Stormwater Source Control Design Guidelines 2005

Greater
Vancouver
Regional
District

Lanarc Consultants Ltd.
Kerr Wood Leidal Associates Ltd.
Goya Ngan

FINAL REPORT

April 2005

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Foreword

This document represents the "Final" Release of Phase 1 research results concerning Stormwater Source Control Design Guidelines for the Greater Vancouver Regional District in British Columbia, Canada.

In the spring of 2003, the Greater Vancouver Sewerage and Drainage District issued a proposal call for initial research work on Stormwater Source Control Design Guidelines. A contract for Phase 1 of the work was established with a consortium of landscape architects and engineers, including:

Lanarc Consultants Ltd.
Kerr Wood Leidal Associates Ltd.
Goya Ngan, Landscape Architect

As required by the terms of reference, the production of Design Guidelines was to be phased. Priorities for Phase One Research were set in consultation with the Client group. On submission and review of an Interim Draft Report in the fall of 2003, it was decided to extend the contract to complete a set of posters that publicized the results of the first phase work. A set of six posters were produced.

In winter 2004, the work was further reviewed by the Stormwater Interagency Liaison Group, a standing committee representing local and regional governments, as well as senior government agencies. The work was well received, and comments were made requesting further work.

While this further work was arranged and completed, an 'Interim' Release provided the benefit of the Phase 1 research findings to member municipalities of the GVRD.

This report is the 'Final' release of the research findings. The Interim Report is superceded by this Final Version. Primary changes in the Final Version include additional chapters on Infiltration Trench and Shaft, a Design Process Chapter, and a web-based Case Study module.

Comments, or queries about the status of the research should be directed to the Greater Vancouver Regional District, in the name of either:

Mark Wellman, P. Eng., Greater Vancouver Regional District
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Acknowledgements

It is a rare opportunity as consultants to be given a mandate to search the world for design precedents and guidelines on any subject – and even moreso when the subject has worldwide innovation taking place – as is the case in stormwater source controls. The authors wish to recognize and thank the many organizations and individuals that provided their time and experience to this project – listed below, in no order of priority:

Lanarc Consultants Ltd.
David Reid, FCSLA, Landscape Architect, Planner, Principal
Harriet Rueggeberg, B.Sc., M.R.M., Environmental/Resource Planner
Don Crockett, BCSLA, Landscape Architect, Principal
Doug Backhouse, BCSLA, Landscape Architect, Principal
Nigel P.I. Gray, B.L.A., Landscape Architectural Intern
Yongxu Yu, Landscape Architectural Intern
Jana Zelenski, Landscape Architectural Intern
Alexe Lohvinen, Graphic Designer
Linda Dawes, Library Assistant

Kerr Wood Leidal Associates Ltd.
Chris Johnston, P.Eng.
Crystal Campbell, P.Eng.
Ken Ferraby, P.Eng.
Troy Jones, P.Eng.

Goya Ngan, Landscape Architect

Greater Vancouver Regional District (Client)
Robert Hicks, P.Eng.
Ed von Euw, P.Eng.
Mark Wellman, P.Eng.
Hugh Kellas, FCIP

Stormwater Interagency Liaison Group

In particular, we would also like to express our gratitude to the many experts around the world that we contacted – either as a part of this research project or in advance – who gave freely of their time and expertise to help us understand that current state of the art in stormwater source controls. For those listed in the Contact List in the body of this report, we give our thanks.

We hope to be able to share this Report with many of those on the Contact List – and would value whatever additional comments or direction that they could offer.

Thank you.

INTRODUCTION

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The Project

The objective of this project is to reduce information barriers that stand in the way of effective implementation of stormwater source controls in the Greater Vancouver Regional District. It focuses on the technical details of practices in landscape areas that treat stormwater through plant materials and soils by infiltration, retention, detention and evapotranspiration.

The Greater Vancouver Regional District (GVRD) provides regional government services to its member municipalities, and is the third largest metropolitan area in Canada. A related body, the Greater Vancouver Sewerage & Drainage District (GVSDD), provides regional utility services. In 1999, the GVSDD produced a Best Management Practices Guide for Stormwater, which can be viewed at http://www.gvrd.bc.ca/sewerage/management_guide.htm.

Stormwater - Rainwater

'Stormwater management' is the term traditionally used – mostly in North America - to refer to managing rainfall runoff using conventional "storm-based" approaches to sizing and designing drainage facilities. Urban design thinking has evolved, however, to address the entire spectrum of rainfall events, not just storms, in ways that reflect more natural water systems. 'Rainwater management' – generally used in Europe - more accurately describes this more holistic approach.

This document uses the more familiar term 'stormwater' with the intent that it refers to the broader scope of 'rainwater' management.

Vancouver, British Columbia, Canada is a world-class city framed by the coastal mountains, the estuary of the Fraser River, and the sea.

The Source Controls

In 2003, a team of consulting engineers and landscape architects was commissioned by the GVSDD to create technical design guidelines for a selection of these Best Management Practices that related to stormwater source control. The team compiled technical literature from regions of the world that have climates similar to Vancouver on the following source control topics:

- *Absorbent landscapes*, including native soils and woods, compost-amended soils, planters and other treatments to reduce runoff from landscape areas;
- *Bioretention facilities*, which can include rain gardens, sunken landscape areas, and infiltration areas, with or without an underdrain;
- *Vegetated swales,* including bioswales and associated vegetated filter strips;
- *Pervious paving*, including both vegetated and unvegetated types;
- *Infiltration trenches, sumps and drywells*, including various underground infiltration devices; and
- *Extensive green roofs*.

The Information

Of particular interest were technical standards or design guidelines that are supported by government agencies or industry associations. The research aimed to acquire a technical level of detail appropriate to a 'typical design standard' that is suitable for testing, and which can be adapted to a given site or context by design professionals – specifically:

- Source control application, performance, scale, site-suitability and limitations;
- Generalized material specifications;
- Consideration of material availability, complexity and costs of construction and maintenance of the technique;
- Typical construction drawings as appropriate;
- Candidate plant species, maintenance requirements and related aspects; and
- Any relevant guidelines, standards, drawings or images of the specified source control.

The Products

The project has two groups of products:

- A *review of technical literature* on source controls and their use from jurisdictions with climates similar to Vancouver, including the Pacific Northwest, Germany, the Netherlands, Belgium, France, the United Kingdom, and parts of Australia and New Zealand. Some aspects of documents have been translated into English. The specific products are:
  - Written literature assembled into a set of binders organized under the six source control topics. These binders are available for viewing at the library of the Greater Vancouver Regional District, in Burnaby, B.C.
  - A report that reviews the status of stormwater management, key concepts, source controls in use and case studies from each jurisdiction. A summary of the report is contained in Part 2 of this document, and the full report is presented in Appendix A.
- *Design guidelines* applicable to Greater Vancouver for selected best management practices (prioritized in Appendix B), including typical details, general specifications, and guidelines for use. These are presented in two formats:
  - A series of posters that presents a summary of the jurisdictional study and the key features of each of the source controls in a highly illustrated and user-friendly manner.
  - A report - Part 3 of this document - that discusses the application, limitations, functions, design guidelines and specifications for each of the six priority source control topics.

The intent is that these posters and report files will be adapted to web delivery as well, so that the information can be made accessible to a wide audience of engineers, landscape architects, architects, planners, developers, builders, inspectors and universities.

However, these design guidelines are not intended to be used as detail designs. Proper site investigation and site-specific designs by appropriate professionals that comply with applicable laws, bylaws or regulations are required. These design guidelines can provide guidance and inspiration on innovative means of achieving stormwater management objectives.

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SUMMARY POSTERS

Summary Posters

The applied research regarding stormwater source controls is only effective if the information is communicated to user groups.

To reach the target audience of design professionals, developers, construction management and approval agency staff, a series of technical posters have been produced to introduce the research results.

Reduced versions of the posters are printed on the following pages. Mid-size (A3 - 11 x 17 inch) versions are available for download through the GVRD website, at

http://www.gvrd.bc.ca/sewerage/stormwater_reports.htm .

Full size (A1 – 24 x 36 inch) versions of the posters may also be available by special arrangement with the GVRD.

STORMWATER

Australia
Belgium
British Columbia
France
Germany
Netherlands
Oregon State
United Kingdom
Washington State

CURRENT PRACTICE

UNITED KINGDOM
"Sustainable Urban Drainage Systems" (SUDS) use "Soakaway" methods such as rock pits, dry wells and infiltration trenches.

400,000 sq.m of permeable paving block designs were sold in 2001. Research is showing that microbes in rock base courses treat oil entering the pavement.

BELGIUM
Some municipalities offer subsidies for source controls; e.g., Mortsel pays $5.60/ sq.m for green roofs and 50% of the cost of an infiltration system.

NETHERLANDS
Infiltration trenches, green roofs and permeable pavement are common. Flood storage on roads is allowed, but not on bikeways!

Dutch wadis are broad vegetated swales that fill with water during heavy rainfalls and then drain in about 24 hours.

FRANCE
Swales ("noues") are valued as visible stormwater treatment. Porous pavements are used both as a source control and to reduce traffic noise.

The grate leads to an underground geo-membrane lined trench filled with sand and pebbles that filters particles and allows infiltration. Excess water flows to further settling and filtration systems.

GERMANY
In use for over 30 years, about 1 in 7 of new flat roofs are green roofs - 13.5 million sq.m in 2001. Most cities reduce stormwater fees when source controls are used.

A swale /trench system reduces stormwater volumes to 1/10th of a conventional system, saving 30% in stormwater fees.

BRITISH COLUMBIA/CANADA
Policies supporting source controls have been in the works since the 1990's. Pilot projects with source controls have been completed and monitoring is on-going. Implementation is accelerating.

Over 600 green roof installations exist in Coastal BC, including this monitored Green Roof at the Vancouver Library.

WASHINGTON
"Low Impact Development" (LID) techniques try to preserve 'natural' watershed characteristics. Stormwater manuals have provided guidance since 1992.

Seattle's "Street Edge Alternatives" (SEA) project captures 98% of the wet season runoff - beautifully.

OREGON
Portland provides "tree credits" in stormwater calculations, and also offers an "eco-roof density bonus" as a green roof incentive.

Buckman Terrace Apartments in Portland uses source controls to avoid runoff into combined sewers.

AUSTRALIA
Australia uses "Water Sensitive Urban Design" (WSUD) to maximize on-site retention, infiltration, treatment and re-use-even in clay soils. Aquifer storage and recovery is widely used.

Rainwater reuse on this site reduces the consumption of water from the main system by 77%.

Precedents Around the World

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Stormwater Source Control Design Guidelines 2005




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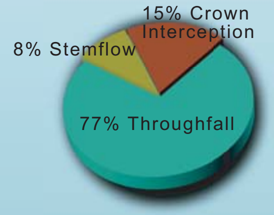
Goya Ngan
Landscape Architect

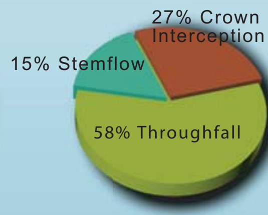
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

DESIGN PRINCIPLES

- Maximize the area of absorbent landscape – either existing or constructed – on the site. Conserve as much existing vegetation and undisturbed soil as possible.
- Minimize impervious area by using multi-storey buildings, narrower roads, minimum parking, larger landscape areas, green roof, and pervious paving.
- Disconnect impervious areas from the storm sewer system, having them drain to absorbent landscape.
- Design absorbent landscape areas as dished areas that temporarily store stormwater and allow it to soak in, with overflow for large rain events to the storm drain system.
- Maximize the vegetation canopy cover over the site. Multi-layered evergreens are ideal, but deciduous cover is also beneficial for stormwater management.
- Ensure adequate growing medium depth for both horticultural and stormwater needs – a minimum 150mm for lawn areas, and 450mm depth for shrub/tree areas. In wetter climates with till subsoils, a minimum depth of 300mm for lawn is required to store 60mm of rainfall.
- Cultivate compost into surface soils to create minimum 8% organic matter for lawns, and 15% for planting beds.
- To avoid surface crusting and maintain surface permeability, install vegetative (grass, groundcovers, shrubs, trees) or organic cover (mulch, straw, wood fibre) as early as possible in the construction process, and prior to winter storms.
- Provide effective erosion control during construction, including erosion control on upstream sites that may flow into the absorbent landscape.



Pear Tree



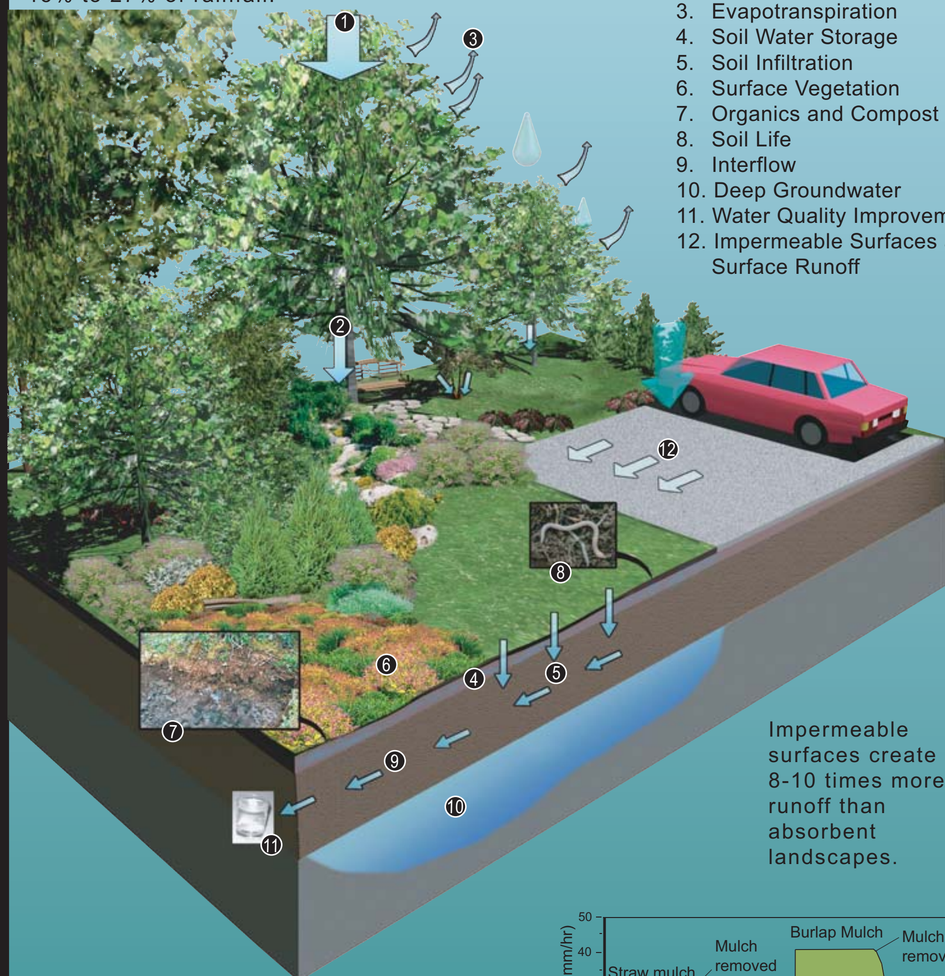
Evergreen Oak Tree

In most natural wooded conditions in the GVRD, 90% of rainfall volume never becomes runoff, but is either soaked into the soils or evaporates / transpirates. Trees, shrubs, grasses, surface organic matter, and soils all play a role.

Variables of **Absorbent Landscape**

1. Crown Interception
2. Throughfall and Stemflow
3. Evapotranspiration
4. Soil Water Storage
5. Soil Infiltration
6. Surface Vegetation
7. Organics and Compost
8. Soil Life
9. Interflow
10. Deep Groundwater
11. Water Quality Improvement
12. Impermeable Surfaces and Surface Runoff

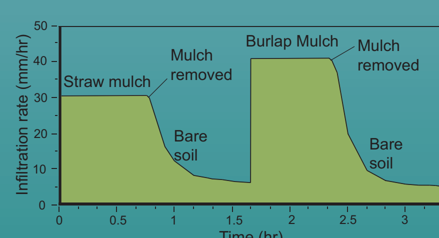
Winter tree canopies intercept 15% to 27% of rainfall.



Impermeable surfaces create 8-10 times more runoff than absorbent landscapes.

Organic matter and soil micro-organisms are vital to maintaining soil infiltration rates.

Rainfall storage in soil is 7% to 18% of soil volume.

