.5% improvement in water savings following an increase of 1,000 Litres in storage capacity.

Figure 4.1.5 University of Guelph and TRCA Rainwater Harvesting System Design Tool

	A	B	C	D	E
1					*Scenario 1*
2	City:	Toronto (Downsview)			
3	Setting:	Residential			
4	Total Number of People:	2			
5	Days Occupied per Week:	7			
6	Roof Surface Area (m^2):	60			
7	Roofing Material:	Asphalt Shingle			
8	Initial Loss Factor (mm):	0.5			
9	Continuous Loss Factor (%)	20			
10	Pre-treatment of Rainwater	N/A			
11	Initial Loss Factor (mm):	0			
12	Continuous Loss Factor (%)	0			
13	COLD				Liters per capita per day (lpcd)
14	Toilets	Dual-flush	*Flushes per day:*	7.0	33.6
15	Urinals	N/A	*Flushes per day:*	0.0	0.0
16	Washing Machine	N/A	*Loads per week:*	0.0	0.0
17		N/A			
18	Irrigation & Landscaping	Efficient - 0.25in	*Area irrigated (m^2)*	10.0	4.6
19			*No. of times irrigated per week:*	1.0	
20	Lavatory/Laundry Faucets (L)	N/A	*Uses per person per day:*	0.0	0.0
21	Other (L)	N/A	*Uses per person per day:*	0.0	0.0
22					
23	HOT				
24	Dishwasher	N/A	*Loads per week:*	0.0	0.0
25	Washing Machine				0.0
26	Shower	N/A	*Minutes per shower:*	0.0	0.0
27	Lavatory/Laundry Faucets (L)	N/A	*Uses per person per day:*	0.0	0.0
28	Other (L)	N/A	*Uses per person per day:*	0.0	0.0
29					
30			Total water use per person per day		38.171
33	**Daily water demand:**	**76 Litres per day**			
35	**Cistern Sizing Analysis**				
36	Analysis:	**Standard Analysis**			
37	Type of Analysis	**Manually calculate based on cistern sizes I input**			
39	**Cistern Volumes to be Analyzed:**				
40	Cistern Volume 1 (L)	1,500	Cistern Volume 1 (L)	0	
41	Cistern Volume 2 (L)	0	Cistern Volume 2 (L)	0	
42	Cistern Volume 3 (L)	0	Cistern Volume 3 (L)	0	
43	Cistern Volume 4 (L)	0	Cistern Volume 4 (L)	0	
44	*Advanced calculation details (hidden by default)*				
45					
46	Contribution of snow melt (%)	50.0%			
47	Rainwater cistern dead space (%)	15.0%			
48	**Analyze rainfall data by Volume**				



Sheet1 | Average House_S1REPORT | **Average House_S1** | Average House_S1P | Average House_S1A | Sheet2 | Sheet3

In situations where the runoff volume or peak flow reduction required to achieve stormwater management objectives exceeds the capacity of the optimum sized storage tank, based on water demand and catchment area, rainwater harvesting systems should overflow to another LID practice. This can be done by directing overflows from the storage tank to a pervious area (*i.e.*, simple downspout disconnection), vegetated filter strip, grass swale, or soakaway. Alternatively, the storage tank could be oversized and combined with an outflow control to provide temporary detention and controlled release of stormwater, similar to a detention pond.

Estimating Rainwater Demand

Sizing the storage tanks and catchment area for rainwater harvesting systems begins with estimation of the rainwater demand. The following factors should be considered in determining rainwater demand for outdoor uses:

- Method of distribution and associated flow rate (*e.g.* sprinkler systems, soaker hoses, pressure washing equipment);
- Frequency of watering based on season and landscaping best management practices;
- Landscaping area to be watered;
- For redevelopment or retrofit installations, the actual water usage by comparing winter and summer water bills.

Dual use rainwater harvesting systems (both outdoor and indoor use) can be sized based on the demand principles used for site-specific traditional water and wastewater design. These estimates can be broken down into usage by aspects of the plumbing system such as toilets.

The University of Guelph and TRCA Rainwater Harvesting System Design Tool (2009) can also be used to generate estimates of rainwater demand. Rainwater demand estimates and assumptions should be included with system design documents submitted for review by approval authorities.

Stormwater Management Requirements

The needed treatment volume for water quality, peak flow control, and water balance objectives should be calculated based on the relevant methodology in the CVC or TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010). Continuous simulation of rainfall and storage tank capacity is necessary to design rainwater harvesting systems to meet stormwater management requirements as the available storage fluctuates based on the temporal rainfall distribution and water usage. This can be done using the University of Guelph and TRCA Rainwater Harvesting System Design Tool (2009). If a different model is used for analysis, it should consider the available storage in the tank during a storm event which varies according to the size of the previous storm event, rainwater demand (rate of use) and the length of time since the previous storm event, all of which vary seasonally. It is important to note that the total volume of the storage tank is not the active storage volume. The active storage volume of the tank does not include the freeboard between the overflow outlet and the top of the tank nor any dead storage below the intake to the distribution system.

Sizing Secondary LID Practices

Compare the rainwater demand storage volume to the stormwater management volume required. The volume not stored in the rainwater harvesting system will have to be treated through a secondary LID practice. For water quality and water balance requirements, simple downspout disconnection, vegetated filter strips, grass swales and bioretention are possible choices. For peak flow control requirements, overflow to a storm sewer that flows to a detention pond or subsurface detention chamber should be considered. With incorporation of a suitable outflow control, an underground rainwater cistern can provide temporary detention and controlled release of stormwater (Coombes, 2002; City of Portland, 2004).

Design Specifications

Recommended design specifications for rainwater harvesting systems are provided in Table 4.1.4.

Table 4.1.4 Design specifications for rainwater harvesting systems

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.	Determined by the size and layout of the catchment and the location of the storage tanks. Include needed bends and tees.
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 (10m^3 or larger) should have a settling compartment for sediment removal	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.		

Construction Considerations
For installation, it is advisable to have an experienced contractor who is familiar with cistern sizing, installation materials, and proper site placement. A minimum one-year warranty is recommended.

Sequencing
Stormwater should not be diverted to the cistern until the catchment area and overflow area have been stabilized.

Construction Inspection
The following items should be inspected prior to final sign-off on the stormwater management construction:

- Catchment area matches plans;
- Overflow system is properly sized and installed;
- Pretreatment system is installed;
- Screens are installed on all openings;
- Cistern foundation is constructed as shown on plans; and
- Catchment area and overflow area are stabilized.

4.1.3 Maintenance and Construction Costs

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 (LID Center, 2003b). The following maintenance tasks should be performed as needed to keep rainwater harvesting systems in working condition:

- keep leaf screens, eavestroughs and downspouts free of leaves and debris;
- check screens (1 mm openings) and patch holes or gaps immediately;
- 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, the following techniques can be used for harvested rainwater intended for landscaping use:

- add a few tablespoons of vegetable oil to smother larvae that come to the surface; and
- use mosquito dunks or pellets containing larvicide.

Winter Operation

Rainwater harvesting systems have a number of components that can be affected by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs. For above-ground systems, winter-time operation may not be possible. These systems must be taken offline for the winter. 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.

Installation and Operation Costs

The cost of rainwater harvesting systems includes the cost of the storage tanks, as well as any necessary pumps, wiring and distribution system piping. Storage tanks often make up the majority of system costs. Their cost varies depending on the size, construction material and whether they are located above or below ground (LID Center, 2003b). The University of Guelph and TRCA Rainwater Harvesting System Design Tool (2009) allows the user to estimate the overall cost of different system designs.

The capital cost to homeowners of an individual rainwater harvesting system can range between $6,000 and $14,000 (in 2006 Canadian dollars), depending on its size and configuration (CMHC, 2009). Based on analysis by the Center for Watershed Protection (2007b), base construction costs per cubic metre of runoff stored (in 2006 US dollars) range from $212 to $777, with a median of $530 (CWP, 2007b).

4.1.4 References

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4.2 Green Roofs

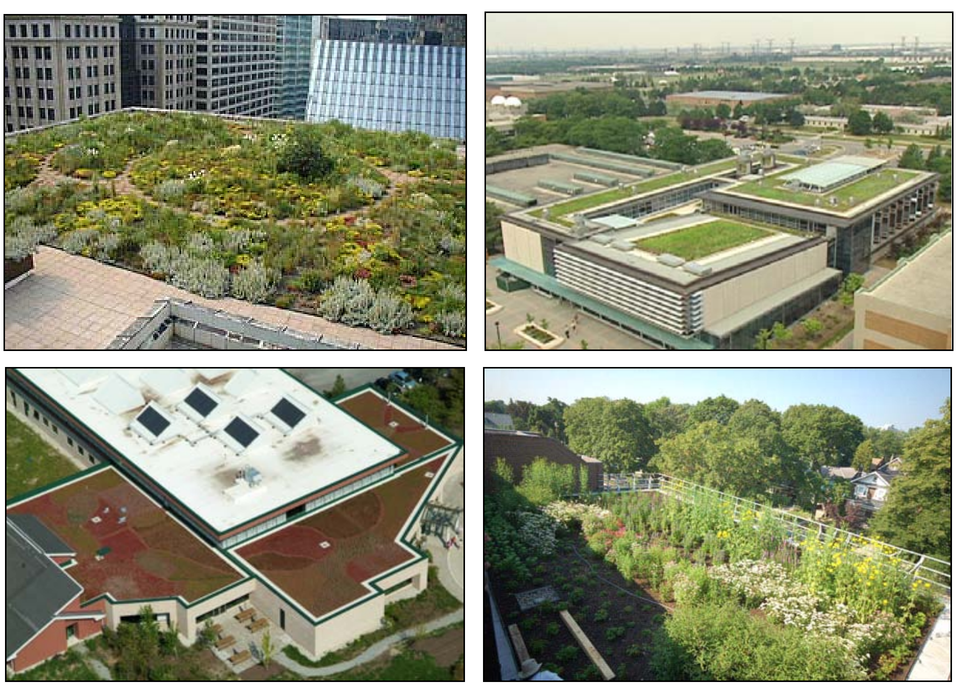
4.2.1 Overview

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 (Figure 4.2.1). 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. To a water resources manager, they are attractive for their water quality, water balance, and peak flow control benefits. From a hydrologic perspective, 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 centimetres depth of growing medium, can be planted with deeply rooted plants and are designed to handle pedestrian traffic. Roof structures supporting intensive green roofs require significantly greater load bearing capacity, thereby increasing their overall cost and complexity of design. Guidance in this guide focuses on extensive green roof design. Extensive green roofs consist of a thin layer of growing medium (15 centimetre depth or less) with a herbaceous vegetative cover. Two installation options are discussed: conventional and modular construction.

Figure 4.2.1 Examples of green roofs



Clockwise from top left: Chicago City Hall (Source: Roofscapes, 2005); York University in Toronto, Jackman Public School in Toronto; and Earth Rangers Building in Vaughan (Source: TRCA)

Common Concerns
Green roofs have multiple benefits including improved aesthetics in urban areas, reduction of the urban heat island effect, improved air quality, and insulation of buildings. However, there are some common concerns that should be addressed through design:

- *Water Damage to Roof:* Ponding water on roofs with drain restrictions is a practice already in use in the Greater Toronto Area. 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, similar to traditional roof installations. 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 (see Appendix B for guidance on plant selection). Irrigation during the first year may be necessary in order to establish vegetation. Vegetation maintenance costs decrease substantially after the first two years of operation, once plants become established.

- *Cost:* An analysis to determine cost effectiveness for a given site should include the roofing 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 by as long as 20 years by reducing exposure of the roofing materials to sun and precipitation (Velazquez, 2005). They can also reduce energy demand by as much as 75% (TRCA, 2006). Some municipalities, such as the City of Toronto, offer green roof incentive programs that should be considered in the cost assessment. A study of the life cycle costs and savings of building and owning a green roof in the Greater Toronto Area was undertaken by TRCA (2007a).

- *Cold Climate:* Green roofs are a feasible BMP for cold climates (Figure 4.2.2). 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.

- *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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

Figure 4.2.2 A green roof during winter

Source: National Research Council Canada, 2006

Physical Suitability and Constraints
Green roofs are physically feasible in most development situations, but should be planned at the time of building design. Some key constraints are addressed below.

- *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. Standards for dead and live design loads are available from ASTM International. 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.

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

- *Drainage Area and 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.

Typical Performance
The ability of green roofs to help meet stormwater management objectives is summarized in Table 4.2.1.

Table 4.2.1 Ability of green roofs to meet SWM objectives

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

Water Balance

Green roofs help achieve water balance objectives by reducing total annual runoff volumes. Considerable research has been conducted in recent years to define the runoff reduction capacity of extensive green roofs. Reported rates for runoff reduction have been shown to be a function of media depth, roof slope, annual rainfall and cold season effects. Based on the prevailing climate for the region, a conservative runoff reduction rate for green roofs of 45 to 55% is recommended for initial screening of LID practices. Results from select monitoring studies are provided in Table 4.2.2.

Table 4.2.2 Monitoring results – green roof runoff reduction

Location	Monitoring Period	Substrate Depth (cm)	Runoff Reduction[1]	Reference
Toronto, Ontario	May ’03 – Aug.’05 excluding winters	14	63%[2]	Van Seters *et al.* (2009)
Toronto, Ontario	Mar.’03 – Nov.’04 excluding winters	7.5 and 10	57%[2]	Liu and Minor (2005)
Ottawa, Ontario	Nov.’00 – Nov.’01	15	54%[2]	Liu (2002)
East Lansing, Michigan	Apr.’05 – Nov.’05 & Apr.’06 – Sep.’06	6	75 to 85%	Getter *et al.* (2007)
East Lansing, Michigan	Aug.’02 – Oct.’03 excluding winter	5.5	61%	VanWoert *et al.* (2005)
Portland, Oregon	May – Oct.’02	11	69%	Hutchinson *et al.* (2003)
Germany	Between 1987 and 2003[3]	10[4]	50%[5]	Mentens *et al.* (2005)
Kinston, North Carolina	July – Aug & Nov.-Dec.’03	10	64%	Hathaway *et al.* (2008)
Athens, Georgia	Nov.’03 – Nov.’04	11	78%	Carter and Rasmussen (2006)
Runoff Reduction Estimate[6]		**45 to 55%**		

Notes:

1. Values represent total precipitation retained by the green roof over the monitoring period unless otherwise noted.
2. Value represents reduction in runoff from the green roof relative to a reference roof, not relative to precipitation.
3. Based on summary of 18 different studies examining 121 extensive green roofs.
4. Value represents the median substrate depth from 121 extensive green roofs.
5. Value represents the average runoff reduction as % of total annual precipitation, based on studies of 121 extensive green roofs.
6. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality – Pollutant Removal Capacity

Only a handful of monitoring studies have measured the pollutant removal performance of green roofs. A TRCA study comparing conventional black roof runoff to green roof runoff in Toronto was completed in 2006. The study conducted a water quality analysis for a total of 21 events during 2003 and 2004**.** Table 4.2.3 summarizes the water quality results. The loading 'percent difference' values shown in the right column represent the difference in loading, expressed as a percentage, between unit area loads from the conventional roof and the green roof. Designers should regard the pollutant load reductions shown below as an initial estimate until more performance monitoring becomes available.

Table 4.2.3 Comparative pollutant load reductions for a green roof

Pollutant	**Loading % Difference*** **(Conventional Roof vs. Green Roof)**
Total Suspended Solids	89
Total Phosphorus	-248
Nitrate	91
Aluminum	69
Zinc	69
Copper	86
E. Coli	11
*Positive values indicate lower pollutant loadings from the green roof. Negative values indicate higher pollutant loadings from the green roof.	

Source: Van Seters et al, 2009

Other studies have also found higher concentrations of nutrients in green roof runoff that can be attributed to leaching from the growing medium (Hathaway *et al*., 2008; Berndtsson *et al.,* 2006; Long *et al.,* 2007). Leaching may be reduced by using less organic matter and coated, controlled release fertilizer in the growing medium (Emilsson *et al.*, 2007). Further reductions in phosphorus may be achieved by filtering runoff through media that are specially engineered to bind phosphorus through sorption processes (Ma and Sansalone, 2007).

Stream Channel Erosion Control

The use of a green roof will reduce the channel erosion control driven detention requirement by decreasing the impervious cover area. If the total detention requirements can't be met by the green roof alone, flow restrictors on roof downspouts may also be used.

Other Benefits

The benefits of green roofs reach beyond the specific stormwater management goals to other social and environmental benefits, including:

- *Energy Conservation:* The layers of growing medium and vegetation on the roof moderate interior building temperatures and provide insulation from the heat and cold. As a result the amount of energy required to heat and cool the building is reduced, providing energy savings to the owner. To illustrate, a recent study by

Environment Canada and the National Research Council of Canada (NRC) planted a green roof with juniper shrubs growing in thick soil. The purpose of the design was to reduce the effect of wind speed (which draws heat from the building) and to increase the building's resistance to heat loss. Indoor temperature variations and energy consumption was compared with a traditional roof building. Measurements showed that heat flow from the building with the green roof was reduced by more than 10 percent (Bass, 2005). At the NRC Ottawa green roof, energy demand for air conditioning was reduced by 75% (Liu, 2002).

- *Acoustic Insulation*: Green roofs can also be designed to insulate the building interior from outside noise, and sound-absorbing properties of green roof infrastructure can make surrounding areas quieter.

- *Urban Heat Island Effect:* Green roofs can reduce the urban heat island effect by cooling and humidifying the surrounding air. Temperature of runoff from the roof will also be lower, which is a benefit to temperature-sensitive aquatic life.

- *Aesthetics and Habitat:* With thoughtful design, green roofs can be aesthetically pleasing and can improve views from neighboring buildings. Additionally, the rooftop vegetation creates habitat for birds and butterflies.

- *Reduced Demand on Downstream Infrastructure*: The reduction in runoff volumes associated with green roofs can lessen the demand on existing downstream stormwater infrastructure, and, in the case of combined sewers, lower the frequency of overflows.

- Increased Longevity of Roof Structure: The green roof mitigates extreme temperatures and exposure to storms and extends the longevity of the roof structure.

4.2.2 Design Template

Applications

Green roofs can be installed on many types of roofs (Figure 4.2.3), from small slanting residential roofs to large commercial roofs. Sometimes only a portion of the roof is dedicated to a green roof. This best management practice is particularly useful in ultra urban sites where space for surface BMPs is limited.

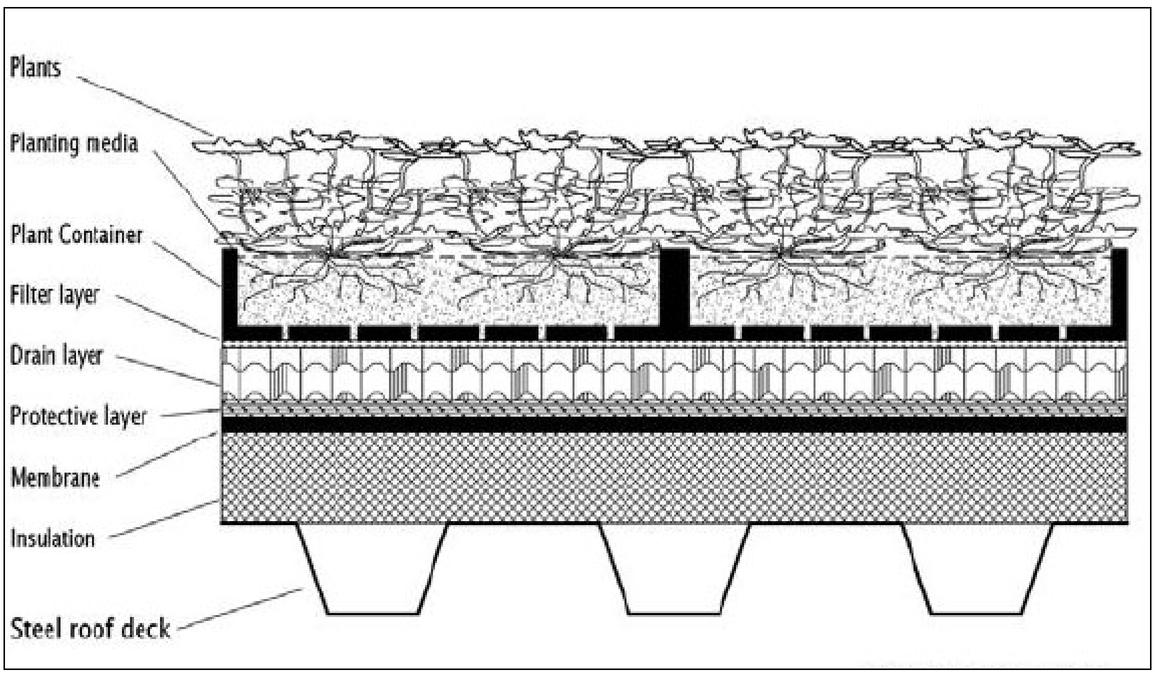
Figure 4.2.3 Other examples of green roofs

Source: City of Toronto (left); CWP (right)

Typical Details

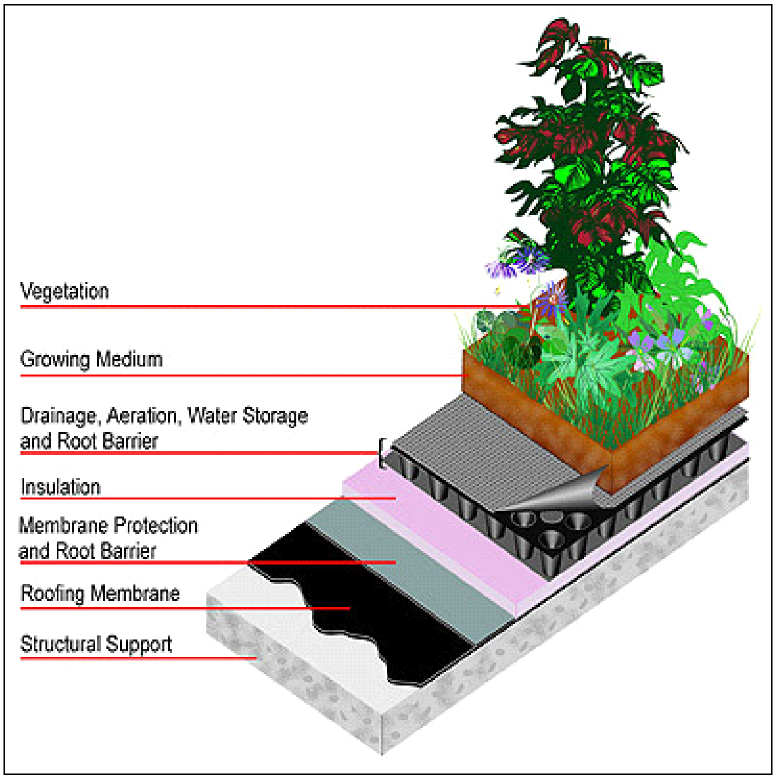
Schematic renderings of typical green roofs are provided in Figures 4.2.4 and 4.2.5.

Figure 4.2.4 Schematic of a green roof



Source: Shade Consulting, 2003

Figure 4.2.5 Green roof layers



Source: Great Lake Water Institute

Design Guidance

Only qualified professionals should design green roofs (*e.g.*, Green Roof Professional certification program, sponsored by Green Roofs For Healthy Cities; www.greenroofs.org).

Green roofs are composed of multiple layers that include:

- a roof structure capable of supporting the weight of a green roof system;
- a waterproofing membrane system designed to protect the building and roof structure;
- a drainage layer that consists of a porous medium capable of water storage for plant uptake;
- a filter layer to prevent fine particulate from the growing medium and roots from clogging the drainage layer;
- growing medium with appropriate characteristics to support selected green roof plants; and
- plants with appropriate tolerance for harsh roof conditions and shallow rooting depths.

Details on these layers are provided below.

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. Generally, a green roof assembly weighing more than 80 kilograms per square metre, when saturated, requires consultation with a structural engineer (Barr Engineering, 2003). Standards for dead and live design loads are available from ASTM International.

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

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 (Barr Engineering, 2003). Materials used around roof openings should be non-leaching to prevent contamination of the green roof growing medium.

Waterproofing System

In a green roof system, the first layer above the roof surface is a waterproofing membrane. Two common waterproofing techniques used for the construction of green roofs 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 (The Folsom Group, 2004).

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% (PDEP, 2006).

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 (*i.e.*, downspout disconnection).

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 millimetres in depth and increases the roof load by 80 to 170 kilograms 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 have less leaching of nitrogen and phosphorus (Moran and Hunt, 2005). Low nutrient growing media also promotes the dominance of stress-tolerant native plants (TRCA, 2006). 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. Application of fertilizer to the growing medium should not exceed a rate of 5 grams of nitrogen per square metre (Emilsson *et al*., 2007).

Landscaping
A qualified botanist or landscape architect should be consulted when choosing plant material. For extensive systems, plant material should be confined to hardier or indigenous varieties of grass and sedum. Some sedums, however are invasive. The use of native plants is encouraged (see Appendix B for guidance regarding plant species selection). Root size and depth should also be considered to ensure that the plant will stabilize the shallow depth of growing medium. The plant material should conform to the following:

- *Type of root preparation, sizing, grading and quality:* should comply with the Canadian Standards for Nursery Stock, 2006 Edition, published by the Canadian Nursery Trades Association.

- *Source of plant material:* should be grown in Zone 4 in accordance with Agriculture Canada's Plant Hardiness Zone Map.

- *Plant material:* should be free of disease, insects, defects or injuries and structurally sound with strong fibrous root systems. Should have been root pruned regularly, but not later than one growing season prior to arrival on site.

- *Bare root stock:* should be nursery grown, in dormant stage, not balled and burlapped or container grown.

- *Seed mixes:* should be Common No.1 Canada certified in accordance with Government of Canada Seeds Act and Regulation.

Modular Systems
Modular systems are essentially 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 a flexible growing medium structure, rather than a rigid structure, allowing them to be rolled out onto the underlying green roof assembly. The advantage of these systems is that they can be removed for maintenance.

Other Design Resources
Several other resources that provide useful design guidance for green roofs are:

Canada Mortgage and Housing Corporation: Design Guidelines for Green Roofs..http://www.cmhc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146

2004 Portland Stormwater Management Manual. http://www.portlandonline.com/bes/index.cfm?c=dfbbh

Philadelphia Stormwater Management Guidance Manual. http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

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

Design 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.

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 different suppliers for each component of the system.

4.2.3 Maintenance and Construction Costs

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 becomes established. A warranty on the vegetation should be included in the construction contract.

Regular operation of a green roof includes:

- *Irrigation:* Watering should be based on actual soil moisture conditions as plants are designed to be drought tolerant. High soil moisture from unnecessary watering will reduce the runoff reduction benefits of the green roof.

- *Leak Detection:* Electronic leak detection is recommended. This system, also used with traditional roofs, must be installed prior to the green roof. Particular attention to leak detection should be paid in the first few months following installation (The Folsom Group, 2004).

Ongoing maintenance should occur at least twice per year (Magco, 2003) and should include:

- *Weeding:* Remove volunteer seedlings of trees and shrubs. Extensive green roofs are not designed for the weight of these plants, and the woody roots can damage the waterproofing.

- *Debris and Dead Vegetation Removal:* Debris and bird feces should be removed periodically. In particular, the overflow conveyance system should be kept clear (TRCA, 2006).

Installation and Operation Costs

The estimated cost for extensive green roofs is $65 to $230 CAD per square meter (TRCA, 2007a), not including the base roof, with modular systems in the lower end of the range. While green roofs are initially more expensive than traditional roofs, their lifecycle costs may be comparable to traditional roofs, when energy savings and extended roof longevity are factored in (TRCA, 2007a). Operation and maintenance costs are generally higher during the first two years of operation than in subsequent years as the vegetation becomes established. Literature estimates of annual maintenance costs during the first two years range from $2.70 to $44.00 per square metre (Peck and Kuhn, 2002; Stephens, *et al*., 2002; TRCA, 2007a). Design costs typically run 5 to 10 percent of the total project cost and administration and review and approval costs are 2.5 to 5 percent of the total project cost (Peck and Kuhn, 2002).

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4.3 Roof Downspout Disconnection

4.3.1 Overview

Description

Simple downspout disconnection involves directing flow from roof downspouts to a pervious area that drains away from the building (see Figure 4.3.1). 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. When the infiltration rate of the soil in the pervious area is less than 15 mm/hr (i.e., hydraulic conductivity of less than $1x10^{-6}$ cm/s), the area should be tilled to a depth of 300 mm and amended with compost to achieve an organic content in the range of 8 to 15% by weight or 30 to 40% by volume.

Figure 4.3.1 Examples of disconnected downspouts draining to a splash pad (left), a rain garden (centre) and an infiltration trench (right)

Source: City of Surrey (left); Riversides (centre); David Elkin (right)

Common Concerns

Some common concerns with downspout disconnection include:

- *On Private Property:* If stormwater management credit is given for roof downspout disconnection, 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

- *Foundations and Seepage:* Discharge locations for roof downspouts should be a distance of 3 metres away from building foundations. This may not be necessary if the topography slopes 1 to 5% away from the building.

- *Compaction:* Compaction of soils in the pervious area to which downspouts are directed will significantly decrease the efficiency of the downspout disconnection. Vehicle traffic and high foot traffic should be prevented. Planting tall vegetation around the perimeter of the pervious area is one technique for preventing traffic in these areas.

- *Standing Water and Ponding:* Pervious areas should infiltrate roof runoff into the underlying native soil. 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 in the maintenance section (section 4.3.3) should be undertaken.

Physical Suitability and Constraints
Some key constraints for downspout disconnection include:

- *Available Space:* Simple downspout disconnection requires a minimum flow path length across the pervious area (at least 5 metres) and suitable soil conditions. If the flow path length is less than 5 metres and soils are hydrologic soil group (HSG) C or D, roof downspouts should be directed to another LID practice such as a rainwater harvesting system, soakaway, swale, bioretention area or perforated pipe system.

- *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.

- *Soils:* If the infiltration rate of soils in the pervious area is less than 15 mm/hr (i.e., hydraulic conductivity less than $1x10^{-6}$ cm/s), as determined from measurements (see Appendix C for acceptable methods), they should be tilled to a depth of 300 mm and amended with compost to achieve an organic content in the range of 8 to 15% by weight or 30 to 40% by volume.

- *Drainage Area:* For simple downspout disconnection the roof drainage area should not be greater than 100 square metres.

- *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.

Typical Performance

The ability of downspout disconnection to meet stormwater management objectives is summarized in Table 4.3.1. Because of its partial ability to meet objectives, downspout disconnection will most likely be used in conjunction with soil amendments or another best management practice.

Table 4.3.1 Ability of Roof downspout disconnection to meet SWM objectives

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Downspout Disconnection	Partial – depends on soil infiltration rate	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 achieve water balance benefits, although it can contribute to water quality improvement. Very limited research has been conducted on runoff reduction rates from roof downspout disconnection, so initial estimates are drawn from research on vegetated filter strips (Table 4.3.2), which operate in a similar manner. Research indicates that runoff reduction is a function of soil type, slope, vegetative cover and flow path length across the pervious surface.

A conservative runoff reduction rate estimate for roof downspout disconnection is 25% for hydrologic soil group[1] (HSG) C and D soils and 50% for HSG A and B soils. These values apply to disconnections that meet the physical suitability and constraints criteria outlined in this section.

Table 4.3.2 Volumetric runoff reduction achieved by vegetated filter strips

LID Practice	Location	Runoff Reduction	Reference
Filter Strip	Guelph, Ontario	20 to 62%[1]	Abu-Zreig et al (2004)
Filter Strip	California	40 to 70%[1]	Barrett (2003)
Runoff Reduction Estimate[2]		**50% on HSG A and B soils; 25% on HSG C and D soils**	

Notes:

1. Where a range is given, the first number is for a flow path length of 2 to 5 metres and the second is from 8 to 15 metres.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets.

[1] Hydrologic soil group (HSG) classification is based on the ability of the soil to transmit water. Soil groups are ranked from A to D with A group soils being the most permeable and D group soils being the least permeable. Group A soils are sand, 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.