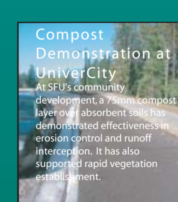


Influence of surface cover on infiltration rate of sandy loam

Absorbent Landscapes

Greater Vancouver Regional District

Stormwater Source Control Design Guidelines 2005



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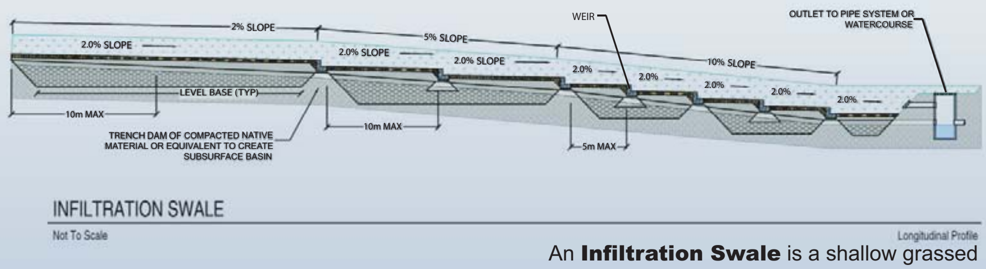
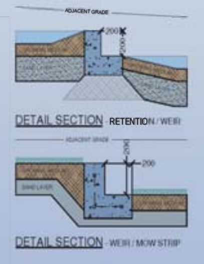
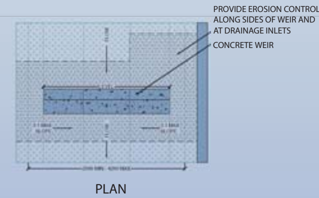
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

DESIGN PRINCIPLES

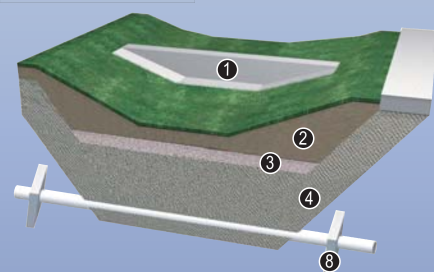
- Literature suggests swale areas of about 10-20% of upstream impervious area. For GVRD, calculate swale area by continuous flow modelling.
- Flow to the swale should be distributed sheet flow, travelling through a grassy filter area at the swale verges. Provide pre-treatment and erosion control to avoid sedimentation in the swale.
- Provide a 25mm drop at the edge of paving to the swale soil surface, to allow for positive drainage and buildup of road sanding/organic materials at this edge.
- Swale planting is typically sodded lawn. Low volume swales can be finished with a combination of grasses, shrub, groundcover and tree planting.
- Swale bottom - flat cross section, 600 to 2400mm width, 1-2% longitudinal slope or dished between weirs.
- Swale side slopes - 3(horizontal):1(vertical) maximum, 4:1 preferred for maintenance.
- Weirs to have level top to spread flows and avoid channelization, keyed in 100mm minimum.
- Maximum ponding level - 150mm. Drawdown time for the maximum surface ponded volume - 24 hours.
- Treatment soil depth - 450mm desirable, minimum 150mm if design professional calculates adequate pollutant removal.
- Design stormwater conveyance using Manning's formula or weir equations whichever governs with attention to channel stability during maximum flows.
- Drain rock reservoir and underdrain may be avoided where infiltration tests by a qualified professional, taken at the depth of the proposed infiltration, show an infiltration rate that exceeds the inflow rate.





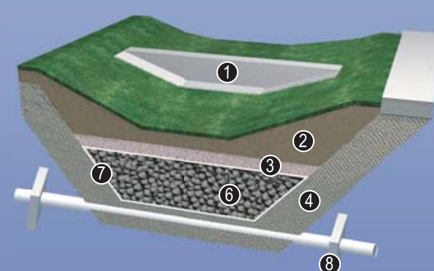


An **Infiltration Swale** is a shallow grassed or vegetated channel designed to capture, detain and treat stormwater and convey larger flows. It takes surface flows from adjacent paved surfaces, holds the water behind weirs, and allows it to infiltrate through a soil bed into underlying soils. The swale and weir structures provide conveyance for larger storm events to the storm drain system. Variations on designs include an underlying drain rock reservoir, with or without a perforated underdrain.



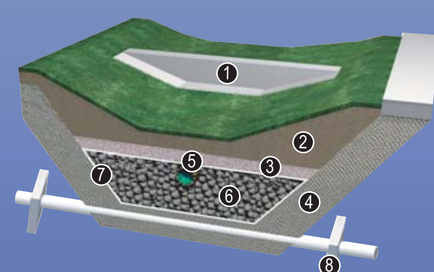
Full Infiltration

Where water entering the swale is filtered through a grass or groundcover layer, and then passes through sandy growing medium and a sand layer into underlying scarified subgrade. Suitable for sites with small catchments and subsoil permeability > 30mm/hr.



Full Infiltration with Reservoir

Designed to reduce surface ponding by providing underground storage in a drain rock reservoir. Suitable for sites with small catchments and subsoil permeability > 15mm/hr.



Partial Infiltration with Reservoir and Subdrain

Where a perforated drain pipe is installed at the top of the reservoir, providing an underground overflow that removes excess water before it backs up to the surface of the swale. Suitable for sites with larger catchments and low infiltration rates into subsoil permeability < 15mm/hr. Provides water quality treatment even if infiltration into subsoils is limited.

1. Weir Keyed into Swale Side Slope
2. Growing Medium (300mm Min.)
3. Sand
4. Existing Scarified Subsoil
5. Perforated Underdrain (150mm Dia. Min.)
6. Drain Rock Reservoir (300mm Min.)
7. Geotextile Along All Sides of Reservoir
8. Trench Dams at All Utility Crossing

Infiltration Swale System

Greater Vancouver Regional District

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Goya Ngan Landscape Architect

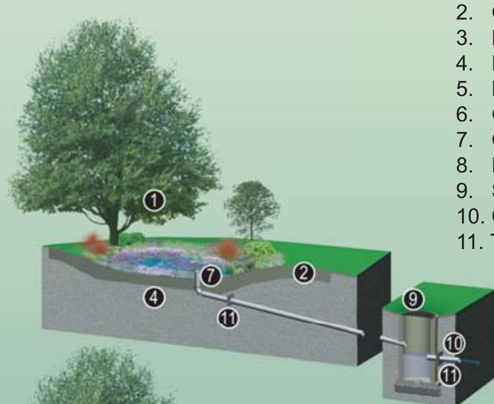
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

DESIGN PRINCIPLES

- Literature suggests rain garden areas of about 10-20% of upstream impervious area. For GVRD, calculate rain garden area by continuous flow modelling. Optimum rain garden size is about 50sq.m. draining 250sq.m. of impervious area.
- Smaller, distributed rain gardens are better than single large scale facilities.
- Locate rain gardens a minimum 30.5m from wells, 3m downslope of building foundations, and only in areas where foundations have footing drains and are not above steep slopes.
- Provide pretreatment and erosion control i.e. grass filter strip to avoid introducing sediment into the garden.
- At point-source inlets, install non-erodable material, sediment cleanout basins, and weir flow spreaders.
- Bottom width - 600mm (Min.) to 3000mm (desirable). Length-width ratio of 2:1.
- Side slopes - 2:1 maximum, 4:1 preferred for maintenance. Maximum ponded level - 150 - 300mm.
- Draw-down time for maximum ponded volume - 72 hours.
- Treatment soil depth - 450mm (Min.) to 1200mm (desirable); use soils with minimum infiltration rate of 13mm/hr.
- Surface planting should be primarily trees, shrubs, and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may include rushes, sedges and grasses as well as lawn areas for erosion control and multiple uses.
- Apply a 50-75mm layer of organic mulch for both erosion control and to maintain infiltration capacity.
- Install a non-erodible outlet or spillway to discharge overflow.
- Avoid utility or other crossings of the rain garden. Where utility trenches must be constructed below the garden, install trench dams to avoid infiltration water following the utility trench.
- Drain rock reservoir and perforated drain pipe may be avoided where infiltration tests by a design professional show a subsoil infiltration rate that exceeds the inflow rate.

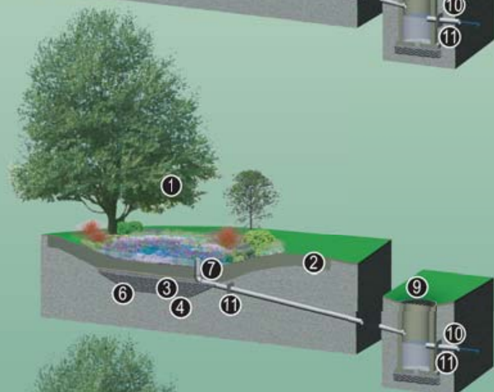
An **Infiltration Rain Garden** is a form of bioretention facility designed to have aesthetic appeal as well as a stormwater function. Rain gardens are commonly a concave landscaped area where runoff from roofs or paving infiltrates into deep constructed soils and subsoils below. On subsoils with low infiltration rates, Rain Gardens often have a drain rock reservoir and perforated drain system to convey away excess water.

1. Tree, Shrub and Groundcover Plantings
2. Growing Medium Minimum 450mm Depth
3. Drain Rock Reservoir
4. Flat Subsoil - scarified
5. Perforated Drain Pipe 150mm Dia. Min.
6. Geotextile Along All Sides of Drain Rock Reservoir
7. Overflow (standpipe or swale)
8. Flow Restrictor Assembly
9. Secondary Overflow Inlet at Catch Basin
10. Outflow Pipe to Storm Drain or Swale System
11. Trench Dams at All Utility Crossings



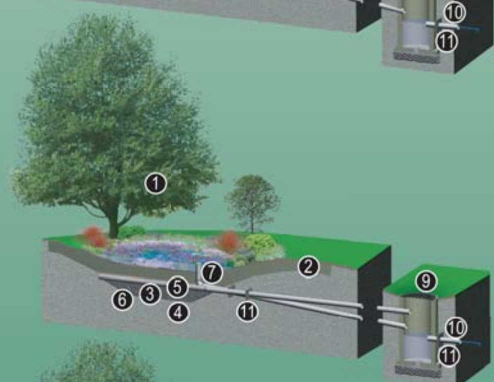
Full Infiltration

Where all inflow is intended to infiltrate into the underlying subsoil. Candidate in sites with subsoil permeability > 30mm/hr. An overflow for large events is provided by pipe or swale to the storm drain system.



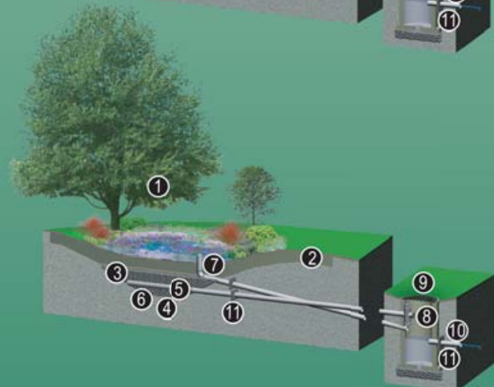
Full Infiltration with Reservoir

Adding a drain rock reservoir so that surface water can move quickly through the installed growing medium and infiltrate slowly into subsoils from the reservoir below. Candidate in sites with subsoil permeability > 15mm/hr.



Partial Infiltration

Designed so that most water may infiltrate into the underlying soil while the surplus overflow is drained by perforated pipes that are placed near the top of the drain rock reservoir. Suitable for sites with subsoil permeability > 1 and < 15mm/hr.



Partial Infiltration with Flow Restrictor

For sites with subsoil permeability < 1mm/hr, the addition of a flow restrictor assembly with a small orifice slowly decants the top portion of the reservoir and rain garden. Provides water quality treatment and some infiltration, while acting like a small detention facility.

Rain Garden

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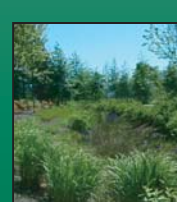
Stormwater Source Control Design Guidelines 2005



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Goya Ngan Landscape Architect

Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

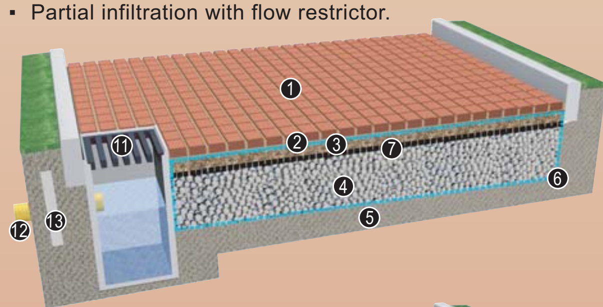
DESIGN PRINCIPLES

- Pervious paving is most suitable for low traffic areas – driveways, parking areas(maximum 1 - 2 vehicles per day per parking space), walkways, recreational vehicle pads, service roads, fire lanes.
- The ratio of impermeable surface area draining onto pervious pavement area should be 1.2:1 maximum.
- To avoid surface plugging, it is critical to protect pervious paving from sedimentation during and after construction.
- Identify pollutant sources, particularly in industrial/ commercial hotspots, that require pre-treatment or source control upstream.
- For designs which rely entirely on infiltration into underlying soils, the infiltration rate should be 12.5mm/hr minimum.
- Soil subgrade analysis should include soil texture class, moisture content, 96 hour soaked California Bearing Ratio (CBR) and on-site infiltration tests at the elevation of the base of the reservoir.
- Surface slope should be 1% minimum to avoid ponding and related sedimentation of fines.
- Wrap paver bedding material with geotextile filter cloth on bottom and sides to maintain water quality performance and keep out intrusion of fines.
- Provide edge restraint to contain pavers, similar to standard unit paving.
- Design reservoir water levels using continuous flow modelling. Drawdown time - 96 hrs max., 72 hrs desirable.
- Bottom of reservoir: flat in full infiltration designs, minimum 0.1% slope to drain in piped systems.
- Where utility trenches must be constructed below the reservoir, install trench dams at exits to avoid infiltration water following the utility trench.
- Pavers with wide joints should not be used for disabled persons parking or pedestrian ramps at street crossings.
- If being designed for heavy loads, optional reinforcing grids may be included in the pavement subbase.



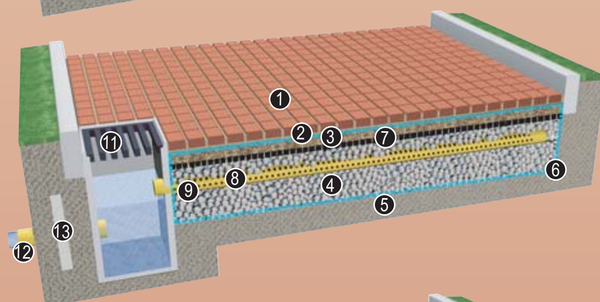

Pervious paving is a surface layer that allows rainfall to percolate into an underlying reservoir base where rainfall is either infiltrated to underlying soils or removed by a subsurface drain. The surface component of pervious paving can be:
- Porous asphalt or porous concrete.
- Concrete or plastic grid structures filled with unvegetated gravel or vegetated soil,
- Concrete modular pavers with gapped joints that allow water to percolate through.

Pervious pavement designs may be one of three types:
- Full infiltration.
- Partial infiltration.
- Partial infiltration with flow restrictor.



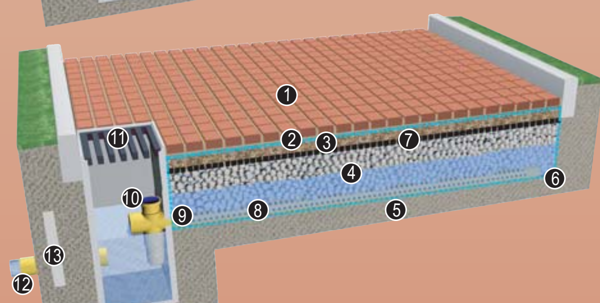
Full Infiltration

Where rainfall is intended to infiltrate into the underlying subsoil. Candidate in sites with subsoil permeability > 15mm/hr.



Partial Infiltration

Designed so that most water may infiltrate into the underlying soil while the surplus overflow is drained by perforated pipes that are placed near the top of the drain rock reservoir. Suitable for subsoil permeability >1 and < 15mm/hr.



Partial Infiltration with Flow Restrictor

Where subsoil permeability is < 1mm/hr, water is removed at a controlled rate through a bottom pipe system and flow restrictor assembly. Systems are essentially underground detention systems, used where the underlying soil has very low permeability or in areas with high water table. Also provides water quality benefits.

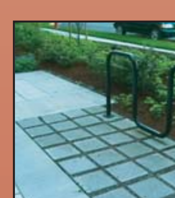
1. Permeable Pavers (Min. 80mm thickness)
2. Aggregate Bedding Course - not sand (50mm depth)
3. Open Graded Base (depth varies by design application)
4. Open Graded Sub-base (depth varies by design application)
5. Subsoil - flat and scarified in infiltration designs
6. Geotextile on All Sides of Reservoir
7. Optional Reinforcing Grid for Heavy Loads
8. Perforated Drain Pipe 150mm Dia. Min.
9. Geotextile Adhered to Drain at Opening
10. Flow Restrictor Assembly
11. Secondary Overflow Inlet at Catch Basin
12. Outlet Pipe to Storm Drain or Swale System. Locate Crown of Pipe Below Open Graded Base (no. 3) to Prevent Heaving During Freeze/Thaw Cycle
13. Trench Dams at All Utility Crossings

Pervious Paving

Greater Vancouver Regional District

Stormwater Source Control Design Guidelines 2005



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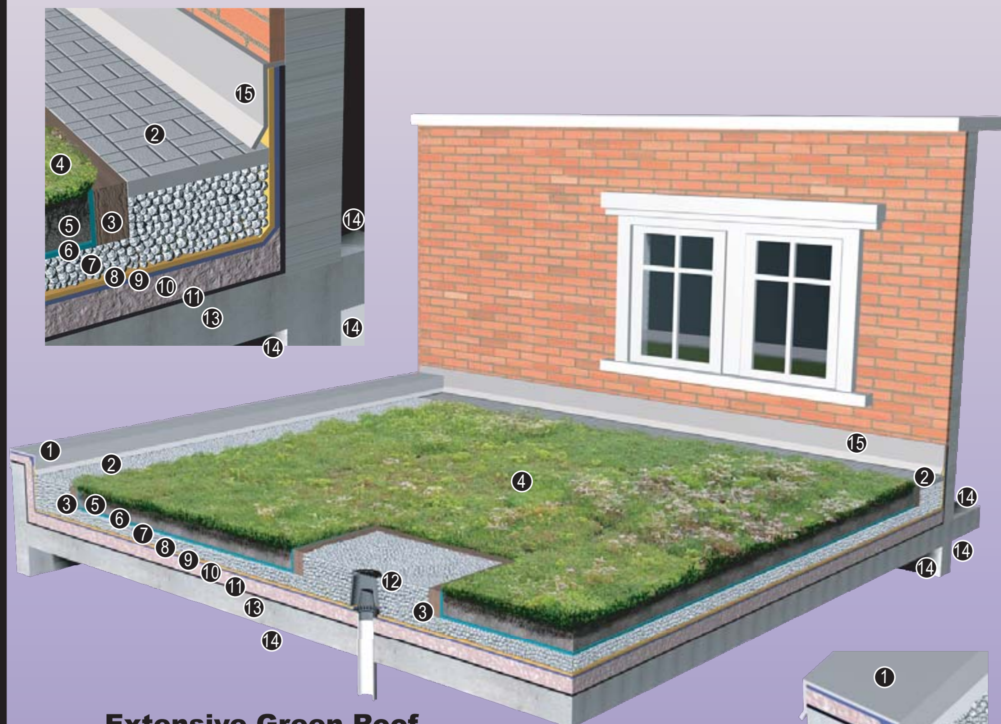
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

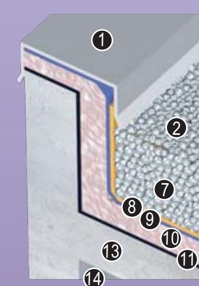
DESIGN PRINCIPLES

- Suitable for flat roofs and, with proper design, roofs of 20º (4:12 roof pitch) or less.
- Suitable for many rooftop situations – industrial, warehousing, commercial buildings, office complexes, hospitals, schools, institutional/ administrative buildings, residential and garages.
- Design a green roof at the same time as designing the building or retrofit, so that the structural load can be balanced with the design of the building.
- In calculating structural loads, always design for the saturated weight of each material.
- Provide construction and maintenance access to extensive green roofs. Access through a 'man door' is preferable to a roof hatch.
- Roofs with less than 2% slope require special drainage construction so that no part of the growing medium is continuously saturated.
- Avoid monocultures when planting a green roof; the success of establishing a self-maintaining plant community is increased when a mix of species is used.
- Provide intensive maintenance for the first 2 years after plant installation – irrigation in dry periods, weed removal, light fertilization with slow release complete fertilizers, and replacement of dead plants.
- To facilitate access and prevent moisture on exposed structural components, provide plant free zones along the perimeter, adjacent facades, expansion joints, and around each roof penetration.
- Fire breaks of non-combustible material, 50cm wide, should be located every 40m in all directions and at roof penetrations.
- Provide protection against root penetration of the waterproof membrane by either adding a root barrier or using a membrane that is itself resistant to root penetration.

A **Green Roof** is a roof with a veneer of drainage and growing media that supports living vegetation. Green roofs provide a wide range of benefits – from reduction in peak flows and volumes to building heat gain reductions. There are two basic types:

- Intensive – deeper growing medium to support larger plants and trees; designed for public use as well as stormwater and insulation functions.
- Extensive - shallow, lightweight growing medium; designed for stormwater, insulation and environmental functions; vegetation is low and hardy; usually no public access.





Extensive Green Roof

1. Wall Cap Flashing, waterproof membrane extends to 100mm above finished grade
2. Drain Rock, Paving Slab, or Other Buffer Equivalent
3. Wood, Steel or Concrete Curb/Edging (Optional)
4. Planting
5. Growing Medium
6. Filter Layer
7. Drainage Layer
8. Protection Layer and Root Barrier
9. Waterproof Membrane
10. Thermal Insulation
11. Vapour Barrier
12. Area Drain
13. Structural Slab
14. Building Interior
15. Wall Flashing, waterproof membrane extends to 150mm above finished grade

Green Roof

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DESIGN PRINCIPLES

■ Infiltration Trench System:

a) Locate infiltration trench at least 3m from any building, 1.5m from property lines, and 6m from adjacent infiltration facilities (or as recommended by a geotechnical engineer).

b) Sump: Provide a lid for periodic inspection and cleanout. Include a T-inlet pipe to trap oils, sediments and debris.

c) Infiltration Trench: installation of distribution pipe and bottom of drainrock to be level. If more than one section of infiltration trench is required, design so that underground water is temporarily 'ponded' in each infiltration section.

d) Install the Infiltration Trench in native ground, and avoid over-compaction of the trench sides and bottom, which reduces infiltration.

e) Observation well for each infiltration trench (optional): vertical standpipe, with perforated sides, and locking lid, to allow the monitoring of water depth.

■ Soakaway Manholes System:

a) Provide a report from an engineer with experience in geotechnical engineering including on-site test data of infiltration rates at the depth of the proposed infiltration. The bottom of the shaft shall be at least 600mm above the seasonal high water table or bedrock, or as recommended by the engineer.

b) If steep slopes or drinking water wells exist within 200m horizontally from the proposed Soakaway Manhole, provide a hydro-geotechnical report to analyze site-specific risks and determine setbacks.

c) Provide a sedimentation manhole, and a maximum of two Soakaway Manholes in series, unless otherwise approved.

d) Provide an overflow from the Soakaway Manhole to the storm drainage system or major storm flow path.

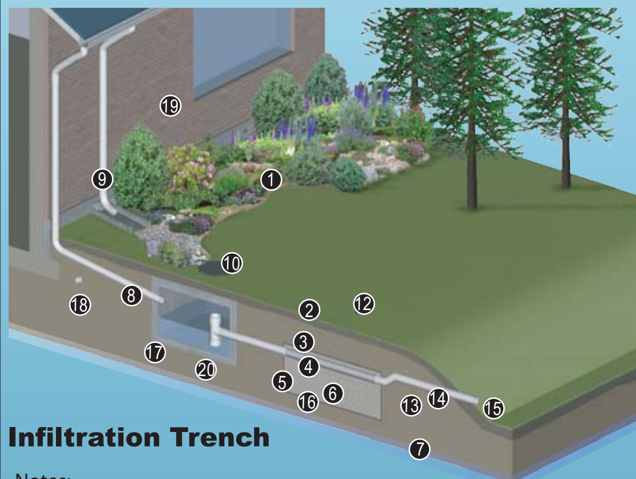
An **Infiltration Trench** System includes an inlet pipe or water source, catch basin sump, perforated distribution pipe, infiltration trench and overflow to the storm drainage system.

A Soakaway Manhole (Sump, or Dry Well) System includes an inlet pipe, a sedimentation manhole, and one or more infiltration shafts with connecting pipes. Use of Infiltration Shaft will be limited by hydro-geotechnical conditions in much of GVRD.

Limitations of Infiltration Trench or Soakaway Manholes:

a) To avoid groundwater pollution, do not direct un-treated polluted runoff to Infiltration Trench or Shaft:
  - Direct clean runoff (roof, non-automobile paving) to Infiltration Trench or Shaft.
  - For polluted runoff (roads > 1000 vehicles / day, parking areas, other pollution sources), provide upstream source control for pollutant reduction prior to release to Infiltration Trench or Shaft.

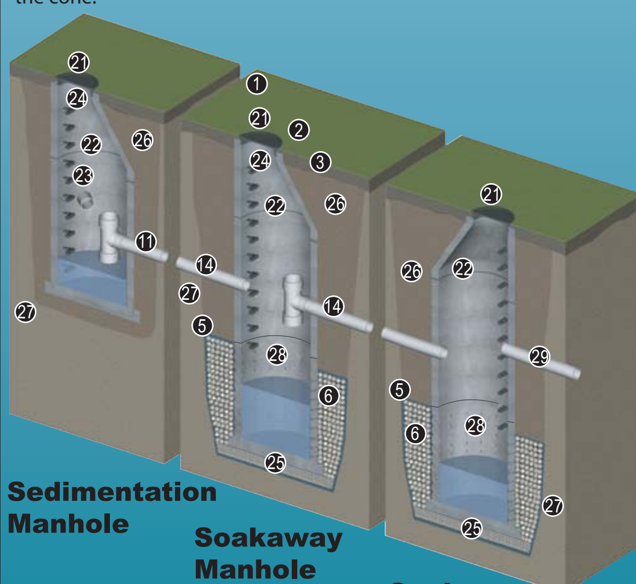
b) Use infiltration trench or shaft only in areas with footing drains.



Infiltration Trench

Notes:
All precast sections shall conform to the requirements of ASTM C 478.
Provide a min. of 150mm of 25mm or 19mm clean crushed rock under all pipes.
Invert shall be level and smooth.
Soakaway Manhole barrel shall not be perforated within 1200mm of the cone.

1. Grass or Other Planting
2. Finish Grade
3. Growing Medium Backfill
4. 100mm Dia PVC DR28 Perforated Pipe
5. Light Non-woven Polyester Geotextile c/w Min. 400mm Laps
6. 50mm Drain Rock or Rock of Equal Porosity
7. Maximum Groundwater Elevation
8. Non-polluted Drainage From Building or Terrace
9. Alternate Surface Route - With Splash Pad and Vegetated Swale to CB
10. CB Lid / Access Hatch for Cleanout, Inspection and Inflow / Overflow from Sump
11. Solid Pipe c/w Inlet Tee
12. Observation Well (Optional)
13. Provide pipe elbows to have outlet pipe invert at top of infiltration pipe
14. PVC Solid Pipe
15. Discharge to Storm Drainage System. Ensure Drainage Does Not Impact Neighbouring Uses. Direct Discharge to Road Right-of-way if Necessary
16. Infiltration Trench with Level Bottom
17. Catch Basin
18. Building Footing Drain (Not Connected to Infiltration Facility)
19. Building
20. 50mm Dia Drain Hole
21. Standard Manhole Frame and Cover
22. Seal Joints with Cement Grout or Approved Mastic
23. Street Inlet Connection
24. Ladder Rung
25. 25mm Crush Gravel or Drain Rock Base
26. Native Soil Back Fill
27. Undisturbed Ground
28. 1200mm Perforated Barrel (Langley Concrete or Equal)
29. Overflow to storm drainage system.



Sedimentation Manhole **Soakaway Manhole** **Soakaway Manhole**

Infiltration Trench & Soakaways

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Stormwater Source Control Design Guidelines 2005

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RAINWATER SOURCE CONTROL

AROUND THE WORLD

Rainwater Source Control Around the World

The research reveals a surprising level of activity in implementation of rainwater source controls around the world. The goals of water quality improvement and management of stormwater volume resonate around the globe. Water reuse is also a major objective in some jurisidictions.

The research findings from jurisdictions with climates similar to GVRD are presented in Appendix A. This section provides a sampling of the efforts that are underway in these jurisdictions.

Washington, U.S.A.

"Low Impact Development" (LID) is the term used in the U.S. Northwest to refer to designs that try to preserve 'natural' characteristics of a watershed, of which source controls are a major component. Since 1992, Washington State's stormwater management manuals have provided guidance for meeting federal and state regulations for protecting water quality and salmon habitat. The long term effectiveness of permeable pavement systems have been a particular focus of research.

Photo Credit: Seattle Public Utilities

The 'Street Edge Alternatives' (SEA) project in Seattle, Wash. aims to reduce runoff as well as create an attractive landscape.

Oregon, U.S.A.

Oregon State, and particularly the City of Portland, have been leaders in promoting LID. For example, Portland provides "tree credits" in stormwater calculations, recognizing the flow control and pollution reduction benefits of urban trees. The City also offers an "eco-roof density bonus" whereby a square foot of green roof can earn additional square feet of developable floor area depending on the extent of the green roof.

Photo Credit: Lanarc Consultants Ltd.

A variety of source control BMPs allows the **Buckman Terrace Apartment** complex in Portland to be built with only an overflow connection to a stormwater sewer system.

British Columbia, Canada

Policies supporting source controls have been in the works since the 1990s, and projects implementing some of these practices are now being developed. Green roofs have been installed and their performance is being monitored at research facilities in Vancouver (BC Institute of Technology) and Ottawa (National Research Council). There is also new focus on alternative road standards to reduce impervious surfaces and promote greater infiltration.

Photo Credit: National Research Council Canada

Participants at a green roof workshop tour the roof garden of the Vancouver Public Library.

Australia

Australia has coined the term **Water Sensitive Urban Design** (WSUD) to focus on controlling runoff sources and maximizing on-site retention, infiltration, treatment and re-use. The use of **infiltration techniques** in different soil types is a focus of attention, especially in the clay soils that predominate in many Australian cities. Aquifer storage and recovery is widely used where land values and evaporation rates are high or catchment areas are intensively developed.

Photo Credit: Melbourne Water

At Figtree Place in Newcastle, rainwater collected and used on-site reduces water consumption by 77%.

United Kingdom

"**Sustainable Urban Drainage Systems**" (SUDS) is the phrase used for stormwater measures that take account of water quantity, quality and amenity issues. "Soakaway" is the term used for such methods as rock pits, dry wells and infiltration trenches. Filter drains – a perforated pipe in a trench filled with filter material - are used extensively to replace catch basins in roads and parking lots, and are reported to be effective in removing suspended solids (85%), total lead (83%), zinc (81%) and oil (estimated 70%). Research at Coventry University is proving that pervious paving is effective in trapping and biodegrading oil due to microbial populations that flourish in the subsurface structure (Newman *et al.*, 2001).

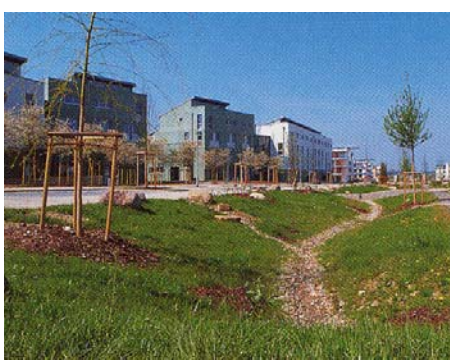
Photo Credit: Bettess, R, 2001,

Use of pervious paving has grown significantly, with some 400,000 m2 of permeable block designs sold in 2001 (Pratt et al., 2002).

Germany

In Germany, where **green roofs** have been used for over 30 years, about 1 in 7 of new flat roofs are green roofs - which translated to 13.5 million m^2 of green roofs in 2001. In most large cities, a **stormwater fee** is charged on the basis of impervious surface area that discharges to a public system; e.g., 1.30 € ($1.95)/$m^2$/year in Berlin. Use of source controls qualifies for a discount from these fees.

Photo Credit: K. Johaentges (Johaentges, K. and E. Holtz, 2000)



In Kronsberg, a *Mulden-Rigolen-System* of combined swales and trenches reduces stormwater volumes to 1/10th of a conventional system. While more expensive to build, the system results in about 30% savings in annual stormwater fees.

France

"La ville est son assainissement" is a national guideline in France covering the principles, methods and tools for integrated urban stormwater management. Swales (*"noues"*) are considered desirable source controls because they integrate into the landscape as well as sensitize the public to stormwater issues by making stormwater management more visible. Porous pavements are also being used as a source control as well as to reduce urban traffic noise.

Photo Credit: Communaute de Lyon

A road run-off purifying system in Lyon, France. The grate leads to an underground geo-textile lined trench filled with sand and pebbles that filters particles and allows some infiltration. Excess water flows to further settling and filtration systems before releasing to a lake.

Netherlands

The Dutch have developed clear national objectives on source control. Separation of stormwater from sewer systems is a primary focus. Infiltration trenches, green roofs and permeable pavement systems are recognized measures. Temporary storage of water on streets is used to reduce peak flows, but bicycle paths and sidewalks are not to be flooded – reflecting that country's transportation preferences.

Photo Credit: Mr. Dubbeling

A common sight in Dutch neighborhoods, wadis are broad swales covered with a layer of humus and planted with grass or vegetation. They are intended to fill with water during heavy rainfalls and then drain in about 24 hours.

Belgium

Like the Netherlands, the emphasis in Belgium is on disconnecting impervious areas from combined sewer systems. Some municipalities offer subsidies for source controls; e.g., the city of Mortsel pays 3.75€ (\$5.60)/ m^2 for green roofs to a maximum of 743.68 € (\$1100) and 50% of the cost of an infiltration system up to a maximum of 309.87 € (\$465).

The roof leader from this building in Belgium empties into a cobble gutter, which takes the rainwater to a pervious lawn surface. Note also the pervious pathway surfacing.

Photo Credit: Vlaamse Milieumaatschappij

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DESIGN GUIDELINES

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Absorbent Landscape

Application

Most landscape – either natural or manmade – acts like a sponge to soak up, store and slowly release rainfall. In most GVRD natural wooded conditions without paving and roof development, 90% of rainfall volume that lands on natural watersheds never becomes runoff, but is either soaked into the soils or evaporates (Stephens *et al.*, 2002). The trees, shrubs, grasses, surface organic matter, and soils all play a role in this absorbent landscape.

Stormwater Variables of Absorbent Landscape

Figure 1-1: Stormwater variables of absorbent landscape.