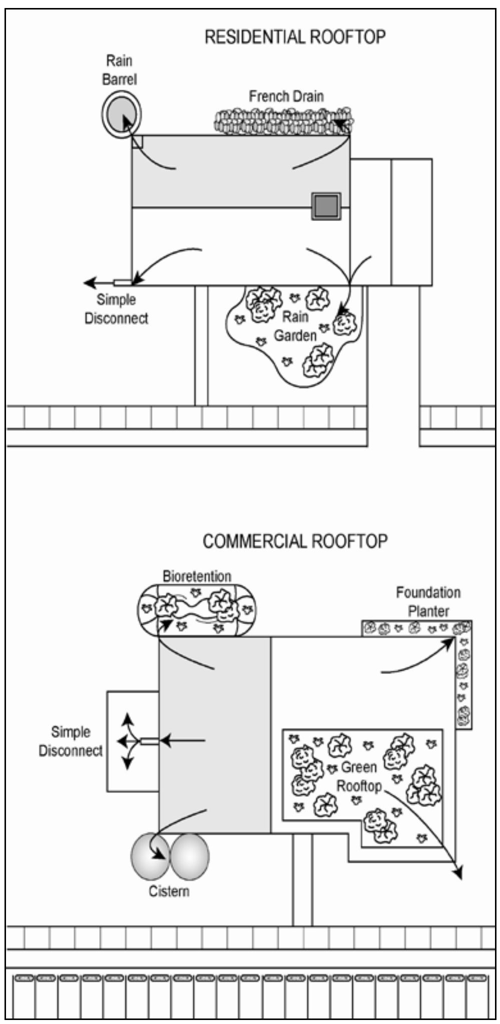
4.3.2 Design Template

Applications

There are many options for keeping roof runoff out of the storm sewer system (Figure 4.3.2). 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 (i.e., rain barrel or cistern) with overflow to a pervious area, vegetated filter strip, swale, bioretention area, soakaway or permeable pavement.

Figure 4.3.2 Roof downspout disconnection options



Typical Details

Typical design criteria are outlined in the Design Guidance section below.

Design Guidance

Roof downspout disconnections should meet the following criteria:

- Pervious areas used for downspout disconnection should be graded to have a slope of 1 to 5%;
- Pervious areas should slope away from the building or discharge location should be at least 3 metres from the building foundation;
- 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 HSG 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.

Other Design Guidance

City of Toronto Downspout Disconnect Program
http://www.toronto.ca/water/protecting_quality/downspout.htm

Region of Peel – Conservation Peel
http://www.peelregion.ca/conservation/

Design Specifications

General design guidance for the disconnection of downspouts is provided above, and, depending on the soil conditions in the pervious area, may be designed in conjunction with tilling and amending of soils with compost to increase infiltration rate and moisture retention capacity.

Construction Considerations
The following recommendations should be considered during the construction of sites with planned downspout disconnection:

- *Soil Disturbance and Compaction:* Soil compaction should be limited in order to ensure infiltration. 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.

- *Soil Tilling and Amendment:* Where the post-construction infiltration rate of the soil at pervious areas to which roof downspouts will be discharged is less than 15 mm/hr, soils should be tilled to a depth of 300 mm and amended with compost to achieve an organic content ratio of 8 to 15% by weight or 30 to 40% by volume.

4.3.3 Maintenance and Construction Costs

Maintenance
Maintenance of disconnected downspouts for stormwater management will generally be no different than maintenance of 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.

Installation and Operation Costs
For new development, there is no added cost associated with simple roof downspout disconnections to pervious areas. Where post construction soil infiltration rate is less than 15 mm/hr or hydraulic conductivity under field saturated conditions (K_{fs}) is less than $1x10^{-6}$ cm/s, as determined from measurements, additional costs associated with soil tilling and amendment with compost will be incurred. Disconnecting roof downspouts from storm sewers in existing developments typically costs $100 per downspout, including materials (*e.g.*, splash pad and downspout extension) and labour.

4.3.4 References

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4.4 Soakaways, Infiltration Trenches and Chambers

4.4.1 Overview

Description
On sites suitable for underground stormwater infiltration practices, there are a variety of facility design options to consider, such as soakaways, infiltration trenches and infiltration chambers.

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 (Figures 4.4.1 and 4.4.3). They typically service individual lots and receive only roof and walkway runoff (City of Toronto, 2002; OMOE, 2003) 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 (Figure 4.4.1). They can also be referred to as infiltration galleries or linear soakaways.

Figure 4.4.1 Construction of a soakaway in a residential subdivision and infiltration trenches in parkland settings

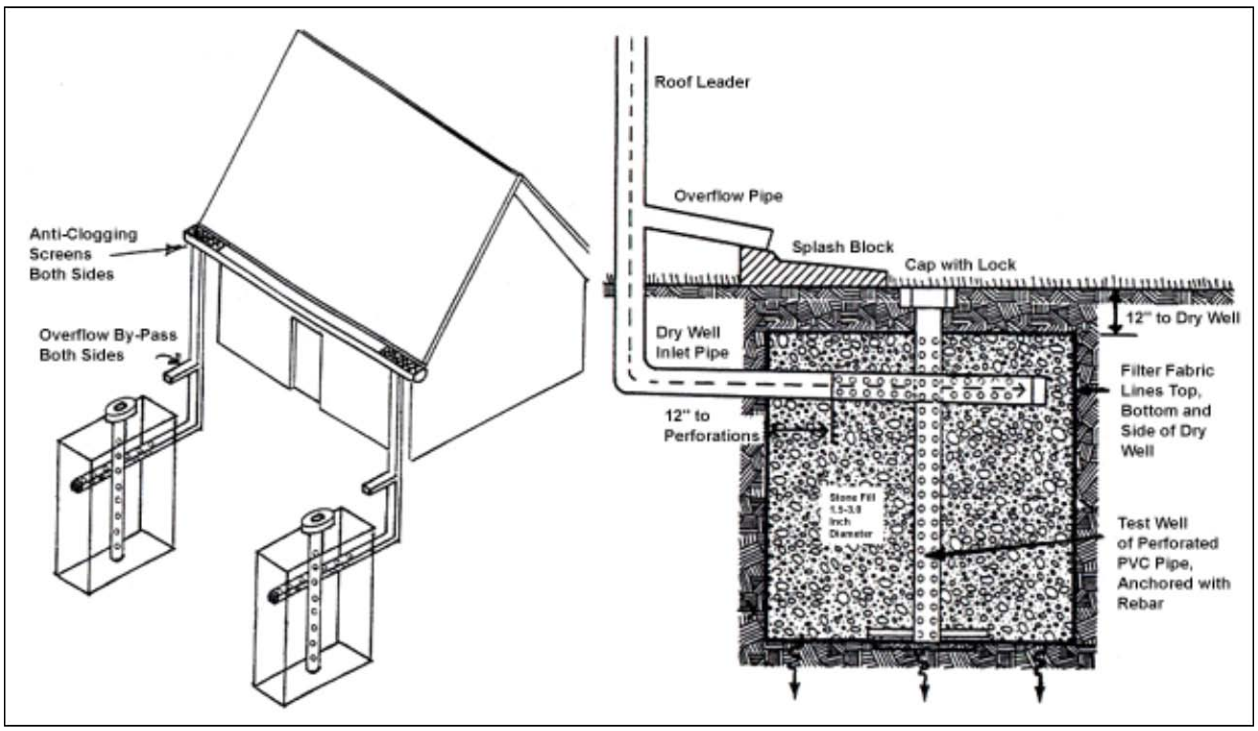
Source: Lanark Consultants (left); Cahill Associates (centre); North Dakota State University (right)

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 runoff and allow it to infiltrate into the underlying native soil (Figure 4.4.2). 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.

Figure 4.4.2 Infiltration chambers under construction in commercial developments

Source: StormTech (left); Cultech (right)

Figure 4.4.3 Schematic of a dry well soakaway



Common Concerns

There are several common concerns associated with the use of soakaways, infiltration trenches and infiltration chambers:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al*., 1999; TRCA, 2009b):

  - 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; 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 (TRCA, 2008).

- *On Private Property:* If soakaways, infiltration trenches or infiltration chambers are installed on private lots, 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 (*i.e.*, does not first drain to a pervious area or LID practice) 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.

- *Standing Water and Mosquitoes:* The detention of water in a soakaway, infiltration trench or chamber should be solely underground.

- *Foundations and Seepage:* Soakaways, infiltration trenches and chambers should be set back at least four (4) metres from building foundations. Overflow pipes should discharge to pervious areas that are located at least 2 metres from building foundations and slope away from the building.

- *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 (MTO, 2005).

Physical Suitability and Constraints
Key constraints for soakaways, infiltration trenches and chambers include:

- *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.

- *Soils:* 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 using the methods described in Appendix C.

- *Drainage Area:* Soakaways and infiltration trenches typically service individual lots and receive roof and walkway runoff only. Infiltration chambers can treat roof, walkway and low to medium traffic road or parking lot runoff with adequate sedimentation pretreatment. They can be 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, 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 soakaways, infiltration trenches or chambers.

- *Setbacks 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.

Typical Performance

The ability of soakaways, infiltration trenches and infiltration chambers to help meet SWM objectives is summarized in Table 4.4.1.

Table 4.4.1 Ability of soakaways, infiltration trenches and chambers 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

Water Balance

The degree to which the water balance objective is met will depend on the amount of runoff stored and infiltrated by the facility. Limited data are available on the runoff reduction capabilities of soakaways, infiltration trenches and chambers, although they are likely similar to perforated pipe systems (Table 4.4.2).

Table 4.4.2 Volumetric runoff reduction[1] achieved by infiltration trenches and perforated pipe systems

LID Practice	Location	Runoff Reduction[1]	Reference
Infiltration trench with underdrain	Virginia	60%	Schueler (1983)
Grass swale/ Perforated pipe system	Ontario	73%	J.F. Sabourin and Associates (2008a)
Grass swale/ Perforated pipe system	Ontario	86%	J.F. Sabourin and Associates (2008a)
Perforated pipe system	Ontario	95%	SWAMP (2005)
Perforated pipe system	Ontario	89%	SWAMP (2005)
Runoff Reduction Estimate[2]		**85%**	

Notes:
1. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional impervious surface over the period of monitoring.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality – Pollutant Removal Capacity

Performance results from a limited number of field studies indicate that subsurface stormwater infiltration practices are effective BMPs for pollutant removal (TRCA, 2009b). These types of practices provide effective removal for many pollutants as a result of sedimentation, filtering, and soil adsorption. It is also important to note that there is a relationship between the water balance and water quality functions. If an infiltration practice infiltrates and evaporates 100% of the runoff from a site, then there is essentially no pollution leaving the site in surface runoff. Furthermore, treatment of infiltrated runoff continues to occur as it leaves the facility and moves through the native soil. The performance of soakaways, infiltration trenches and chambers would be expected to reduce pollutants in runoff in a manner similar to perforated pipe systems. Table 4.4.3 summarizes pollutant removal results from performance studies of soakaways, infiltration trenches and perforated pipe systems.

Table 4.4.3 Pollutant removal efficiencies[1] for soakaways, infiltration trenches and perforated pipe systems (in percent)

BMP	Reference	Location	Lead	Copper	Zinc	TSS[2]	TP[3]	TKN[4]
Soakaway	Barraud *et al*. (1999)	Valence, France	98	NT	54 to 88	NT	NT	NT
Infiltration trench	ASCE (2000)[5]	Various	70 to 90	70 to 90	70 to 90	70 to 90	50 to 70	40 to 70
Grass swale/ perforated pipe system	SWAMP (2002)	North York, Ontario	75	96	93	24	84	84
Grass swale/ perforated pipe system	J.F. Sabourin & Associates (2008a)	Nepean, Ontario	>99[6]	66	0	81	81	72
Grass swale/ perforated pipe system	J.F. Sabourin & Associates (2008a)	Nepean, Ontario	>99[6]	>99[6]	90	96	93	93

Notes:

NT = not tested

1. Pollutant removal efficiency refers to the pollutant load reduction from the inflow to the outflow (from an underdrain) of the practice, over the period of monitoring and are reported as percentages).
2. Total suspended solids (TSS)
3. Total phosphorus (TP)
4. Total Kjeldahl nitrogen (TKN)
5. Pollutant removal efficiencies are reported as ranges because they are based on a synthesis of several performance monitoring studies that were available as of 2000.
6. Concentrations at the outlet were below the detection limit.

Stream Channel Erosion Control

While soakaways and infiltration trenches are not specifically designed to store the channel erosion control volume, their ability to reduce runoff volume should help protect downstream channels from erosion. Recent research on the performance of an infiltration chamber system installed at the University of New Hampshire has shown a mean annual peak flow reduction of 87% over a two year monitoring period (Roseen *et al.,* 2009), indicating that such facilities can provide significant downstream erosion control benefits.

4.4.2 Design Template

Applications

Soakaways and infiltration trenches are typically applied to capture and treat roof and walkway runoff from residential lots, but can also be designed for other types of development sites. Infiltration chambers can treat roof, walkway, parking lot and low to medium traffic road runoff with adequate pretreatment. Each practice serves a relatively small drainage area, such as a single roof, parking lot or road. Infiltration chambers have greater storage volumes than soakaways or trenches of the same dimensions and may receive runoff from larger or multiple source areas. Because the majority of components associated with these facilities are located underground, they have a very small surface footprint, which makes them highly suited to high density development contexts (*i.e.*, ultra urban areas). Other components of a development site, such as parking lots, parks, or sports fields can be located on top of the facilities, thereby helping to conserve highly valued developable land.

Typical Details
Typical details of soakaways, infiltration trenches and chambers are provided in Figures 4.4.4 to 4.4.6. Planners should also refer to Figures 4.5 and 4.6 in the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Design Guidance

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 (GVRD, 2005). Facilities should have level or nearly level bed bottoms.

Pretreatment
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. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the facility.

- *In-ground filters*: Filters placed between a conveyance pipe and the facility (*e.g.*, oil and grit separators, sedimentation chamber or sump), that can be designed to remove both large and fine particulate from runoff. A number of proprietary stormwater filter designs are available. Like leaf screens, they require regular cleaning to ensure they do not become clogged.

- *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. The swale could be designed as a simple grass channel, an enhanced grass swale (section 4.8) or dry swale (section 4.9).

Figure 4.4.4 Roundabout island soakaway

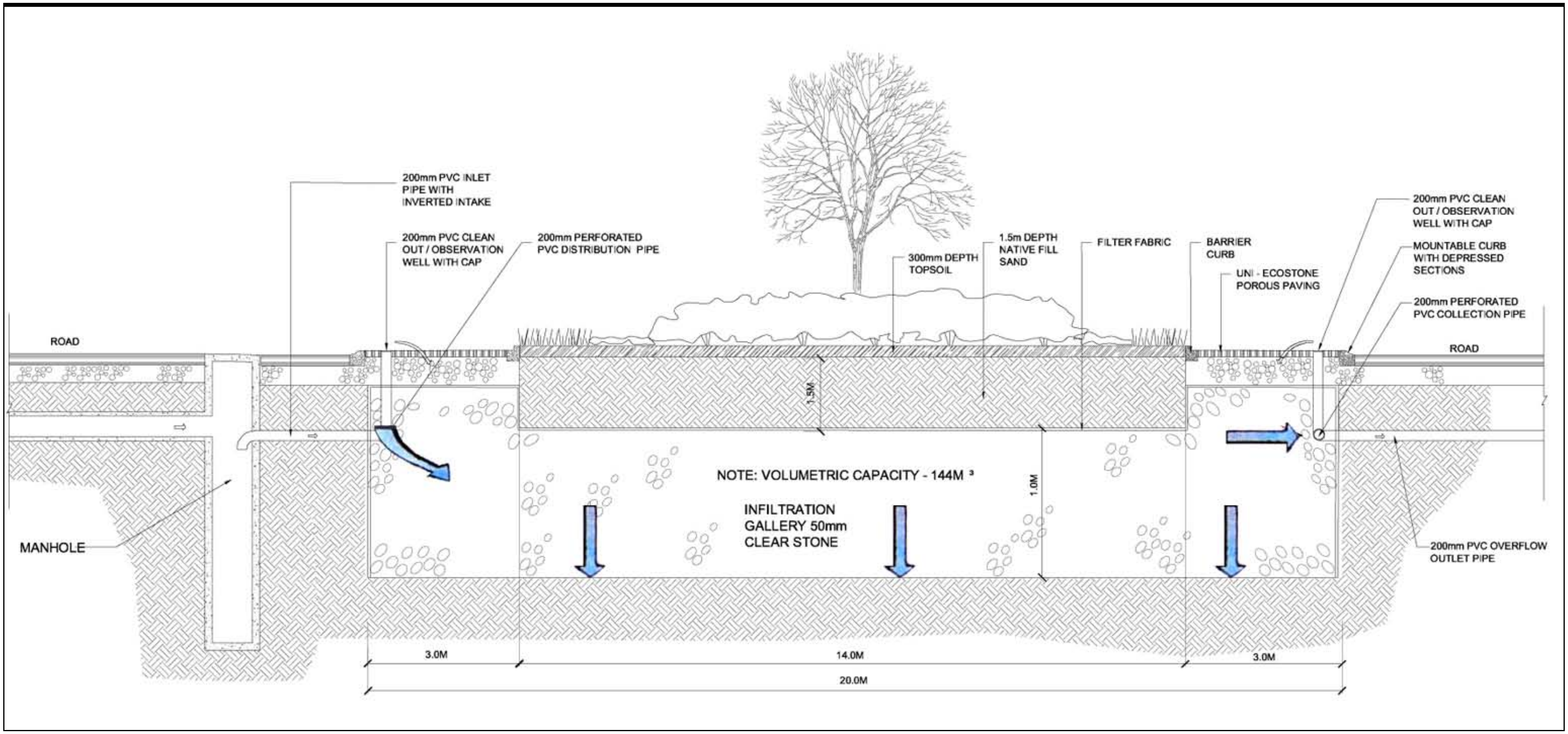


Figure 4.4.5 Plan view of an infiltration trench below a laneway

Figure 4.4.6 Cross section of an infiltration trench system below a laneway

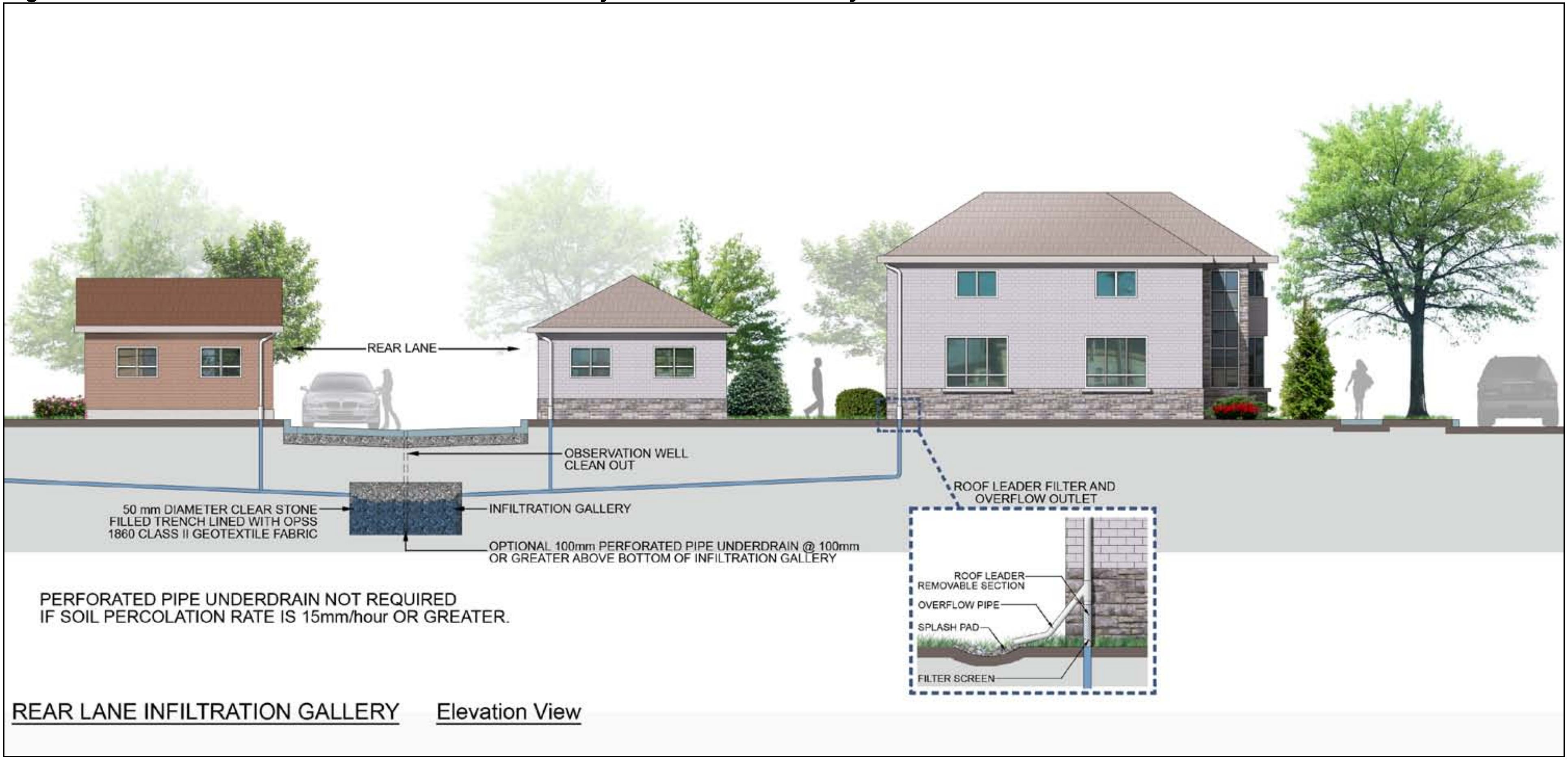


Figure 4.4.7 Schematic of an infiltration chamber system below a parking lot

INFILTRATION CHAMBER SYSTEM BELOW A PARKING LOT

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 (MTO, 2005). 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 (OMOE, 2003) or can be a pipe that is at or near 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.

Monitoring Wells

Capped vertical non-perforated pipes connected to the inlet and outlet pipes are recommended 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 millimetre 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.

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. The primary function of the geotextile is separation between two dissimilar soils. When a finer grained soil overlies a coarser grained soil or aggregate layer (*e.g.*, stone reservoir), the geotextile prevents clogging of the void spaces from downward migration of soil particles. When a coarser grained aggregate layer (*e.g.*, stone reservoir) overlies a finer grained native soil, the geotextile prevents slumping from downward migration of the aggregate into the underlying soil. Geotextile may also enhance the capacity of the facility to reduce petroleum hydrocarbons in runoff, as microbial communities responsible for their decomposition tend to concentrate in geotextile fabrics (Newman *et al.*, 2006a). Specification of geotextile fabrics in soakaways and infiltration trenches 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. Table 4.4.4 provides further detail regarding geotextile specifications.

Other Design Resources

Several other manuals that provide useful design guidance for soakaways, infiltration trenches and infiltration chambers are:

Ontario Ministry of the Environment (OMOE). 2003. Stormwater Management Planning and Design Manual. Toronto, Ontario.

Center for Watershed Protection (CWP). 2007b. Urban Stormwater Retrofit Manual. Ellicott City, MD.

Greater Vancouver Regional District (GVRD). 2005. Stormwater Source Control Guidelines 2005.

New York State Stormwater Management Design Manual. http://www.dec.ny.gov/chemical/29072.html

Pennsylvania Department of Environmental Protection (PDEP). 2006. Stormwater Best Management Practices Manual.

BMP Sizing

The depth of the soakaway or infiltration trench is dependent on the native soil infiltration rate, porosity (void space ratio) of the gravel storage layer media (i.e, aggregate material used in the stone reservoir) and the targeted time period to achieve complete drainage between storm events. The maximum allowable depth of the stone reservoir for designs without an underdrain can be calculated using the following equation:

$$d_{r\ max} = i * t_s / V_r$$

Where:

- $d_{r\ max}$ = Maximum stone reservoir depth (mm)
- i = Infiltration rate for native soils (mm/hr)
- V_r = Void space ratio for aggregate used (typically 0.4 for 50 mm clear stone)
- t_s = Time to drain (design for 48 hour time to drain is recommended)

The value for native soil infiltration rate (i) used in the above equation should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2). On highly permeable soils (e.g., infiltration rate of 45 mm/hr or greater), a maximum stone reservoir depth of 2 metres is recommended to prevent soil compaction and loss of permeability from the mass of overlying stone and stored water.

For designs that include an underdrain, the above equation can be used to determine the maximum depth of the stone reservoir below the invert of the underdrain pipe.

Once the depth of the stone reservoir is determined the water quality volume, computed using the methods in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010), can be used to determine the footprint needed using the following equation:

$A_f = WQV / (d_r * V_r)$

Where:

A_f = Footprint surface area (m^2)
WQV = Water quality volume (m^3)
d_r = Stone reservoir depth (m)
V_r = Void space ratio for aggregate used (typically 0.4 for 50 mm clear stone)

The ratio of impervious drainage area to footprint surface area of the practice should be between 5:1 and 20:1 to limit the rate of accumulation of fine sediments and thereby prevent clogging.

Design Specifications

Recommended design specifications for soakaways and infiltration trenches are provided in Table 4.4.4 below. Infiltration chambers are typically proprietary designs with material specifications provided by the manufacturers.

Table 4.4.4 Design specifications for soakaways and infiltration trenches

Component	Specification	Quantity
Inlet/Overflow Pipe	Pipe should be continuously perforated, smooth interior, HDPE or equivalent material, with a minimum inside diameter of 100 millimetres.	Perforated pipe inlet/outlet should run lengthwise through the facility. Non-perforated pipe should be used for conveyance to the facility.
Stone	The facility should be filled with 50 mm clear stone with a 40% void ratio.	Volume of the facility is calculated by method in the previous section of this guide.
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	Based on the volume of the facility.

Component	Specification	Quantity
	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 native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA) For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) Hydraulic Conductivity (k, in cm/sec) k (fabric) > k (soil) Permittivity (in sec^{-1}) Where, Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1}	

Component	Specification	Quantity
	For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	

Construction Considerations
Erosion and sediment control and compaction are the main construction concerns.

- *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 (PWD, 2007).

Infiltration facilities are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the pit. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. This includes:

1. Heavy equipment and traffic should avoid traveling over the proposed location of the facility to minimize compaction of the soil.

2. Facilities should be kept "off-line" until construction is complete. They should never serve as a sediment control device during site construction. Sediment should be prevented from entering the infiltration facility using super silt fence, diversion berms or other means

3. Upland drainage areas need to be properly stabilized with a thick layer of vegetation, particularly immediately following construction, to reduce sediment loads.

4. The facility should be excavated to design dimensions from the side using a backhoe or excavator. The base of the facility should be level or nearly level.

5. The bottom of the facility should be scarified to improve infiltration. An optional 150 mm of sand could be spread for the bottom filter layer. The monitoring well should be anchored and stone should be added to the facility in 0.3 metre lifts.

6. Geotextile fabric should be correctly installed in the soakaway or infiltration trench excavation. Large tree roots should be trimmed flush with the sides of the facility to prevent puncturing or tearing of the fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the facility and for a 150 mm minimum top overlap. Voids may occur between the fabric and the excavated sides of the facility. Natural soils should be placed in any voids to ensure fabric conformity to the excavation sides.

4.4.3 Maintenance and Construction Costs

Inspection and Maintenance

As with all infiltration practices, these facilities require regular inspection to ensure they continue to function. 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 (PDEP, 2006). The expected lifespan of infiltration practices is not well understood, however, it can be expected that it will vary depending on pretreatment practice maintenance frequency, and the sediment texture and load coming from the catchment. Soakaways have been observed to continue to function well after more than 30 years of operation (Barraud *et al*., 1999; Norrström, 2005).

Installation and Operation Costs

Very limited information is available regarding construction costs for soakaways, infiltration trenches and infiltration chambers. Due to similarities in design, soakaways and infiltration trench construction costs are likely comparable to those for bioretention systems. In a study by the Center for Watershed Protection to estimate and compare construction costs for various stormwater BMPs, the median base construction cost for bioretention was estimated to be $62,765 (2006 USD) per impervious hectare treated with estimates ranging from $49,175 to $103,165 (CWP, 2007b). These estimates do not include design and engineering costs, which could range from 5 to 40% of the base construction cost (CWP, 2007b).

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4.5 Bioretention

4.5.1 Overview

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, which can also be referred to as a biofilter. The primary component of a bioretention practice is the filter bed which is a mixture of sand, fines and organic material. Other important elements of bioretention include a mulch ground cover and plants adapted to the conditions of a stormwater practice. Pretreatment, such as a settling forebay, vegetated filter strip, or stone diaphragm, often precedes the bioretention to remove particles that would otherwise clog the filter bed. 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 provides a convenient area for snow storage and treatment. In a low density development, it might have a soft edge and gentle slopes, while a high density application might have a hard edge with vertical sides. A number of common forms of bioretention design are illustrated in Figure 4.5.1.

Common Concerns

Bioretention is a popular LID practice as it can meet local stormwater requirements while using space that would be landscaped anyway. However, there are some common concerns that can be addressed during design. These include:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):
    - 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; 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 more than 10 years of operation (TRCA, 2008).

- *Performance in Winter Conditions and Spring Snowmelt*: Performance studies show that bioretention effectively captures and treats runoff during winter months with average daily temperatures in the -5 to 10 ºC range (Traver, 2005; UNHSC, 2005, Roseen *et al.*, 2009). Frost penetration of filter media varied from zero to 17 cm in studies at the University of New Hampshire (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 (TRCA, 2008b). 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.

- *Vegetation Maintenance*: Vegetation maintenance requirements are similar to those of other landscaped areas. The landscaping design should account for the expected level of maintenance. Formal landscape designs will require more maintenance than naturalized landscaping designs. Bioretention in higher density urban areas will need frequent routine maintenance to remove trash, check for clogging, and maintain vegetation.

- *Standing Water and Mosquitoes:* The maximum allowable surface ponding time is 24 hours after the storm event, which is less than the time required for one mosquito breeding cycle. Maximum ponding depth will be between 150-250 millimetres at the end of a storm, but most water is stored in voids within soil and gravel layers. In high density urban landscapes, it may be desirable to have a shorter ponding time.

Figure 4.5.1 Forms of bioretention

Bioretention Cells can be used in development types with large landscaping areas, parks, parking lot islands, or any areas without tight space constraints. They will have side slopes of 2:1 or shallower. Often, they take inflow as sheet flow, but in some cases, such as parking lots, they may be surrounded by curbs and have concentrated inflow.

Left – York University (Source: TRCA); Right – Riverwood Park, Mississauga, Ontario (Source: CVC)

Rain gardens capture roof, lawn and driveway runoff from low to medium density residential lots in a shallow depression in the front, side, or rear yard of the home depending on the development's drainage pattern. These can be simple gardens constructed by the homeowner as a retrofit, or they can be professionally designed into a residential development and may have an underdrain connected to the main storm drain pipe.

Left and Right - front yard rain gardens that takes runoff from the residential lot and street (Source: City of Maplewood, Minnesota)

Stormwater planters (or foundation planters) are typically used in ultra urban areas adjacent to buildings and in plazas. They differ from traditional landscaping beds by receiving runoff from other surfaces.

(Source: City of Portland, BES)

Extended tree pits (also known as parallel bioretention) are located within the road right of way and take advantage of the landscaped space between the sidewalk and street. They can be designed to take runoff from the sidewalk or street. They are typically designed to be offline, that is when they are full the stormwater will bypass the practice and flow to the downstream street inlet.


Source: left – City of Portland, BES; right – CVC.

Curb extensions are, like extended tree pits, installed in the road right-of-way and can also act as a traffic calming device. In place of an otherwise raised concrete surface, the area is constructed as a depression with vegetation and used for stormwater treatment.


Source: City of Portland, BES

- *On Private Property*: If bioretention practices are installed on private lots, property owners or managers will need to be educated on their routine 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices. Alternatively, bioretention areas 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.

- *Foundations and Seepage:* Bioretention facilities should be set back at least 4 metres from building foundations. Stormwater planters located near building foundations will need to have an impermeable liner under the bioretention media or the foundation will need to be waterproofed.

- *Roadway Stability:* Design standards on roadway drainage should be consulted. It may be necessary to provide a barrier to keep water from saturating the road's sub-base.

- *Pedestrian Traffic:* Many bioretention applications are located in areas of high foot traffic. Designers should consider methods to prevent pedestrian traffic through the facility, such as shrub placement, curbing, and protective railings.

Physical Suitability and Constraints
Some of the key constraints and design mitigation strategies for bioretention include:

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

- *Available Space:* Designers should reserve open areas of about 10 to 20% of the size of the contributing drainage area. These are areas that would be typically set aside for landscaping. More space is required for designs with soft and shallow side slopes than those with hard, vertical edges.

- *Site Topography*: Bioretention is best applied when contributing slopes are between 1 to 5%. Ideally, the proposed treatment area will be located in a natural depression to minimize excavation. The surface of the filter bed should be flat to allow flow to spread out and not concentrate in one area of the practice. However, for linear bioretention practices, such as those along roadways, the longitudinal slope must be considered. A stepped multi-cell design can be used when a flat surface cannot be maintained along the length of a linear bioretention.

- *Available Head:* If an underdrain is used, then 1 to 1.5 metres elevation difference is needed between the inflow point and the downstream storm drain invert. This is generally not a constraint due to the standard depth of storm drains. For bioretention without an underdrain, the design will only require enough elevation difference to move large event flows through the overflow or bypass without generating a backflow or flooding problem.

- *Water Table:* Bioretention should be separated from the seasonally high water table by a minimum of one (1) metre to ensure groundwater does not intersect the filter bed, as this could lead to groundwater contamination or practice failure.