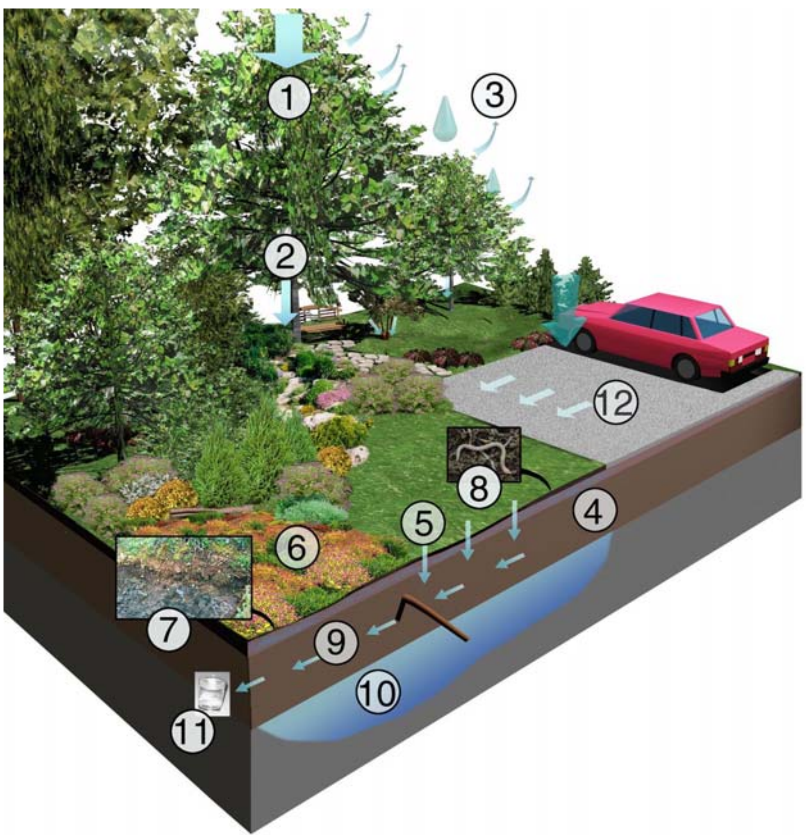


Figure 1-1 shows a schematic representation of the 12 stormwater variables of absorbent landscape discussed below. Keeping these variables in balance is the key to successful stormwater source control using absorbent landscape.

Winter Tree Canopies Intercept 15%-27% of Rainfall

1. Crown Interception

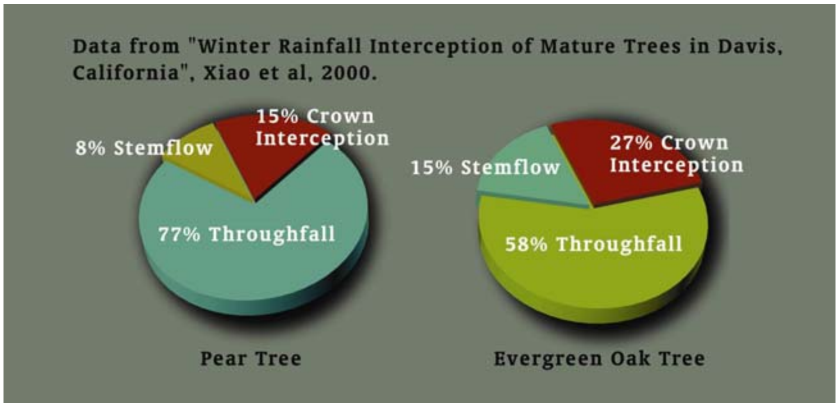


Figure 1-2: Interception, stemflow and throughfall data from California (Xiao *et al.*, 2000)

Scientific studies have shown that a significant amount of gross precipitation is intercepted (i.e., never reaches the ground) by tree crowns. A 50 year old evergreen forest in Scotland had canopy interception of 28% of annual rainfall (Johnston, 1990). Studies of open grown urban trees in Davis, California (average annual rainfall of 446 mm) have shown significant crown interception even in winter - about 15% by a leafless pear tree, and about 27% by a broadleaf evergreen oak (Figure 1-2 - Xiao *et al.*, 2000).

2. Throughfall and Stemflow

Plants provide a stormwater detention function, slowing down rain before it hits the ground surface. Although some rain falls through the canopy as free throughfall, a significant portion lands on either leaf or twigs, where it is delayed prior to creating canopy drip. Some of this rainfall flows down twigs and branches to become stemflow at the tree trunk. The twigs, branches and rough bark of leafless deciduous trees play a significant role in stormwater detention.

3. Evapotranspiration

Trees, shrubs, grasses and other plants draw water up from the soil to the leaves, where the stomata (openings) in the leaves allow for evapo-transpiration. Evaporation also occurs from surface water (puddles, lakes, streams, rooftops) and from surface soils, snow and tree/plant surfaces. The combination of tree canopy interception and evapotranspiration in a natural rainforest can approach 40% of annual rainfall (Stephens *et al.*, 2002).

Rainfall Storage in Soil is 7% to 18% of Soil Volume

4. Soil Water Storage

Soils are the most significant landscape storage mechanism for stormwater. Landscape soils typically store from 7% (sand) to 18% (loam) of their volume as water before becoming saturated to field capacity and generating flow-through or runoff. Loamy soils store more water than sandy soils (Ferguson, 1994).

5. Soil Infiltration

The rate at which water soaks into soils (the infiltration rate or saturated hydraulic conductivity) varies depending on the texture and amount of organic matter in the soil. Fine textured soils with silt and clay exceeding 35% by volume tend to have low infiltration rates (0.6 to 6 mm/hr), whereas sand surface soils are very open to infiltration (210 mm/hr), with loam soils having moderate infiltration rates (13 mm/hr).

Surface crusting and compaction of the top 2 mm of soil can be an important limitation. Thin crusts can be formed on all bare soil surfaces , including fine sand, due to raindrop impact. Surface crusting risks can be addressed by avoiding erosion and sedimentation that carries fines onto the soil surface, and by providing surface mulching, vegetation, organic matter and related soil life in the surface soil (Figure 1-3 - Ferguson, 1994).

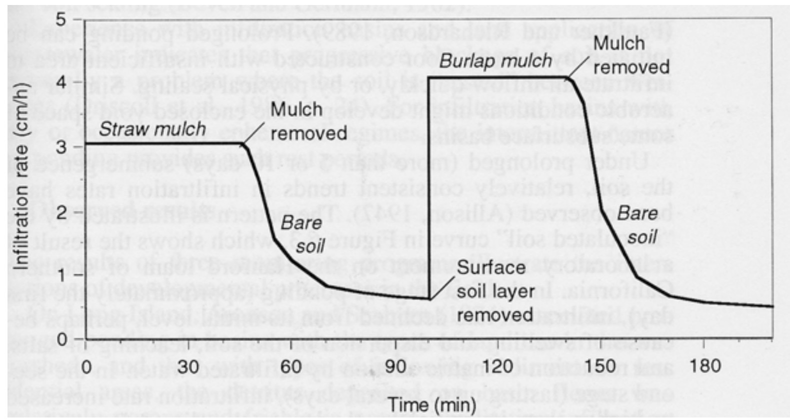


Figure 1-3: Infiltration rate of a sandy loam under continous water sprinkling at a rate in excess of intake with a series of 4 surface conditions (Ferguson, 1994: 191)

Organic Matter Maintains Soil Infiltration Rates

6. Surface Vegetation

Plant materials work to condition the soil – providing a regular supply of organic matter through leaf drop, and opening up macropores in the soil through the process of root growth, death and decay. Soils with vegetated surfaces have higher maintained surface infiltration rates than bare soils, because macroporosity of the soil is continually regenerated by plants and animals (Ferguson, 1994). Surface vegetation is also very effective at stopping erosion from starting. Leaves of grasses and similar plants on the soil surface also act as physical filters to runoff – causing sediments and attached pollutants like metals and phosphorus to drop out of the water.

7. Organics and Compost

Addition of organic matter or compost to soils increases the infiltration and moisture holding capability of sandy, silt/clay or till soils that are not permanently saturated. Organic matter in the soil reduces the need for fertilization and can reduce the need for supplementary watering by 60% when compared to sites with unamended topsoil (Chollak and Rosenfeld, 1999). For stormwater purposes, organic matter targets of 8% for lawn areas and 15% for shrub areas are recommended. Compost blankets and berms for erosion control have been tested and proven to be as effective as silt fence (Tyler, 2002).

8. Soil Life

Compost and soil is a living material – a mature topsoil with 5% organic matter can contain as much as 7.5 tons of organisms per hectare (Carpenter-Biggs, 2002). Together with plant roots, soil fauna such as earthworms, insects, ants, and moles form and maintain macropores in the soil. These larger organisms rely on a soil ecosystem of microscopic species sustained by organic matter. In soils or surface crusts of low conductivity, even a small amount of macroporosity can increase hydraulic conductivity by more than 10 times (Ferguson, 1994).

9. Interflow

Summer base flow in streams is maintained by 'interflow' of rainfall in shallow soils. With a typical water flow rate of 12.5mm/hr in loam, a raindrop would travel through the soil at 300mm/day, taking 100 days to travel 30 metres.

10. Deep Groundwater

Soil water also flows by gravity through soils or fractured rock to deep groundwater, which stores 98.4% of the unfrozen fresh water of the earth, as compared to 1.4% in lakes and streams (Montgomery, 1987). Protection of the quality of this groundwater through the filtration processes in surface soils is critical to drinking water supplies.

11. Water Quality Improvement

Infiltration of stormwater through healthy soil is one of the most effective practices to improve water quality and remove urban pollutants.

Impermeable Surfaces Create 8-10 times the Runoff of Absorbent Landscape

12. Impermeable Surfaces and Surface Runoff

Impermeable pavement and rooftop removes the functions of absorbent landscape. Volume of runoff from impermeable roof and pavement without any best management practices is 8-10 times the runoff from absorbent landscape. This increased runoff dramatically increases flows in streams, exceeding the mean annual flood level more often, which results in stream erosion, flooding and loss of property and habitat (Stephens *et al.*, 2002).

Typical Infiltration Rates of Soils

Soil is comprised of sand, silt, clay and organic matter in varying proportions that affect the infiltration rate. For design purposes, infiltration rates should be measured at the location and depth of the proposed infiltration using a percolation test or a double-ring infiltrometer.

Typical published infiltration rates shown in Table 1-1 are Saturated Hydraulic Conductivity (Ferguson, 1994).

Even minor infiltration rates are significant when applied over time – a 1mm/hour infiltration rate absorbs 24mm per day, or 168mm per week.

Table 1-1: Typical Infiltration Rates

USDA Soil Class	Saturated hydraulic conductivity (mm/hr)
Sand	210
Loamy sand	61*
Sandy loam	26*
Loam	13
Silt loam	6.8
Sandy clay loam	4.3
Clay loam	2.3
Silty clay loam	1.5
Sandy clay	1.2
Silty clay	0.9
Clay	0.6

*Target soil texture for growing medium Level 2 “Groomed” and Level 3 “Moderate” landscape areas in B.C. Landscape Standard, which represent a good balance between infiltration performance and water retention capabilities.

Limitations

- Absorbent landscape needs to be implemented properly to avoid conditions that would cause reduced infiltration at the surface due to sedimentation, excessive compaction, or lack of vegetative cover. Quality control is necessary regarding installed soil properties, erosion and sediment control, and establishment of vegetation.
- Site plans that drain large areas of impervious area into small areas of landscape risk overwhelming the absorbent capabilities of soil. All designs should calculate the projected flows and water balance, and should provide for an overflow – surface or piped – to the major storm flood control system.
- To meet typical performance targets (e.g., infiltrating the first 25 – 60mm of rainfall), the amount of absorbent landscape area on a site or in a drainage basin must be balanced with the amount of impervious area. This will impact many aspects of urban design - e.g., by promoting building forms that minimize impervious building footprints, by placing landscape over parking or rooftops, or by designing narrower roads and larger landscape islands in parking areas.

Design Guidelines

Photo Credit: Lanarc Consultants Ltd.

Drainage from parking area to landscape.

1. Maximize the area of absorbent landscape – either existing or constructed – on the site.
2. Conserve as much natural forest land, existing trees and undisturbed soil as is compatible with the project. Provide temporary fencing of these protected areas during construction.
3. Minimize impervious area through such techniques as multi-storey buildings, narrower roads, minimum parking, larger landscape areas, green roof, and pervious paving.
4. Disconnect impervious areas from the storm sewer system, having them drain to absorbent landscape with only an overflow to the storm drainage system.
5. Design absorbent landscape areas as gently sloping (2%) or dished (concave) areas that temporarily store stormwater and allow it to soak in (maximum ponding time of 2 days), with overflow only occurring in large rain events.
6. When planting, maximize the vegetation canopy cover over the site. Cover by multi-layered evergreen trees and shrubs is ideal, but deciduous tree cover also is beneficial for stormwater management.
7. Use native planting species where feasible. Non-native plantings with similar attributes to native may be suitable in conditions where natives would grow too large or not meet other urban design objectives.
8. Ensure adequate growing medium depth for both horticultural and stormwater needs – generally a minimum of 150mm depth for lawn areas, and 450mm depth for shrub/tree areas. In wetter areas of the GVRD near the mountains with till subsoils, a minimum growing medium depth of 300mm for lawn areas is required to store 60mm of rainfall.
9. Test growing medium for physical and chemical properties, and amend it to provide approximately 8% organic matter for lawns, and 15% organic matter for planting beds, in the upper 200mm of growing medium.
10. Do not over-compact landscape subgrade or growing medium. Optimum compaction is firm against deep footprints (about 80% Proctor Density). Excessive compaction reduces infiltration rates. Rip or till subsoils that are excessively compacted. Aerate compacted surface soils.

11. Scarify subgrade surfaces prior to placing growing medium, and rototill through layers of growing medium to create a transition in soil texture rather than discrete soil layers. Do not install soils in layers of different textures, as this can create barriers to infiltration.
12. Provide vegetative cover (grass, groundcovers, shrubs, trees) or organic cover (mulch, straw, wood fibre) to absorbent landscape as early as possible in the construction process, and prior to winter storms, to avoid surface crusting from raindrop impact and to maintain surface permeability.
13. Provide effective erosion control during construction, including erosion control on upstream sites that may flow into the absorbent landscape. Delay installation of constructed absorbent landscape until sources of potential erosion in the upstream drainage area have been permanently stabilized.

Photo Credit: Lanarc Consultants Ltd.

Straw laid on surface to prevent erosion and crusting from raindrop impact.

Guideline Specifications

Materials and methods shall meet Master Municipal Construction Document 2000 requirements, including the Section 02921 requirements for Growing Medium, with organic matter requirements amended as follows:

For lawn areas	minimum 8%
For planting areas	minimum 15%

Infiltration Swale System

Description

The Infiltration Swale System combines aspects of grass swales and infiltration trenches.

The surface component of an infiltration swale is a shallow grassed channel, accepting flows from small areas of adjacent paved surfaces such as roads and parking. The swale is designed to hold the water quality storm behind a weir, and then allow it to infiltrate slowly through a soil bed to an underlying drain rock reservoir system.

The surface soils and drain rock reservoir are sized to store the design storm event, and to allow it to infiltrate slowly into underlying soils. A perforated drain placed near the top of the drain rock reservoir provides an underground overflow, which also maintains drainage of adjacent road base courses. The surface swale and weir structures provide conveyance for larger storm events to a surface outlet.

Other common terms used are *Dry Swale with Underdrain* (Stephens *et al.*, 2002) or *Swale/Trench Element* (MUNLV-NRW, 2001).

Photo Credit: Lanarc Consultants

Drop curb at pavement edge to grass infiltration swale.

Application

- Designed to treat the water quality volume and convey larger flows (Stephens *et al.*, 2002).
- Provision of underground overflow allows use of the technique in most soils, including clay with infiltration rates as low as 0.6mm/hr.
- Suitable for most development situations – residential areas, municipal office complexes, rooftop runoff, parking and roadway runoff, parks and greenspace, golf courses (Stephens *et al.*, 2002).
- With proper weir spacing, practical for profiles up to 10% slope.

Limitations

- Maximum contributing area 2 ha (Stephens *et al.*, 2002).
- Minimum depth from base of drain rock reservoir to water table 610 mm (Stephens *et al.*, 2002).
- Identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this BMP. (Maryland Dept. Environmental Resources Program, 2000).

- Design should provide for drain rock reservoir to drain in 96 hours to allow aerobic conditions for water quality treatment.

Design Guidelines

1. The swale infiltration area should be approximately 10-20% of the upstream impervious area that it serves, with its sizing preferably calculated by continuous flow modelling.
2. Flow to the swale should be distributed sheet flow, travelling through a grassy filter area at the swale verges (500 mm min., >3000 mm desirable). Provide pre-treatment erosion control to avoid sedimentation in the swale. Provide non-erodable material, sediment cleanout basins, and weir flow spreaders at point-source inlets (Maryland Dept. Environmental Resource Programs, 2001).
3. Provide vegetated erosion control along all sides of weir and at drainage inlets.
4. Pavement edge at the swale may be wheel stop, flush curb, or reverse curb (Figure 2E). Provide a 25mm drop at the edge of paving to the swale soil surface, to allow for positive drainage and buildup of road sanding/organic materials at this edge.
5. Swale planting is typically sodded lawn. Low volume swales can be finished with a combination of grasses, shrub, groundcover and tree planting to provide a 100% vegetated cover within 2 years of planting.
6. Swale longitudinal slope should be 1-2%, or dished between weirs.
7. Swale bottom width - 600mm minimum, 2400mm maximum, flat in cross section.
8. Swale surface side slopes - 3(horizontal):1(vertical) maximum, 4:1 preferred for maintenance.
9. Weirs to have level top to spread flows and avoid channelization, keyed in 100mm minimum. Integrated mowing strip is desirable in lawn areas.
10. Design stormwater conveyance using Manning's formula, with attention to erosion and channel stability during maximum flows.
11. Maximum ponded level: 150mm (Maryland Dept. Environmental Resource Programs, 2001).
12. Drawdown time for the maximum surface ponded volume – 48 hours maximum (24 hours maximum - Maryland Dept. Environmental Resource Programs, 2001).

Photo Credit: Lanarc Consultants

Flush curb (left) to grass filter to vegetated (shrubs, groundcover) swale.

13. Minimum freeboard to adjacent paving: 100mm or in accordance with swale conveyance design.
14. Treatment soil depth: 450mm is desirable, minimum 150mm if design professional calculates adequate pollutant removal (Maryland Dept. Environmental Resource Programs, 2001), or 100 min. growing medium over 100mm min washed sand (MUNLV-NRW, 2001).
15. Drain rock reservoir bottom shall be level.
16. Underground weirs (Figure 2A) of undisturbed native material or constructed ditch blocks shall be provided to create underground pooling in the reservoir sufficient for infiltration performance.
17. A non-erodible outlet or spillway must be established to discharge overflow (Maryland Dept. Environmental Resource Programs, 2001).
18. Avoid utility or other crossings of the swale. Where utility trenches must be constructed crossing below the swale, install trench dams to avoid infiltration water following the utility trench.

Design Options

Drain rock reservoir and underdrain may be deleted where infiltration tests by the design professional taken at the level of the base of the proposed construction show an infiltration rate that exceeds the maximum inflow rate for the design storm.

The attached Drawings 2B through 2D, and the Infiltration Swale System Summary Poster illustrate the options.

Photo Credit: Water Concept Kronsberg

Swale with check dams under construction.

Photo Credit: Water Concept Kronsberg

Swale with check dams in operation.

Photo Credit: Lanarc Consultants

Infiltration swale in parking area – Water Pollution Control Laboratory, Portland, Oregon.

Guideline Specifications

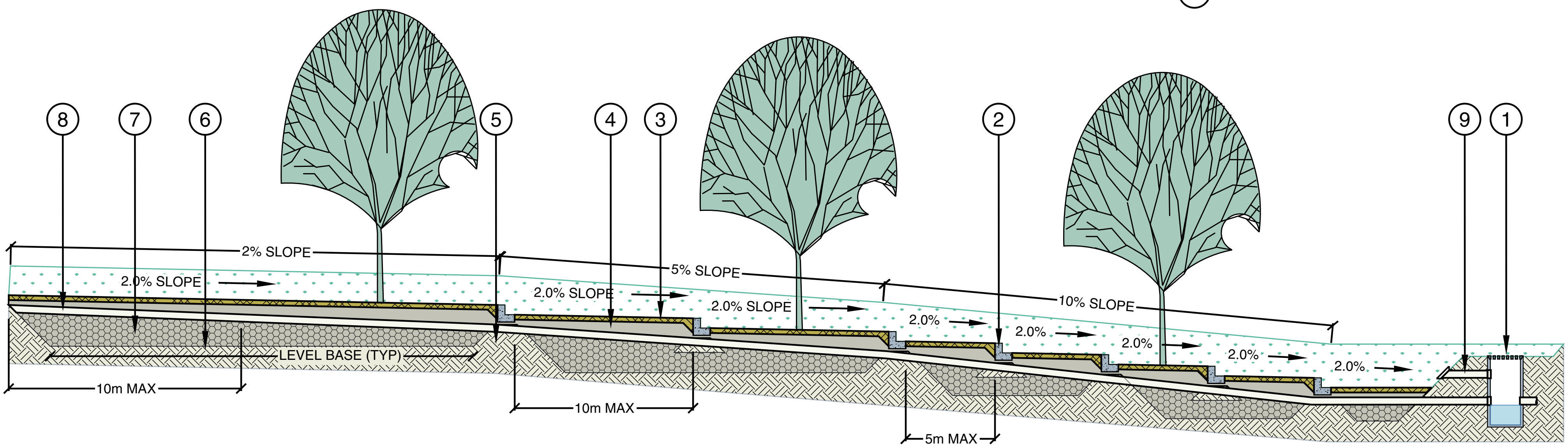
Materials shall meet Master Municipal Construction Document 2000 requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, 75mm max, 38mm min, 40% porosity (Maryland Dept. Environmental Resource Programs, 2001).
2. Pipe: PVC, DR 35, 150 mm min. dia. with cleanouts.
3. Geosynthetics: as per Section 02498, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 02226.
5. Growing Medium: As per Section 02921 Topsoil and Finish Grading, Table 2, including the requirement for minimum saturated hydraulic conductivity of 2 cm/hr., with organic matter requirements amended as follows:
   a. For lawn areas minimum 8%
   b. For planting areas minimum 15%
6. Seeding: to Section 02933 Seeding or 02934 Hydraulic Seeding (note – sodding will be required for erosion control in most swales, subject to the erosion control professional's decision).
7. Sodding: to Section 02938 Sodding.

Construction practices shall meet Master Municipal Construction Document 2000 requirements, and:

1. Isolate the swale site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300mm of material over the final subgrade of the swale until after all sediment-producing construction in the drainage area has been completed (Maryland Dept. Environmental Resource Programs, 2001).
2. Prevent natural or fill soils from intermixing with the Infiltration Drain Rock. All contaminated stone aggregate must be removed and replaced (Maryland Dept. Environmental Resource Programs, 2001).
3. Infiltration Drain Rock shall be installed in 300mm lifts and compacted to eliminate voids between the geotextile and surrounding soils (Maryland Dept. Environmental Resource Programs, 2001).
4. Maintain grass areas to mowed height between 50mm and 150mm., but not below the design water level. Landscape Maintenance standards shall be to the BC Landscape Standard, 6th Edition, Maintenance Level 4: Open Space / Play Area.

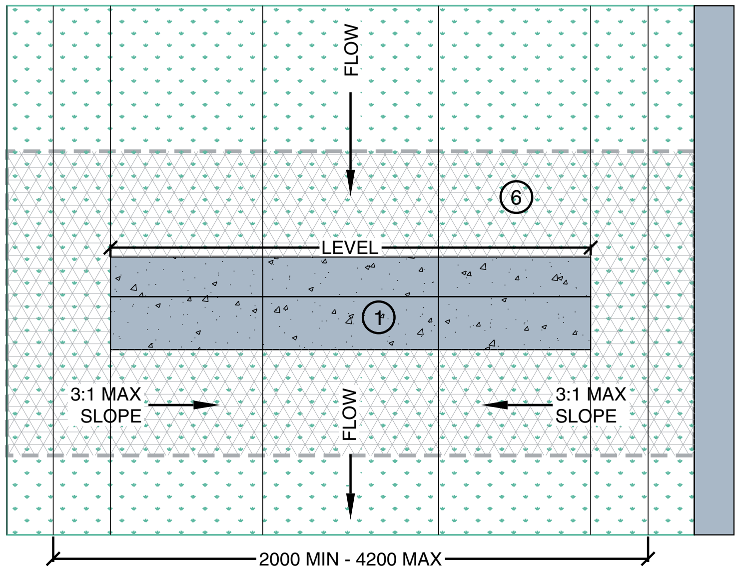
1 OUTLET TO PIPE SYSTEM OR WATERCOURSE
2 WEIR KEYED INTO SWALE SIDE SLOPE
3 GROWING MEDIUM
4 SAND
5 UNDERGROUND WEIR OF COMPACTED NATIVE MATERIAL OR EQUIVALENT TO CREATE SUBSURFACE BASIN
6 EXISTING SCARIFIED SUB-SOIL
7 DRAIN ROCK RESERVOIR (OPTIONAL)
8 PERFORATED DRAIN PIPE (OPTIONAL)
9 HIGH FLOW OVERFLOW



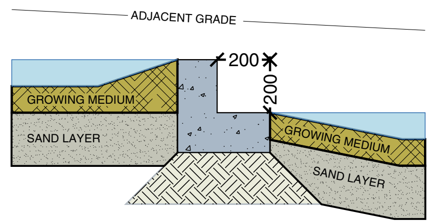
2/A INFILTRATION SWALE

Not To Scale

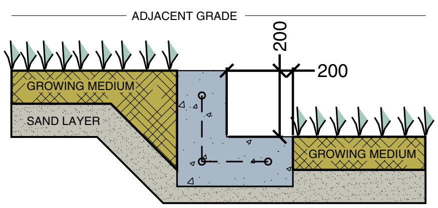
Longitudinal Profile



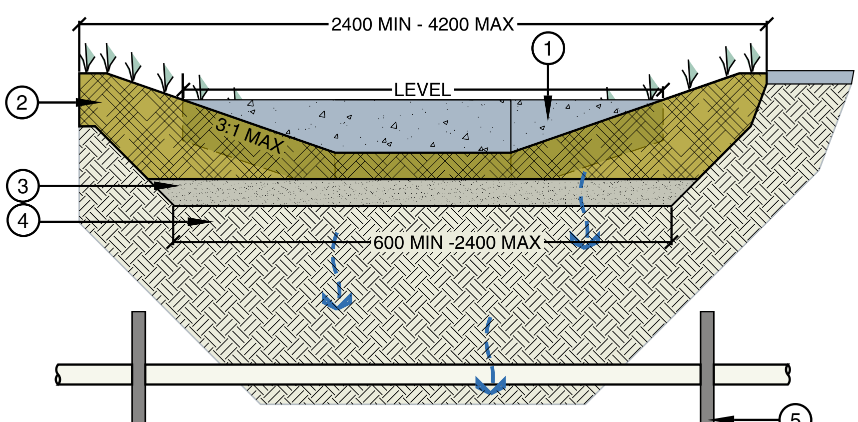
PLAN



DETAIL SECTION - WEIR WITH PONDING



DETAIL SECTION - WEIR WITHOUT PONDING



SECTION

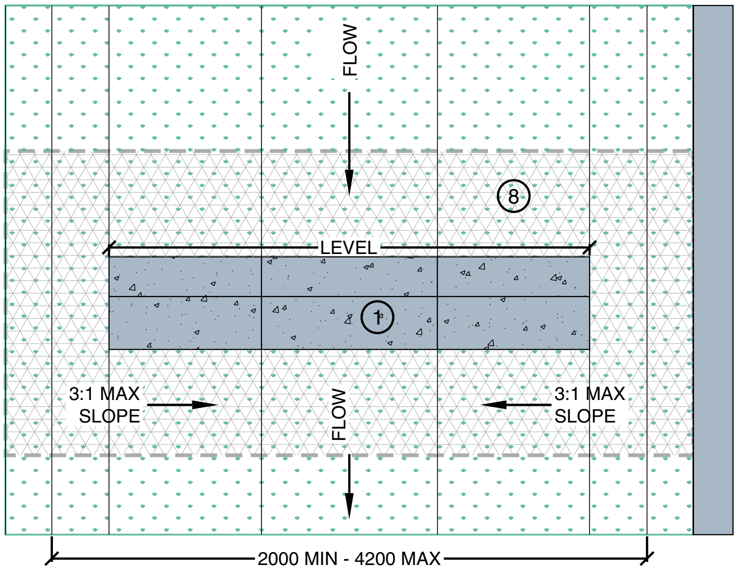
1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. TRENCH DAMS AT ALL UTILITY CROSSING
6. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND AT DRAINAGE INLETS

2
B

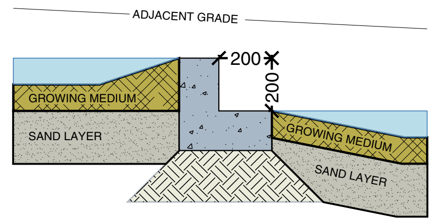
FULL INFILTRATION SWALE

Not To Scale

Plan / Section



PLAN



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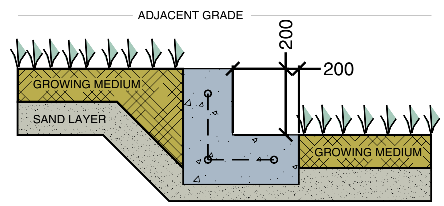
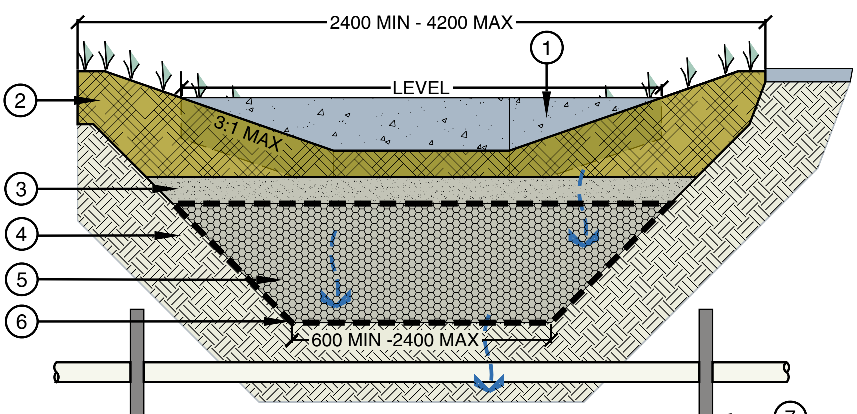


DETAIL SECTION - WEIR WITHOUT PONDING



SECTION

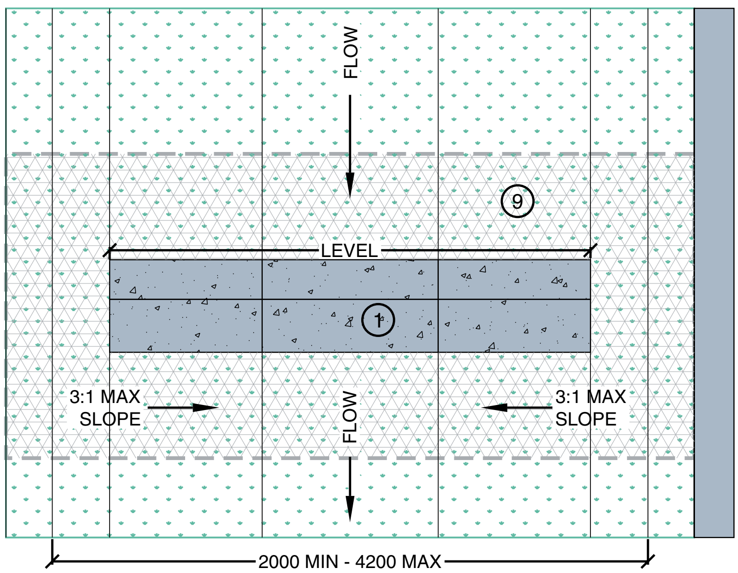
1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. DRAIN ROCK RESERVOIR
6. GEOTEXTILE FILTER ALONG ALL SIDES OF RESERVOIR
7. TRENCH DAMS AT ALL UTILITY CROSSINGS
8. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND AT DRAINAGE INLETS

2
C

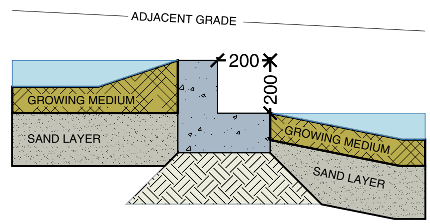
FULL INFILTRATION SWALE WITH RESERVOIR

Not To Scale

Plan / Section



PLAN



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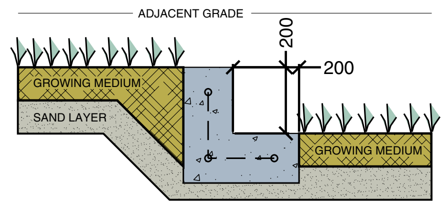

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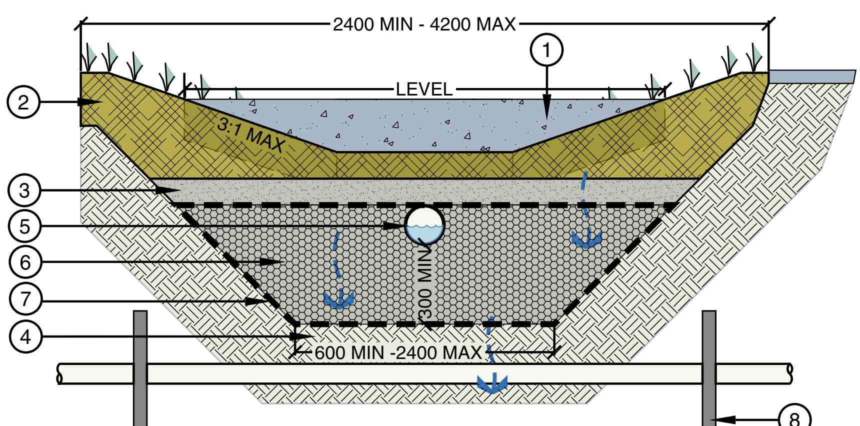

SECTION

1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. PERFORATED UNDERDRAIN (150mm DIA MIN.)
6. DRAIN ROCK RESERVOIR
7. GEOTEXTILE FILTER ALONG ALL SIDES OF RESERVOIR
8. TRENCH DAMS AT ALL UTILITY CROSSING
9. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND AT DRAINAGE INLETS

2 / D

PARTIAL INFILTRATION SWALE WITH RESERVOIR AND SUBDRAIN

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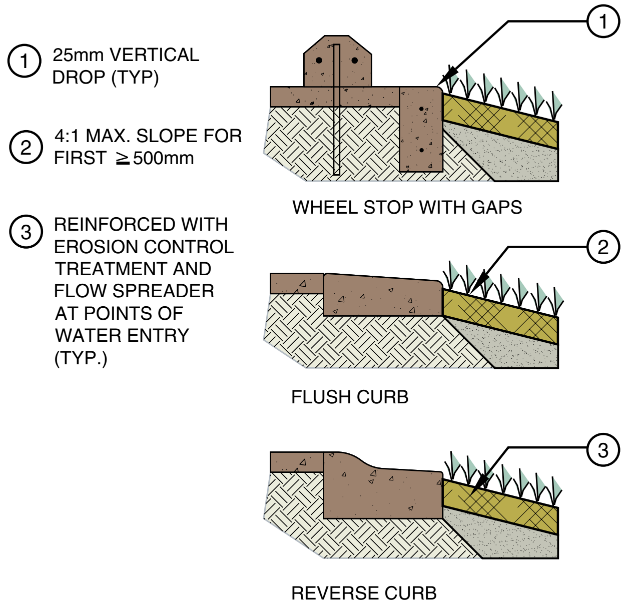
Plan / Section



2
E

CURBING OPTIONS

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Infiltration Rain Garden

Description

The Infiltration Rain Garden is a form of bioretention facility, designed to have the aesthetic appeal of a garden, as opposed to a purely functional appearance. Rain Gardens are commonly a concave landscape area where treated runoff from roofs or paving is allowed to pond temporarily while infiltrating into deep constructed soils below (See Drawing 3A).