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

- *Drainage Area and Runoff Volume:* Bioretention cells work best for smaller drainage areas, as flow distribution over the filter bed is easier to achieve. Typical drainage areas are between 100 m^2 to 0.5 hectares. The maximum recommended drainage area to one bioretention facility is approximately 0.8 hectares (Davis *et al*., 2009). Ideally, bioretention should be used as a source control for small drainage areas and not as an end of pipe control. Typical ratios of impervious drainage area to bioretention cell area range from 5:1 to 15:1.

- *Pollution Hot Spot Runoff:* To protect groundwater from possible contamination, source areas where land uses or human activities have the potential to generate highly contaminated runoff (*e.g.*, vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites) should not be treated by bioretention facilities designed for full or partial infiltration. Facilities designed with an impermeable liner (filtration only facilities) can be used to treat runoff from pollution hot spots.

- *Proximity to Underground Utilities:* Designers should consult local utility design guidance for the horizontal and vertical clearances required between storm drains, ditches, and surface water bodies. It is feasible for on-site utilities to cross linear bioretention; however, this may require design of special protection for the utility. For road right-of-way applications, care should be taken to provide utility-specific horizontal and vertical offsets. However, conflicts with water and sewer laterals (house connections) may be unavoidable. If so, revisit the off-sets with the utility company, and sequence construction to avoid impacts to services.

- *Overhead Wires*: Designers should also check whether maximum future tree canopy height in the bioretention area will not interfere with existing overhead phone and power lines.

- *Setbacks from Buildings:* If an impermeable liner is used, no setback is needed. If not, a four (4) metre setback from buildings should be applied.

Typical Performance

Bioretention is suited to meet both water quality and water balance objectives. It may also be used in a treatment train with traditional detention practices that meet the regional event peak discharge requirements. The ability of bioretention to meet the stormwater management objectives is shown in Table 4.5.1.

Table 4.5.1 Ability of bioretention 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

Water Balance

Bioretention has been shown to reduce runoff volume through evapotranspiration and infiltration of runoff. The research can be classified into bioretention applications that include underdrains and those that do not (and therefore rely on full infiltration into underlying soils). Aside from the underdrain, many other factors can impact the water balance such as the native soil infiltration rate, rainfall patterns, and sizing criteria. Table 4.5.2 presents the runoff reduction results from various bioretention studies, each with their own set of environmental contexts and design factors influencing the results.

Table 4.5.2 Volumetric runoff reduction[1] achieved by bioretention

LID Practice	Location	% Runoff Reduction[1]	Reference
Bioretention without underdrain	Connecticut	99%	Dietz and Clausen (2005)
	Pennsylvania	80%	Ermilio (2005)
	Pennsylvania	70%	Emerson and Traver (2004)
Bioretention with underdrain	North Carolina	40 to 60%	Smith and Hunt (2007)
	North Carolina	33 to 50%	Hunt and Lord (2006)
	Maryland and North Carolina	20 to 50%	Li *et al.* (2009)
Runoff Reduction Estimate[2]		**85% without underdrain 45% with underdrain**	

Notes:

1. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional impervious surface over the period of monitoring.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality - Pollutant Removal Capacity

Performance results from both laboratory and field studies indicate that bioretention systems have the potential to be one of the most effective BMPs for pollutant removal (TRCA, 2009b). Bioretention provides effective removal for many pollutants as a result of sedimentation, filtering, soil adsorption, microbial processes and plant uptake. It is also important to note that there is a relationship between the water balance and water quality functions. If a bioretention cell infiltrates and evaporates 100% of the runoff from a site, then there is essentially no pollution leaving the site in surface runoff. Furthermore, treatment of infiltrated runoff continues to occur as it moves through the native soil. Table 4.5.3 summarizes pollutant removal results from some recent performance studies.

Table 4.5.3 Pollutant removal efficiencies[1] for bioretention (in percent)

Reference	Location	Lead	Copper	Zinc	TSS[2]	TP[3]	TKN[4]	PAH[5]	Bacteria[6]
Dietz and Clausen (2005)	Haddam, Connecticut	NT	NT	NT	NT	-111	31	NT	NT
Hunt *et al.* (2006)	Greensboro, North Carolina	81	99	98	-170	-240	-5	NT	NT
Hunt *et al.* (2006)	Chapel Hill, North Carolina	NT	NT	NT	NT	65	45	NT	NT
Davis, (2007)	College Park, Maryland	88	83	54	59	79	NT	NT	NT
Davis, (2007)	College Park, Maryland	84	77	69	54	77	NT	NT	NT
Muthanna *et al.* (2007)	Trondheim, Norway	99	89	96	100	NT	NT	NT	NT
Hunt *et al.* (2008)[7]	Charlotte, North Carolina	31	54	77	60	31	44	NT	71
Roseen *et al.* (2009[7])	Durham, New Hampshire	NT	NT	95	86	0	NT	NT	NT
Roseen *et al.* (2009)[7]	Durham, New Hampshire	NT	NT	80	86	27	NT	NT	NT
Diblasi *et al.* (2009)	College Park, Maryland	NT	NT	NT	NT	NT	NT	87	NT

Notes:

NT = not tested

1. Pollutant removal efficiency refers to the pollutant load reduction from the inflow to the outflow (from an underdrain) of the practice, over the period of monitoring unless otherwise noted. Negative values represent net increases in load between the inflow and outflow.
2. Total suspended solids (TSS)
3. Total phosphorus (TP)
4. Total Kjeldahl nitrogen (TKN)
5. Polycyclic aromatic hydrocarbons (PAH)
6. Measured as *E.coli* coliform units (CFU) per 100 mL
7. Values represent efficiency ratios based on differences in average event mean concentrations between the inflow and outflow (from an underdrain) of the practice, over the period of monitoring.

Excellent pollutant removal rates have been observed through field studies for total suspended solids (Roseen *et al.*, 2009), polycyclic aromatic hydrocarbons (TRCA, 2008b; Diblasi *et al.*, 2009), and metals (Davis *et al.*, 2003; Hunt *et al.*, 2006; Roseen *et* *al.*, 2006; Davis, 2007; TRCA, 2008b). Good removal rates for metals have even been observed in bioretention facilities receiving snow melt that contains de-icing salt constituents (Muthanna *et al.*, 2007).

Field investigations of nutrient removal by bioretention facilities have produced more variable results (TRCA, 2009b). Some facilities have been observed to increase total phosphorus in infiltrated water (Dietz and Clausen, 2005; Hunt *et al.*, 2006; TRCA, 2008b). These findings have been attributed to leaching from filter media soil mixtures which contained high phosphorus content. To avoid phosphorus export, the phosphorus content (*i.e.*, Phosphorus Index) of the filter media soil mixture should be examined prior to installation and kept between 10 to 30 ppm (Hunt and Lord, 2006). While moderate reductions in total nitrogen and ammonia nitrogen have been observed in laboratory studies (Davis *et al.*, 2001) and field studies (Dietz and Clausen, 2005), nitrate nitrogen has consistently been observed to be low.

Little data exists on the ability of bioretention to reduce bacteria concentrations, but preliminary laboratory and field study results report good removal rates for fecal coliform bacteria (Rusciano and Obropta, 2005; Hunt *et al.*, 2008; TRCA, 2008b).

Several site-specific conditions and design factors can greatly increase or decrease the median removal rates (Table 4.5.4).

Table 4.5.4 Factors that influence bioretention pollutant removal rates

Factors That Reduce Removal Rates	Factors That Enhance Removal Rates
Filter bed less than 500 mm deep	Filter bed deeper than 750 mm
Filter media P-Index values $\geq$ 30 ppm[1]	Filter media P-Index values < 30 ppm[1]
Oversized underdrain system	Properly sized (or no) underdrain system
No pretreatment provided	Pretreatment provided
Single bioretention cell	Multiple bioretention cells, including forebay
Parsely landscaped with ground cover only	Densely landscaped with trees, shrubs and ground cover
Filter media comprised predominantly of sand	Filter media comprised of a mixture of sand, fines and organic matter
Filter surface left uncovered or covered with stone	Filter surface covered with mulch and vegetation

Notes:
1. P-index values refers to phosphorus soil test index values in parts per million (ppm). See www.omafra.gov.on.ca for information on soil testing and a list of accredited soil laboratories.

Stream Channel Erosion Control

The feasibility of storing the channel erosion control volume within bioretention areas will be dependent on the size of the drainage area and available space. It may prove infeasible due to the large footprint needed to maintain the recommended maximum ponding depth of 200 mm. Meeting the channel erosion control requirement through bioretention is most feasible in the regions of the Greater Toronto Area with A and B soils. In these situations, the reduction in runoff volume through infiltration and evapotranspiration may be sufficient. It is important to note that the bioretention practice will infiltrate runoff throughout the course of the storm; so the actual capacity of the bioretention cell to capture runoff from the drainage area will be larger than its designed storage volume.

Other Benefits

The benefits of bioretention reach beyond the specific stormwater management goals to other social and environmental benefits, including:

Reduced thermal aquatic impacts: Bioretention and other filtration and infiltration practices benefit aquatic life by reducing thermal impacts on receiving waters from urban runoff (Jones and Hunt, 2009). Unlike detention ponds, bioretention does not raise water temperature and can help maintain baseflows through infiltration.

Snow Storage: Bioretention areas can be used for snow storage and snow melt treatment from the contributing drainage area during winter, especially those located adjacent to parking lots and roadways. To function as snow storage, bioretention must include an overflow for snow melt in excess of the designed ponding depth. Additionally, the plant material must be salt-tolerant, perennial and tolerant of periodic inundation.

Reduced Urban Heat Island: Bioretention is able to reduce the local urban heat island by introducing soils and vegetation into urban areas, such as parking lots. Vegetation absorbs less solar radiation than hard urban surfaces. Also, the water vapor emitted by plant material also cools ambient temperatures.

4.5.2 Design Template

Applications

Bioretention can be used wherever water can be conveyed to a landscaped area. Facilities have been installed at commercial, institutional, and residential sites in spaces that are traditionally pervious and landscaped. Bioretention facilities are installed close to the impervious area that generates the runoff. Typical locations are in and around parking lots, in traffic islands and near building roof leaders. Bioretention planters, extended tree pits, and curb extension are able to fit into ultra-urban development contexts. Typical locations for each bioretention design variant are illustrated in Figure 4.5.2.

Figure 4.5.2 Example applications of bioretention

Bioretention Cells	
Landscaped islands in parking lots: Parking islands can be used to both improve parking lot aesthetics and treat lot runoff. The parking lot grading is designed for sheet flow towards linear landscaping areas between rows of spaces. A curb-less edge or curb cuts are used to convey water into the depressed landscaped area. (Source: CWP)	
Parking lot edges: Small parking lots can be graded so that flows reach a curb-less edge or curb cut before reaching catchbasins or inlets. The turf at the edge of the parking lot is used as filter strip pretreatment and the depression for bioretention is located in the pervious area adjacent to the parking lot. (Source: CWP).	
Rights-of-way, traffic islands, and medians: Landscaped or unused space within the right-of-way can be turned into bioretention for treating road runoff. The road cross section can be designed to slope towards the center median or traffic islands rather than the outer edge. A linear configuration can be used to receive sheet flow from the roadway or a grass channel or pipe may convey flows to the bioretention. (Source: Seattle Public Utilities)	
Roundabouts, cul-de-sacs, and entrance loops: The road cross section is designed to slope towards the center island. A curb-less edge or curb cuts are used. (Source: CWP)	

Pervious areas between buildings and sidewalks: Landscaping around buildings and between buildings and sidewalks can be turned into multi-functional spaces with bioretention. Roof leaders, sidewalks and other impervious areas around the building can be directed to these practices. Densely vegetated practices can also provide some urban heat island cooling to the site. (Source: CWP)

Courtyards: Runoff collected in a storm drain system or roof leaders can be directed to bioretention in courtyards. (Source: City of Portland, BES)

Rain Garden

Rain gardens capture roof, lawn, and driveway runoff from lots in a shallow depression. These can be simple gardens constructed as a retrofit, or professionally designed and may have an underdrain. They are designed to capture runoff from small drainage areas, typically less than 1000 square metres.

Left – Single family home rain garden (Source: City of Maplewood, MN); Right – commercial development rain garden (Source: City of Burnsville, MN).

Stormwater Planters

Stormwater planters generally receive runoff from adjacent rooftop downspouts. They can also be used to establish a pervious area within the hardscape of a plaza, courtyard, pedestrian zone, or streetscape. While they treat a very small drainage area, a significant portion of rooftop and plaza runoff may be captured and treated this way.

Source: Left – City of Portland, BES; Right – CWP

Extended Tree Pits

These facilities are installed in the sidewalk area where tree pits are typically found. Instead of using only the small square pit area, a row of pits is utilized as an enlarged planting area. Stormwater from the roadway is diverted into the expanded tree pit using curb cuts or trench drains. If large mature canopy trees are desired, then additional soil volume should be provided in the tree pit.

Sources: Left - City of Portland, BES; Right - Tavella Design Group, Bridgeport, CT.

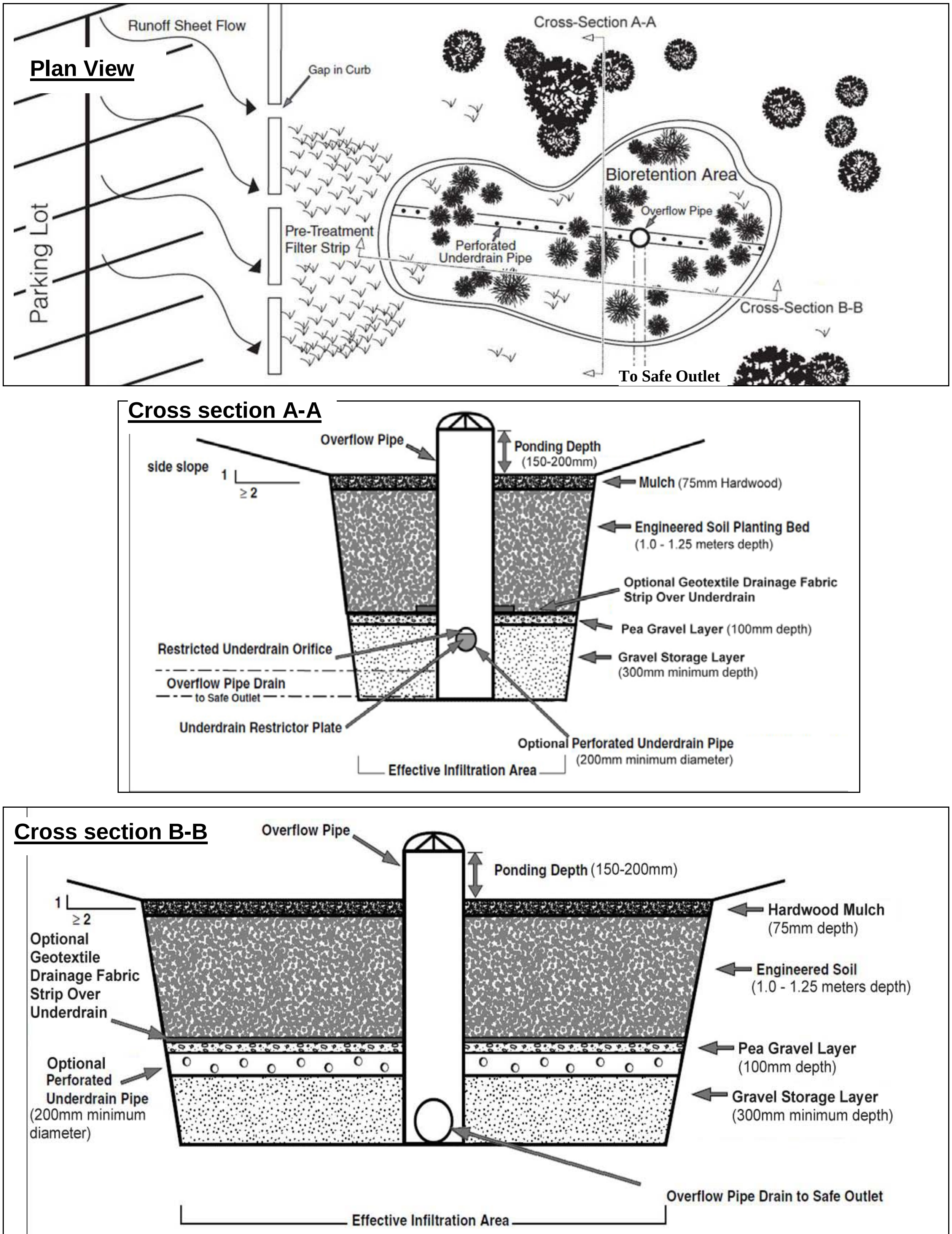
Stormwater Curb Extensions

Similar to extended tree pits, these practices are also installed in the public right-of-way. However, curb extensions are typically traffic calming and street parking control device. In its adaptation to a stormwater BMP, the otherwise raised concrete is constructed as a depressed vegetation area and used for stormwater treatment. These practices work well as retrofits to residential neighborhoods.

Source: Left – City of Portland, BES; Middle and Right – CWP

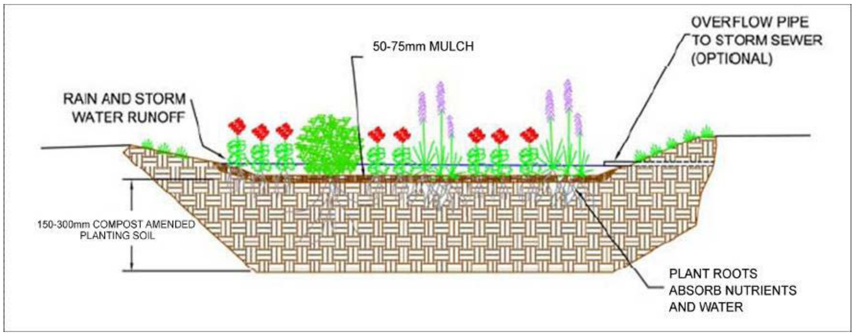
Typical Details

Figure 4.5.3 Plan view and cross sections of a typical bioretention cell



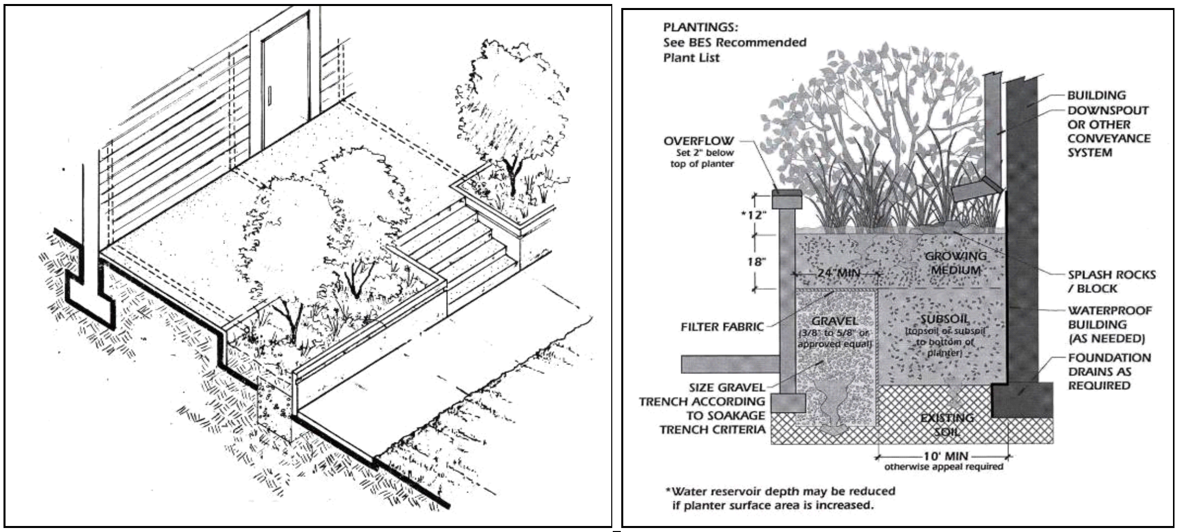
Source: adapted from Wisconsin Department of Natural Resources bioretention details

Figure 4.5.4 Rain garden cross section



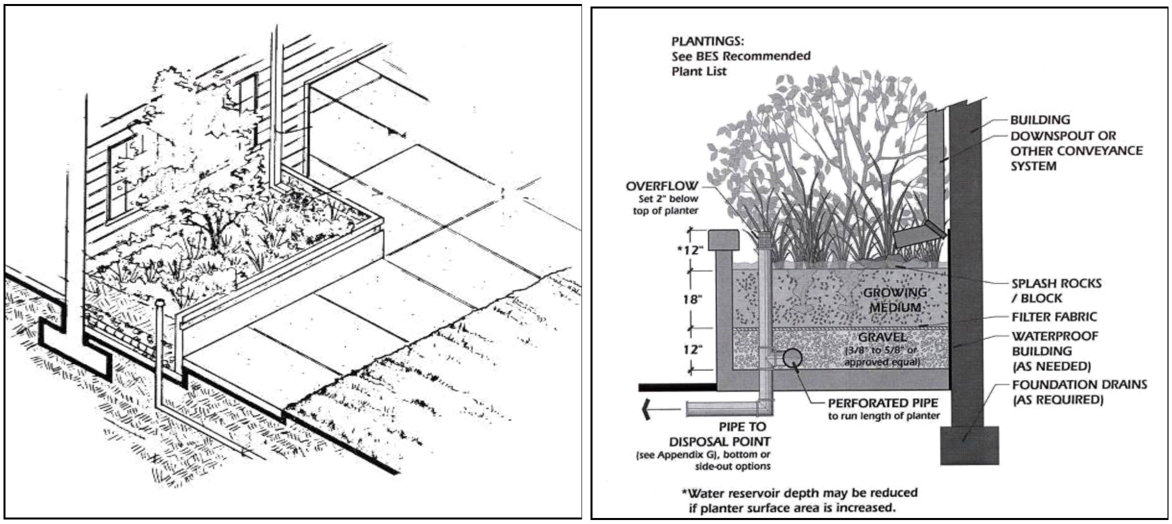
Source: MDE, 2000

Figure 4.5.5 Infiltrating stormwater planter box



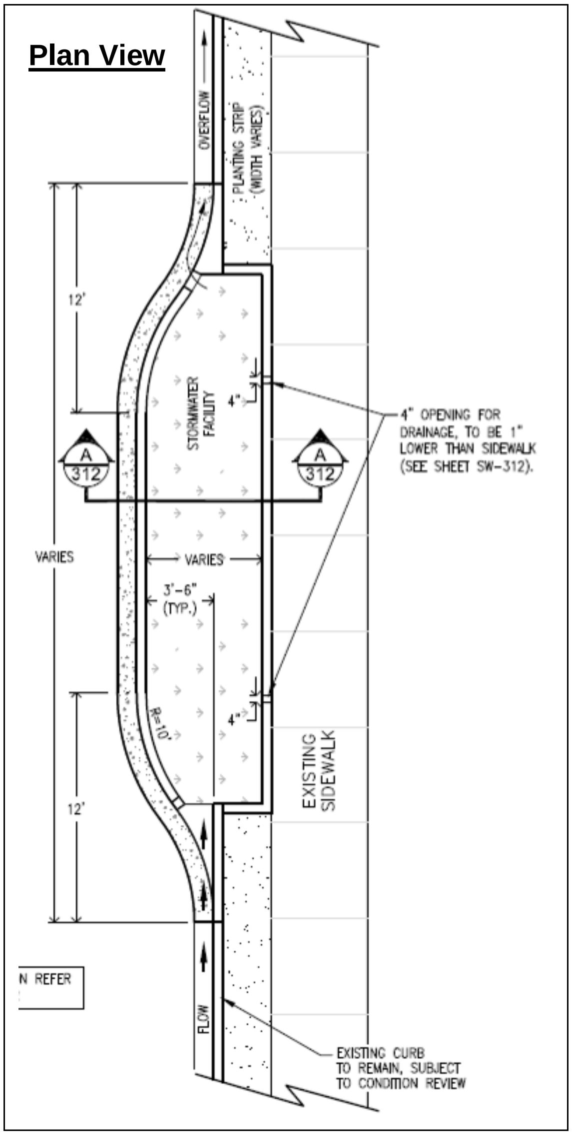
Source: City of Portland, 2004

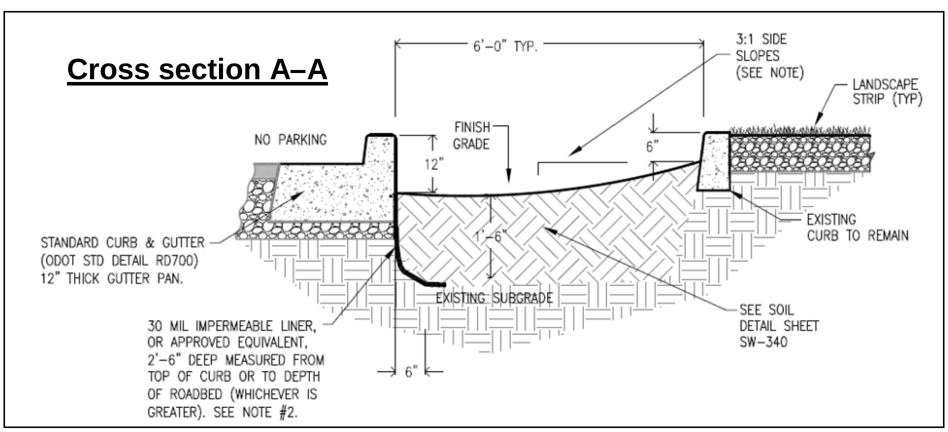
Figure 4.5.6 Stormwater planter box biofilter (filtration only)



Source: City of Portland, 2004

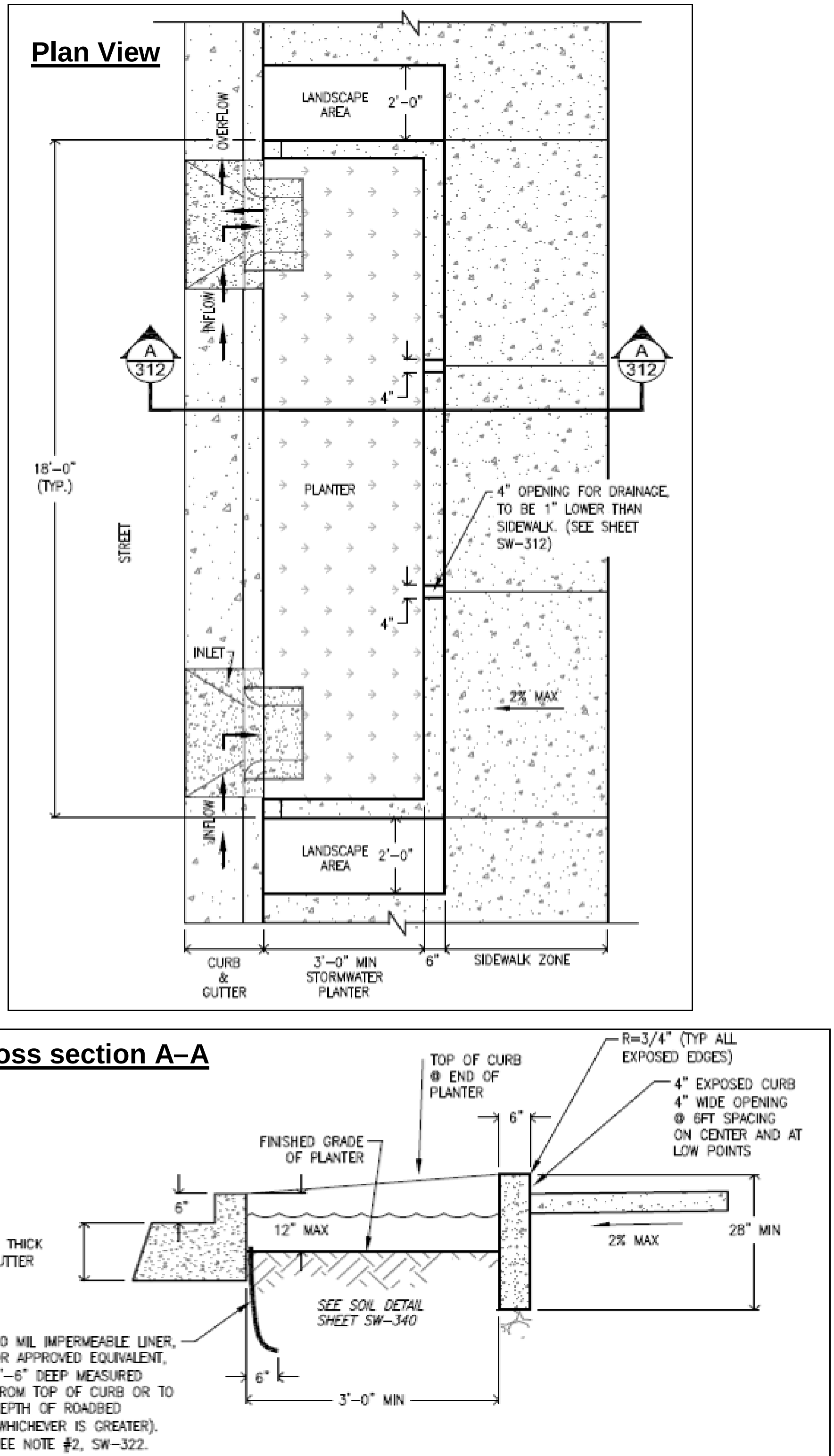
Figure 4.5.7 Plan view and cross section of a stormwater curb extension





Source: City of Portland, 2004

Figure 4.5.8 Plan view and cross section of an extended tree pit



Source: City of Portland, 2004

Design Guidance

Geometry and Site Layout

There are several key geometry and site layout factors to take into account:

- The minimum footprint of the filter bed area is based on the drainage area. Typical drainage areas to bioretention are between 100 m^2 to 0.5 hectares. The maximum recommended drainage area to one bioretention facility is approximately 0.8 hectares (Davis *et al.*, 2009). Footprints far in excess of the calculated area are not desirable, as the bioretention plants may not receive adequate water. Undersized bioretention may result in early failure and more frequent overflows.

- If multiple small bioretention practices are planned, such as in landscaped islands of a parking lot or between residential lots, then the sizing and spacing of these need to be considered early in the site planning.

- The geometric design of bioretention will be dictated by other elements of the landscape such as buildings, sidewalks, utility corridors, retaining walls, etc. Bioretention can be configured to fit into many locations and shapes. However, cells that are narrow or have narrow sections 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. Ponding in one location of the bioretention will result in increased sedimentation and clogging at the ponding location and uneven watering of the vegetation.

Pretreatment

Pretreatment prevents premature clogging of bioretention facilities by capturing coarse sediment particles before they reach the filter bed. In some cases, where the drainage areas produce little sediment, such as rooftops, bioretention can function effectively without pretreatment (Heasom *et al.* 2006). A two-cell design that incorporates a forebay is recommended for bioretention with the available space and high sediment load drainage areas. Several pretreatment measures are feasible, depending on the method of conveyance and the drainage area:

- *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. This pre-treatment device is the most effective and can be designed for easy sediment-removal.

- *Vegetated filter strip (sheet flow):* Should ideally be a minimum of three (3) metres in width. However, space constraints at some bioretention sites prohibit this width. If smaller strips are used, more frequent maintenance of the filter bed can be anticipated. See Section 4.6 for additional detail about vegetated filter strips.

- *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. It also acts as a level spreader, maintaining sheet flow into the facility. If the contributing drainage area is steep, then larger stone should be used in the diaphragm. 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):* These energy dissipation techniques are acceptable pretreatment on small bioretention cells with a drainage area of less than 100 square metres.

- *Gutter screens:* Screens are appropriate for pretreatment of runoff from roof leaders.

Conveyance and Overflow

Bioretention can be designed to be inline or offline from the drainage system (Figure 4.5.9). Inline bioretention accepts all of the flow from a drainage area and conveys larger event flows through an overflow outlet. Overflow structures need to be sized to safely convey larger storm events out of the bioretention cell. The invert of the overflow should be placed at the maximum water surface elevation of the bioretention area, which is typically 150-250 millimetres above the surface of the filter bed. The overflow capture device should be scaled to the application – this may be a landscaped grade outlet, stand pipe with trash guard, or a transportation-type yard inlet.

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 the maintenance frequency.

Figure 4.5.9 Examples of inline and offline bioretention

Source: Left – CWP; Right – Low Impact Development Center

The inflow conveyance may take one of the following forms (Figure 4.5.10):

- downspouts to a forebay or stone energy dissipater;
- sheet flow off of a depressed curb;
- One or more curb cuts;
- covered drains that convey flows across sidewalks from the curb or downspouts;
- grates or trench drains that capture runoff from the sidewalk or plaza.

Figure 4.5.10 Examples of inlets to bioretention practices

Clockwise from upper left: pipe with riprap (Source: NC Stormwater Manual); trench drain through curb walk (Source: Biohabitats), Curb and gutter inlet structure to bioretention in highway median; curb cut or depressed curb to parking lot bioretention

Whatever the design, flows should enter the bioretention in a safe and non-erosive manner. Using a river rock channel within large bioretention cells can help evenly distribute flows throughout the filter bed while avoiding erosion of the mulch layer.

All conveyance structures should be designed to prevent clogging by trash or organic matter. In high-litter areas, trash racks at the inlet are a possible solution. A trash rack installed in the pretreatment cell can limit the area requiring frequent clean-out.

Artistic Design Elements

Bioretention gives stormwater engineers and urban landscape architects the chance to merge their creative efforts. Functional stormwater treatment can be combined with art when incoming stormwater cascades over waterfalls, turns water wheels, swishes through chutes, or rings rain chimes.

Monitoring Wells
A capped vertical stand pipe consisting of an anchored 100 to 150 millimetre 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.

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*: The recommended bioretention filter media soil mixture is:

Component	Percent by Weight
Sand (2.0 to 0.050 mm dia.)	85 to 88 %
Fines (< 0.050 mm dia.)	8 to 12 %
Organic matter	3 to 5 %

  To ensure a consistent and homogeneous bed, filter media should come pre-mixed from an approved vendor. The filter media soil mixture should have the following properties:

  - The recommended Phosphorus soil test (P- index) value is between 10 to 30 ppm (Hunt and Lord, 2006). Visit the Ontario Ministry of Agriculture, Food, and Rural Affairs website (www.omafra.gov.on.ca) for information on soil testing and a list of accredited soil laboratories.
  - Soils with cationic exchange capacity (CEC) exceeding 10 milliequivalents per 100 grams (meq/100 g) are preferred for pollutant removal (Hunt and Lord, 2006).
  - The mixture should be free of stones, stumps, roots, or other similar objects larger than 50 mm.
  - For optimal plant growth, the recommended pH is between 5.5 to 7.5. Lime can be used to raise the pH, or iron sulphate plus sulphur can be used to lower the pH. The lime and iron sulphate need to be uniformly mixed into the soil (Low Impact Development Center, 2003a).
  - The media should have an infiltration rate of greater than 25 mm/hr.

  One adaptation is to design the media as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the plants. If grass is the only vegetation, the ratio of compost may be reduced (Hirschman, 2008; Smith and Hunt, 2007).

- *Depth:* The recommended filter bed depth is between 1 and 1.25 metres. However, in constrained applications, pollutant removal benefits may be achieved in filter beds as shallow as 500 millimetres. (Davis *et al*., 2009; and Hunt *et al.,* 2006). If trees are included in the bioretention design, then the filter bed depth must be at least 1 metre and have soil volume to accommodate the root structure of mature trees. A minimum of 12 cubic metres of shared root space is recommended for healthy canopy trees. Use perennials, shrubs or grasses instead of trees when landscaping shallower filter beds.

- *Mulch:* A 75 millimetre layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter bed. Shredded hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away. The mulch layer also plays a key role in the removal of heavy metals, sediment, and nutrients (Davis *et al*., 2001; Davis *et al*., 2003; Davis *et al*., 2006; Dietz and Clausen, 2006; Hunt, 2003; and Hsieh and Davis, 2005).

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 of the gravel storage layer.
- HDPE or equivalent material perforated pipes with smooth interior walls should be used. Pipes should be over-sized to accommodate freezing conditions. A minimum 200 mm diameter underdrain is recommended for this reason (MPCA, 2005). Underdrains should be capped on the upstream end(s).
- 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. Table 4.5.7 provides further detail regarding geotextile specifications.
- A vertical standpipe connected to the underdrain can be used as a cleanout and monitoring well.

Landscaping

Landscaping is critical to the function and appearance of bioretention and will determine the level of maintenance. Some of the factors that will drive landscaping choices are listed below:

- Bioretention cells can be formal gardens or naturalized landscaping.
- Where possible, a combination of native trees, shrubs, and perennial herbaceous materials should be used.
- A planting mix with evergreen and woody plants will provide appealing textures and colors year round, but they may not be appropriate for snow storage areas.
- In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model.
- If trees are to be used, or the bioretention is located in a shaded location, then ensure that the chosen herbaceous plants are shade tolerant.
- Spaces for herbaceous flowering plants can be included. This may be attractive at a community entrance location or in a residential rain garden.

- Snow storage areas in bioretention should be vegetated with salt-tolerant, herbaceous perennials. Tree and shrub locations cannot conflict with plowing and piling of snow into storage areas.
- Snow melt from roads, parking lots, driveways, or sidewalks will have high chloride levels, so designers should only select salt-tolerant species.
- “Wet footed” plants, such as wetland forbs, should be planted near the center, whereas upland species are better for the edges of the bioretention area.

A complete list of landscape design considerations and a list of plants suitable for bioretention is provided in Appendix B.

Other Details
In urban settings, the trash load and pedestrian traffic call for special consideration. Consider using the following adaptations:

- To protect the vegetation and prevent soil compaction, fencing (low, wrought iron fences), low walls, bollards and chains, curbs, and constructed walkways can be incorporated. These will also serve as a protective barrier to pedestrians from the sometimes steep drop off from the pavement to the depressed bioretention practice.
- Trash racks can be installed between the pre-treatment cell and the main filter bed. This will allow trash to be collected from one location.
- A trash rack can be placed across curb cuts. While this trash rack may clog occasionally, it keeps trash in the gutter to be picked up by street sweeping equipment.
- For maintenance access, a pre-treatment area can be placed above ground or a manhole or grate cover directly over the pre-treatment area can be used.
- Educational signage can be incorporated into the designs.
- Landscaping stone, river rock, or boulders can be used to protect structures or discourage traffic through the practice.
- Log or stone check dams can be used to slow flow and catch litter.

Other Design Resources
Many stormwater manuals provide useful design guidance for bioretention, including:

- City of Toronto’s Design Guidelines for ‘Greening’ Surface Parking Lots include guidelines for the use of biofilters to treat runoff from parking lots. http://www.toronto.ca/planning/urbdesign/greening_parking_lots.htm

- Lake County, OH Bioretention Guidance Manual http://www2.lakecountyohio.org/smd/Forms.htm

- Portland, OR Stormwater Management Manual http://www.portlandonline.com/bes/index.cfm?c=dfbcc

- Stormwater Source Control Design Guidelines 2005, Greater Vancouver Regional District http://www.gvrd.bc.ca/sewerage/stormwater_reports.htm

- Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites http://www.cwp.org/forestry/index.htm

- Wisconsin Stormwater Management Technical Standards http://www.dnr.state.wi.us/runoff/stormwater/techstds.htm

BMP Sizing

The depth of a bioretention cell designed for full infiltration (i.e., no underdrain) is dependent on the native soil infiltration rate, porosity (void space ratio) of the filter bed and gravel storage layer media (i.e., aggregate material used in the stone reservoir) and the targeted time period to achieve complete drainage between storm events. Assuming a void space ratio of 0.4 for both the filter bed and gravel storage layer media, the maximum allowable depth of the cell can be calculated using the following equation:

$$d_{c\,max} = i * (t_s - d_p / i) / V_r$$

Where:

$d_{c\,max}$ = Maximum bioretention cell depth (mm)
i = Infiltration rate for native soils (mm/hr)
V_r = Void space ratio for filter bed and gravel storage layer (assume 0.4)
t_s = Time to drain (design for 48 hour time to drain is recommended)
d_p = Maximum surface ponding depth (mm)

For designs that include an underdrain, the filter media bed should be 1 to 1.25 metres in depth. The following equation can be used to determine the maximum depth of the stone reservoir below the invert of the underdrain pipe:

$$d_{r\,max} = i * t_s / V_r$$

Where:

$d_{r\,max}$ = Maximum depth of stone reservoir below the underdrain pipe

The value for native soil infiltration rate (i) used in the above equations should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2).

For designs with no underdrain that are located on less permeable soils, a minimum filter bed depth of 0.5 metres is recommended to ensure water quality benefits will be achieved. For designs with filter bed depths less than 1 metre, a maximum surface ponding depth of 85 to 100 mm is recommended.

Once the depth of the bioretention cell is determined the water quality volume, computed using the methods in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010), can be used to determine the footprint needed using the following equation:

$A_f = WQV / (d_c * V_r)$

Where:

A_f = Footprint surface area (m^2)
WQV = Water quality volume (m^3)
d_c = Bioretention cell depth (m)
V_r = Void space ratio for filter bed and gravel storage layer (assume 0.4)

The ratio of impervious drainage area to footprint surface area of the practice should be between 5:1 and 15:1 to limit the rate of accumulation of fine sediments and thereby prevent clogging.

Design Specifications

Table 4.5.5 Bioretention specifications

Material	Specification	Quantity
Filter Media Composition	Filter Soil Mixtures to contain: ▪ 85 to 88% sand ▪ 8 to 12% soil fines ▪ 3 to 5% organic matter in form of leaf compost Other Criteria: ▪ Phosphorus soil test (P-Index) value 10 to 30 ppm ▪ Cationic exchange capacity (CEC) greater than 10 meq/100 g ▪ pH between 5.5 to 7.5	Recommended depth is between 1.0 and 1.25 metres. Alternative depths may be appropriate in constrained applications. Volumetric computation based on surface area and depth used in design computations.
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. 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; - Texture (*i.e.*, grain size distribution) of the overlying native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): <u>Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA)</u>	Strip over the perforated pipe underdrain (if present) between the filter media bed and gravel storage layer (stone reservoir)

Material	Specification	Quantity
	For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) Hydraulic Conductivity (k, in cm/sec) k (fabric) > k (soil) Permittivity (in sec^{-1}) Where, Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	
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. Bioretention locations should not be used as the site of sediment basins during construction, as the concentration of fines will prevent post-construction infiltration. They should also not be used for storing materials. To prevent sediment from clogging the surface of a bioretention cell, stormwater should be diverted away from the bioretention site until the drainage area is fully stabilized. Due to the locations of many bioretention practices in the road right-of-way or tight urban spaces, considerations of traffic control and utility conflicts must be part of the plans and inspections.

The following is a typical construction sequence to properly install a bioretention practice. The steps may be modified to reflect different bioretention applications or expected site conditions.

1. Bioretention areas should be fully protected by silt fence or construction fencing to prevent compaction by construction traffic and equipment.

2. Installation may only begin after entire contributing drainage area has been either stabilized or flows have been safely routed around the area. The designer should check the boundaries of the contributing drainage area to ensure it conforms to original design.

3. The pretreatment forebay should be excavated first and sealed until full construction is completed.

4. Excavators or backhoes working adjacent to the proposed bioretention area should excavate the cell to the appropriate design depth.

5. It may be necessary to rip the bottom soils to promote greater infiltration or excavate any sediment that may have built up during construction.

6. There are three options at this step depending on the design:
    a. No infiltration: Place an impermeable liner on the bed of the bioretention area with 150 mm overlap on sides. Lay the perforated underdrain pipe, Pack 50 mm diameter clear stone to 75 mm above top of underdrain, an optional 75 mm choking coarse of pea gravel, and then lay the non-woven geotextile drainage fabric over the stone and underdrain.
    b. Partial infiltration: Place desired depth of stone for the infiltration volume on bed and then lay the perforated underdrain pipe over it. Pack 50 mm diameter clear stone to 75 mm above the top of the underdrain, an optional 75 mm choking coarse of pea gravel and then lay the non-woven geotextile drainage fabric over the stone and underdrain.
    c. Full infiltration: Stone can be placed to provide added stormwater volume storage or the bioretention media can be added directly to the bottom of the excavation.

7. Bioretention filter media should be obtained premixed from a vendor. Apply in 300 mm lifts until desired top elevation of bioretention area is achieved. Thoroughly wet each lift before adding the next and wait until water has drained through the soil before adding the next lift. Wait a few days to check for settlement, and add additional media as needed.

8. Prepare planting holes for any trees and shrubs, install vegetation, and water accordingly. Install any temporary irrigation.

9. Plant landscaping materials as shown in the landscaping plan, and water them weekly in the first two months.

10. Lay down surface cover in accordance with the design (mulch, riverstone, or turf).

11. Conduct final construction inspection, checking inlet, pretreatment cell, bioretention cell and outlet elevations.

Construction Inspection
Common construction pitfalls can be avoided by careful construction supervision that focuses on the following aspects:

Erosion and Sediment Control
- Bioretention locations should be blocked from construction traffic and should not be used for erosion and sediment control.
- Proper erosion and sediment controls should be in place for the drainage area.

Materials
- Gravel for the underdrain should be clean and washed; no fines should be present in the material.
- Underdrain pipe material should be perforated and of the correct size.
- A cap should be placed on the upstream (but not the downstream) end of the underdrain.
- Filter media should be tested to confirm that it meets specifications.
- Mulch composition should be correct.

Elevations
Elevations of the following items should be checked for accuracy:
- Depth of the gravel and invert of the underdrain
- Inverts for inflow and outflow points
- Filter depth after media is placed
- Ponding depth provided between the surface of the filter bed and the overflow structure
- Mulch depth

Landscaping and Stabilization
- Correct vegetation should be planted.
- Pretreatment area should be stabilized.
- Drainage area should be stabilized prior to directing water to the bioretention.

The following items should be checked after the first rainfall event, and adjustments should be made as necessary:
- Outfall protection/energy dissipation at concentrated inflow should be stable.
- Flow should not concentrate and should spread evenly over the filter bed.

- Ponded water at the surface of the bioretenton facility should drain within 24 hours of the end of the storm event. The filter media bed should fully drain within a maximum period of 72 hours.
- Excessive sediment accumulation should not be present.

4.5.3 Maintenance and Construction Costs

Inspection 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. Routine operation and maintenance tasks are key to public acceptance of highly visible bioretention units.

Periodic inspections after major storm events will determine whether corrective action is necessary to address gradual deterioration or abnormal conditions. 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.

While maintenance can be performed by landscaping contractors who are already providing similar landscape maintenance services on the property, they will need some additional training on bioretention needs. This training should focus on elevation differences needed for ponding, mulching requirements, acceptability of ponding after a rainstorm, and fertilizer requirements. The planting plan should be kept for maintenance records and used to help maintenance staff identify which plants are weeds or invasive.

Aside from homeowner initiated rain garden projects, legally binding maintenance agreements are a necessity for bioretention facilities on private property. Agreements should specify the property owner's responsibilities and the municipality's right to enter the property for inspection or corrective action. Agreements must require regular inspection and maintenance and should refer to an inspection checklist. The construction contract should include a care and replacement warranty to ensure vegetation is properly established and survives during the first growing season following construction.

The expected lifespan of infiltration practices is not well understood, however, it can be expected that it will vary depending on pretreatment practice maintenance frequency, and the sediment texture and load coming from the catchment.

Routine Maintenance and Operation

Routine inspection and maintenance activities as shown in Table 4.5.6 are necessary for the continued operation of bioretention areas.

Table 4.5.6 Suggested routine inspection and maintenance activities for bioretention

Activity	Schedule
▪ 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.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years until vegetation is established;	As needed for first two years of operation.
▪ Remove trash and debris from pretreatment devices, the bioretention area surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the bioretention area surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the surface, regrading and revegetating may be required.	Annually or as needed

Annual Inspection and Maintenance

The annual spring cleaning should consist of an inspection and corrective maintenance tasks described in Table 4.5.7

Table 4.5.7 Suggested inspection items and corrective actions for bioretention

Inspection Item	Corrective Actions
Vegetation health, diversity and density	• Remove dead and diseased plants. • Add reinforcement planting to maintain desired vegetation density. • Prune woody matter. • Check soil pH for specific vegetation. • Add mulch to maintain 75 mm layer.
Sediment build up and clogging at inlets	• Remove sand that may accumulate at the inlets or on the filter bed surface following snow melt. • Examine drainage area for bare soil and stabilize. Apply erosion control such as silt fence until the area is stabilized. • Check that pretreatment is properly functioning. For example, inspect grass filter strips for erosion or gullies. Reseed as necessary.
Ponding for more than 48 hours	• Check underdrain for clogging and flush out. • Apply core aeration or deep tilling • Mix amendments into the soil • Remove the top 75 mm of bioretention soil • Replace bioretention soil

Installation and Operation Costs

Due to the wide range in bioretention types and designs, the costs can vary widely. Rain gardens can be very economical if constructed by the homeowner. The costs for a simple rain garden excavated by a homeowner would only include the plants, mulch, and, if necessary, soil amendments. On the other end of the spectrum, stormwater planters will cost much more per square meter because of the concrete sidewalls, underdrain structure, and professional design costs. The materials used in the construction of bioretention are typical of construction and landscaping projects.

In a study by the Center for Watershed Protection to estimate and compare construction costs for various stormwater BMPs, the median base construction cost for bioretention was estimated to be $62,765 (2006 USD) per impervious hectare treated with estimates ranging from $49,175 to $103,165 (CWP, 2007b). These estimates do not include design and engineering costs, which could range from 5 to 40% of the base construction cost (CWP, 2007b).

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4.6 Vegetated Filter Strips

4.6.1 Overview

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 (Figure 4.6.1). They function by slowing runoff velocity and filtering out suspended sediment and associated pollutants, and by providing 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 (see Appendix B for guidance on plant species selection). With proper design and maintenance, filter strips can provide relatively high pollutant removal. 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 (Figure 4.6.2). If used for snow storage, the area should be planted with salt-tolerant, non-woody plant species. Because of the simplicity of filter strip designs, physical changes to the practice are not needed for winter operation.

Filter strips are included in Section 4.5.12 of the OMOE 2003 *Stormwater Management Planning and Design Manual*. The guidance is this guide is intended to supplement that resource.

Figure 4.6.1 Filter strips along a residential road and as pretreatment to a dry swale

Source: Trinkaus Engineering (left), Seattle Public Utilities (right)

Figure 4.6.2 Snow storage on a filter strip in Markham, Ontario

Common Concerns

There are some common concerns associated with vegetated filter strips:

- *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 (Pitt *et al*., 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):
    - 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; 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 more than 10 years of operation (TRCA, 2008).

- *Maintenance*: Requirements are greatest during the first two years, when vegetation is becoming established and involve regular inspection, replacing dead or invasive vegetation and possibly watering. Once vegetation is established, maintenance is limited to periodic mowing, pruning, aeration and removal of trash, debris and accumulated sediment from pretreatment devices and the filter strip.

- *Erosion:* Limits on the allowable slope of the filter strips and use of level spreaders should prevent erosion.

- *On Private Property*: If vegetated filter strips are installed on private lots, property owners or managers will need to be educated on their routine 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

- *Standing Water and Mosquitoes:* On properly designed filter strips, standing water should not occur. If pools of standing water are observed along the slope, regrading and revegetation may be required.

- *Winter Performance and Operation:* When immediately next to roads or parking lots, filter strips can act as a permeable snow storage area. Extra maintenance may be needed to remove accumulated sand following the spring melt event or to replace vegetation damaged by road de-icing salt constituents.

Physical Suitability and Constraints
Vegetated filter strips can be used in a variety of situations however there are several constraints to their use:

- *Available Space:* The flow path length across the vegetated filter strip should be at least 5 metres to provide substantial water quality benefits (Barrett *et al.*, 2004). Vegetated filter strips incorporated as pretreatment to another water quality best management practice 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%. Though steeper slopes increase the likelihood of erosion, incorporation of multiple level spreaders in series or terraces can counteract this.

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

- *Soils:* 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.

- *Flow Path Length Across Impermeable Surface:* A limiting design factor is that the maximum flow path length across the impermeable surface should be less than 25 metres. This is because runoff flowing as sheet flow over an impermeable surface tends to concentrate after 25 metres (Claytor and Schueler, 1996). Once runoff from an impervious surface becomes concentrated, a swale design should be used instead of a vegetated filter strip (Barrett *et al.*, 2004).

- *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.

Typical Performance

Vegetated filter strips are primarily a practice used to achieve water quality improvements although some infiltration can occur, depending on the soil type and infiltration rate. The ability of filter strips to help meet stormwater management objectives is summarized in Table 4.6.1.

Table 4.6.1 Ability of vegetated filter strips 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 length of flow path over the pervious area	Partial - depends on soil infiltration rate

Water Balance

Research indicates that runoff reduction from vegetated filter strips is a function of soil type, slope, vegetative cover and flow path length across the pervious surface. Table 4.6.2 summarizes available research regarding runoff reduction rates.

A conservative runoff reduction rate for vegetated filter strips is 25% for HSG C and D soils and 50% for HSG A and B soils. These values apply to filter strips that meet the design criteria outlined in this section.

Table 4.6.2 Volumetric runoff reduction achieved by vegetated filter strips

LID Practice	Location	Runoff Reduction	Reference
Filter Strip	Guelph, Ontario	20 to 62%[1]	Abu-Zreig et al (2004)
Filter Strip	California	40 to 70%[1]	Barrett (2003)
Runoff Reduction Estimate:		**50% on HSG A and B soils; 25% on HSG C and D soils**	

Notes:
1. Where a range is given, the first number is for a flow path length of 2 to 5 metres and the second is from 8 to 15 metres.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality

Vegetated filter strips can provide moderate pollutant removal from runoff. Research suggests that runoff pollutant concentrations and loads decrease when treated with filter strips and that steady state pollutant levels are typically achieved within five (5) metres of the pavement edge (Barrett *et al.*, 2004).

Based on a synthesis of performance monitoring studies as of 2000, it was reported that pollutant removal efficiencies of vegetated filter strips are highly variable (Table 4.6.3). For this reason, filter strips should be used in conjunction with other water quality best management practices (*e.g.*, as pretreatment).

Table 4.6.3 Pollutant removal efficiencies of vegetated filter strips

Pollutant	Removal Efficiency[1]
Total Suspended Solids (TSS)	20 to 80%
Total Nitrogen	20 to 60%
Total Phosphorus	20 to 60%
Total Heavy Metals	20 to 80%

Source: ASCE, 2000

Notes:
1. Removal efficiencies are based on differences between event mean concentrations of pollutants in runoff from vegetated filter strips relative to an untreated impervious surface.

Performance of filter strips has also been evaluated based on the Roadside Vegetated Treatment Sites Study (Barrett, 2003) and the BMP Retrofit Pilot Study (Caltrans, 2004). These studies concluded that concentration reductions consistently occur for TSS and total heavy metals and frequently for dissolved metals. Nutrient concentrations remained generally unchanged. When vegetation cover on the filter strip is below 80% water quality performance declines.

4.6.2 Design Template

Applications

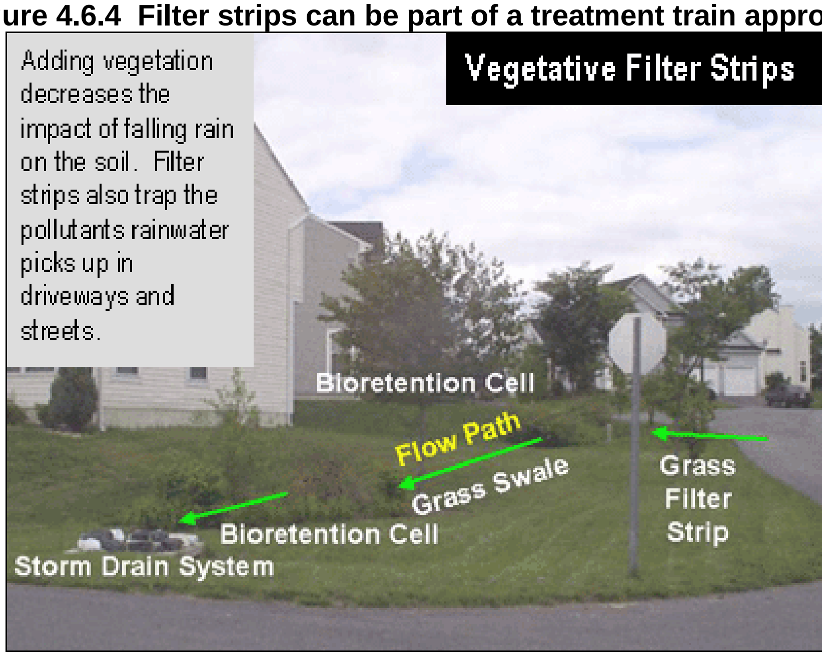
Filter strips are best suited for pretreatment of runoff from roads and parking lots prior to it being treated by other best management practices (*e.g.*, Figure 4.6.3). They are also an ideal practice within stream or wetland buffer zones. Filter strips can be used as part of a treatment train approach (Figure 4.6.4). Filter strips may also be applied at roof leaders, outfalls, or large parking lots if level spreaders are used to create sheet flow. They are often impractical in densely developed urban areas because they consume a large amount of space.

Properly functioning filter strips should not pond water on the surface and do not contribute to stream warming. Thus, filter strips are a good stormwater treatment option for cold water streams that support species sensitive to changes in stream temperature.

Figure 4.6.3 Filter strips providing pretreatment of parking lot runoff

Source: CWP (left), Aquafor Beech (right)

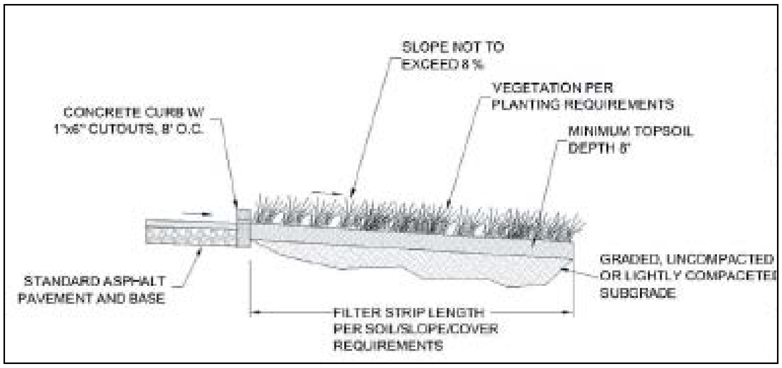
Figure 4.6.4 Filter strips can be part of a treatment train approach



Source: U.S. EPA

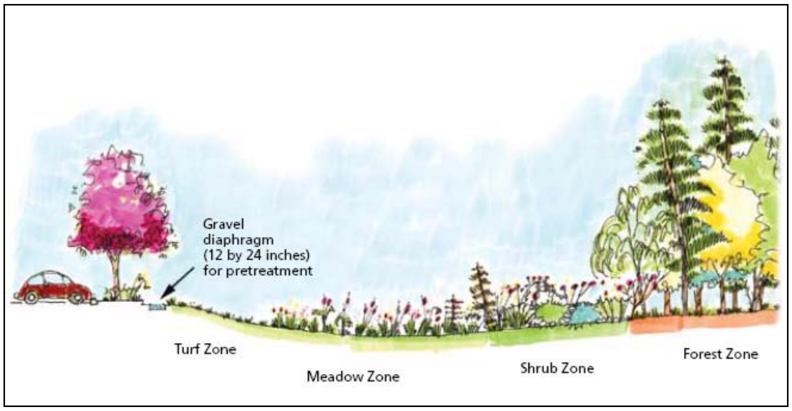
Typical Details

Figure 4.6.5 Filter strip with curb cut-outs



Source: GVRD, 2005

Figure 4.6.6 Multi-zone filter strip profile



Source: Cappiella *et al.*, 2006

See also Figure 4.16 in the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Design Guidance

While filter strips are a simple technology, proper design requires attention to detail because small problems, such as concentration of inflowing runoff or improper grading, can decrease effectiveness and create nuisance soil erosion or ponding of water conditions.

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 flow path length across the vegetated filter strip should exceed the maximum flow path length across the impervious surface draining to it.

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. The pea gravel diaphragm (a small, gravel filled trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out coarse particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. If the contributing drainage area is steep, then larger stone should be used in the diaphragm.

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. Some common type of level spreader devices are pea gravel diaphragms, concrete curbs with cutouts or earthen berms.

The filter strip should drain continuously as sheet flow until reaching a swale, other LID practice or a storm sewer inlet. 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 of sand and gravel 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 (Cappiella *et al.*, 2006). Runoff ponds behind the berm and gradually flows through it, into the perforated pipe underdrain connected to the storm sewer system. The volume ponded behind the berm should be equal to the water quality storage requirement. During larger storms, runoff will overtop the berm and flow directly into a storm sewer inlet (Cappiella *et al.,* 2006). This berm is not needed when filter strips are used as pretreatment to another stormwater best management practice.

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.

Landscaping
Filter strip vegetation can consist of turf grasses, meadow grasses, wildflowers and herbs, shrubs, and trees. Designers should choose vegetation that stabilizes the soil and is salt tolerant where the filter strip will be used for snow storage or to treat road runoff. Filter strips used for snow storage and treatment should be planted with non-woody vegetation. Vegetation at the toe of the slope, where ponding will occur, should be able to withstand both wet and dry soil conditions. The planting areas can be divided into zones to account for differences in moisture conditions and slope.

Traditional filter strips are grass slopes that treat sheet flow from adjacent impervious areas. An alternative design is a forested filter strip. In a forested filter strip, the entire filter strip is planted with trees and shrubs. Another design is the multi-zone filter strip, which features several vegetation zones that provide a gradual transition from turf to meadow to shrub and forest. The multi-zone filter strip design can be effective as a buffer zone to an existing natural heritage feature.

Trees and shrubs with deep rooting capabilities are recommended for planting to maximize soil infiltration capacity (PWD, 2007). Appendix B provides guidance regarding planting and selection of suitable species.

Maintenance Agreement
The filter strip should be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure no future development, disturbance or clearing can occur within the area.

Other Design Resources
Stormwater resources that provide useful guidance for filter strips are:

North Carolina State University Level Spreader Design Worksheet
http://www.bae.ncsu.edu/cont_ed/main/handouts/lsworksheet.pdf

Philadelphia Stormwater Management Guidance Manual
http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

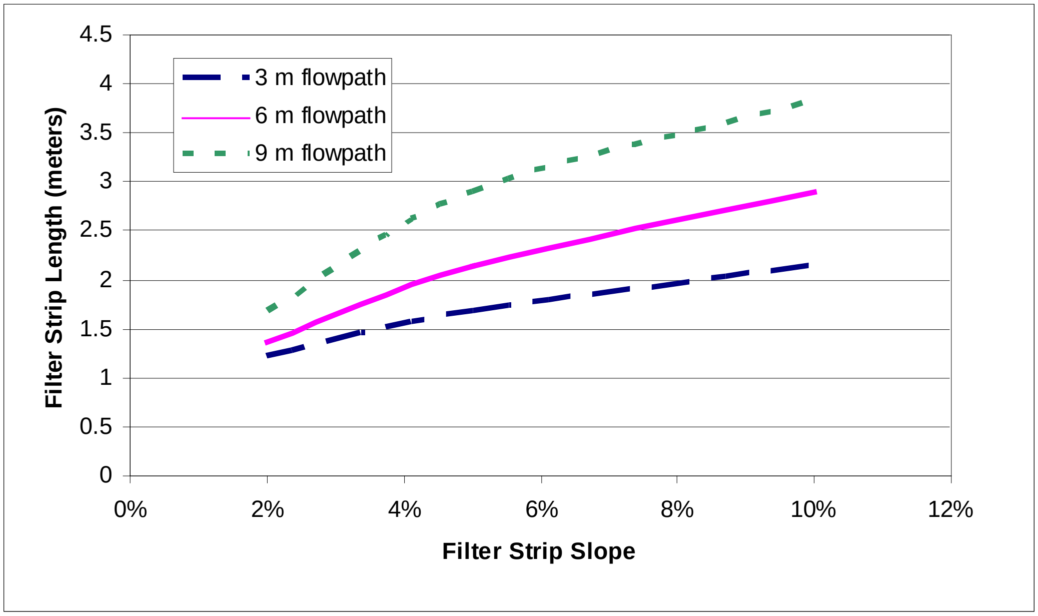
2004 Portland Stormwater Management Manual
http://www.portlandonline.com/bes/index.cfm?c=dfbbh

BMP Sizing
Water quality benefits can be achieved when vegetated filter strips are designed as follows:

1) Where the contributing flow path length (across the impermeable surface) is 9 metres or less, filter strip length and slope should be designed based on the relationship shown in Figure 4.6.7.

2) Where the contributing flow path length is greater than 9 metres and less than 25 metres, filter strips should be designed with a maximum velocity of 0.5 metres/second and a length that is greater than the contributing flow path length.

Figure 4.6.7 Filter strip length sizing based on slope and contributing flow path



Source: adapted from PWD, 2007

For further guidance regarding BMP sizing, refer to the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003)

Design Specifications

Table 4.6.4 below gives the specifications for pretreatment to filter strips.

Table 4.6.4 Filter strip pretreatment specifications

Material	Specification	Quantity
Pea Gravel Diaphragm	Washed aggregate that is 3 to 10 mm in diameter	Diaphragm should be a minimum of 300 mm wide and 600 mm deep (MDE, 2000)
Gravel or 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	Based on width of the filter strip

Construction Considerations

The following should be considered during the construction of filter strips:

- *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 (City of Portland, 2004). Micro-grading is critical to ensure sheet flow.

- *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.