The surface planting of Rain Gardens is dominated by trees, shrubs, and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may also include rushes, sedges and other grass-like plants, as well as sodded lawn areas for erosion control and multiple uses.

On subsoils with low infiltration rates, Rain Gardens often have a drain rock reservoir and perforated drain system to collect excess water. (See Drawing 3B &3C). The perforated drain system may connect to a control structure in a catch basin that provides overflow while maintaining a slow decanting of the water in the rain garden between storms (See Drawing 3D).

While usually designed as a 'standalone' facility without conveyance, new designs are evolving that put a series of Rain Gardens along linear areas like roads – with weirs and surface conveyance similar to Infiltration Swales.

Other common terms used are *Bioretention and Dry Swale with Underdrain* (Stephens *et al.*, 2002) or *Swale / Trench Element* (MUNLV-NRW, 2001).

Application and Limitations

Application and Limitations are similar to Infiltration Swales.

Photo Credit: Lanarc Consultants Ltd.

Formal rain garden, Buckman Terrace, Portland Oregon.

Photo Credit: Lanarc Consultants Ltd.

Informal rain garden, Water Pollution Control Laboratory, Portland Oregon

Photo Credit: Lanarc Consultants Ltd.

Rain garden overflow, Buckman Terrace, Portland Oregon.

Design Guidelines

1. The Rain Garden area should be 10-20% of the upstream impervious area that it serves, preferably sized by continuous flow modelling. Common rain garden size is about 50 m^2 draining 250m^2 of impervious area, although this sizing and proportion will vary by rainfall and soil characteristics. Smaller, distributed Rain Gardens are better than single large scale facilities.
2. Site Rain Gardens similar to other infiltration facilities – minimum 30m from wells, minimum 3 m downslope of building foundations, and only in areas where foundations have footing drains.
3. Provide pretreatment erosion control to avoid sedimentation in the garden. Provide non-erodable material, sediment cleanout basins, and weir flow spreaders at point-source inlets. Flow to the swale should be distributed sheet flow, travelling through a grassy filter area or grass swale prior to entering the Rain Garden (500 mm minimum, greater than 3000 mm desirable grassy pretreatment swale length; Claytor and Schueler, 1996).
4. Rain Garden bottom (Drawing 3A): flat cross section, with a longitudinal slope of 2% (or 1% by US001, or dished by GE004). Provide a 50mm – 75mm layer of organic mulch – well aged compost, bark mulch or similar weed free material. The mulch is important for both erosion control and maintaining infiltration capacity.
5. Rain Garden bottom width: 600mm minimum, 3000mm desirable, length:width ratio of 2:1 (Gibb *et al.*, 1999).
6. Rain Garden side slopes 2 horizontal : 1 vertical maximum, 4:1 preferred for maintenance. Provide organic mulch on side slopes similar to bottom.
7. Maximum ponded level: 150mm (Gibb *et al.*, 1999), 300mm (NRW).
8. Drawdown time for the maximum surface ponded volume: 48 hours (72 hours max. - Maryland Dept. Environmental Resource Programs, 2001).
9. Treatment soil depth: 450mm minimum (City of Portland, 2002), 1200mm desirable (Gibb *et al.*, 1999). Treatment soil should have a minimum infiltration rate of 13mm/hr, with 6mm/hr used for design.
10. Slope of the drain rock reservoir bottom shall be level.
11. A non-erodible outlet or spillway must be established to discharge overflow (Maryland Dept. Environmental Resource Programs, 2001).

12. Avoid utility or other crossings of the Rain Garden. Where utility trenches must be constructed crossing below the garden, install trench dams to avoid infiltration water following the utility trench.
13. Rain gardens can be constructed in a variety of shapes, including formal rectalinear flow-through planters (Drawing 3E). Get geotechnical advice prior to siting rain gardens closer than 3m to building foundations.

Design Options:

Infiltration Rain Gardens may take a variety of shapes, from informal, organically shaped 'bowls' to formal, rectilinear planting areas and planters.

Drain rock reservoir and underdrain may be deleted where infiltration tests by the design professional taken at the level of the base of the proposed construction show an infiltration rate that exceeds the inflow rate for the design storm.

Photo Credit: Lanarc Consultants Ltd.

Flow-thru planter – a formal-shaped rain garden that provides water quality treatment and limited flow attenuation – adapted to a near-building location at Buckman Terrace in Portland, Oregon.

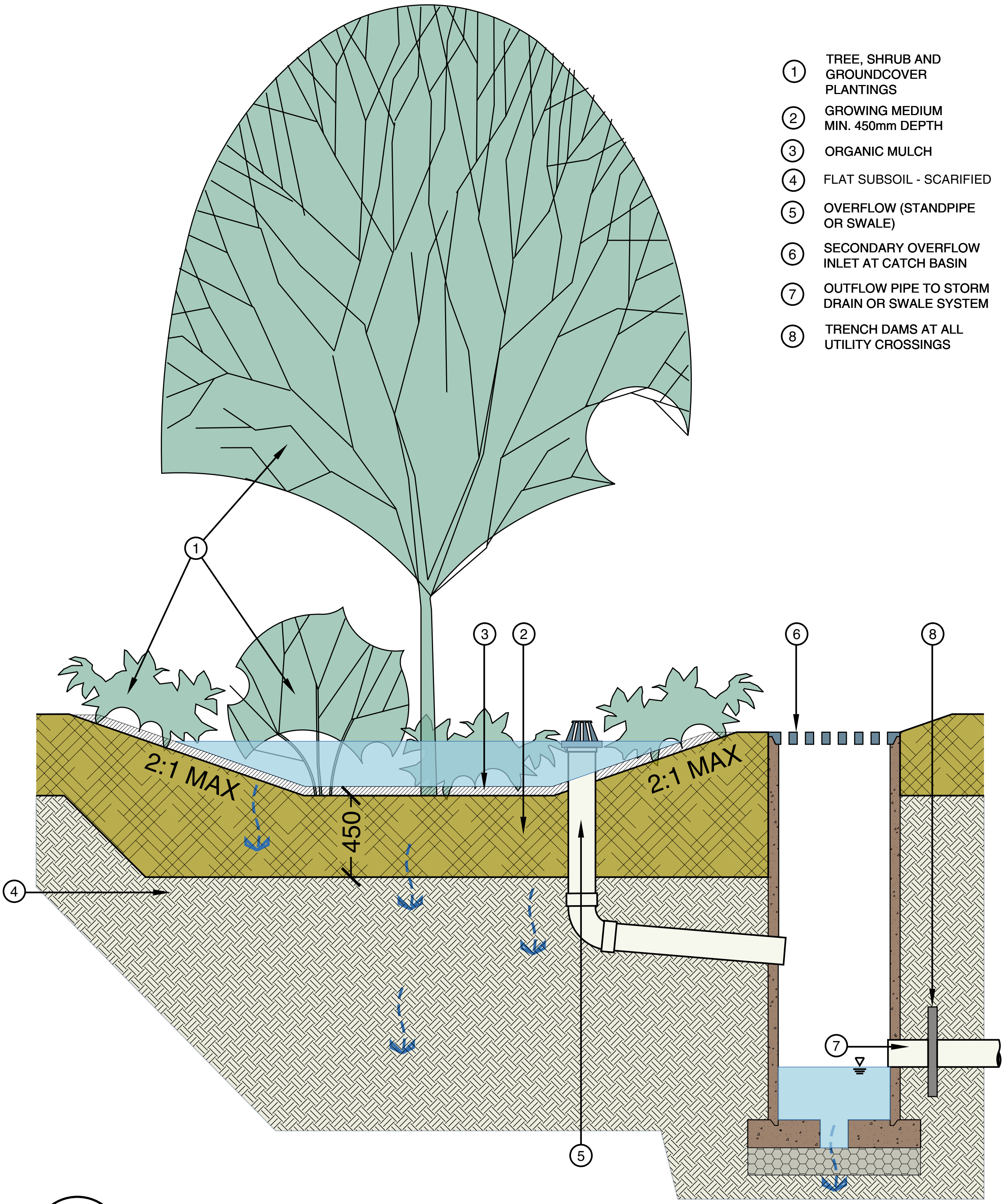
Guideline Specifications

Materials shall meet Master Municipal Construction Document 2000 requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, 75mm max, 38mm min, 40% porosity (Maryland Dept. Environmental Resource Programs, 2001).
2. Pipe: PVC, DR 35, 150 mm min. dia., with cleanouts.
3. Geosynthetics: as per Section 02498, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 02226.
5. Growing Medium: As per Section 02921 Topsoil and Finish Grading, Table 2, including the requirement for minimum saturated hydraulic conductivity of 2 cm/hr., with organic matter requirements amended as follows:
    a. For lawn areas minimum 8%
    b. For planting areas minimum 15%
6. Seeding: to Section 02933 Seeding or 02934 Hydraulic Seeding (note – sodding will be required for erosion control in most instances).
7. Sodding: to Section 02938 Sodding.

Construction Practices shall meet Master Municipal Construction Document 2000 requirements, and:

1. Isolate the swale site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300mm of material over the final subgrade of the swale until after all sediment-producing construction in the drainage area has been completed (Maryland Dept. Environmental Resource Programs, 2001).
2. Prevent natural or fill soils from intermixing with the Infiltration Drain Rock. All contaminated stone aggregate must be removed and replaced (Maryland Dept. Environmental Resource Programs, 2001).
3. Infiltration Drain Rock shall be installed in 300mm lifts and compacted to eliminate voids between the geotextile and surrounding soils (Maryland Dept. Environmental Resource Programs, 2001).
4. Maintain grass areas to mowed height between 50mm and 150mm., but not below the design water quality flow level. Landscape Maintenance standards shall be to the BC Landscape Standard, 6th Edition, Maintenance Level 4: Open Space / Play.



3
A

RAIN GARDEN - FULL INFILTRATION

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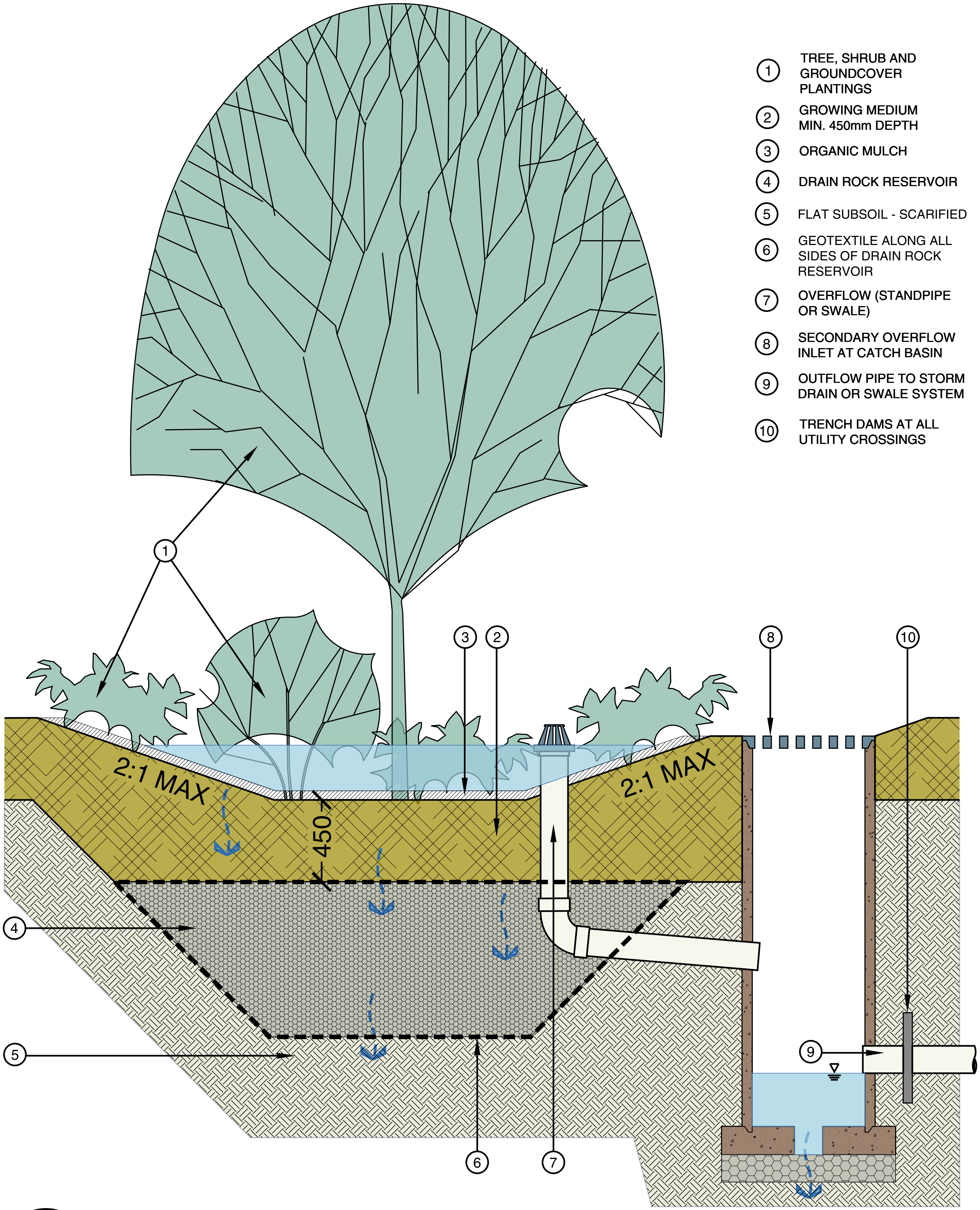
Section



3
B

RAIN GARDEN - FULL INFILTRATION WITH RESERVOIR

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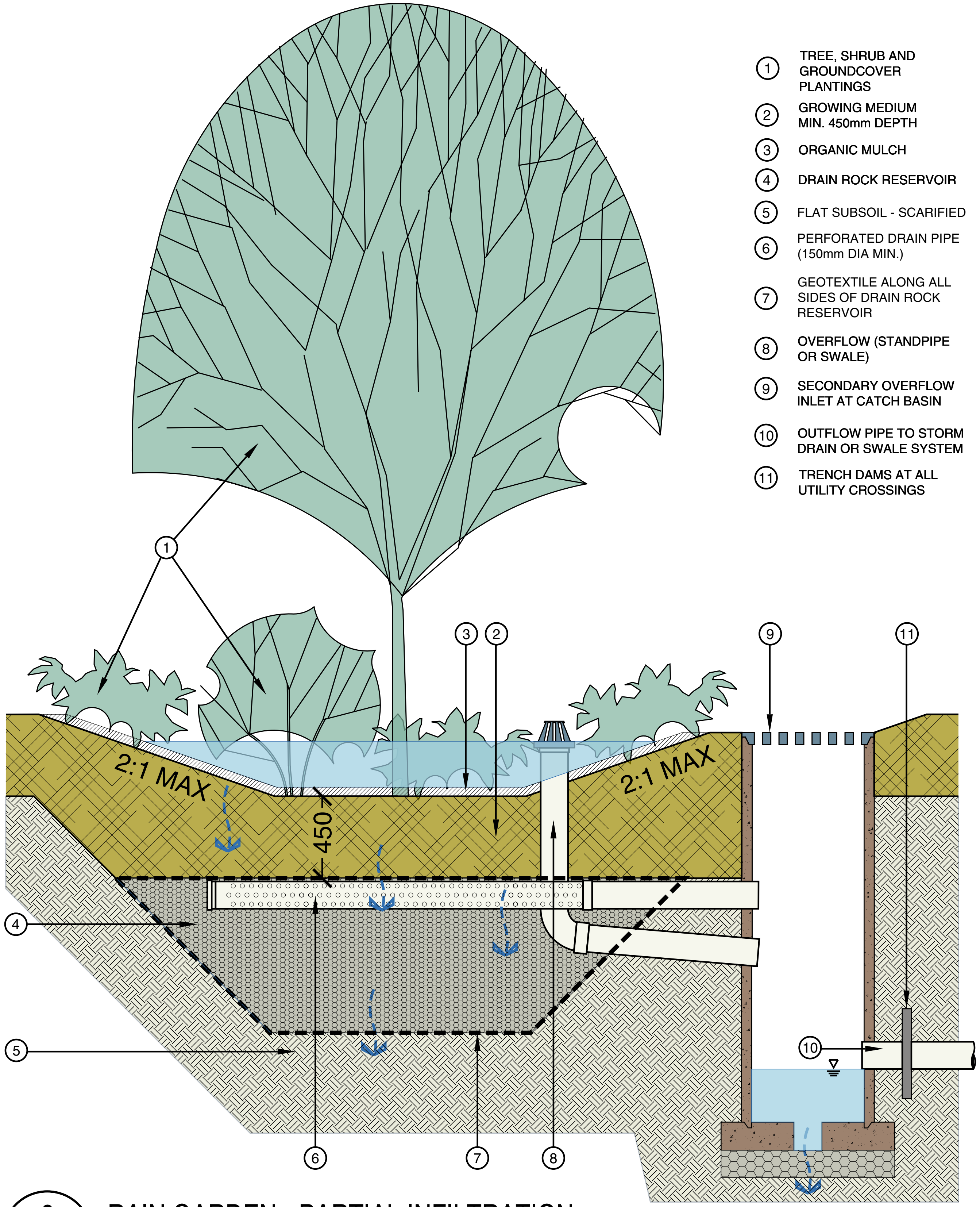
Section