- *Vegetation:* If necessary, filter strips should be regularly inspected between April and September of the first two years and watered when necessary to establish healthy vegetation. Ideally, filter strips should be planted in the spring, when vegetation can become established with minimal irrigation (Barrett *et al.*, 2004).

4.6.3 Maintenance and Construction Costs

Maintenance

Maintenance requirements for vegetated filter strips are similar to enhanced grass swales and typically involve a low level of activity after vegetation becomes established. Routine inspection is 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. The activities outlined in Table 4.6.5 should be incorporated into the maintenance plan.

Table 4.6.5 Typical maintenance activities for vegetated filter strips

Activity	Schedule
▪ 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 and level spreader devices.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years while vegetation is becoming established; ▪ Mow grass to maintain height between 50 to 150 mm; ▪ Remove trash and debris from level spreaders, pretreatment devices and the filter strip surface..	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment and level spreader devices; ▪ Replace mulch in spring; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth, dethatch, remove thatching and aerate (PDEP, 2006); ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the filter strip or bottom of the slope when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If pools of standing water are observed along the slope, regrading and revegetating may be required.	Annually or as needed

Installation and Operation Costs
Little data are available on the actual construction costs of vegetated filter strips. One rough estimate can be the cost of seed or sod, which is approximately $3.50 per square metre for seed or $9 per square metre for sod.

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4.7 Permeable Pavement

4.7.1 Overview

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. The following permeable pavement types are illustrated in Figure 4.7.1:

- 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 (Figure 4.7.3). Permeable paving allows for filtration, storage, or infiltration of runoff, and can reduce or eliminate surface stormwater flows compared to traditional impervious paving surfaces like concrete and asphalt.

Common Concerns

Common concerns about permeable paving include the following:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):
  - 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; 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 more than 10 years of operation (TRCA, 2008).

- *Winter Operation:* 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 (Cahill Associates, 1993; Roseen, 2007). Systems installed in the Greater Toronto Area have generally not suffered from heaving or slumping (TRCA, 2008b). Permeable 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 a capillary barrier to freeze-thaw. Permeable pavers have the added benefit of having enough flexibility to handle minor heaving without being damaged. Permeable 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 porous pavement. Sand should not be applied for winter traction on permeable pavement as this can quickly clog the system.

- *On Private Property*: If permeable pavement systems are installed on private lots, property owners or managers will need to be educated on their routine 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

- *Clogging:* Susceptibility to clogging is the main concern for permeable paving systems. The bedding layer and joint filler should consist of 2.5 mm clear stone or gravel rather than sand. Key strategies to prevent clogging are to ensure that adjacent pervious areas have adequate vegetation cover and a winter maintenance plan that does not include sanding. For concrete and asphalt designs, regular maintenance that includes vacuum-assisted street sweeping is necessary. Isolated areas of clogging can be remedied by drilling small holes in the pavement or by replacing the media between permeable pavers.

Figure 4.7.1 Permeable pavement types

Permeable interlocking concrete pavers (block pavers): Concrete pavers are designed with gaps between them that allow stormwater to infiltrate into the aggregate reservoir. The gaps are approximately 10% of the surface area and are filled with small stone.

Permeable paver parking lot in Mississauga, ON (Source: CVC)

Plastic or concrete grid systems are concrete or durable plastic grids filled with gravel or a pervious planting mix for grass or low ground cover. The grids provide support for vehicles or foot t*raffic while preven*ting compaction and rutting of the fill material. Grid systems are appropriate for applications such as walkways, overflow parking, firelanes, maintenance and utility acccess lanes, or driveways.

Residential driveway (Source: R. Bannerman); Plastic grid filled with gravel (Source: Gravelpave©**)**

Pervious Concrete and Porous Asphalt have pavement mixes with reduced or no fines which creates stable void spaces. The void spaces allow stormwater to drain through to the underlying stone reservoir. They require different pouring and setting procedures than their impervious versions.

Pervious concrete(Source: Hunt and Collins, 2008); Porous asphalt parking lot (Source: University of New Hampshire Stormwater Center)

- *Road Salt*: Care needs to be taken when applying road salt to permeable pavement surfaces since dissolved constituents from the road salt will migrate through the bedding and into the groundwater system. A well draining surface will reduce the occurrence of black ice or frozen puddles and requires less salt than is applied to impervious pavement (Roseen, 2007).

- *Structural Stability*: Adherence to design guidelines for pavement design and base courses will ensure structural stability. In most cases, the depth of aggregate material required for the stormwater storage reservoir will exceed the depth necessary for structural stability. Reinforcing grids can be installed in the bedding for applications that will be subject to very heavy loads.

- *Heavy Vehicle Traffic*: Permeable pavement is not typically used in locations subject to heavy loads. Some permeable pavers are designed for heavy loads and have been used in commercial port loading and storage areas.

Physical Suitability and Constraints
In general, permeable pavement systems can be used almost anywhere a traditionally paved system might have been installed. However, these systems have the same site constraints of any infiltration practice and should meet the following criteria:

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

- *Winter Operations:* Sand or other granular materials should not be applied as anti-skid agents during winter operation because they can quickly clog the system. Winter maintenance practices should be limited to plowing, with de-icing salts applied sparingly (*i.e.*, not as a preventative measure).

- *Site Topography:* The slope of the permeable pavement surface should be at least one percent and no greater than five percent. The impervious land surrounding and draining into the pavement should not exceed 20% slope (Smith, 2006). Pervious surfaces should not drain onto the pavement.

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

- *Soils:* Systems located in low permeability soils with an infiltration rate of less than 15 mm/hr (i.e., hydraulic conductivity of less than $1x10^{-6}$ cm/s), require incorporation of 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 using methods described in Appendix C.

- *Drainage Area and Runoff Volume:* In general, the impervious area treated should not exceed 1.2 times the area of permeable pavement which receives the runoff (GVRD, 2005). The storage layer under the permeable pavement must be sized to accommodate runoff from the pavement itself and any impermeable areas draining to it.

- *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 permeable pavement.

- *Setbacks from Buildings:* Permeable pavement should be located downslope from building foundations. If the pavement does not receive runoff from other surfaces, no setback is required from building foundations. Otherwise, a minimum setback of four (4) metres down-gradient from building foundations is recommended*.*

- *Proximity to Underground Utilities:* Local utility design guidance should be consulted to define the horizontal and vertical offsets. Generally, requirements for underground utilities passing under or near permeable pavement will be no different than for utilities in other pervious areas. However, permeable pavement has a deeper base than conventional pavement which may impact shallow utilities.

Typical Performance

Table 4.7.1 Ability of permeable pavement 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	Parital – based on available storage volume and soil infiltration rates
Permeable pavement with underdrain	Partial – 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 rates
Permeable pavement with underdrain and liner	Partial – some volume reduction occurs through evaporation	Partial – limited filtering and settling of sediments	Partial – based on available storage volume and detention time

Water Balance

Studies have examined the runoff reduction potential for permeable pavers that are designed with the water quality storage requirement and allow infiltration beneath the paver. The research studies have been classified into two categories – permeable paver applications that have underdrains and those that do not, and therefore rely on full infiltration into underlying soils (Table 4.7.2). Studies in North Carolina have shown the average curve number of permeable pavements to range from a low of 45 to a high of 89 (Bean *et al.*, 2007b).

Table 4.7.2 Volumetric runoff reduction[1] from permeable pavement

LID Practice	Location	Runoff Reduction[1]	Reference
Permeable pavement without underdrain	Guelph, Ontario	90%	James (2002)
	Pennsylvania	90%	Kwiatkowski *et al.* (2007)
	France	97%	Legret and Colandini (1999)
	Washington	97 to 100%	Brattebo and Booth (2003)
	Connecticut	72%[2]	Gilbert and Clausen (2006)
Permeable pavement with underdrain	King City, Ontario	99%[4]	TRCA (2008b)
	North Carolina	98 to 99%	Collins *et al.* (2008)
	United Kingdom	50%	Jefferies (2004)
	United Kingdom	53 to 66%	Pratt *et al.*, 1995
	Maryland	45 to 60%	Schueler *et al.* (1987)
Runoff Reduction Estimate[3]		**85% without underdrain; 45% with underdrain**	

Notes:
1. Runoff reduction estimates are based on differences between runoff volume from the practice and total precipitation over the period of monitoring unless otherwise noted.
2. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional impervious surface over the period of monitoring.
3. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.
4. In this study, there was no underdrain in the pavement base, but an underdrain was located 1 m below the native soils to allow for sampling of infiltrated water.

Water Quality - Pollutant Removal Capacity

Like other infiltration practices, the capacity of permeable pavements to remove pollutants is closely associated with their ability to infiltrate runoff. Full infiltration designs are more effective because little if any of the pollutants generated on the impermeable surfaces leave the site as surface runoff. Partial infiltration designs with underdrains generate more runoff, and as a result, are often used in studies investigating the water quality impact of permeable pavements on surface waters. These studies show load reductions above 50% for total suspended solids, most metals, and hydrocarbons (Legret and Collandini, 1999); Pratt *et al.*, 1995); Pagotto *et al.*, 2000). A substantial portion of the pollutants are captured in the surface pores and underlying granular base of the permeable pavements (Pratt *et al.*, 1995).

Another group of studies of permeable pavements examines the quality of water infiltrated through soils beneath the installations. In these studies the quality of infiltrated water is used as a measure of the potential for contamination of groundwater. One such study of a permeable interlocking concrete pavement installed in a college parking lot in King City, Ontario, showed that stormwater infiltrated through a 60 cm granular reservoir and 1 metre of native soil had significantly lower concentrations of several typical parking lot contaminants relative to runoff from an adjacent asphalt surface (TRCA, 2008b). These results are consistent with research on the quality of infiltrated water from permeable pavements in Washington (Brattebo and Booth, 2003) and Pennsylvannia (Kwiatkowski *et al.*, 2007). As with all stormwater infiltration practices, risk of groundwater contamination from infiltration of runoff laden with road de-icing salt constituents (typically sodium and chloride) is a significant concern. Chloride ions are extremely mobile in the soil and are readily transported by percolating water to aquifers.

Stream Channel Erosion Control
The storage capacity of a specific system should be compared to the channel erosion control detention requirement. Limits to the depth of the stone base are discussed in the Design Template part of Section 4.7.2.

Other Benefits

- *Winter Performance:* Snow plow and deicing costs are reduced due to rapid snow and ice melt drainage. Puddling and flooding on parking lots is also reduced.

- *Urban Heat Island Effect Reduction:* Porous materials have less thermal conductivity and thermal capacity than traditional impervious pavement, thereby reducing the urban heat island effect (Ferguson, 2005).

- *Quiet Streets:* Porous surfaces absorb sound energy and dissipate air pressure around tires before any noise is generated. Tire noise is lower in loudness and pitch for a porous surface than a corresponding dense pavement (Ferguson, 2005).

- *LEED Credits*: Permeable pavement has the potential for earning Canadian Green Building Council LEED sustainable sites credits for reducing stormwater pollution and runoff, urban heat island mitigation, and conservation of materials and resources.

4.7.2 Design Template

Applications
Permeable pavements are designed to provide treatment for the rain that falls directly onto their surface, but can also be designed to receive runoff from adjacent conventional paving and building roof downspouts. They are particularly useful in high density areas with limited space for other stormwater BMPs. Treatment of runoff from pervious areas is discouraged due to clogging potential. Permeable pavement may be applied on residential lots, school grounds, parks, shopping centres, and around commercial, institutional or municipal buildings (Figure 4.7.2).

Permeable pavement practices should not be applied in pollution hot spots such as vehicle fuelling, service or demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites.

Figure 4.7.2 Examples of permeable pavement applications

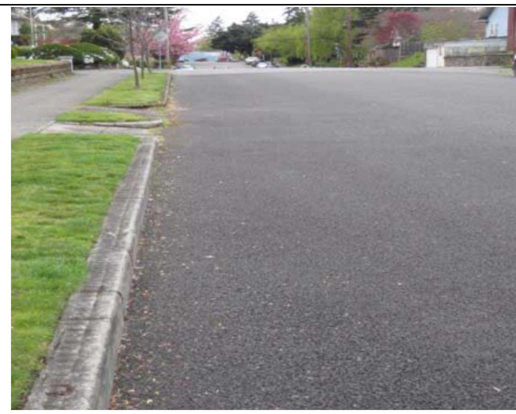
Pervious Concrete

Pervious concrete walkway plaza (Source: Villanova Urban Stormwater Partnership)

Pervious concrete applied to an alleyway in Chicago (Source: City of Chicago)

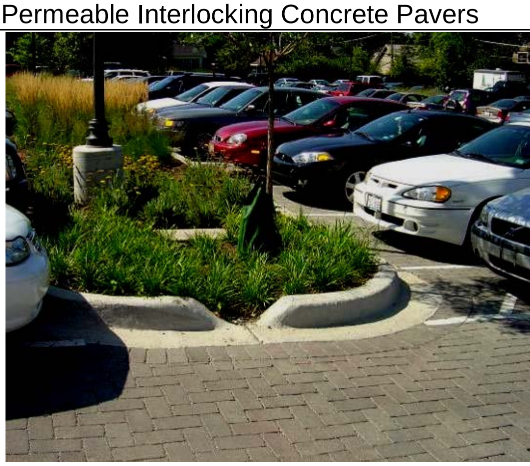
Porous Asphalt

Porous asphalt parking lot (Source: Villanova Urban Stormwater Partnership)



Porous asphalt installed curb to curb on a residential street (Source: City of Portland, Bureau of Environmental Services)

Permeable Interlocking Concrete Pavers

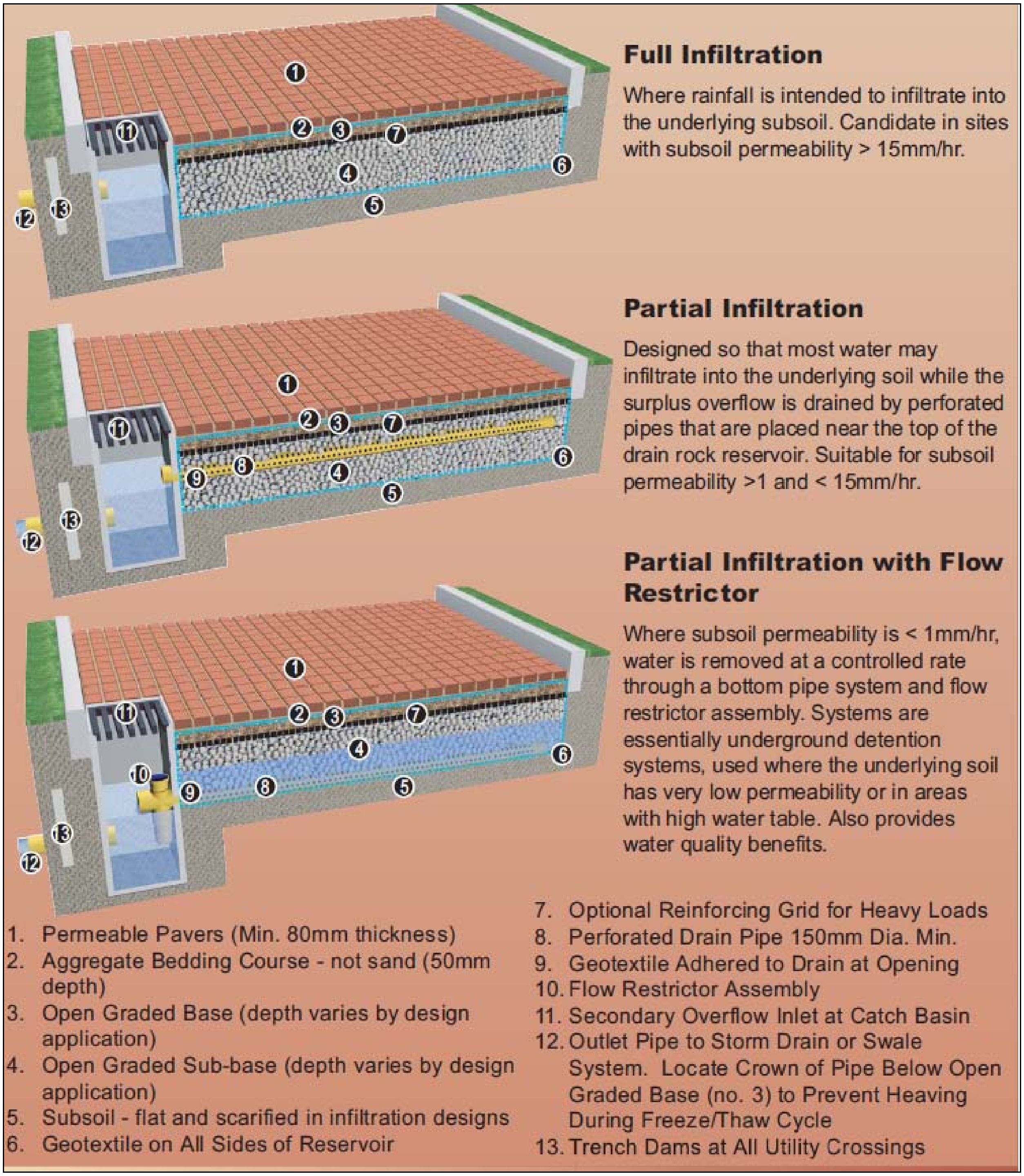


Permeable pavers used in combination with bioretention in a parking lot in Elmhurst, IL (Source: ICPI).

Permeable pavers in Hoboken, NJ used around trees which allow air and water to reach the roots (Source: Bruce Ferguson).

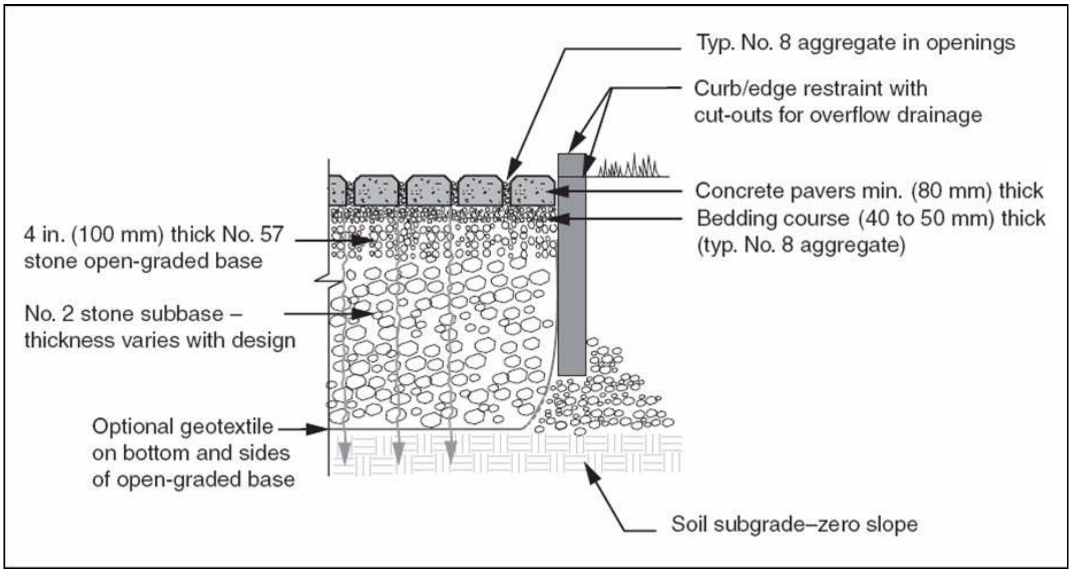
Typical Details

Figure 4.7.3 Permeable pavement cross sections



Source: GVRD, 2005

Figure 4.7.4 Close up cross section of permeable pavement full infiltration design



Source: Smith, 2006

*Note the detail above, along with most specifications for permeable pavement, use the US ASTM reference numbers to refer to aggregate mixes. Generally, ASTM #8 = 5 mm clear crush open graded bedding course; ASTM #57 = 20 mm clear crush open-graded aggregate; and ASTM #2 = 63 mm clear crush open-graded aggregate (commonly referred to as rail ballast).

** The structure for pervious concrete and porous asphalt will have the same base and subbase but no bedding layer. If grid systems are used, then the manufacturer design specifications should be followed.

Design Guidance

Geometry and 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 paved surfaces. For example, the parking spaces of a parking lot can be permeable pavers while the drive lanes are impervious asphalt or vice versa depending on the drainage pattern. In general, the impervious area should not exceed 1.2 times the area of the permeable pavement which receives the runoff. A hybrid permeable pavement/soakaway design can feature connection of a roof downspout directly to the stone reservoir of the permeable pavement system, which is sized to store runoff from both the pavement surface and the roof drainage area.

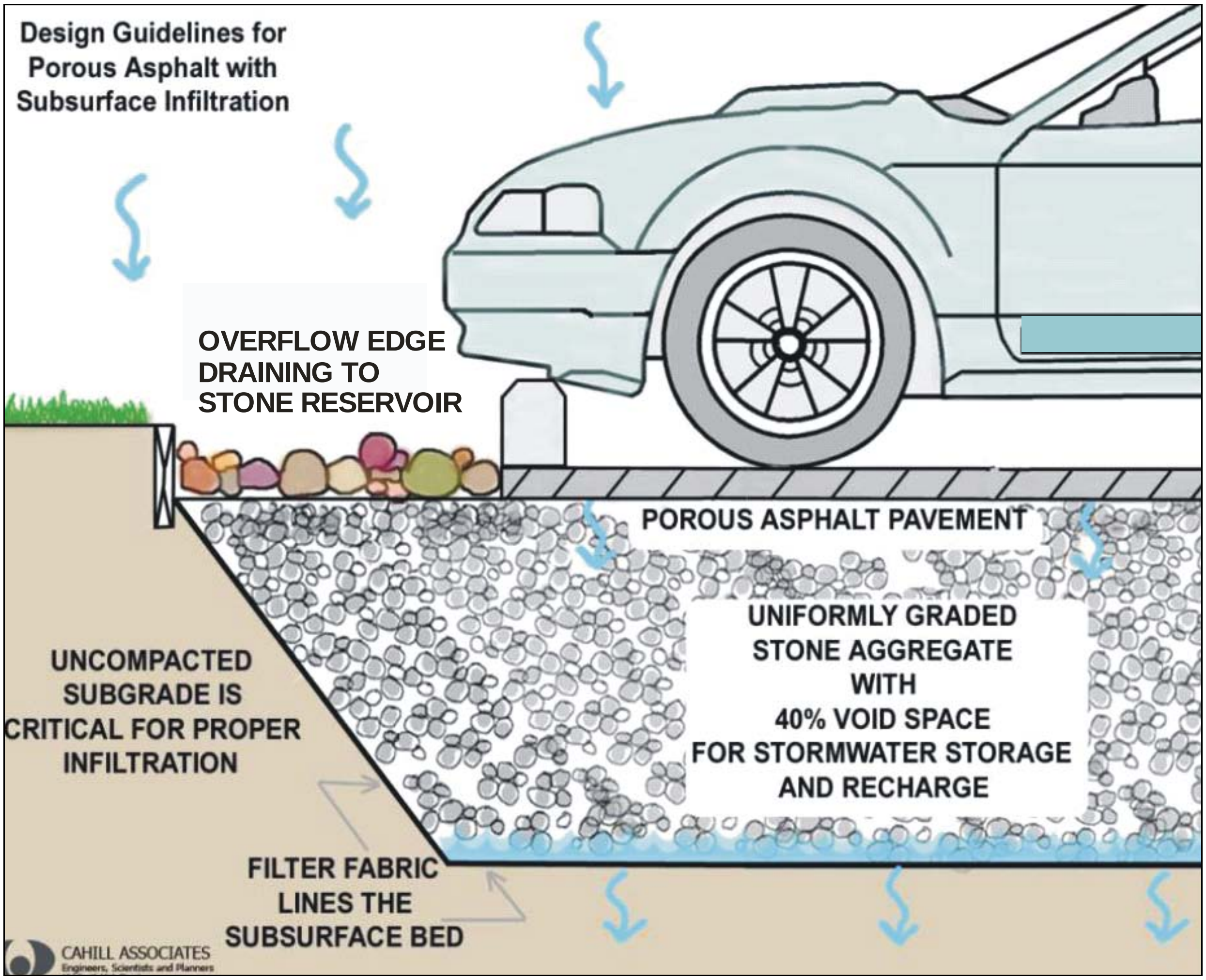
Pretreatment

In most permeable pavement designs, the surface 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 (see Maintenance Section). Another pretreatment element is a pea gravel choking layer above the coarse gravel storage reservoir.

Conveyance and Overflow

All pavement 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. If the surface is overloaded or clogged, then flows that are too large to be treated by the system can be bypassed through the storm drain inlets. Another design option intended as a backup water removal mechanism is an overflow edge (Figure 4.7.5). An overflow edge is a gravel trench along the downgradient edge of the pavement surface that drains to the stone reservoir below. If the pavement surface is overloaded or clogs, stormwater will flow over the surface and into the overflow edge and underlying stone reservoir, where infiltration and treatment can still occur. On smaller sites, overflow can simply sheet flow onto the traditional paving and drain into the storm sewer system.

Figure 4.7.5 Permeable pavement system featuring an overflow edge



Source: Cahill Associates Ltd.

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 (i.e., hydraulic conductivity less than $1x10^{-6}$ cm/s) 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 (Figure 4.7.3).

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 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 (Smith, 2006). 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. A hybrid permeable pavement/soakaway design can feature connection of a roof downspout directly to the stone reservoir of the permeable pavement system, which is sized to store runoff from both the pavement surface and the roof drainage area.

Geotextile

A non-woven needle punched, or woven monofilament geotextile fabric should be installed between the stone reservoir and native soil. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. The primary function of the geotextile is separation between two dissimilar soils. When a finer grained soil or aggregate bedding layer overlies a coarser grained soil or aggregate layer (*e.g.*, stone reservoir), the geotextile prevents clogging of the void spaces from downward migration of soil particles. When a coarser grained aggregate layer (*e.g.*, stone reservoir) overlies a finer grained native soil, the geotextile prevents slumping from downward migration of the aggregate into the underlying soil. Geotextile may also enhance the capacity of the facility to reduce petroleum hydrocarbons in runoff, as microbial communities responsible for their decomposition tend to concentrate in geotextile fabrics (Newman *et al.*, 2006a). Specification of geotextile fabrics in permeable pavement systems 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, the load bearing ratio and permeability of the underlying native soil, and the texture (*i.e.*, grain size distribution) of the overlying pavement bedding material. Table 4.7.5 provides further detail regarding geotextile specifications.

Pavement

The costs and benefits vary for each of the permeable pavement types. Review the design specifications in Table 4.7.5 and consult the other design resources to determine which pavement type is appropriate for your application.

Edge Restraints

The provision of suitable edge restraints is critical to the satisfactory performance of permeable pavements. Pavers must abut tightly against the restraints to prevent rotation under load and any consequent spreading of joints. The restraints must be sufficiently stable that, in addition to providing suitable edge support for the paver units, they are able to withstand the impact of temperature changes, vehicular traffic and/or snow removal equipment. Metal or plastic stripping is acceptable in some cases, but concrete edges are preferred (Figure 4.7.6). Edge restraints should be used for pervious concrete and porous asphalt to prevent pavement unravelling at the edges.

Curbs, gutters, or curbed gutter, constructed to the dimensions of municipal standards (these standards generally refer to cast-in-place concrete sections), are considered to be acceptable edge restraints for heavy duty installations. Where extremely heavy industrial equipment is involved such as container handling equipment, the flexural strength of the edge restraint should be carefully reviewed, particularly if a section that is flush with the surface is used and may be subjected to high point loading. Concrete edge restraints should be supported on a minimum base of 150 mm of aggregate.

Figure 4.7.6 Examples of edge restraints

Metal stripping edge restraint for permeable pavement. (Source: CVC)

Curb and at grade concrete edge restraints around a permeable paver parking lane. (Source: City of Portland, Bureau of Environmental Services)

Landscaping

Landscaping plans should reflect the permeable pavement application. 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. Permeable pavers used around the base of a tree can be removed as the tree grows.

Other Design Resources

Several resources that provide useful design guidance for permeable pavement techniques are:

City of Toronto Green Development Standards – Design Guidelines for 'Greening' Surface Parking Lots

Ferguson, B. 2005. Porous Pavements. CRC Press. Taylor and Francis Group. Boca Raton, FL.

National Asphalt Pavement Association
http://www.hotmix.org/images/stories/better_water_quality.pdf

National Concrete Pavement Technology Center. Mix Design Development for Pervious Concrete for Cold Weather Climates,
http://www.ctre.iastate.edu/reports/mix_design_pervious.pdf

National Ready Mixed Concrete Association
http://www.perviouspavement.org/

Pennsylvania Stormwater Best Management Practices Manual.
http://164.156.71.80/WXOD.aspx?fs=2087d8407c0e00008000071900000719&ft=1

Smith, D. 2006. *Permeable Interlocking Concrete Pavements; Selection, Design, Construction, Maintenance.* 3rd Edition. Interlocking Concrete Pavement Institute. Burlington, ON.

University of New Hampshire Stormwater Center. Design Specifications for Porous Asphalt Pavement and Infiltration Beds,
http://www.unh.edu/erg/cstev/pubs_specs_info/unhsc_pa_spec_09_09.pdf

Villanova Urban Stormwater Partnership. Lessons Learned – Porous Concrete Demonstration Site
http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_Web_Folder/PC_web_folder/PC_Research.htm

BMP Sizing

Permeable pavement systems are typically sized to treat the water quality storage requirement. In some cases, the aggregate base depth required for load bearing capacity or to be below the local maximum frost penetration depth may exceed the depth required for stormwater management. Permeable pavement techniques can also be used as part of a treatment train, where overflows from the pavement drain to another BMP.

Infiltration Rate of Pavement Surface

The initial pavement permeability will be reduced over the long-term by eventual clogging. Note that initial pavement surface permeability is extremely high. Even with clogging of pavement surface as high as 90%, the pavement should still function under design rainfall rates. The soil underlying the pavement is usually the limiting infiltration rate. A conservative design rate of 75 mm/hr is recommended for the design surface infiltration rate for a 20-year life, which takes into account most storms (Smith, 2006).

Sizing Stone Reservoirs

The following calculation is used to size the stone storage bed (reservoir) used as a base course for designs without underdrains. It is assumed that the footprint of the stone bed will be equal to the footprint of the pavement. The following equations are taken from the ICPI Manual (Smith, 2006).

The equation for the depth of the stone bed is as follows:

$$d_b = [Q_c * R + P – i * T] / V_r$$

Where:

- d_b = Stone bed depth (m)
- Q_c = Depth of runoff from contributing drainage area, not including permeable paving surface (m)
- R = A_c/A_p = Ratio of contributing drainage area (A_c) to permeable paving area (A_p)
- P = Rainfall depth (m)
- i = Infiltration rate for native soils (m/day)
- T = Time to fill stone bed (typically 2 hr)
- V_r = Void ratio for stone bed (typically 0.4 for 50 mm dia. stone)

Note that the contributing drainage area (A_c) should not contain pervious areas.

For designs that include an underdrain, the maximum depth of the stone reservoir below the invert of the underdrain pipe can be calculated as follows:

$$d_{r\,max} = i * t_s / V_r$$

Where:

- $d_{r\,max}$ = Maximum stone reservoir depth (m)
- i = Infiltration rate for native soils (m/hr)
- V_r = Void space ratio for aggregate used (typically 0.4 for 50 mm clear stone)
- t_s = Time to drain (design for 48 hour time to drain is recommended)

The value for native soil infiltration rate (i) used in the above equations should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2). On highly permeable soils (e.g., infiltration rate of 45 mm/hr or greater), a maximum stone reservoir depth of 2 metres is recommended to prevent soil compaction and loss of permeability from the mass of overlying stone and stored water.

If trying to size the area of permeable paving based on the contributing drainage area, the following equation may be used:

$$A_p = Q_c * A_c / [V_r * d_p - P + i * T]$$

Alternatively, there is permeable pavement design software available on the market or from product manufacturers.

Design Specifications

Table 4.7.3 below gives specifications for pervious concrete, porous asphalt, and permeable pavers. Grid systems are not included due to the wide range in types and designs. For example, products using turf may specify a sand layer or no gravel storage area at all in order to maintain the vegetation health. The manufacturer should be consulted for the design specifications of their product. In pervious concrete and porous asphalt systems, the concrete or asphalt mix specifications and construction procedure are key to proper functioning. These systems require well trained and experienced contractors for installation.

Table 4.7.3 Permeable pavement specifications

Material	Specification	Quantity
Pervious Concrete	▪ Schaefer *et al*. (2006) found that mix NO4-RG-S7 with air entrainment showed 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 (NCPTC, 2006).
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 (NAPA 2008).
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. 1. Average compressive strength 8000 psi (55MPa) with no individual unit under 7,250 psi (50MPa) in accordance with ASTM C396 or CAN3-A231.2-M85.	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.

Material	Specification	Quantity
	2. Average absorption of 5% with no unit greater than 7% when tested according to ASTM C 140. 3. Resistance to 50 freeze-thaw cycles, when tested according to ASTM C 67 or CAN3-A231.2-M85, with no breakage greater than 1.0% loss in dry weight of any individual unit. This test method shall be conducted not more than 12 months prior to delivery. ▪ Pigment in concrete pavers shall conform to ASTM C 979. ACI Report No. 212.3R provides guidance on the use of pigments. ▪ Maximum allowable breakage of product is 5%.	
Stone Reservoir	All aggregates should meet the following criteria (PWD, 2007): ▪ 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 Sub-base</u> The granular sub-base 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). Aggregate materials used in the construction of permeable pavements shall be clean, have zero plasticity and contain no No. 200 sieve size materials. The aggregate materials must serve as the structural load bearing platform of the pavement as well as a temporary receptor for the infiltrated water that is collected through openings in the pavement surface.	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:	Between stone reservoir and native soil.

Material	Specification	Quantity
	- 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 native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): <u>Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA)</u> For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) <u>Hydraulic Conductivity (k, in cm/sec)</u> k (fabric) > k (soil) <u>Permittivity (in sec^{-1})</u> Where, Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}.	

Material	Specification	Quantity
	For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	
Underdrain (optional)	▪ These pipes should be HDPE or equivalent material, continuously perforated and have a smooth interior with a minimum inside diameter of 100 mm. ▪ Perforations in pipes should be 10 mm in diameter (Smith, 2006). ▪ 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 vandal proof lock.	Pipes should terminate 0.3 m short from the sides of the base (Smith, 2006).

Construction Considerations

Construction of permeable pavement is a specialized project and should involve experienced contractors. The following general recommendations apply:

- *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, and proper erosion and sediment controls must be maintained on site.

- *Base Construction:* For structural applications in parking lots, the stone aggregate should be placed in 100 mm to 150 mm lifts and compacted with a minimum 9,070 kilograms (10 ton) steel drum roller. Stone materials should be moist during compaction. Equipment drivers are advised to avoid rapid acceleration, hard braking, and sharp turning on the compacted layers so that the base surfaces are not disturbed (Smith, 2006).

- *Weather:* Porous asphalt and pervious concrete will not properly pour and set in extremely high and low temperatures (City of Portland, 2004; U.S. EPA, 1999). One benefit to using permeable pavers is that their installation is not weather dependent.

- *Pavement mix:* Industry reps familiar with the porous pavement specifications should be consulted for specifications on batching. Testing of concrete and asphalt materials on site is critical. Deviations from specified proportions and additives can result in an early failure of the pavement.

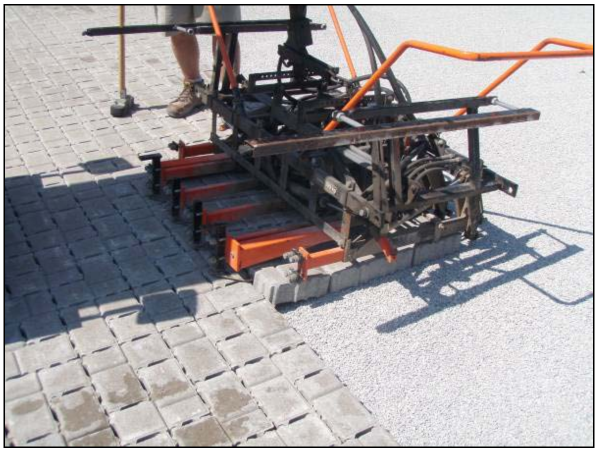
- *Pavement placement:* Properly installed permeable pavement requires trained and experienced producers and construction contractors.

    - **Porous Asphalt** uses the same equipment for mixing and laying as conventional asphalt (Figure 4.7.6). To avoid closing the pore spaces, compaction will use minimal pressure and the surface should not be smoothed or finished. The porous pavement will have a slightly rougher surface than conventional asphalt. The pavement should be allowed to set for 24 to 48 hours before vehicle or foot traffic is permitted (NAPA, 2008).

- **Pervious concrete** has a low initial slump and fast set-times; meaning the pavement will rapidly harden and mistakes are not easily corrected. Pervious concrete needs to be poured within one hour of mixing, but that time can be extended with the use of admixtures. Once poured, the concrete is leveled using a manual or mechanical screed set 13 mm above the finished height. To avoid closing off pore spaces, do not use floating and troweling. The concrete should be consolidated, typically with a steel roller, within 15 minutes of placement. Pervious concrete also requires a longer time to cure. The concrete requires a minimum of 7 days to cure and should be covered by plastic sheeting (NRMCA, 2008).

- **Permeable Pavers** can be placed by hand or some are designed to be placed mechanically in segments to reduce labour costs (Figure 4.7.7). The main difference between laying conventional pavers and permeable pavers is the addition of the stone filler in the pore spaces. Most pavers are designed with the pore spaces built into their design or with nubs which provide an even spacing from the adjacent paver. The filler stone is swept over the pavement until all of the spaces are filled (Smith, 2006).

Figure 4.7.7 Examples of permeable pavement installations



Permeable pavers being mechanically placed in sections (Source: CVC)

Porous asphalt installation (Source: Villanova Urban Stormwater Partnership)

4.7.3 Maintenance and Construction Costs

Inspection and Maintenance

Like all other stormwater practices, permeable pavement requires regular inspection and maintenance to ensure that it functions properly. Well maintained permeable pavers are expected to last at least 20 years (*e.g.*, Applied Research Associates, 2008). The limiting factor for permeable pavers is clogging within the aggregate layers, filler, or underdrain. The pavers themselves can be reused. Legally binding maintenance agreement which clearly specifies how to conduct routine maintenance tasks are essential for permeable pavement installed on private property. Ideally, signs should be posted on the site identifying permeable paver and porous pavement areas. This can also serve as a public awareness and education opportunity. 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 to mitigate sediment accumulation and ensure continued porosity. Permeable pavement should not be washed with high pressure water systems or compressed air units, because they will push particles deeper into the pavement (PWD, 2007).

- *Inlet Structures:* Drainage pipes and structures within or draining to the subsurface bedding beneath porous pavement should be cleaned out on regular intervals (PWD, 2007).

- *Heavy Vehicles:* Trucks and other heavy vehicles can ground dirt into the porous surface and lead to clogging. These vehicles should be prevented from tracking or spilling dirt onto the pavement (PWD, 2007). Signage and training of facilities personnel is suggested.

- *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 (PWD, 2007).

- *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 the pavement or at least be well stabilized with vegetation.

- *Grid Pavers:* Paver or grid systems that have been planted with grass should be mowed regularly and the clippings should be removed (PWD, 2007). Water and fertilize as needed.

- *Seal Coating*: Seal coats should never be applied to permeable pavements. Current and future owners and operations staff must be aware of permeable pavement areas and the importance of not applying any sealants. Porous asphalt and pervious concrete look very similar to their impervious versions and could be inadvertently sealed over.

- *Potholes*: For porous asphalt or pervious concrete, isolated potholes can be patched with standard patching mixes. Patching can continue until the structural integrity of the pavement has been compromised or stormwater can no longer drain to the aggregate base. Then the surface will need to be torn up and replaced.

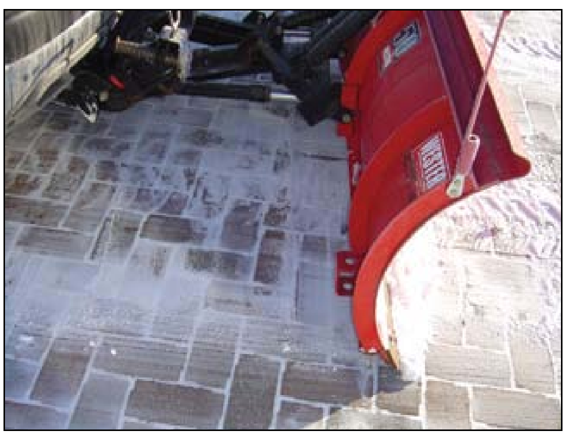
- *Uneven Pavers:* An uneven paver surface can be repaired by pulling up the pavers, redistributing the bedding layer, and then placing the pavers back. New filler stone will need to be swept into the replaced pavers. Typically the pavers are packed very tightly, and breaking one or more pavers will be necessary to pull up a group of pavers. Keeping a set of replacement pavers after construction will be useful for making future repairs.

- *Weeds:* Over time, weed growth may become a problem, particularly on surfaces with infrequent traffic. Weeds can be an aesthetic issue and may also reduce the infiltration through the pavement. Keeping the pavement surface free of organic material through regular sweeping and vacuuming can impede weeds from taking root. Pulling weeds when they are small will limit damage to the pavement and loss of filler material between pavers. Ontario has banned the use of cosmetic herbicides.

- *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 because dissolved constituents are not removed by the pavement system. Pilot studies at the University of New Hampshire Stormwater Center have found that permeable pavement requires 75% less salt than conventional pavement over the course of a typical winter season (UNHSC, 2007).

- *Snow Plowing:* Permeable pavement is plowed for snow removal like any other pavement (Figure 4.7.8). When groundwater contamination from chlorides is a concern, plowed snow piles and snow melt should not be directed to permeable paver and porous pavement systems (Smith, 2006).

Figure 4.7.8 Permeable pavement is plowed like any other pavement.



Source: ICPI

Annual inspections of permeable pavement should be conducted in the spring to ensure continued infiltration performance. These inspections should check for spilling or deterioration and test to whether water is draining between storms. The pavement reservoir should drain completely within 72 hours of the end of the storm event.

Installation and Operation Costs
Initial construction costs for permeable pavements are typically higher than conventional asphalt pavement surfaces, largely due to thicker aggregate base needed for stormwater storage. However, the cost difference is reduced or eliminated when total life-cycle costs, or the total cost to construct and maintain the pavement over its lifespan, are considered. Other savings and benefits may also be realized, including reduced need for storm sewer pipes and other stormwater practices, less developable land consumed for stormwater treatment, and ancillary benefits such as improved aesthetics and reduced urban heat island effect. These systems are especially cost effective in existing urban development where parking lot expansion is needed, but there is not sufficient space for other types of BMPs. They combine parking, stormwater infiltration, retention, and detention into one facility.

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4.8 Enhanced Grass Swale

4.8.1 Overview

Description

Enhanced grass swales are vegetated open channels designed to convey, treat and attenuate stormwater runoff (also referred to as enhanced vegetated swales). Check dams and vegetation in the swale slows the water to allow sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and infiltration into the underlying native soil. Simple grass channels or ditches have long been used for stormwater conveyance, particularly for roadway drainage. Enhanced grass swales incorporate design features such as modified geometry and check dams that improve the contaminant removal and runoff reduction functions of simple grass channel and roadside ditch designs (Figure 4.8.1). A dry swale is a design variation that incorporates an engineered soil media bed and optional perforated pipe underdrain system (see Section 4.9 – Dry Swale). Enhanced grass swales are not capable of providing the same water balance and water quality benefits as dry swales, as they lack the engineered soil media and storage capacity of that best management practice.

Where development density, topography and depth to water table permit, enhanced grass swales are a preferred alternative to both curb and gutter and storm drains as a stormwater conveyance system. When incorporated into a site design, they can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits.

Figure 4.8.1 Enhanced grass swales can be applied in road rights-of-way or along parking lots

Source: Seattle Public Utilities (left); Sue Donaldson (right)

Figure 4.8.2 Enhanced grass swales feature check dams that temporarily pond runoff to increase pollutant retention and infiltration and decrease flow velocity

Source: Delaware Department of Transportation (left); Center for Watershed Protection (right)

Common Concerns

If they are properly designed and maintained, enhanced grass swales can provide stormwater treatment and improved site aesthetics. However, there are some common concerns associated with their use:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):
  - 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; 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 more than 10 years of operation (TRCA, 2008).

- *On Private Property*: If enhanced grass swales are installed on private lots, property owners or managers will need to be educated on their routine 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices. Alternatively, swales 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.

- *Maintenance*: The major maintenance requirement associated with grass swales is mowing. Occasionally, sediment will need to be removed, although this can be minimized by ensuring that upstream areas are stabilized and incorporating pretreatment devices (*e.g.*, vegetated filter strips, sedimentation forebays, gravel diaphragms). If grass swales are installed on private lots, homeowners need to be educated on routine maintenance requirements.

- *Erosion:* Erosion can be prevented by limiting the allowable longitudinal slope and incorporating check dams. Additionally, designers can use permanent reinforcement matting on swales designed for high velocity flows and temporary matting during the vegetation establishment period.

- *Standing Water and Mosquitoes:* Properly designed grass swales will not pond water for longer than 24 hours following a storm event. However, poor design, installation, or maintenance can lead to nuisance conditions.

Physical Suitability and Constraints

Enhanced grass swales are suitable on sites where development density, topography and water table depth permit their implementation. Some key constraints to their application include:

- *Available Space:* Grass swales usually consume about 5 to 15 percent of their contributing drainage area. A width of at least 2 metres is needed.

- *Site Topography:* Site topography constrains the application of grass swales. Longitudinal slopes between 0.5 and 6% are allowable. This prevents ponding while providing residence time and preventing erosion. On slopes steeper than 3%, check dams should be used.

- *Water Table*: Designers should ensure that the bottom of the swale is separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre.

- *Soils:* Grass swales can be applied on sites with any type of soils.

- *Drainage Area and Runoff Volume:* The conveyance capacity should match the drainage area. Sheet flow to the grass swale is preferable. If drainage areas are greater than 2 hectares, high discharge through the swale may not allow for filtering and infiltration, and may create erosive conditions. Typical ratios of impervious drainage area to swale area range from 5:1 to 10:1.

- *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 grass swales.

- *Setbacks from Buildings:* Enhanced grass swales should be located a minimum of four (4) metres from building foundations to prevent water damage.

- *Proximity to Underground Utilities:* Utilities running parallel to the grass swale should be offset from the centerline of the swale. Underground utilities below the bottom of the swale are not a problem.

Typical Performance

The ability of enhanced grass swales to help meet stormwater management objectives is summarized in Table 4.8.1.

Table 4.8.1 Ability of enhanced grass swales to meet SWM objectives

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Enhanced Grass Swale	Partial – depends on soil infiltration rate	Yes, if design velocity is 0.5 m/s or less for a 4 hour, 25 mm Chicago storm	Partial – depends on soil infiltration rate

Water Balance

Runoff reduction by grass swales is generally low, but is strongly influenced by soil type, slope, vegetative cover and the length of the swale. Recent research indicates that a conservative runoff reduction rate of 20 to 10% can be used depending on whether soils fall in hydrologic soil groups A/B or C/D, respectively. The runoff reduction rates can be doubled if the native soils on which the swale is located have been tilled to a depth of 300 mm and amended with compost to achieve an organic content of between 8 and 15% by weight or 30 to 40% by volume.

Table 4.8.2 Volumetric runoff reduction achieved by enhanced grass swales

LID Practice	Location	% Runoff Reduction	Reference
Grass Swale	Virginia	0%	Schueler (1983)
Grass Swale	Various	40%	Strecker *et al.*(2004)
Grass Swale	California	27 to 41%	Barrett *et al.* (2004)
Runoff Reduction Estimate[1]		**20% on HSG A or B soils; 10% on HSG C or D soils**	

Notes:
1. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality – Pollutant Removal Capacity

Research has shown the pollutant mass removal rates of grass swales are variable, depending on influent pollutant concentrations (Bäckström *et al.*, 2006), but generally moderate for most pollutants (Barrett *et al.*, 1998; Deletic and Fletcher, 2006). Median pollutant mass removal rates of swales from available performance studies are 76% for total suspended solids, 55% for total phosphorus, and 50% for total nitrogen (Deletic and Fletcher, 2006). Significant reductions in total zinc and copper event mean concentrations have been observed in performance studies with a median value of 60%, but results have varied widely (Barrett, 2008). Site specific factors such as slope, soil type, infiltration rate, swale length and vegetative cover also affect pollutant mass removal rates. In general, the dominant pollutant removal mechanism operating in grass swales is infiltration, rather than filtration, because pollutants trapped on the surface of the swale by vegetation or check dams are not permanently bound (Bäckström *et al.*, 2006). Designers should maximize the degree of infiltration achieved within a grass swale by incorporating check dams and ensuring the native soils have infiltration rates of 15 mm/hr or greater or specifying that the soils be tilled and amended with compost prior to planting.

Several of the factors that can significantly increase or decrease the pollutant removal capacity of grass channels are provided in Table 4.8.3.

Table 4.8.3 Factors that influence the pollutant removal capacity of grass swales

Factors that Reduce Removal Rates	Factors that Enhance Removal Rates
Longitudinal slope > 1%	Longitudinal slope < 1%
Measured soil infiltration rate < 15 mm/hr	Measured soil infiltration rate is 15 mm/hr or greater
Flow velocity within channel > 0.5 m/s during a 4 hour, 25 mm Chicago storm event	Flow velocity within channel is 0.5 m/s or less during a 4 hour, 25 mm Chicago storm event
No pretreatment	Pretreatment with vegetated filter strips, gravel diaphragms and/or sedimentation forebays
Side slopes steeper than 3:1 (H:V)	Side slopes 3:1 (H:V) or less

4.8.2 Design Template

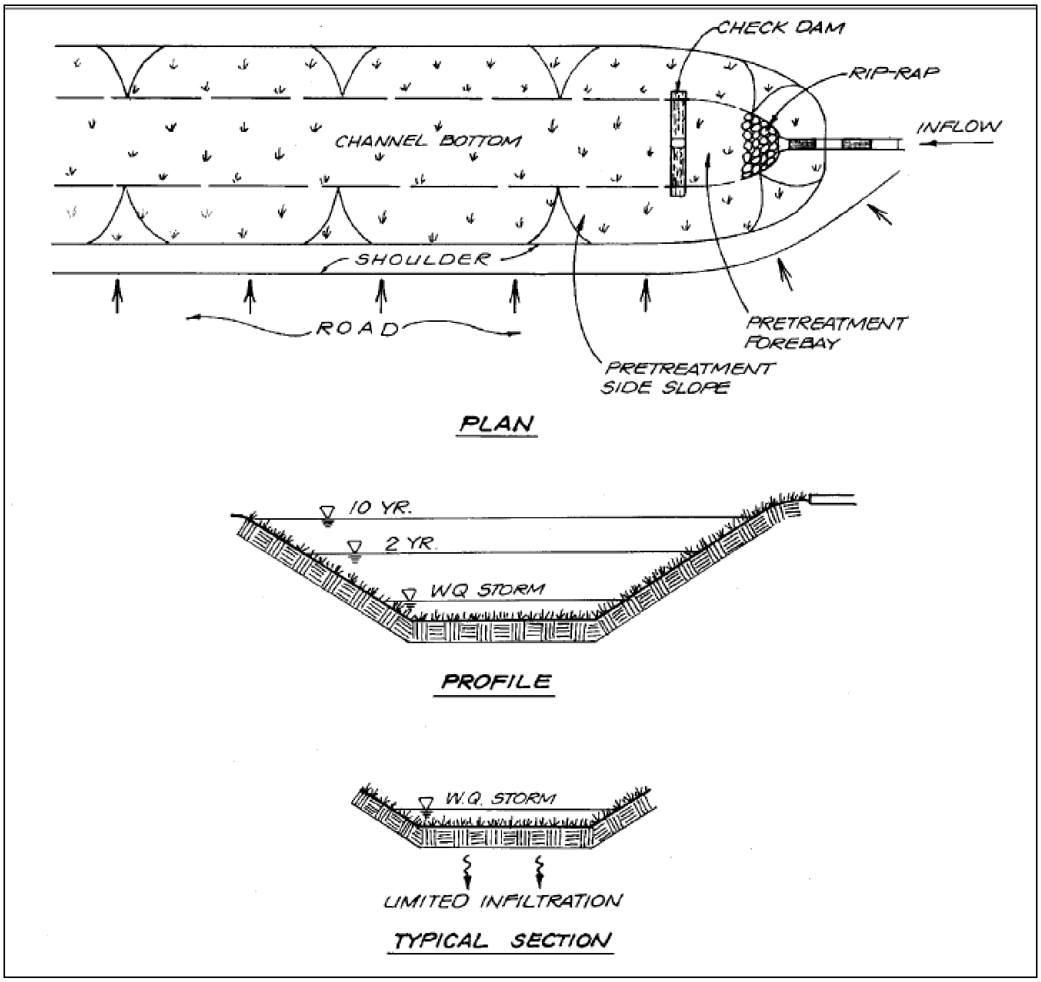
Applications

Enhanced grass swales are well suited for conveying and treating runoff from highways and other roads because they are a linear practice and easily incorporated into road rights-of-way. They are also a suitable practice for managing runoff from parking lots, roofs and pervious surfaces, such as yards, parks and landscaped areas. Grass swales can be used as snow storage areas.

Grass swales can also provide pretreatment for other stormwater best management practices, such as bioretention areas, soakaways and perforated pipe systems or be designed in series with other practices as part of a treatment train approach. They are often impractical in densely developed urban areas because they consume a large amount of space. Where development density and topograph permit, grass swales can be used in place of conventional curb and gutter and storm drain systems.

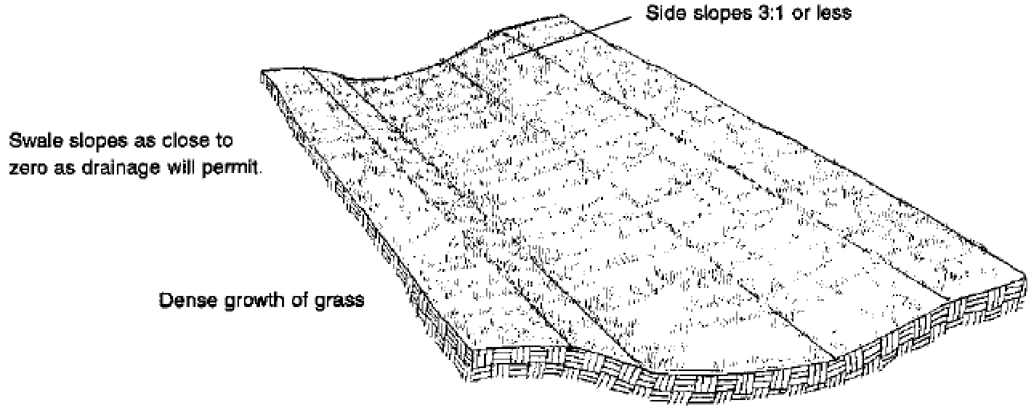
Typical Details

Figure 4.8.3 Plan, profile, and section views of a grass swale



Source: ARC, 2001

Figure 4.8.4 Plan view of a grass swale



Source: ARC, 2001

Design Guidance

Geometry and Site Layout

Design guidance regarding the geometry and layout of grass swales is provided below.

- *Shape:* Grass swales should be designed with a trapezoidal or parabolic cross section. Trapezoidal swales will generally evolve into parabolic swales over time, so the initial trapezoidal cross section design should be checked for capacity and conveyance assuming it is a parabolic cross section. Swale length between culverts should be 5 metres or greater.

- *Bottom Width:* Grass swales should be designed with a bottom width between 0.75 and 3.0 metres. The design width should allow for shallow flows and adequate water quality treatment, while preventing flows from concentrating and creating gullies.

- *Longitudinal Slope:* Slopes should be between 0.5% and 4%. Check dams should be incorporated on slopes greater than 3% (PDEP, 2006).

- *Length*: When used to convey and treat road runoff, the length simply parallels the road, and therefore should be equal to, or greater than the contributing roadway length.

- *Flow Depth:* The maximum flow depth should correspond to two-thirds the height of the vegetation. Vegetation in some grass swales may reach heights of 150 millimetres; therefore a maximum flow depth of 100 millimetres is recommended during a 4 hour, 25 mm Chicago storm event.

- *Side Slopes:* The side slopes should be as flat as possible to aid in providing pretreatment for lateral incoming flows and to maximize the swale filtering surface. Steeper side slopes are likely to have erosion gullying from incoming lateral flows. A maximum slope of 2.5:1 (H:V) is recommended and a 4:1 slope is preferred where space permits.

Pretreatment
A pea gravel diaphragm located along the top of each bank can be used to provide pretreatment of any stormwater runoff that may be entering the swale laterally along its length. Vegetated filter strips or mild side slopes (3:1) also provide pretreatment for any lateral sheet flow entering the swale. Sedimentation forebays at inlets to the swale are also a pretreatment option.

Conveyance and Overflow
Grass swales must be designed for a maximum velocity of 0.5 m/s or less for the 4 hour 25 mm Chicago storm. The swale should also convey the locally required design storm (usually the 10 year storm) at non-erosive velocities.

Soil Amendments
If soils along the location of the swale 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.

Landscaping
Designers should choose grasses that can withstand both wet and dry periods as well as relatively high velocity flows within the swale. For applications along roads and parking lots, where snow will be plowed and stored, non woody and salt tolerant species should be chosen. Taller and denser grasses are preferable, though the species of grass is less important than percent coverage (Barrett *et al.*, 2004). Appendix B provides further guidance regarding suitable species and planting.

Other Design Resources
Section 4.9.8 of the OMOE *Stormwater Management Planning and Design Manual* (2003) provides further guidance regarding design and modelling performance of enhanced grass swales. Several other stormwater manuals that provide useful design guidance for grass swales include:

Minnesota Stormwater Manual
http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Virginia Stormwater Management Handbook
http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml

Georgia Stormwater Management Manual
http://www.georgiastormwater.com/

BMP Sizing

Enhanced grass swale designs are flow rate based. The swale should be designed for a maximum flow velocity of 0.5 m/s and flow depth of 100 mm during a 4 hour 25 mm Chicago storm event. The suggested Manning's n for use in Manning's equation is 0.027 (grass swale) to 0.050 (shrub vegetated or cobble lined swale). Given typical urban swale dimensions (0.75 m bottom width, 2.5:1 side slopes and 0.5 m depth), the contributing drainage area is generally limited to ≤ 2 hectares to maintain flow ≤ 0.15 m^3/s and velocity ≤ 0.5 m/s. Table 4.8.4 describes the relationship between imperviousness of the development and maximum drainage area that can be treated by a grass swale.

Table 4.8.4 Grassed swale drainage area guidelines

Percent Imperviousness	Maximum Drainage Area (hectares)
35	2.0
75	1.5
90	1.0

Source: OMOE, 2003.

For further guidance regarding BMP sizing, refer to the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Design Specifications

Recommended design specifications for enhanced grass swales are provided in Table 4.8.5

Table 4.8.5 Design specifications for enhanced grass swales

Component	Specification	Quantity
Check Dams	Check dams should be constructed of a non-erosive material such as suitably sized aggregate, wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.	Spacing should be based on the longitudinal slope and desired ponding volume
Pea Gravel Diaphragm	Washed stone between 3 and 10 mm in diameter.	Minimum of 300 mm wide and 600 mm deep

Construction Considerations

Grass swales should be clearly marked before site work begins to avoid disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within the swale site. Any accumulation of sediment that does occur within the swale must be removed during the final stages of grading to achieve the design cross section. Final grading and planting should not occur until the adjoining areas draining into the swale are stabilized. Flow should not be diverted into the swale until the banks are stabilized.

Preferably, the swale should be planted in the spring so that the vegetation can become established with minimal irrigation. Installation of erosion control matting or blanketing to stabilize soil during establishment of vegetation is highly recommended. If sod is used, it should be placed with staggered ends and secured by rolling the sod. This helps to prevent gullies.

4.8.3 Maintenance and Construction Costs

Inspection and Maintenance

Maintenance requirements for enhanced grass swales is similar to vegetated filter strips and typically involve a low level of activity after vegetation becomes established. Grass channel maintenance procedures are already in place at many municipal public works and transportation departments. These procedures should be compared to the recommendations below (Table 4.8.6) to assure that the infiltration and water quality benefits of enhanced grass swales are preserved. Routine roadside ditch maintenance practices such as scraping and re-grading should be avoided at swale locations. Vehicles should not be parked or driven on grass swales. For routine mowing, the lightest possible mowing equipment should be used to prevent soil compaction.

For swales located on private property, the property owner or manager is responsible for maintenance as outlined in a legally binding maintenance agreement. Roadside swales in residential areas generally receive routine maintenance from homeowners who should be advised regarding recommended maintenance activities.

Table 4.8.6 Typical inspection and maintenance activities for enhanced grass swales

Activity	Schedule
▪ 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.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years while vegetation is becoming established; ▪ Mow grass to maintain height between 75 to 150 mm; ▪ Remove trash and debris from pretreatment devices, the swale surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Replace dead vegetation, remove invasive growth, dethatch, remove thatching and aerate (PDEP, 2006; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the swale surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the swale, regrading and revegetating may be required.	Annually or as needed

Installation and Operation Costs
In study by the Center for Watershed Protection to estimate and compare construction costs for various stormwater BMPs, the median base construction cost for grass swales was estimated to be $44,850 (2006 USD) per impervious hectare treated with estimates ranging from $26,935 to $89,700 (CWP, 2007b). These estimates do not include design and engineering costs, which could range from 5 to 40% of the base construction cost, nor land acquisition costs (CWP, 2007b). However, since grass swales serve as a conveyance measure, their cost is offset by the savings in curb and gutter, inlets, and storm sewer pipe as well as the reduction in other stormwater best management practices needed.

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4.9 Dry Swales

4.9.1 Overview

Description
A dry swale can be thought of as an enhanced grass swale that incorporates an engineered soil (*i.e.*, filter media or growing media) bed and optional perforated pipe underdrain or a bioretention cell configured as a linear open channel (Figure 4.9.1). 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 components. 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. Dry swales may be planted with grasses or have more elaborate landscaping (Figure 4.9.1).

Figure 4.9.1 Dry swales can be vegetated with turf grass or more elaborate vegetation

Source: SVR Design (left); Seattle Public Utilities (right)

Common Concerns
If properly designed and maintained, dry swales can provide stormwater treatment while accenting the natural landscape and providing improved site aesthetics. Concerns associated with their use should be addressed through design and may include:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):

- o 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);
- o prioritize infiltration of runoff from source areas that are comparatively less contaminated such as roofs, low traffic roads and parking areas; and,
- o apply sedimentation pretreatment practices (*e.g.*, vegetated filter strip, pea gravel diaphragm, sedimentation forebay) 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 more than 10 years of operation (TRCA, 2008).

- *On Private Property*: If dry swales are installed on private lots, 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 (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices. Alternatively, dry swales 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.

- *Maintenance*: The major maintenance requirement associated with dry swales is mowing or trimming vegetation. Occasionally, sediment will need to be removed, although this can be minimized by ensuring that upstream areas are stabilized and incorporating pretreatment devices (*e.g.*, vegetated filter strips, sedimentation forebays, gravel diaphragms).

- *Erosion:* Erosion can be prevented by limiting the allowable longitudinal slope and incorporating check dams. Additionally, designers can provide permanent reinforcement matting for swales with high velocity and temporary matting during the vegetation establishment period.

- *Standing Water and Mosquitoes:* Properly designed dry swales will not pond water at the surface for longer than 24 hours following a storm event. However, poor design, installation, or maintenance can lead to nuisance conditions.

Physical Suitability and Constraints
Dry swales can be implemented on a variety of development sites where development density, topography and depth to water table permit their application. Some key constraints for dry swales include:

- *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:* Dry swale footprints are approximately 5 to 15% of their contributing drainage area. When applied to residential areas, the swale segments between driveways should be at least 5 metres in length.

- *Site Topography:* Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%, and no greater than 6% (PDEP, 2006). On slopes steeper than 3%, check dams should be used.

- *Water Table:* Designers should ensure that the bottom of the swale is separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre to prevent groundwater contamination.

- *Soils:* 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 using the methods described in Appendix C.

- *Drainage Area and Runoff Volume to Site:* Dry swales typically treat drainage areas of less than two hectares. If dry swales are used to treat larger areas, the velocity through the swale becomes too great to treat runoff or prevent erosion. Typical ratios of impervious drainage area to dry swale area range from 5:1 to 15:1.

- *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 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.

- *Setbacks from Buildings:* Dry swales should be setback four (4) metres from building foundations. When located within 3 metres of building foundations, an impermeable liner and perforated pipe underdrain system should be 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. It is feasible for on-site utilities to cross dry swales; however, this may require the use of special protection (*e.g.*, double-casing) for the subject utility line.

Typical Performance

The ability of various dry swale design variations to help meet stormwater management objectives is summarized in Table 4.9.1.

Table 4.9.1 Ability of dry swales 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 infiltration rates
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

Water Balance

Limited data are available to define the typical runoff reduction rate for dry swales. Since they incorporate many of the same design elements, dry swales can be expected to perform similar to bioretention cells (Table 4.9.2).

Water Quality - Pollutant Removal Capacity

While few field studies of the pollutant removal capacity of dry swales are available from cold climate regions like Ontario, it can be assumed that they would perform similar to bioretention facilities (see Section 4.5.1). Bioretention provides effective removal for many pollutants as a result of sedimentation, filtering, plant uptake, soil adsorption, and microbial processes. It is important to note that there is a relationship between the water balance and water quality functions. If a dry swale infiltrates and evaporates 100% of the flow from a site, then there is essentially no pollution leaving the site in surface runoff. Furthermore, treatment of infiltrated runoff will continue to occur as it moves through the native soils.