3
C

RAIN GARDEN - PARTIAL INFILTRATION

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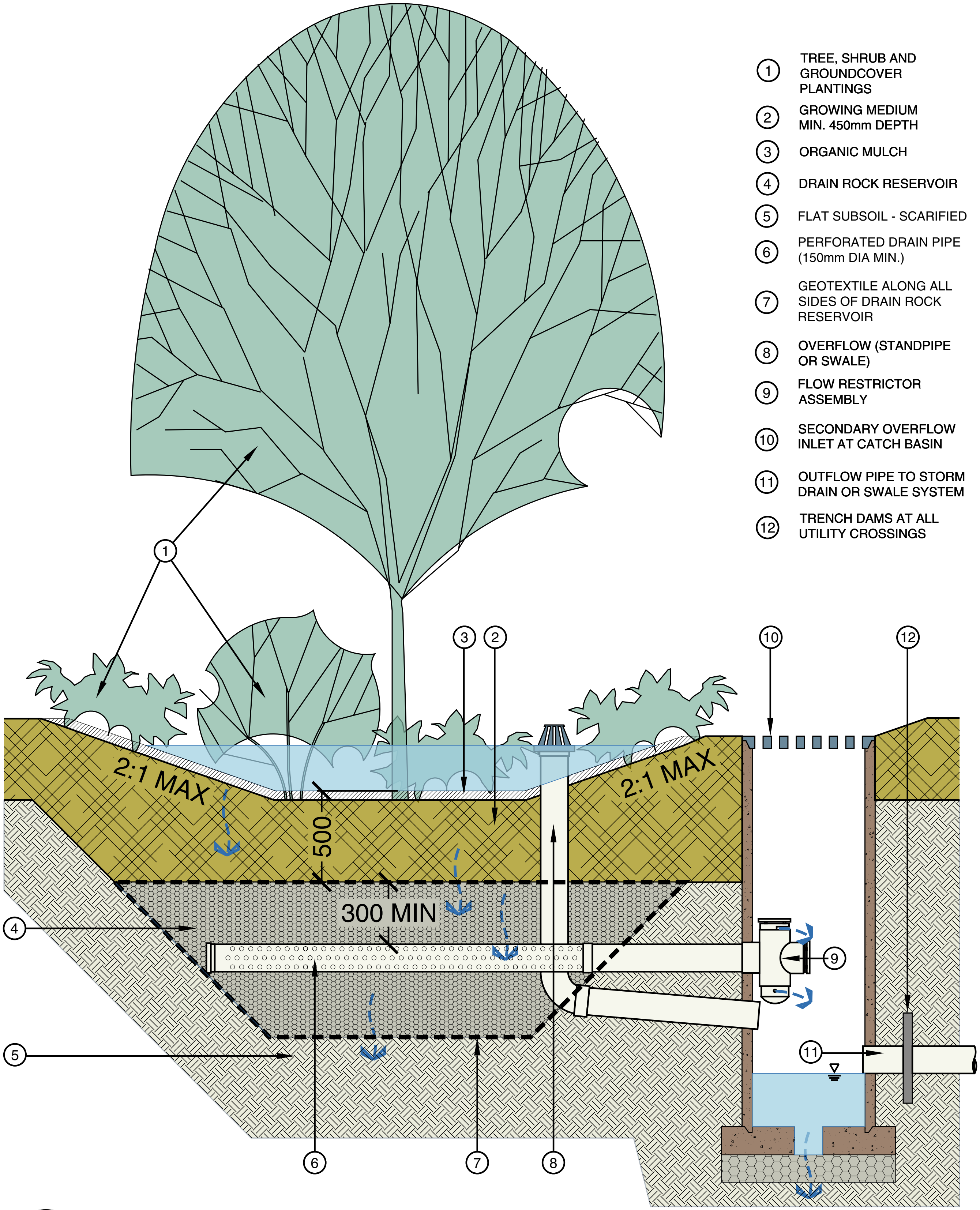
Section



3
D

RAIN GARDEN - PARTIAL INFILTRATION WITH FLOW RESTRICTOR

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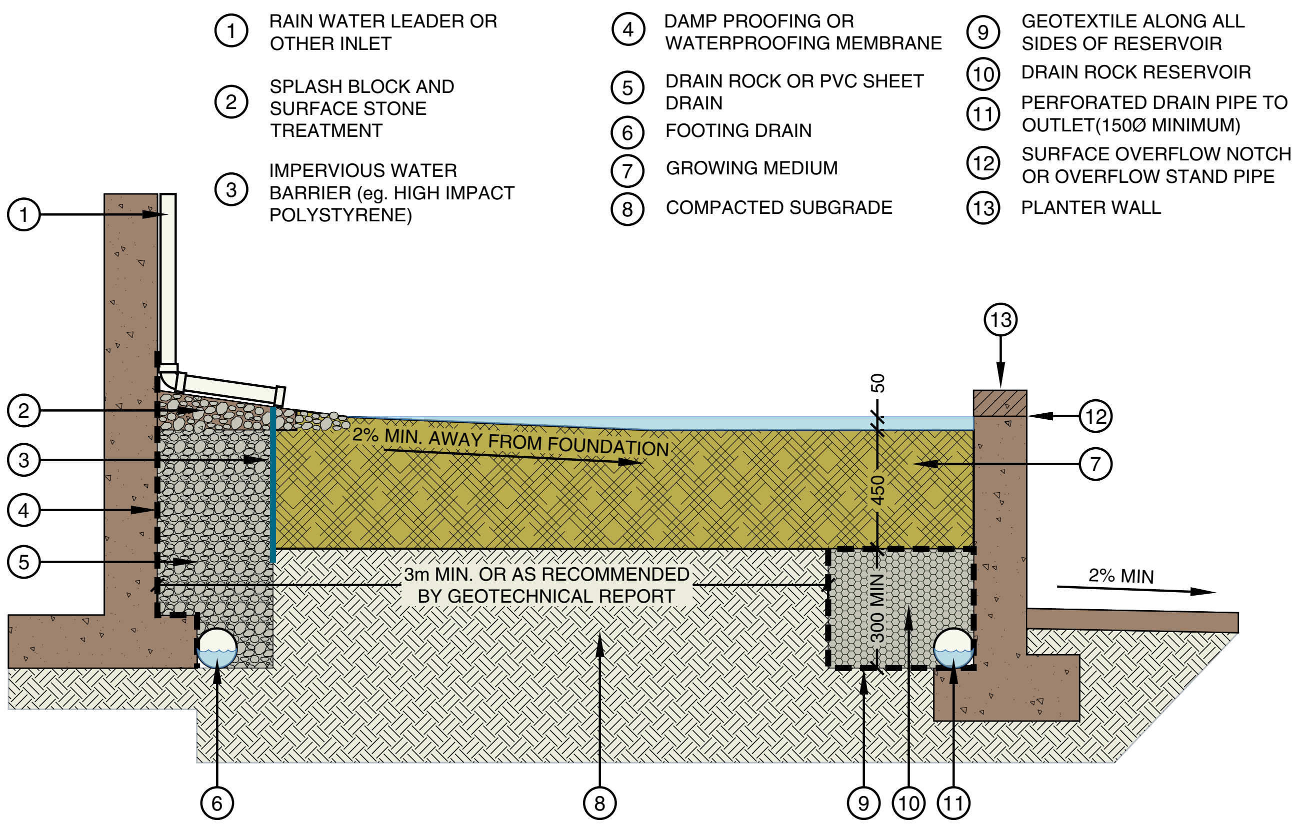
Section



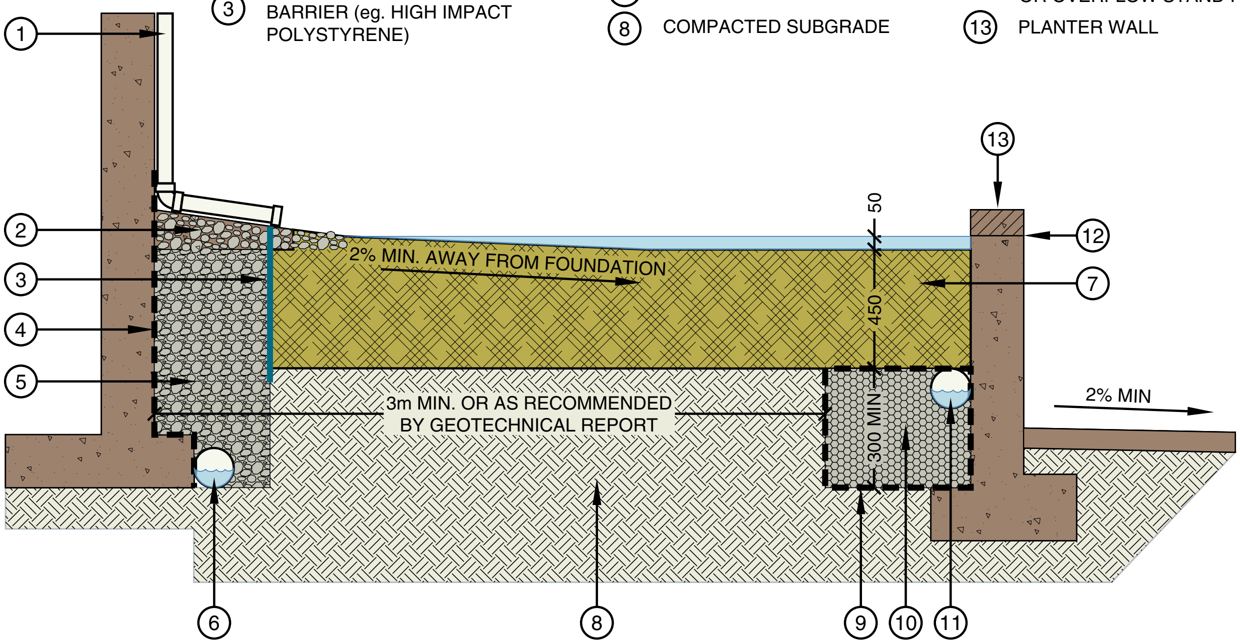
3 / E

FLOW THROUGH PLANTER

Not To Scale

Section

1. RAIN WATER LEADER OR OTHER INLET
2. SPLASH BLOCK AND SURFACE STONE TREATMENT
3. IMPERVIOUS WATER BARRIER (eg. HIGH IMPACT POLYSTYRENE)
4. DAMP PROOFING OR WATERPROOFING MEMBRANE
5. DRAIN ROCK OR PVC SHEET DRAIN
6. FOOTING DRAIN
7. GROWING MEDIUM
8. COMPACTED SUBGRADE
9. GEOTEXTILE ALONG ALL SIDES OF RESERVOIR
10. DRAIN ROCK RESERVOIR
11. PERFORATED DRAIN PIPE TO OUTLET(150Ø MINIMUM)
12. SURFACE OVERFLOW NOTCH OR OVERFLOW STAND PIPE
13. PLANTER WALL



3
F

INFILTRATION PLANTER

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Section

Pervious Paving

Description

Pervious paving is a surface layer of paving systems which allows rainfall to percolate into an underlying reservoir base, where rainfall is stored and either exfiltrated to underlying subgrade, or removed by a subdrain.

The surface component of pervious paving can be:

- Porous asphalt or porous concrete, where fines are not included in the mix, providing a high void ratio that allows water to pass through. There have been problems with surface clogging of this type of pavement.
- Concrete or plastic grid pavers, where a structural load bearing matrix has large voids that are filled with a permeable material – usually gravel or soil - and which often have grass in these voids.
- Permeable unit pavers, made up of impervious concrete modular pavers with gapped joints that allow water to percolate between the pavers.

The focus of this section is on the permeable unit pavers, as they have been used with consistent success and appear more resilient to clogging than porous paving alternatives. (James *et al*., 2003)

Application

- ❑ Suitable for low traffic areas – e.g., driveways, parking areas, storage yards, bike paths, walkways, recreational vehicle pads, service roads, fire lanes (GVSDD, 1999).
- ❑ Can receive runoff from other areas, provided protection from sediment loads is provided (GVSDD, 1999).
- ❑ Suitable for reduction in peak flows and runoff volumes, contaminant removal, groundwater recharge (GVSDD, 1999).
- ❑ May be used to retrofit existing developments and redeveloping areas as well as new developments (GVSDD, 1999).

Photo Credit: Lanarc Consultants Ltd.

Plastic grid pavers in parking, White Rock Operations Centre.

Photo Credit: Lanarc Consultants Ltd.

Plastic grid paver detail

Limitations

- A greater design and construction control effort is required when compared with impermeable pavements (Smith, 2001).
- Minimum depth from base of drain rock reservoir to water table or solid bedrock 610 mm (Smith, 2001).
- The pavement should be downslope from building foundations, and the foundations should have piped drainage at the footing (Smith, 2001).
- At least 30m should be maintained between permeable pavements and water supply wells (Smith, 2001).
- Total catchment area draining onto the permeable pavement is not greater than 2 ha (Smith, 2001).
- To avoid surface plugging, it is critical to protect this BMP from sedimentation both during and after construction. In addition, identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this BMP (Maryland Dept. Environmental Resource Programs, 2001).
- For designs which rely on full exfiltration from the reservoir into underlying soils, the infiltration rate of underlying soil should be 12.5 mm/hr. minimum (Smith, 2001), or as determined by detailed geotechnical engineering.
- Types of permeable interlocking concrete pavements that have wide joints (some manufacturers) should not be used for disabled persons parking stalls or pedestrian ramps at street crossings (Smith, 2001).

Photo Credit: Lanarc Consultants Ltd.

Permeable unit paving streetside parking in the Netherlands.

Design Guidelines for Permeable Interlocking Concrete Paving

Photo Credit: Lanarc Consultants Ltd.

Pervious paving reservoir base.

Pervious pavement designs may be one of three types (Smith, 2001):

- Full Infiltration – where all inflow is intended to infiltrate into the underlying subsoil (See Drawing 4A).
- Partial Infiltration – designed so that some water may infiltrate into the underlying soil while the remainder is drained by perforated pipes (See Drawing 4B).
- Partial Infiltration with Flow Restrictor – designed with a perforated pipe and flow restrictor located at the bottom of the drain rock reservoir. A small orifice in the flow restrictor allows the gradual decanting of water above the perforated pipe, with infiltration occuring as much as possible. These systems are essentially underground detention systems, and are used in cases where the underlying soil has low permeability or there is high water table (See Drawing 4C).

Design Guidelines for all three types include the following:

1. Soil subgrade sampling and analysis should be provided by a professional engineer knowledgable in the local soils. Testing of soil cores taken at the proposed area to be paved should include soil texture classification, sampled moisture content, 96 hour soaked California Bearing Ratio (CBR) with a target of at least 5% for light vehicular traffic, 15% for heavy vehicles, and on-site infiltration tests using a Double-Ring Infiltrometer taken at the elevation of the proposed base of the reservoir.
2. Minimum recommended tested infiltration rate for a full infiltration pavement design is 12.5 mm/hr. Sites with lower rates will require partial infiltration solutions with drain pipes, and care must be taken that the subbase will remain stable while saturated. (Smith, 2001)
3. Where it is proposed to drain impermeable surfaces onto pervious pavement surfaces, it is recommended that a maximum ratio of 2:1 impermeable to permable is used (Formpave, 2003). This may vary by rainfall and soil characteristics as determined by modelling.
4. Permeable Unit Pavers should be selected and designed based on a manufacturer's tests that the installed unit paving system can maintain a minimum 28mm/hr infiltration rate over the pavement life (usually 20 years). This rate includes a factor of safety of 10 – the initial infiltration rate should be >280mm/hr (Smith, 2001).

5. Permeable unit pavers are usually 80mm depth. Provide edge restraint to contain the pavers, similar to standard unit paving. Edgers that use spikes are not recommended (Smith 2001).
6. Permeable unit paving surface slope should be 1% minimum to avoid ponding on the surface, and related settlement of clay sized particles (Smith, 2001).
7. Provision of vegetated joints, and overhanging trees which drop needles onto the pavement have, in research studies, helped to maintain high infiltration capabilities of pervious unit paving (James *et al*., 2003). Vegetated joints are not suitable in heavily shaded areas such as under long-term parking.
8. Paver bedding material shall be wrapped with geotextile filter cloth on bottom and all sides. This is critical to the water quality performance of the pavement, and also keeps any intrusion of fines near the surface, where localized clogging could be repaired by replacing only the aggregate above the filter cloth and patching the cloth, reusing the pavers.
9. Bottom of reservoir: flat in full infiltration designs, minimum 0.1% slope to drain in piped systems (Formpave, 2003).
10. If the pavement is being designed for heavy loads, optional reinforcing grids may be included in the pavement subbase.
11. With infiltration designs, the bottom and sides of all reservoir base and subbase courses shall be contained by a geotextile filter cloth. Geotextile shall be adhered to the drains (Formpave 2003).
12. Design reservoir water levels and stormwater detention using a continuous modelling program. Drawdown time for the reservoir: 96 hours maximum, 72 hours desirable.
13. If the design is for partial infiltration with a flow restrictor assembly, size the orifice for a design flow that meets local requirements or replicates base flow from the drainage area.
14. Provide a secondary overflow inlet and inspection chamber (catch basin or manhole) at the flow control assembly. If no secondary overflow inlet is installed, provide a non-erodible outlet or spillway to the major storm flow path. (Smith, 2001).
15. Underground weirs of undisturbed native material or constructed ditch blocks shall be provided to create underground pooling in the reservoir sufficient for infiltration performance.

16. Avoid utility or other crossings of the pervious pavement area. Where utility trenches must be constructed crossing below the reservoir, install trench dams at exits to avoid infiltration water following the utility trench.