Table 4.9.2 Volumetric runoff reduction1 achieved by dry swales

LID Practice	Location	Runoff Reduction[1]	Reference
Dry Swale without underdrain	Washington	98%	Horner *et al.* (2003)
	United Kingdom	94%	Jefferies (2004)
Dry Swale with underdrain	Maryland	46 to 54%	Stagge (2006)
Bioretention without underdrain	Connecticut	99%	Dietz and Clausen (2006)
	Pennsylvania	80%	Ermilio (2005)
	Pennsylvania	70%	Emerson and Traver (2004)
Bioretention with underdrain	Ontario	58%	TRCA (2008b)
	North Carolina	40 to 60%	Smith and Hunt (2007)
	North Carolina	33 to 50%	Hunt and Lord (2006)
	Maryland and North Carolina	20 to 50%	Li *et al.* (2009)
Runoff Reduction Estimate[2]		**85% without underdrain; 45% with underdrain**	

Notes:

1. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional impervious surface over the period of monitoring.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Performance results from both laboratory and field studies indicate that bioretention systems have the potential to be one of the most effective BMPs for pollutant removal (TRCA, 2009b). Excellent pollutant removal rates have been observed through field studies for total suspended solids (Roseen *et al.*, 2009), polycyclic aromatic hydrocarbons (TRCA, 2008b; Diblasi *et al.*, 2009), and metals (Davis *et al.*, 2003; Hunt *et al.*, 2006; Roseen *et al.*, 2006; Davis, 2007; TRCA, 2008b). Good removal rates for metals have even been observed in bioretention facilities receiving snow melt that contains de-icing salt constituents (Muthanna *et al.*, 2007).

Field investigations of nutrient removal by bioretention facilities have produced more variable results (TRCA, 2009b). Some facilities have been observed to increase total phosphorus in infiltrated water (Dietz and Clausen, 2005; Hunt *et al.*, 2006; TRCA, 2008b). These findings have been attributed to leaching from the filter media soil mixture which contained high phosphorus content. To avoid phosphorus export, the phosphorus content (*i.e.*, Phosphorus Index) of the filter media soil mixture should be examined and kept between 10 to 30 ppm (Hunt and Lord, 2006). While moderate reductions in total nitrogen and ammonia nitrogen have been observed in laboratory studies (Davis *et al.*, 2001) and field studies (Dietz and Clausen, 2005), nitrate nitrogen has consistently observed to be low.

Little data exists on the ability of bioretention to reduce bacteria concentrations, but preliminary results report good removal rates for fecal coliform bacteria (Rusciano and Obropta, 2005; Hunt *et al.*, 2008; TRCA, 2008b).

Several factors that can greatly increase or decrease the pollutant removal capacity of dry swales are provided in Table 4.9.4.

Table 4.9.3 Factors that influence the pollutant removal capacity of dry swales

Factors that Reduce Removal Rates	Factors that Enhance Removal Rates
Longitudinal slope > 3%	Longitudinal slope between 0.5 to 3%
Measured soil infiltration rate is less than 15 mm/hr	Measured soil infiltration rate is 15 mm/hr or greater
Filter media P-Index values ≥ 30 ppm[1]	Filter media P-Index values < 30 ppm[1]
Flow velocity within swale > 0.5 m/s during a 4 hour, 25 mm Chicago storm event	Flow velocity within swale is 0.5 m/s or less during a 4 hour, 25 mm Chicago storm event
No pretreatment	Pretreatment with vegetated filter strips, gravel diaphragms and/or sedimentation forebays
Swale side slopes steeper than 3:1 (H:V)	Swale side slopes 3:1 (H:V) or less

Notes:
1. P-index values refers to phosphorus soil test index values in parts per million (ppm). See www.omafra.gov.on.ca for information on soil testing and a list of accredited soil laboratories.

Stream Channel Erosion Control

While most dry swales are not designed to provide channel erosion control storage volume, the high degree of runoff reduction reported in performance monitoring studies suggests that they have the potential to protect downstream channels from erosion. If space is available, they may be designed for extended detention.

4.9.2 Design Template

Applications

The linear nature of dry swales makes them well-suited to treat road runoff as they can be incorporated into road rights-of-way (see Figure 4.9.2). They are also a suitable practice for managing runoff from parking lots, roofs and pervious surfaces, such as yards, parks and landscaped areas. Dry swales can be used for storing and treating snow from the contributing drainage area.

Dry swales require a considerable amount of space, often making them impractical in densely developed urban areas. Where development density, topography and depth to water table permit, dry swales can be used to provide stormwater conveyance in place of conventional curb and gutter and storm drain systems.

Dry swales vary in appearance based on the type of vegetation. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees (Figure 4.9.2).

Figure 4.9.2 Dry swales are well suited to road rights-of-way and parking lots

Source: City of Portland (left); Lake County Illinois (centre); Portland Public Schools (right)

Design Guidance

Geometry and Site Layout

Design guidance regarding the geometry and layout of dry swales is provided below:

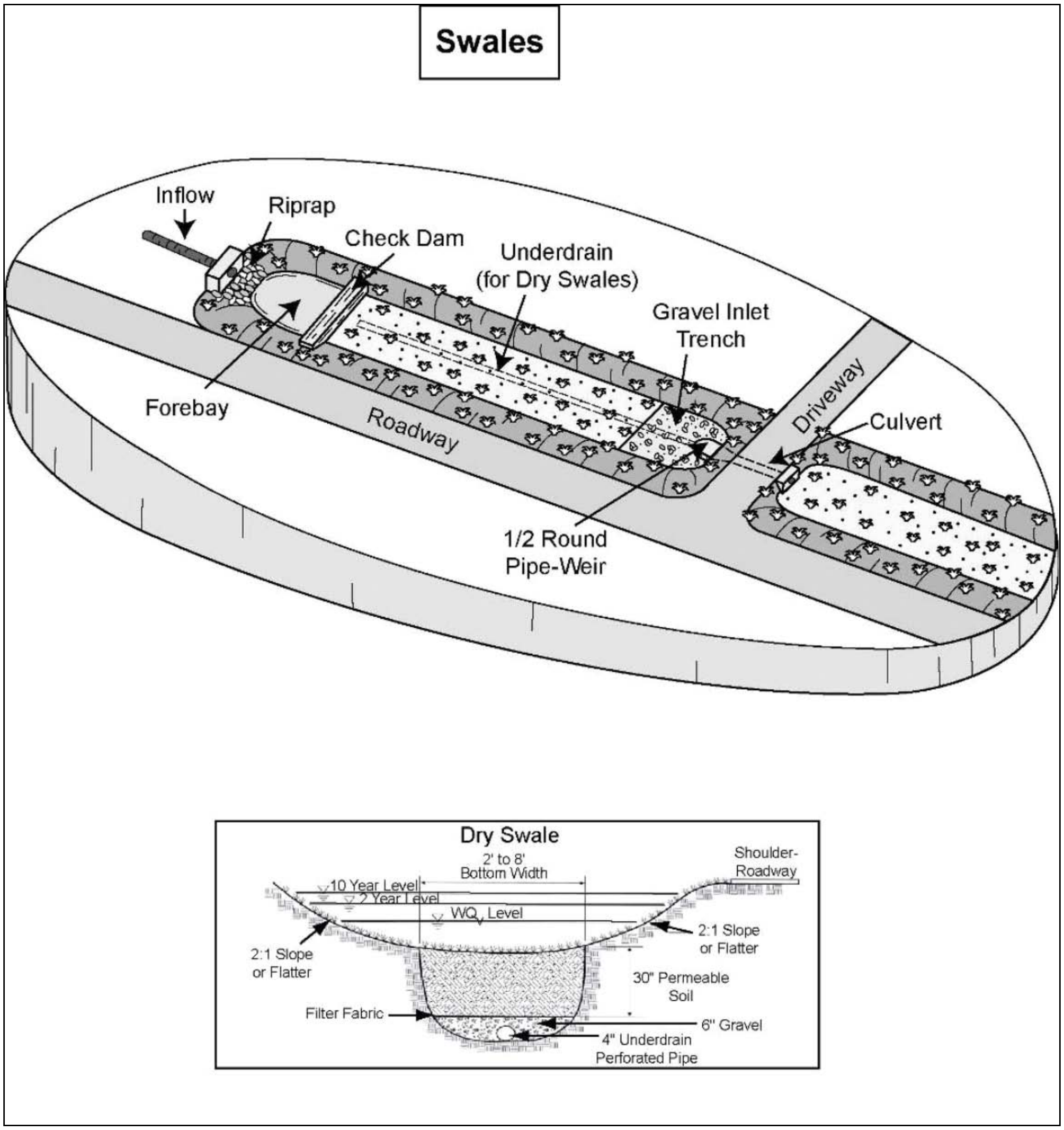
- *Shape:* A parabolic shape is preferable for aesthetic, maintenance and hydraulic reasons. However, design may be simplified with a trapezoidal cross section as long as the engineered soil (filter media) bed boundaries lay in the flat bottom areas. Swale length between culverts should be 5 metres or greater.
- *Bottom Width:* For the trapezoidal cross section, the bottom width should be between 0.75 and 3 metres. When greater widths are desired, bioretention cell designs (Section 4.5) should be used.

- *Side Slopes:* The side slopes of the channel should be no steeper than 3:1 for maintenance considerations (mowing). Flatter slopes are encouraged where adequate space is available to aid in providing pretreatment for sheet flows entering the swale.

- *Longitudinal Slope*: The slope of the swale should be as gradual as possible to permit the temporary ponding of the water quality storage requirement. Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%. 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).

Typical Details

Figure 4.9.3 Schematic of a dry swale



Also see Figure 4.10 from the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Pretreatment

Pretreatment devices capture and remove coarse sediment particles before they reach the engineered soil (*i.e.*, filter media) bed to prevent premature clogging and prolong effective function of dry swales. A two-cell design that incorporates a sedimentation forebay is recommended as it provides the most-effective pretreatment. Several pretreatment measures are feasible, depending on the method of conveyance and the drainage area:

- *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. This pre-treatment device is the most effective and has the easiest sediment-removal mechanism.

- *Grass filter strip (sheet flow):* These grass strips should ideally be a minimum of three metres in width. However, space constraints at some sites prohibit this width. If smaller strips are used, more frequent maintenance of the filter bed can be anticipated.

- *Gravel diaphragm (sheet flow):* A gravel diaphragm at the end of pavement should run perpendicular to the flow path to promote settling. The pea gravel diaphragm (a small trench running along the top of the dry swale) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow into the dry swale. If the contributing drainage area is steep, then larger stone should be used in the diaphragm._ A 50 to 150 mm drop from a hard-edged surface into a gravel or stone diaphragm can be used to dissipate energy and promote settling.

- *Rip rap and/or dense vegetation (channel flow):* These energy dissipation techniques are acceptable as pre-treatment on small swales with a drainage area of less than 100 square metres.

Conveyance and Overflow
Dry swales 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.

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*: The recommended bioretention filter media soil mixture is:

Component	Percent by Weight
Sand (2.0 to 0.050 mm dia.)	85 to 88 %
Fines (< 0.050 mm dia.)	8 to 12 %
Organic matter	3 to 5 %

  To ensure a consistent and homogeneous bed, filter media should come pre-mixed from an approved vendor. The filter media soil mixture should have the following properties:

  - The recommended Phosphorus soil test (P- index) value is between 10 to 30 ppm (Hunt and Lord, 2006). Visit the Ontario Ministry of Agriculture, Food, and Rural Affairs website (www.omafra.gov.on.ca) for information on soil testing and a list of accredited soil laboratories.
  - Soils with cationic exchange capacity (CEC) exceeding 10 milliequivalents per 100 grams (meq/100 g) are preferred for pollutant removal (Hunt and Lord, 2006).
  - The mixture should be free of stones, stumps, roots, or other similar objects larger than 50 mm.
  - For optimal plant growth, the recommended pH is between 5.5 to 7.5. Lime can be used to raise the pH, or iron sulphate plus sulphur can be used to lower the pH. The lime and iron sulphate need to be uniformly mixed into the soil (Low Impact Development Center, 2003a).
  - The media should have an infiltration rate of greater than 25 mm/hr.

  One adaptation is to design the media as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the plants. If grass is the only vegetation, the ratio of compost may be reduced (Hirschman, 2008; Smith and Hunt, 2007).

- *Depth:* The recommended filter bed depth is between 1.0 and 1.25 metres. However, in constrained applications, pollutant removal benefits may be achieved in filter beds as shallow as 500 millimetres. (Davis *et al*., 2009; and Hunt *et al.,* 2006). If trees are included in the bioretention design, then the filter bed depth must be at least 1.0 metre and have soil volume to accommodate the root structure of mature trees. A minimum of 12 cubic metres of shared root space is recommended for healthy canopy trees. Use perennials, shrubs or grasses instead of trees when landscaping shallower filter beds.

- *Mulch:* A 75 millimetre layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter bed. Shredded hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away. The mulch layer also plays a key role in the removal of heavy metals, sediment, and nutrients (Davis *et al*., 2001; Davis *et al*., 2003; Davis *et al*., 2006; Dietz and Clausen, 2006; Hunt, 2003; and Hsieh and Davis, 2005). Alternately, temporary or permanent erosion control matting can be used in lieu of the mulch layer. The matting should be coconut fiber or another durable material, and should be installed prior to the landscaping. Matting is recommended where flow velocities would likely wash the mulch away.

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 of the gravel storage layer.
- HDPE or equivalent material perforated pipes with smooth interior walls should be used. Pipes should be over-sized to accommodate freezing conditions. A minimum 200 mm diameter underdrain is recommended for this reason (MPCA, 2005). Underdrains should be capped on the upstream end(s).
- 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. Table 4.5.7 provides further detail regarding geotextile specifications.
- A vertical standpipe connected to the underdrain can be used as a cleanout and monitoring well.

Landscaping

Designers should choose grasses, herbaceous plants, or trees that can withstand both wet and dry periods as well as relatively high velocity flows within the swale. Where possible a combination of native trees, shrubs and perennial herbs should be used in addition to grasses. For applications along roads and parking lots, where snow may be plowed or stored, non-woody and salt tolerant species should be chosen. A list of native plant species suitable for dry swale applications and direction on picking the right plants is provided in Appendix B.

Other Details

Check dams or weirs may be used to obtain the necessary water quality storage volume. The check dams should be spaced based on the longitudinal slope and ponding requirements, while considering the maximum ponding depth. Check dams should be composed of wood or stone. Alternatively, driveway culverts can be used for this purpose.

In urban settings, trash accumulation and pedestrian traffic call for special consideration. Consider the following adaptations:

- To protect vegetation and prevent soil compaction, fencing (low, wrought iron fences), low walls, bollards and chains, curbs, and constructed walkways can be incorporated.
- Trash racks can be installed between pretreatment devices and the swale or across curb cuts.

Other Design Resources
Several other manuals that provide useful design guidance for dry swales are:

Center for Watershed Protection (CWP). 2007b. Urban Stormwater Retrofit Practices: Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD.

Ontario Ministry of the Environment (OMOE). 2003. Stormwater Management Planning and Design Manual. Ontario, Canada.

BMP Sizing
The surface channel component of dry swales should be designed for a maximum flow velocity of 0.5 m/sec. during the 25 mm, 4 hour Chicago storm event over the drainage area.

The sizing methodology for the filter media bed component of dry swales is the same as that for bioretention practices. The depth of a dry swale filter media bed designed for full infiltration (i.e., no underdrain) is dependent on the native soil infiltration rate, porosity (void space ratio) of the filter bed and gravel storage layer media (i.e, aggregate material used in the stone reservoir) and the targeted time period to achieve complete drainage between storm events. Assuming a void space ratio of 0.4 for both the filter bed and gravel storage layer media, the maximum allowable depth of the filter bed can be calculated using the following equation:

$$d_{b\ max} = i * (t_s - d_p / i) / V_r$$

Where:

$d_{b\ max}$ = Maximum filter media bed depth (mm)
i = Infiltration rate for native soils (mm/hr)
V_r = Void space ratio for filter bed and gravel layer (assume 0.4)
t_s = Time to drain (design for 48 hour time to drain is recommended)
d_p = Maximum surface ponding depth (mm)

For designs that include an underdrain, the filter media bed should be 1 to 1.25 metres in depth. The following equation can be used to determine the maximum depth of the stone reservoir below the invert of the underdrain pipe:

$d_{r\,max} = i * t_s / V_r$

Where:

$d_{r\,max}$ = Maximum depth of stone reservoir below the underdrain pipe

The value for native soil infiltration rate (i) used in the above equations should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2). For designs with no underdrain that are located on less permeable soils, a minimum filter bed depth of 0.5 metres is recommended to ensure water quality benefits will be achieved. For designs with filter bed depths less than 1 metre, a maximum surface ponding depth of 85 to 100 mm is recommended.

Once the depth of the filter media bed is determined the water quality volume, computed using the methods in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010), can be used to determine the footprint needed using the following equation:

$A_f = WQV / (d_b * V_r)$

Where:

A_f = Footprint surface area (m^2)
WQV = Water quality volume (m^3)
d_b = Filter media bed depth (m)
V_r = Void space ratio for filter bed and gravel layer (assume 0.4)

The ratio of impervious drainage area to footprint surface area of the practice should be between 5:1 and 15:1 to limit the rate of accumulation of fine sediments and thereby prevent clogging.

Design Specifications

Recommended design specifications for dry swales are provided in Table 4.9.4.

Table 4.9.4 Design specifications for dry swales

Component	Specification	Quantity
Filter Media Composition	Filter Soil Mixtures to contain: ▪ 85 to 88% sand ▪ 8 to 12% soil fines ▪ 3 to 5% organic matter in form of leaf compost Other Criteria: ▪ Phosphorus soil test (P-Index) value 10 to 30 ppm ▪ Cationic exchange capacity (CEC) greater than 10 meq/100 g ▪ pH between 5.5 to 7.5	Recommended depth is between 1.0 and 1.25 metres. Alternative depths may be appropriate in constrained applications. Volumetric computation based on surface area and depth used in design computations.

Component	Specification	Quantity
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; - Texture (*i.e.*, grain size distribution) of the overlying native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): <u>Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA)</u> For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) <u>Hydraulic Conductivity (k, in cm/sec)</u> k (fabric) > k (soil) <u>Permittivity (in sec^{-1})</u> Where,	Between the filter media bed and gravel storage layer (stone reservoir).

Component	Specification	Quantity
	Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	
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 swale where required. ▪ Non-perforated pipe as needed to connect with storm drain system. ▪ One or more caps. ▪ T's for underdrain configuration.
Check Dams	▪ Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. ▪ Wood used for check dams 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	▪ Mulch should be shredded hardwood bark at least 75 mm deep. ▪ Where flow velocities dictate, use erosion and sediment control matting – coconut fiber or equivalent.	▪ A 75 mm layer on the surface of the filter bed. ▪ Matting – based on surface area of filter bed.

Construction Considerations

Sequencing

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 sediment from clogging the surface of a dry swale, stormwater should be diverted away from the practice until the drainage area is fully stabilized.

The construction sequence for dry swales is similar to that used for bioretention (for further details see section 4.5). Three key steps should be emphasized. First, the contributing drainage area has been fully stabilized prior to dry swale construction. Second, designers should check elevations at driveway culverts and check dams to ensure ponding depths are achieved. Lastly, the swale channel and side slopes should be rapidly stabilized using biodegradable geotextile blankets and seeding before bringing the swale “on line”.

Construction Inspection

Common construction pitfalls can be avoided by careful construction supervision that focuses on the following aspects:

Erosion and Sediment Control

- Dry swale locations should be blocked from construction traffic and should not be used for erosion and sediment control.
- Proper erosion and sediment controls should be in place for the drainage area during construction, including sediment fencing around the swale.

Materials

- Gravel for the underdrain should be clean and washed; no fines should be present in the material.
- Underdrain pipe material should be perforated and of the correct size.
- A cap should be placed on the upstream (but not the downstream) end of the underdrain.
- Filter media should be tested to confirm that it meets specifications.
- Mulch composition should be correct.
- Matting, if used, should be correct specification, and durable enough to last at least 2 growing seasons.

Elevations

Elevations of the following items should be checked for accuracy:

- Depth of the gravel and invert of the underdrain
- Inverts for inflow and outflow points
- Filter depth after media is placed
- Ponding depth provided between the surface of the filter bed and the overflow structure
- Mulch depth

Landscaping and Stabilization

- Correct vegetation should be planted.
- Pretreatment area should be stabilized.
- Drainage area should be stabilized prior to directing water to the swale.

The following items should be checked after the first rainfall event, and adjustments should be made as necessary:

- Sheet flow should occur as designed.
- Outfall protection/energy dissipation at concentrated inflow should be stable.
- Ponded water on the surface of the swale should drain within 24 hours of the end of the storm event. The filter media bed should fully drain within 72 hours.
- Sediment accumulation should not be present.

4.9.3 Maintenance and Construction Costs

Inspection and Maintenance

Maintenance of dry swales mostly involves maintenance of the vegetative cover as well as periodic inspection for less frequent maintenance needs. Generally, routine maintenance will be the same for any other landscaped area; weeding, pruning, mowing and litter removal. Inspections annually and after every major storm event (> 25 mm), will determine whether corrective action is necessary to address gradual deterioration or abnormal conditions.

For the first six months following construction, the site should be inspected after each storm event greater than 10 mm, or a minimum of twice. Subsequently, inspections should be conducted in the spring of each year and after rainfall events greater than 25 mm. Two or three growing seasons may be required to establish vegetation to the desired level. During this period, erosion and sediment control practices, such as mats or blankets, should be used to help protect swale structure.

The expected lifespan of infiltration practices is not well understood, however, it can be expected that it will vary depending on pretreatment practice maintenance frequency, and the sediment texture and load coming from the catchment.

Routine Inspection and Maintenance

Routine inspection and maintenance activities, as shown in Table 4.9.5, are necessary for the continued operation of dry swales. Suggested inspection items and corrective actions are provided in Table 4.9.6.

Table 4.9.5 Suggested routine inspection and maintenance activities for dry swales

Activity	Schedule
▪ 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.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years while vegetation is becoming established;	As needed for the first two years of operation.
▪ Mow grass to maintain height between 75 to 150 mm; ▪ Remove trash and debris from pretreatment devices, the swale surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth, dethatch, remove thatching and aerate (PDEP, 2006; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the swale surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the swale, regrading and revegetating may be required.	Annually or as needed

Table 4.9.6 Suggested inspection items and corrective actions for dry swales

Inspection Item	Corrective Actions
Vegetation health, diversity and density	• Remove dead and diseased plants. • Add reinforcement planting to maintain desired vegetation density. • Prune woody matter. • Check soil pH for specific vegetation. • Add mulch to maintain 75 mm layer.
Sediment build up and clogging at inlets	• Remove sand that may accumulate at the inlets or on the filter bed surface following snow melt. • Examine drainage area for bare soil and stabilize. Apply erosion control such as silt fence until the area is stabilized. • Check that pretreatment is properly functioning. For example, inspect filter strips for erosion or gullies. Reseed as necessary.
Ponding for more than 48 hours	• Check underdrain for clogging and flush out. • Apply core aeration or deep tilling • Mix amendments into the soil • Remove the top 75 mm of filter media soil • Replace filter media soil

Installation and Operation Costs

Very limited information is available regarding dry swale construction costs. Due to similarities in design, dry swale construction costs are likely comparable to those for bioretention. In a study by the Center for Watershed Protection to estimate and compare construction costs for various stormwater BMPs, the median base construction cost for bioretention was estimated to be $62,765 (2006 USD) per impervious hectare treated with estimates ranging from $49,175 to $103,165 (CWP, 2007b). These estimates do not include design and engineering costs, which could range from 5 to

40% of the base construction cost (CWP, 2007b). However, since dry swales serve as a conveyance measure, their cost is offset by the savings in curb and gutter, inlets, and storm sewer pipe as well as the reduction in other stormwater best management practices needed downstream.

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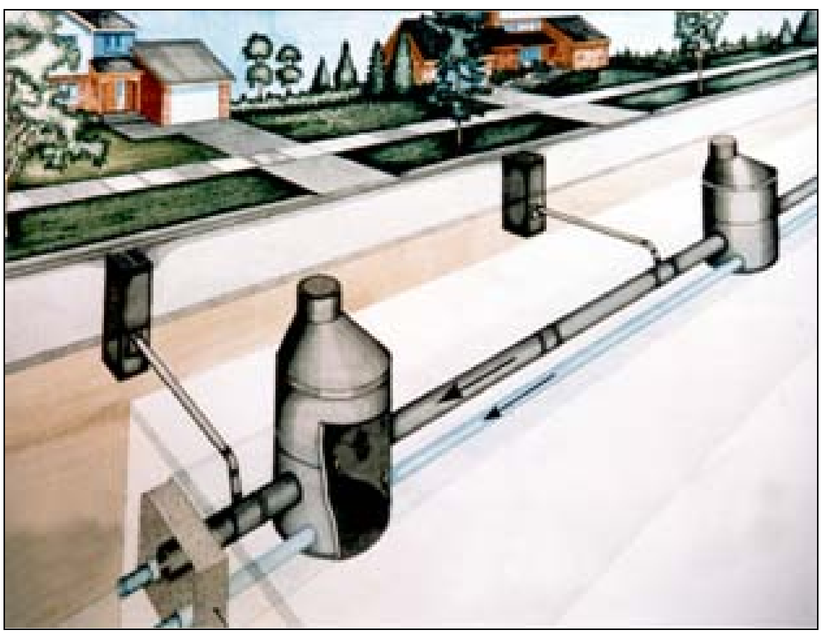
4.10 Perforated Pipe Systems

4.10.1 Overview

Description

Perforated pipe systems can be thought of as long infiltration trenches or linear soakaways that are designed for both conveyance and infiltration of stormwater runoff. They are underground stormwater conveyance systems designed to attenuate runoff volume and thereby, reduce contaminant loads to receiving waters. They are composed of perforated pipes installed in gently sloping granular stone beds that are lined with geotextile fabric that allow infiltration of runoff into the gravel bed and underlying native soil while it is being conveyed from source areas or other BMPs to an end-of-pipe facility or receiving waterbody. Perforated pipe systems can be used in place of conventional storm sewer pipes, where topography, water table depth, and runoff quality conditions are suitable. They are suitable for treating runoff from roofs, walkways, parking lots and low to medium traffic roads, with adequate pretreatment. A design variation can include perforated catchbasins, where the catchbasin sump is perforated to allow runoff to infiltrate into the underlying native soil. Perforated pipe systems can also be referred to as pervious pipe systems, exfiltration systems, clean water collector systems and percolation drainage systems.

Figure 4.10.1 Conceptual drawing of a perforated pipe system



Common Concerns

If properly located, designed and maintained, perforated pipe systems can greatly reduce runoff volume while having little or no surface footprint, which helps to conserve highly valued developable land. Some common concerns associated with their use that should be addressed through siting and design include:

- *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 (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):
    - 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; 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 more than 10 years of operation (TRCA, 2008).

- *Maintenance*: With proper location and adequate pretreatment, perforated pipe systems can continue to function effectively with very low levels of maintenance activities (J.F. Saborin and Associates, 2008a). Like conventional stormwater conveyance infrastructure (*i.e.*, catchbasins and storm sewers), perforated pipe systems are typically located on public property (*e.g.*, within road rights-of-way). An advantage to incorporating these systems in stormwater management systems is that legal agreements with property owners or managers, to ensure long term operation and maintenance, are not needed.

- *Standing Water and Mosquitoes*: The detention of water in a perforated pipe system should be solely underground.

- *Foundations and Seepage*: Perforated pipe systems should be setback at least four (4) metres from building foundations to prevent basement flooding and damage during freeze/thaw cycles.

- *Winter Operation*: Perforated pipe systems will continue to function during winter months if the inlet pipe and top of the gravel bed is located below the local maximum frost penetration depth (MTO, 2005).

Physical Suitability and Constraints
Key constraints to locating perforated pipe systems include:

- *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:* Perforated pipe systems should be located below shoulders of roadways, pervious boulevards or grass swales where they can be readily excavated for servicing. An adequate subsurface area outside of the four (4) metre setback from building foundations and suitable distance from other underground utilities must be available.

- *Site Topography:* Systems cannot be located on natural slopes greater than 15%. The gravel bed should be designed with gentle slopes between 0.5 to 1%.

- *Water Table:* Designers should ensure that the bottom of the gravel bed is separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre to prevent groundwater contamination.

- *Soils:* Underlying native soil conditions do not constrain the use of perforated pipe systems but greatly influence their runoff reduction performance. In order to predict facility performance so that downstream end-of-pipe facility designs can be adjusted accordingly, designers should verify the site-specific soil infiltration rates at the proposed facility locations and depths using the methods described in Appendix C.

- *Drainage Area:* Systems typically receive foundation drain water and runoff from roofs, walkways, roads and parking lots from multiple lots. They are typically designed with an impervious drainage area to treatment facility area ratio of between 5:1 to 10:1 (SWAMP, 2005).

- *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 perforated pipe systems.
- *Setbacks 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 perforated pipe systems near other underground utilities.

Typical Performance

Table 4.10.1 Ability of perforated pipe systems to meet SWM objectives

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Perforated Pipe Systems	Yes	Yes	Partial, depends on soil infiltration rate

Water Balance

The degree to which water balance objectives are met will depend on the underlying native soil type on which the system is located. Several Ontario studies have assessed the performance of perforated pipe systems in cold climates. Table 4.10.2 summarizes the runoff reduction benefits achieved.

Table 4.10.2 Volumetric runoff reduction[1] achieved by perforated pipe systems

LID Practice	Location	Native Soil Type	Runoff Reduction[1]	Reference
Grass swale/ Perforated pipe system	Nepean, Ontario	Silty till	73%	J.F. Sabourin and Associates (2008a)
Grass swale/ Perforated pipe system	Nepean, Ontario	Sandy Silty till	86%	J.F. Sabourin and Associates (2008a)
Perforated pipe system	Etobicoke, Ontario	Clay to clayey silt till over silty sand	95%	SWAMP (2005)
Perforated pipe system	North York, Ontario	Silty sand	89%	SWAMP (2005)
Runoff Reduction Estimate[2]		**85% on HSG A and B soils; 45% on HSG C and D soils.**		

Notes:
1. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional catchbasin and storm sewer system over the period of monitoring.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality – Pollutant Removal Capacity

Performance results from a limited number of field studies indicate that subsurface stormwater infiltration practices are effective BMPs for pollutant removal (TRCA, 2009b). These types of practices provide effective removal for many pollutants as a result of sedimentation, filtering, and soil adsorption. It is also important to note that there is a relationship between the water balance and water quality functions. If an infiltration practice infiltrates and evaporates 100% of the runoff from a site, then there is essentially no pollution leaving the site in surface runoff. Furthermore, treatment of infiltrated runoff continues to occur as it leaves the facility and moves through the native soil. The performance of perforated pipe systems would be expected to reduce pollutants in runoff in a manner similar to infiltration trenches. Table 4.4.3 summarizes pollutant removal results from performance studies of infiltration trenches and perforated pipe systems.

Several studies of perforated pipe systems in Ontario have examined their water quality benefits (Table 4.10.3). Seasonal contaminant load reductions in the order of 80% were observed for most constituents, with the exception of chloride, in the study of the system installed in a low density residential neighbourhood in Etobicoke (SWAMP, 2002; SWAMP, 2005). Perforated pipe systems that incorporate grassed swales as pretreatment have been observed to reduce loads of suspended sediment, phosphorus, nitrogen copper, lead and zinc in runoff flowing from the system between 75 to 90% in comparison to a similar catchment with conventional catchbasins and storm sewers (J.F. Sabourin and Associates, 1999; and 2008a). The Nepean systems were shown to release significantly less pollutants than the conventional sewer system, even after 20 years of operation (J.F. Sabourin and Associates, 2008a).

Table 4.10.3 Pollutant removal efficiencies[1] for soakaways, infiltration trenches and perforated pipe systems (in percent)

BMP	Reference	Location	Lead	Copper	Zinc	TSS[2]	TP[3]	TKN[4]
Soakaway	Barraud *et al.* (1999)	Valence, France	98	NT	54 to 88	NT	NT	NT
Infiltration trench	ASCE (2000)[5]	Various	70 to 90	70 to 90	70 to 90	70 to 90	50 to 70	40 to 70
Grass swale/ perforated pipe system	SWAMP (2002)	North York, Ontario	75	96	93	24	84	84
Grass swale/ perforated pipe system	J.F. Sabourin & Associates (2008a)	Nepean, Ontario	>99[6]	66	0	81	81	72
Grass swale/ perforated pipe system	J.F. Sabourin & Associates (2008a)	Nepean, Ontario	>99[6]	>99[6]	90	96	93	93

Notes:

NT = not tested

1. Pollutant removal efficiency refers to the pollutant load reduction from the inflow to the outflow (from an underdrain) of the practice, over the period of monitoring.
2. Total suspended solids (TSS)
3. Total phosphorus (TP)
4. Total Kjeldahl nitrogen (TKN)
5. Pollutant removal efficiencies are reported as ranges because they are based on a synthesis of several performance monitoring studies that were available as of 2000.
6. Concentrations at the outlet were below the detection limit.

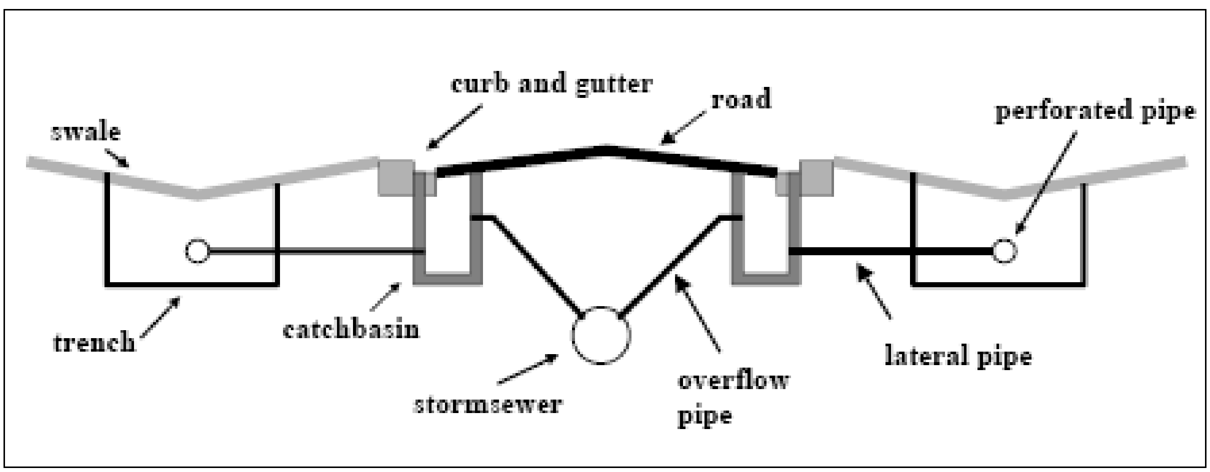
Stream Channel Erosion Control
While perforated pipe systems are not specifically designed to store the channel erosion control volume, their ability to reduce runoff volume should help protect downstream channels from erosion. The Nepean grass swale/perforated pipe systems were observed to reduce peak flow rates by 90% in 1998 (J.F. Sabourin and Associates, 1999) and by 47% and 86% in 2006 (J.F. Sabourin and Associates, 2008a).

4.10.2 Design Template

Applications
Like a conventional catchbasin and storm sewer pipe systems, perforated pipe systems typically receive foundation drain water and runoff from roofs, walkways, road and parking lots from multiple lots. They should not receive runoff from pollutant hot spots nor high traffic roads where large quantities of de-icing salts are spread during winter. Pretreatment of road runoff, which may contain high levels of suspended sediment, is necessary before it reaches the pervious pipes to reduce the risk of clogging and groundwater contamination. Like other subsurface SWM practices, (*e.g.*, soakaways, infiltration trenches and chambers), the majority of components associated with perforated pipe systems are located underground resulting in very small surface footprints. This makes them highly suited to high density development contexts (*i.e.*, ultra-urban areas) when being designed for new developments. Opportunities to retrofit high density development areas with perforated pipe systems will likely be highly constrained by proximity to building foundations and other underground utilities.

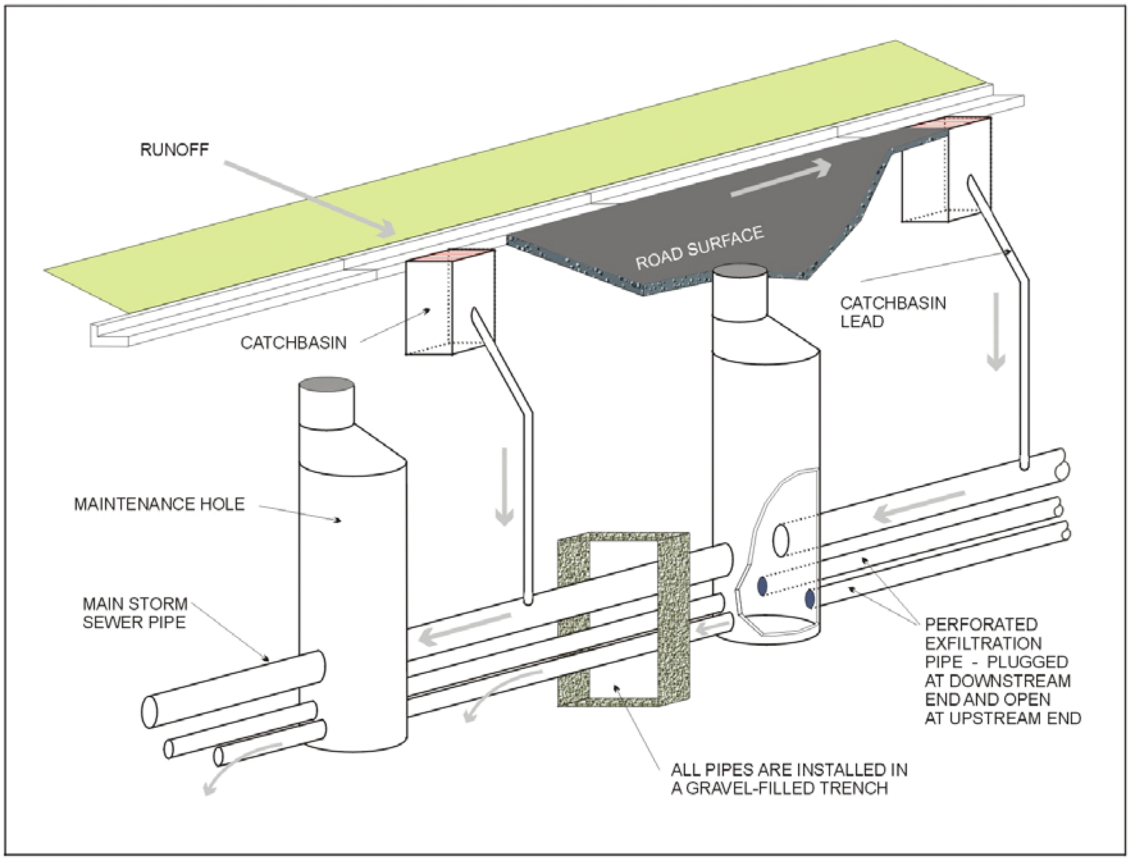
Typical Details
Schematics of different types of perforated pipe systems are provided in Figures 4.10.2 to 4.10.5. Planners should also refer to Figures 4.11 to 4.13 in the OMOE Stormwater Management Planning and Design Guideline (OMOE, 2003).

Figure 4.10.2 Simplified schematic of a perforated pipe system integrated with a grass swale



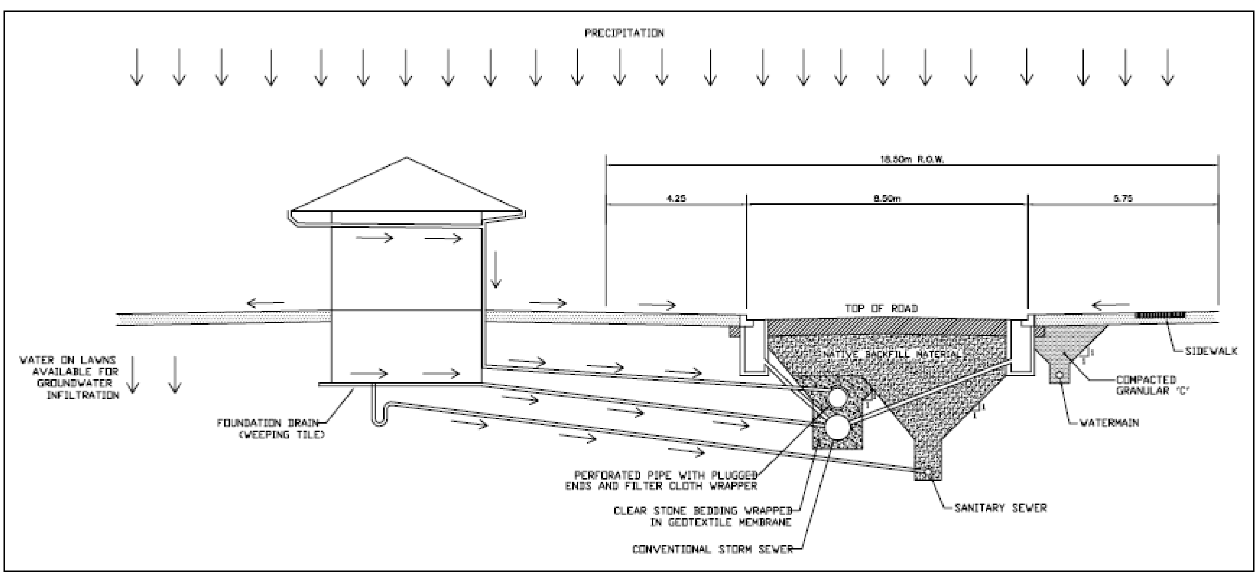
Source: SWAMP, 2005

Figure 4.10.3 Schematic of a perforated pipe system connected to catchbasins



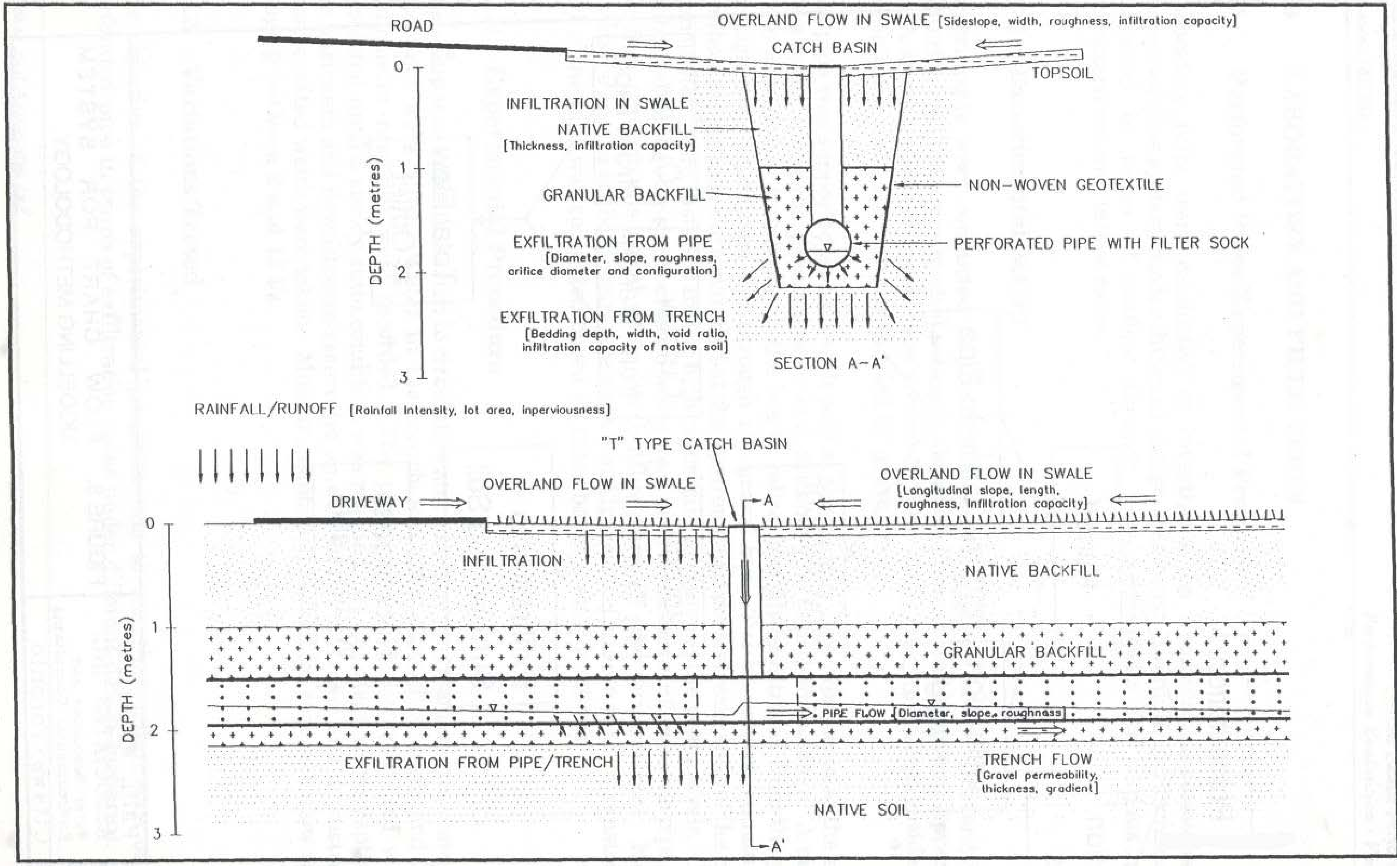
Source: SWAMP, 2005

Figure 4.10.4 Schematic of a perforated pipe system receiving roof runoff only



Source: Clarifica and Schaeffers, 2005

Figure 4.10.5 Schematic of perforated pipe system integrated with a grass swale



Source: Paul Wisner and Associates, 1994

Design Guidance

Soil Characteristics

Perforated pipe systems can be constructed over any soil type, but HSG A or B soils are best for achieving water balance objectives. If possible, facilities should be located in portions of the site with the highest native soil infiltration rates. Designers should verify site-specific soil infiltration rate at the proposed location and depth using the methods for on-site investigation presented in Appendix C.

Geometry and Site Layout

Gravel beds in which perforated pipe systems are installed are typically rectangular excavations with a bottom width between 600 and 2400 mm (GVRD, 2005). The gravel beds should have gentle slopes between 0.5 to 1%.

Pretreatment

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 pre-treatment 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. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the facility.

- *In-ground devices*: Devices placed between a conveyance pipe and the facility (*e.g.*, oil and grit separators, sedimentation chambers, goss traps), that can be designed to remove both large and fine particulate from runoff. A number of proprietary filter designs are also available. Like leaf screens, they require regular cleaning to ensure they do not become clogged.

- *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 perforated pipe system (*e.g.*, Figures 4.10.4 and 4.10.5). The swale could be designed as a simple grass channel, an enhanced grass swale (section 4.8) or dry swale (section 4.9).

Conveyance and Overflow

Collection and conveyance of runoff into the perforated pipe system can be accomplished through conventional catchbasins and non-perforated pipes leading from foundation drains and roof downspouts. Perforated pipes should be smooth walled. Smooth walled interior pipe is recommended because it reduces the potential for clogging and facilitates clean out in the event of excessive sediment accumulation (OMOE, 2003). A minimum diameter of 200 mm should be used to facilitate maintenance. The gravel filled trench should be 75 to 150 mm deep above the perforated pipe (OMOE, 2003). The depth of the gravel trench below the pipe is dependent on the volume of runoff to be infiltrated and the infiltration rate of the native soil material (see BMP Sizing section). On-line concrete, clay or plastic trench baffles or other barriers can be installed across the granular filled trench to reduce flow along the system, thereby increasing the retention volume and the potential for infiltration (J.F. Sabourin and Associates, 2008b). Overflows from the granular filled trench should either back up into manholes that are also connected to a conventional storm sewer (*e.g.*, Figures 4.10.2 and 4.10.5) or conveyed to a receiving waterbody by overland flow.

Filter Media

- *Gravel filled trench:* 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 perforated pipe systems 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. The primary function of the geotextile is separation between two dissimilar soils. When a finer grained soil overlies a coarser grained soil or aggregate layer (*e.g.*, stone reservoir), the geotextile prevents clogging of the void spaces from downward migration of soil particles. When a coarser grained aggregate layer (*e.g.*, stone reservoir) overlies a finer grained native soil, the geotextile prevents slumping from downward migration of the aggregate into the underlying soil. Geotextile may also enhance the capacity of the facility to reduce petroleum hydrocarbons in runoff, as microbial communities responsible for their decomposition tend to concentrate in geotextile fabrics (Newman *et al.*, 2006a). Specification of geotextile fabrics in perforated pipe systems 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. Table 4.10.4 provides further detail regarding geotextile specifications.

Other Details

As in conventional storm sewer systems, manholes should be must be installed to provide access to the system of pipes for inspection and maintenance activities.

Other Design Resources

Clarifica Incorporated and Schaeffers Consulting Engineers. 2005. *Clean Water Collector System Implementation Report - Block 12 Development Lands*, City of Vaughan. Ontario.

Greater Vancouver Regional District. 2005. *Stormwater Source Control Design Guidelines 2005*. Prepared by Lanarc Consultants Limited, Kerr Wood Leidal Associates Limited and Goya Ngan

J.F. Sabourin and Associates. 2008b. *Grass Swale and Perforated Pipe Drainage Systems Design Manual and Design Tool*. Prepared for the City of Ottawa, Infrastructure Management Division. Project No. 524 (01).

Ontario Ministry of the Environment. 2003. Stormwater Management Planning and Design Manual.

BMP Sizing

The gravel trench should be 75 to 150 mm deep above the perforated pipe. The depth of the trench below the pipe is dependent on the native soil infiltration rate, porosity (void space ratio) of the gravel storage layer media (i.e, aggregate material used in the stone reservoir) and the targeted time period to achieve complete drainage between storm events. The maximum allowable depth below the pipe can be calculated using the following equation:

$$d_{r\,max} = i * t_s / V_r$$

Where:

$d_{r\,max}$ = Maximum stone trench depth below pipe (mm)
i = Infiltration rate for native soils (mm/hr)
V_r = Void space ratio for aggregate used (typically 0.4 for 50 mm clear stone)
t_s = Time to drain (design for 48 hour time to drain is recommended)

The value for native soil infiltration rate (i) used in the above equation should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2). On highly permeable soils, a maximum stone reservoir depth of 2 metres is recommended to prevent soil compaction and loss of permeability from the mass of overlying stone and stored water.

Once the depth of the stone reservoir has been determined the water quality volume, computed using the methods in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010), can be used to determine the footprint needed using the following equation:

$$A_f = WQV / (d_r * V_r)$$

Where:

A_f = Footprint surface area (m^2)
WQV = Water quality volume (m^3)
d_r = Stone reservoir depth (m)
V_r = Void space ratio for aggregate used (typically 0.4 for 50 mm clear stone)

Further guidance regarding sizing of perforated pipe systems is provided in sections 4.5.10 and 4.9.4 of the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Design Specifications

Recommended design specifications for perforated pipe systems are provided in Table 4.10.4 below.

Table 4.10.4 Design specifications for perforated pipe systems

Component	Specification	Quantity
Perforated pipe	Pipe should be continuously perforated, smooth interior, with a minimum inside diameter of 200 millimetres.	Perforated pipe should run lengthwise through the facility at least 100 mm above the bottom of the gravel filled trench. Non-perforated pipe should be used for conveyance to the facility.
Stone	The trench in which perforated pipes are installed should be filled with 50 mm clear stone with a 40% void ratio.	Volume of the facility is calculated by methods referenced in the previous section of this guide.
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 native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): <u>Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA)</u> For fine grained soils with more than 85% of	Around the gravel filled trench (stone reservoir)

Component	Specification	Quantity
	particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) <u>Hydraulic Conductivity (k, in cm/sec)</u> k (fabric) > k (soil) <u>Permittivity (in sec^{-1})</u> Where, Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	

Construction Considerations

Erosion and sediment control and compaction are the main construction concerns.

- *Soil Disturbance and Compaction:* Before site work begins, locations of facilities should be clearly marked. Only vehicular traffic used for construction 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, to the extent possible. After the site is vegetated, erosion and sediment control structures can be removed and the system brought online. If catchbasins draining to the perforated pipe system must be used for flood flow conveyance during construction, an engineer approved erosion and sediment control plan must be implemented.

Sequencing
Infiltration facilities are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the pit. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. This includes:

1. Heavy equipment and traffic should avoid traveling over the proposed location of the facility to minimize compaction of the soil.

2. Facilities should be kept "off-line" until construction is complete. They should never serve as a sediment control device during site construction. Sediment should be prevented from entering the infiltration facility using super silt fence, diversion berms or other means

3. Upland drainage areas need to be properly stabilized with a thick layer of vegetation, particularly immediately following construction, to reduce sediment loads.

4. The facility should be excavated to design dimensions from the side using a backhoe or excavator. The base of the facility should be level or nearly level.

5. Geotextile filter fabric should be correctly installed in the infiltration trench excavation. Large tree roots should be trimmed flush with the sides of the facility to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the facility and for a 150 mm minimum top overlap. Voids may occur between the fabric and the excavated sides of the facility. Natural soils should be placed in any voids to ensure fabric conformity to the excavation sides.

4.4.3 Maintenance and Construction Costs

Inspection and Maintenance
As with all infiltration practices, these facilities require regular inspection to ensure continued functioning. Maintenance typically consists of cleaning out leaves, debris and accumulated sediment caught in pretreatment devices annually or as needed. Inspection via manholes 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 by flushing. If slow drainage persists, the system may need removal and replacement of granular material and/or geotextile liner. Perforated pipe systems should be located below shoulders of roadways, pervious boulevards or grass swales where they can be readily excavated for servicing. The expected lifespan of infiltration practices is not well understood, however, it can be expected that it will vary depending on pretreatment practice maintenance frequency, and the sediment texture and load coming from the catchment. Perforated pipe systems with grass swales as pretreatment have been observed to continue to function well after 20 years of operation (J.F. Sabourin and Associates, 2008).

Installation and Operation Costs
Very limited information is available regarding construction costs for perforated pipe systems. Due to similarities in design components, base construction costs would likely be similar to infiltration trenches or dry swales.

4.10.4 References

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5.0 MONITORING

A fundamental component of implementing stormwater management plans and operating facilities is a monitoring program to evaluate if the facilities are functioning as designed and how effective the plan was in meeting the environmental and public health and safety objectives they were designed to meet. Too often, stormwater management systems are not evaluated with regard to performance, nor the cumulative environmental effects, so little knowledge or experience is available about the benefits or which aspects of the project were successful versus which aspects failed.

Most agencies have adopted a new approach to project development and implementation that recognizes the importance of monitoring as a feedback mechanism that can improve the effectiveness of future projects. The approach is called “Adaptive Environmental Management” (AEM) and can be defined as follows:

> “Adaptive management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding, and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptife management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.”

AEM makes monitoring a key link in this knowledge building and learning process (Figure 5.1).

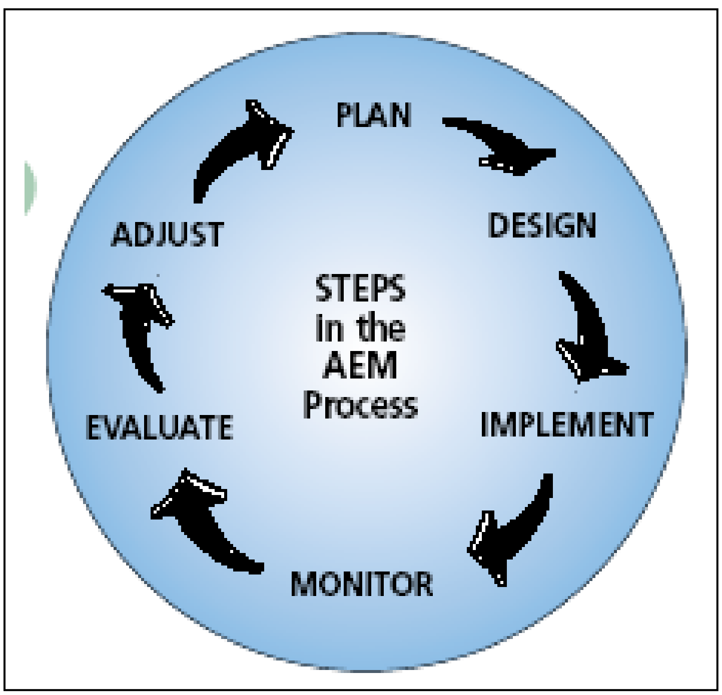

Figure 5.1
The adaptive environmental management cycle

As indicated in Chapter 1, the field of stormwater management has evolved rapidly in the past several decades and stormwater management practices (SWMPs) are now being designed to address a broad range of environmental and public health/safety objectives and targets. It is also widely recognized that the watershed response to changing land use occurs over an extended period of time, in the order of decades, therefore it may be yecrs before the effectiveness of stormwater management systems is truly understood. For example, early facilities were designed to reduce post-development peak flows to pre-development peaks, and this practice was implemented for many years, until monitoring studies showed that while this design addressed flooding objectives, it actually increased in-stream erosion (Aquafor Beech Ltd., 2006). Subsequently, facilities are now being designed to address both the peak and the volume of flows to ensure that erosion objectives are also addressed. This monitoring work also indicated that not only was there a need to look at a wider range of monitoring parameters but also a need to look at different spatial scales.

Monitoring can be generally separated into three types:

- *Compliance Monitoring:* Monitoring designed to evaluate whether a management measure or facility is functioning as designed to meet minimum acceptable requirements (*e.g.*, MOE Certificates of Approval for stormwater management facilities, municipal requirements prior to assumption of stormwater management facilities).

- *Performance Monitoring:* Monitoring designed to evaluate how well a management measure or facility performs in comparison with a range of performance indicators or targets to allow comparison with other facilities, technologies and/or development contexts.

- *Environmental Effects Monitoring:* Monitoring designed to assess the environmental health of a watershed, subwatershed, or individual community or feature (measured based on a range of environmental indicators). Such monitoring programs can be designed to evaluate the cumulative effects of the various management measures implemented to mitigate environmental impacts associated with changes affecting the watershed, subwatershed, community or feature.

5.1 Compliance Monitoring

Compliance monitoring typically focuses on assessing whether the facility is built as designed and whether it meets minimum acceptable regulatory requirements. Generally the emphasis is on measuring inlet versus outlet conditions; primarily outlet flow characteristics and selected water quality parameters. In addition, assessments of plant survival, condition of inlet/outlet structures and any maintenance issues are also undertaken. A typical timeframe for compliance monitoring for new facilities is within 2 to 5 years following construction, which is generally sufficient to expose the facility and the receiving waterbody to a broad range of environmental conditions and to allow conditions to stabilize post-construction. Typical monitoring components may include:

- flow;
- water quality;
- erosion and slope stability;
- vegetation cover/plant survival;
- condition of inlet/outlet structures; and,
- sediment accumulation or other maintenance issues.

Compliance monitoring typically is undertaken as part of the construction and commissioning of a facility (*e.g.*, as condition of Certificate of Approval or assumption of the facility by a municipality), or as part of a municipal stormwater infrastructure operations and maintenance program. Compliance monitoring for new facilities is the responsibility of the developer of the facility, and is undertaken to demonstrate that requirements for commissioning of the facility have been met. Once facilities on public property are assumed by municipalities, compliance monitoring becomes their responsibility and is undertaken as part of a municipal stormwater infrastructure operations and maintenance program. For facilities on private property, provisions need to be included in legal agreements between property owners/managers and the municipality to allow the municipality to undertake compliance monitoring from time to time in order to ensure that the facilities are being operated and maintained properly. Alternatively, the legal agreements could stipulate that property owners/managers must undertake compliance monitoring from time to time and submit the results to the municipality to demonstrate that the facility is being operated and maintained properly.

5.2 Performance Monitoring

Performance monitoring measures how well (or poorly) a management practice or stormwater management facility performs according to design objectives and targets. Performance monitoring programs are typically undertaken when little information is available regarding the effectiveness of a certain type of facility in a certain environmental context, or when a new technology is being implemented for the first time in a certain context or geographic region. Performance monitoring programs differ from compliance monitoring in that they typically require different parameters to be monitored and the rigor of the evaluation typically goes beyond whether or not the facility meets minimum regulatory requirements.

New or emerging technologies need to be assessed in terms of their performance in order to gain acceptance by review and approval agencies. Performance monitoring is also needed to develop a better understanding of how the design of conventional end-of-pipe facilities can be adapted when LID practices are implemented upstream as part of a treatment train approach. TRCA, CVC and other agencies have been monitoring and evaluating new and emerging technologies under two jointly funded programs, called the Sustainable Technologies Evaluation Program (STEP) and the Stormwater Assessment Monitoring and Performance Program (SWAMP).

Sustainable Technologies Evaluation Program (STEP)
STEP is a multi-agency program, led by TRCA. The program was developed to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. Its main objectives are to:

- monitor and evaluate clean water and clean air technologies;
- develop strategies to overcome implementation barriers;
- develop tools, guidelines and policies; and
- promote broader use of effective technologies through research, education and advocacy.

The mandate and organizational structure for the water component builds upon experiences from the Stormwater Assessment Monitoring and Performance (SWAMP) program and feedback from various agency and industry representatives. The technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, implementation protocols, alternative urban site designs, or other practices which promote more sustainable lifestyles. To date, a number of different types of facilities have been constructed and evaluated under the STEP program. These include:

- Green roofs;
- Permeable pavement;
- Rainwater harvesting;
- Erosion and sediment control practices;
- Bioretention systems;
- Perforated pipe systems; and
- Infiltration chambers.

Stormwater Assessment Monitoring and Performance (SWAMP) Program
SWAMP was initiated in 1995 by the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, TRCA and the Municipal Engineer's Association, along with host municipalities and other owner/operators. The major goals of the program were to evaluate the effectiveness of stormwater technologies and disseminate study results and recommendations within the stormwater management community. Between 1995 and 2002, ten stormwater management facilities were monitored and evaluated. These included:

- Wet ponds and constructed wetlands (4 studies)
- Underground storage tanks (1 study)
- Flow balancing systems (1 study)
- Oil and grit separators (2 studies)
- Infiltration/ exfiltration systems (2 studies)

Other products of the SWAMP program included an investigation of the storage and transport of chloride (a major constituent of road salt) in stormwater ponds, a discussion paper summarizing data analysis and statistical evaluation methodologies used in SWAMP studies, a stormwater pond sediment maintenance guide, and the proceedings of three major conferences.

5.3 Environmental Effects Monitoring

Both TRCA and CVC have established a network of regional environmental monitoring stations in the last decade. These integrated watershed monitoring programs (IWMPs) were designed to help determine progress in achieving a broad goal of ensuring environmentally healthy river systems for economically and socially healthy communities. The major objectives of the programs are:

- to protect and improve water quality and quantity in the watersheds; and
- to protect and improve the biological diversity and productivity of the watersheds.

The IWMPs use a diverse range of monitoring parameters that act as indicators of ecosystem health (Table 5.3.1). Integrating expertise from such disciplines as meteorology, hydrogeology, hydrology, terrestrial ecology, fluvial geomorphology, water quality, and aquatic ecology allows for many facets of the environment to be simultaneously analyzed and measured against benchmarks or environmental targets representing healthy conditions. Collectively, the two agencies have established over 300 monitoring locations throughout their jurisdictions representing both reference (un-impacted) and impacted conditions.

The intent of IWMPs is to detect environmental changes (both spatially and temporally) within the watershed over time. The parameters measured provide a benchmark against which historical conditions can be compared and future conditions can be assessed to identify trends in environmental health. They also allow comparison of current conditions with environmental targets established at a watershed scale. The following table illustrates some of the physical (including hydrologic), chemical and biological components of these monitoring programs.

This regional IWMP databases are invaluable in answering the following questions:

- Are watershed goals, objectives and targets being achieved?
- Are trends in indicators moving closer to, or further from achieving the goals, objectives or targets?

Table 5.3.1 Components of integrated watershed monitoring programs

Discipline Name	Area of Focus	Example Indicator
Meteorology	weather	precipitation, temperature
Hydrogeology	groundwater	baseflow and groundwater levels
Hydrology	stream flow regimes	temporal trends, time series flows
Terrestrial Natural Heritage	forests, meadows, wetlands, shorelines and their flora and fauna,	quantity of natural cover, vegetation communities
Fluvial Geomorphology	stream form and channel shaping processes	channel stability, RGA protocols
Water Quality	water chemistry, benthic invertebrate species, populations and communities	parameters of concern, community composition
Aquatic Biology	fish species, populations and communities	Index of Biotic Integrity, OSAP protocols

These regional databases can also provide some insight into cumulative effects of changes and impact mitigation measures implemented within a watershed over time.

Environmental effects monitoring at finer scales, such as the subwatershed, community or individual feature scales, requires special studies or more detailed programs to establish baseline conditions and allow change to be detected. Such monitoring programs are undertaken to evaluate the extent to which objectives and targets for subwatershed, community or individual features have been achieved through implementation of a management strategy. These types of environmental effects monitoring programs typically include assessments of “before” and “after” receiving water conditions, from physical, chemical and aquatic habitat perspectives. For example, CVC has been monitoring the cumulative effects of land use changes and management measures implemented within Fletchers Creek, which has undergone rapid urbanization within the last decade. Preliminary results indicate that the water quality, stream stability and aquatic habitats have deteriorated; indicating that the stormwater management measures implemented have not achieved the stated subwatershed objectives (CVC, 2007c).

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