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2000 requirements, and:

1. Pavers: Permeable Interlocking Concrete Pavers meeting CSA A231.2, designed and tested by the manufacturer for use as part of a permeable unit paving system with a initial infiltration rate >280mm/hr. and a maintained >28mm/hr infiltration rate over the pavement life (usually 20 years) (Smith, 2001).
2. Paver bedding course (50mm thick) and joint filling material shall be open-graded crush 5mm aggregate (or ASTM No.8 - no sand). A surface finish of 3mm clean crush aggregate (or ASTM No 89) should be applied to the finish surface and brushed in (Formpave, 2003; Smith, 2001).
3. Reservoir Base course shall be clean crushed stone graded from 5mm to 20mm (approximately 100mm deep or greater – varies with design) (Formpave, 2003). In cases where this finer base is not required for water quality treatment, the Reservoir Base may be the same material as the Reservoir Subbase.
4. Reservoir Subbase shall be clean crushed stone graded from 10mm to 63mm, with void space ratio >35% (or ASTM No. 57 – approximately 250mm deep or greater – varies with design) (Formpave, 2003; Smith 2001).
5. Pipe: PVC, DR 35, 150 mm min. diameter, with cleanouts. Practical depth of cover over the pipe may be a determinant in depth of base courses.
6. Geosynthetics: as per Section 02498, select for filter criteria or from approved local government product lists.

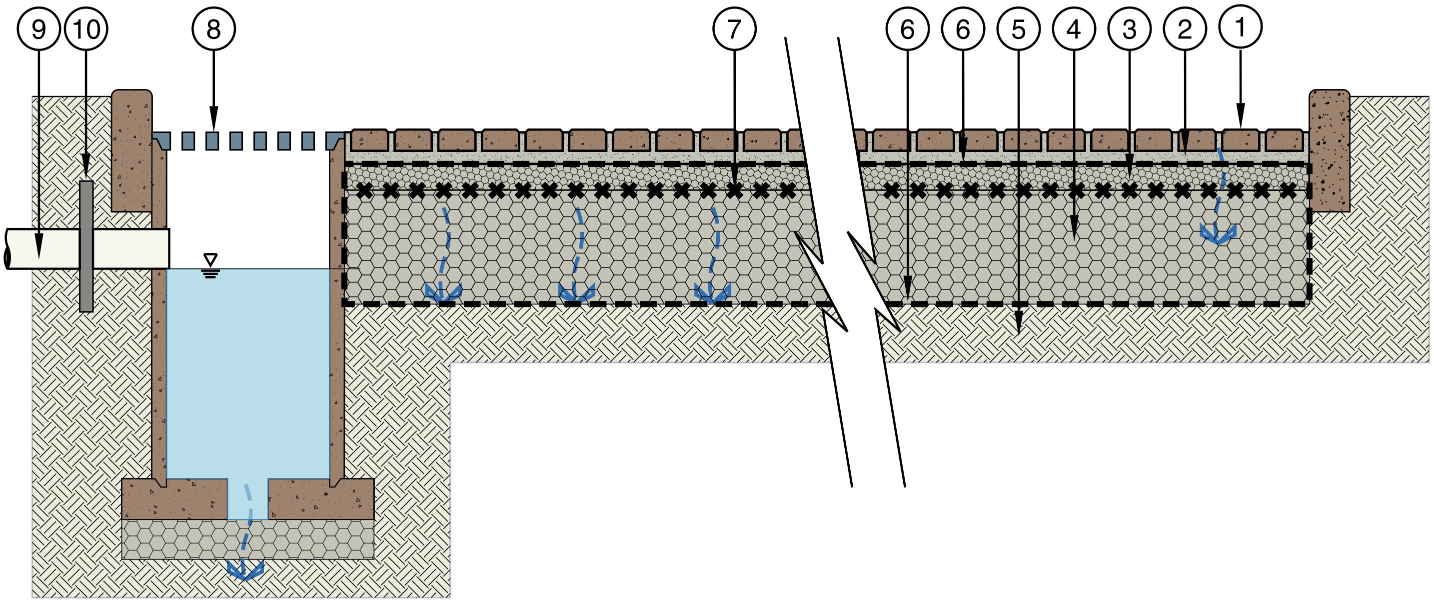
Construction Practices shall meet Master Municipal Construction Document 2000 requirements, and:

1. Isolate the permeable paving site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300mm of material over the final subgrade of the pavement until after all sediment-producing construction in the drainage area has been completed (Maryland Dept. Environmental Resource Program, 2001).
2. The subgrade should be compacted to 95% standard proctor for walk/bike areas, and 95% modified proctor for vehicular areas. Remove and replace soft areas (Smith, 2001).
3. Prevent natural or fill soils from intermixing with the reservoir base, sub-base, or bedding courses and filter cloths. All contaminated stone aggregate and cloth must be removed and replaced (Smith, 2001).
4. Reservoir drain rock sub base and base courses shall be installed in 100 to 150mm lifts and compacted with at least 4 passes with a minimum 9 T steel drum roller (Smith, 2001).
5. When all base courses are compacted the surface should be topped with filter cloth and a layer of bedding aggregate, and the surface graded carefully to final slopes, as the bedding aggregate will compact down much less than sand. Unit pavers shall be placed tightly butt jointed according to manufacturers specifications. Blocks should be vibrated with a vibrating plated compactor. Following a first pass, a light dressing of 3mm single size clean stone should be applied to the surface and brushed in, approximately 2 kg/m2. Blocks should again be vibrated and any debris brushed off (Formpave, 2003).
6. For maintenance, the surface should be brushed at least twice a year with a mechanical suction brush (vacuum sweeper) – in the spring and in autumn after leaf fall (Formpave, 2003).

Photo Credit: Lanarc Consultants

Pervious unit paving with aggregate joints at bike rack.

1. PERMEABLE PAVERS (MIN. 80mm THICKNESS)
2. AGGREGATE BEDDING COURSE -NOT SAND (50mm DEPTH)
3. OPEN GRADED BASE (DEPTH VARIES BY DESIGN APPLICATION)
4. OPEN GRADED SUB-BASE (DEPTH VARIES BY DESIGN APPLICATION)
5. SUBSOIL - FLAT AND SCARIFIED IN INFILTRATION DESIGNS
6. GEOTEXTILE ON ALL SIDES OF RESERVOIR
7. OPTIONAL REINFORCING GRID FOR HEAVY LOADS
8. OVERFLOW INLET AT CATCH BASIN
9. OUTLET PIPE TO STORM DRAIN OR SWALE SYSTEM. LOCATE CROWN OF PIPE BELOW OPEN GRADED BASE (NO. 3) TO PREVENT HEAVING DURING FREEZE/THAW CYCLE
10. TRENCH DAMS AT ALL UTILITY CROSSINGS



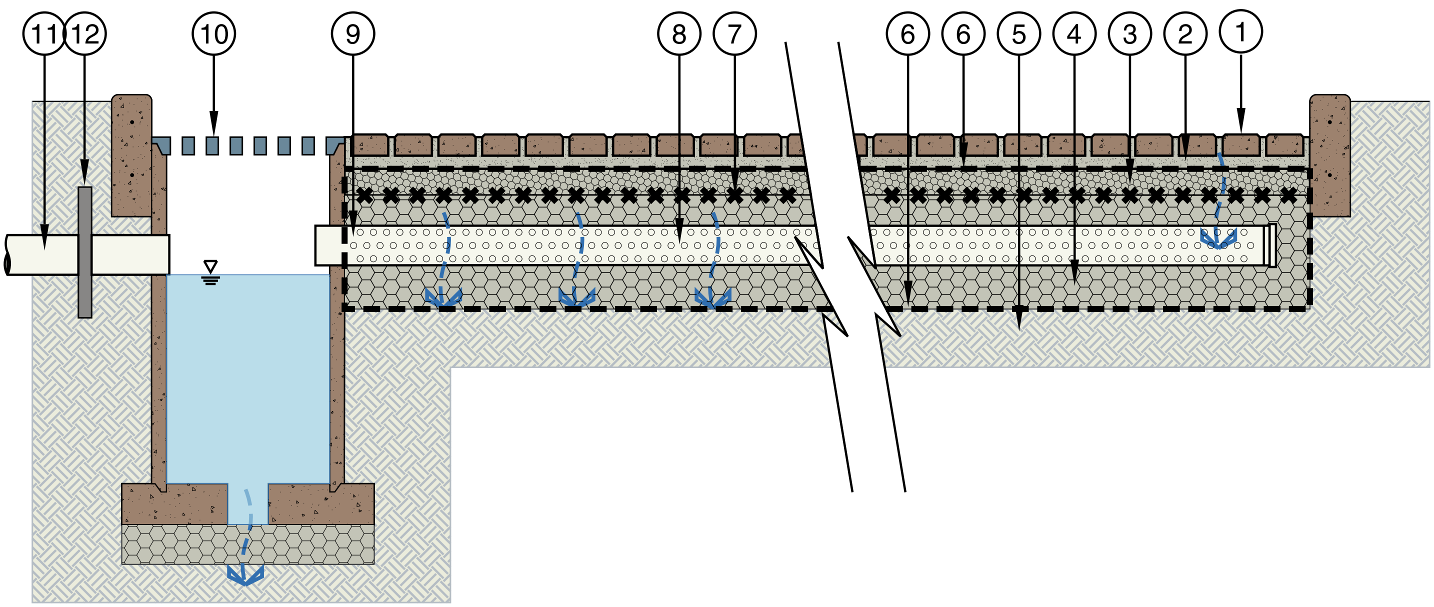
4
A

PERVIOUS PAVING - FULL INFILTRATION

Not To Scale

Section

1. PERMEABLE PAVERS (MIN. 80mm THICKNESS)
2. AGGREGATE BEDDING COURSE -NOT SAND (50mm DEPTH)
3. OPEN GRADED BASE (DEPTH VARIES BY DESIGN APPLICATION)
4. OPEN GRADED SUB-BASE (DEPTH VARIES BY DESIGN APPLICATION)
5. SUBSOIL - FLAT AND SCARIFIED IN INFILTRATION DESIGNS
6. GEOTEXTILE ON ALL SIDES OF RESERVOIR
7. OPTIONAL REINFORCING GRID FOR HEAVY LOADS
8. PERFORATED DRAIN PIPE 150mm DIA MIN.
9. GEOTEXTILE ADHERED TO DRAIN AT OPENING
10. OVERFLOW INLET AT CATCH BASIN
11. OUTLET PIPE TO STORM DRAIN OR SWALE SYSTEM. LOCATE CROWN OF PIPE BELOW OPEN GRADED BASE (NO. 3) TO PREVENT HEAVING DURING FREEZE/THAW CYCLE
12. TRENCH DAMS AT ALL UTILITY CROSSINGS



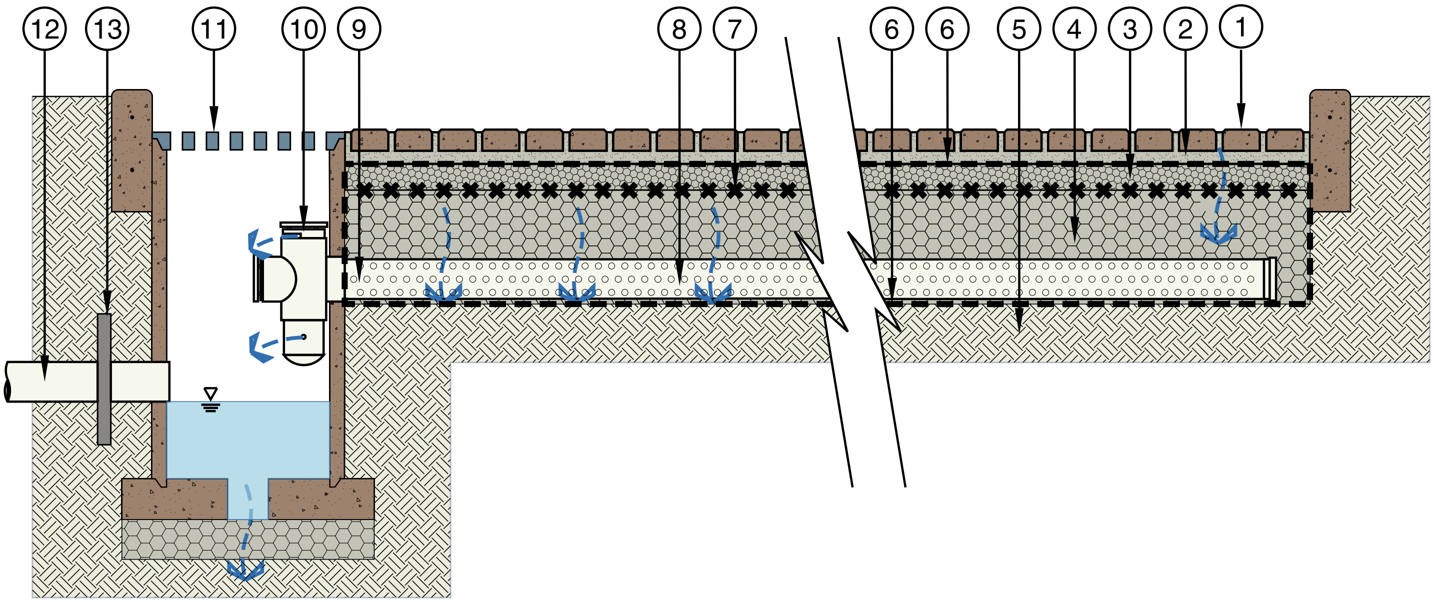
4
B

PERVIOUS PAVING - PARTIAL INFILTRATION

Not To Scale

Section

1. PERMEABLE PAVERS (MIN. 80mm THICKNESS)
2. AGGREGATE BEDDING COURSE -NOT SAND (50mm DEPTH)
3. OPEN GRADED BASE (DEPTH VARIES BY DESIGN APPLICATION)
4. OPEN GRADED SUB-BASE (DEPTH VARIES BY DESIGN APPLICATION)
5. SUBSOIL - FLAT AND SCARIFIED IN INFILTRATION DESIGNS
6. GEOTEXTILE ON ALL SIDES OF RESERVOIR
7. OPTIONAL REINFORCING GRID FOR HEAVY LOADS
8. PERFORATED DRAIN PIPE 150mm DIA MIN.
9. GEOTEXTILE ADHERED TO DRAIN AT OPENING
10. FLOW RESTRICTOR ASSEMBLY
11. OVERFLOW INLET AT CATCH BASIN
12. OUTLET PIPE TO STORM DRAIN OR SWALE SYSTEM. LOCATE CROWN OF PIPE BELOW OPEN GRADED BASE (NO. 3) TO PREVENT HEAVING DURING FREEZE/THAW CYCLE
13. TRENCH DAMS AT ALL UTILITY CROSSINGS



4
C

PERVIOUS PAVING - PARTIAL INFILTRATION WITH FLOW RESTRICTOR

Not To Scale

Section

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Green Roof

Description

A green roof is a conventional roof with a veneer of drainage and growing media that supports living vegetation.

Green roofs with a relatively shallow growing medium thickness are generally called 'Extensive Green Roofs'. These are often designed for stormwater, insulation and climate amelioration functions, and usually have no public access. Vegetation is selected for its ability to withstand harsh conditions and its ability to maintain itself over the long-term.

'Intensive Green Roofs' are usually designed with public access and use in mind, and have deeper growing medium depths to support larger plants and trees. Intensive green roofs also have stormwater benefits, but are heavier and more expensive to develop, and therefore less affordable for the large flat roof expanses that are common in industrial/commercial developments.

This section is focused on the stormwater aspects of Extensive Green Roofs.

Photo Credit: Goya Ngan

Extensive green roof – Halle Zoo, Germany

Photo Credit: Lanarc Consultants

Extensive green roof – Amsterdam

Applications

- Suitable for many rooftop situations – industrial and warehousing, commercial buildings, municipal office complexes, hospitals, schools, institutional/administrative buildings and offices, residential developments and garages.
- Suitable for flat roofs and, with proper design, roofs of 20° slope or more (Peck & Kuhn, 2001). These may be inverted or traditional roofing systems. Shingle and tile roofs are not suitable for greening (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V (FLL), 2002).

- Green roofs provide multiple benefits, including:
  - Reduction in stormwater peak flows.
  - Reduction in rainfall volume leaving the roof due to evaporation and evapo-transpiration. A typical extensive green roof of about 75mm in growing media can be designed to reduce annual runoff by more than 50% (Miller, 2001b; FLL, 2002).
  - Mitigation of the urban heat island effect, which is raising the temperatures of cities and increasing energy use as well as increasing the effects of air pollution (Peck & Kuhn, 2001).
  - Air filtration, removing fine particulates from the air (Peck & Kuhn, 2001).
  - Reduction in heat gain and the need for air conditioning in the summer – modeled savings are as high as 25% (Peck & Kuhn, 2001).
  - Reducing heat loss in the winter; studies show that with 30 cm of growing medium, roof temperatures do not drop below 0°C even when outside temperatures are -20°C (Peck & Kuhn, 2001).
  - Roof membrane protection and life extension. European studies have revealed that green roof installation can double the life span of a conventional roof, by helping to protect the membrane from extreme temperature fluctuations, ultraviolet radiation, and mechanical damage (Peck & Kuhn, 2001).
  - Sound insulation – tests show that 12 cm of growing medium can reduce sound by 40 db (Peck & Kuhn, 2001).
  - Increasing biodiversity in urban areas by providing habitat for birds, insects, native plants, and rare or endangered species.
  - Aesthetic value and increased urban green space.

Limitations

- Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing media has created solutions where saturated growing media can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction. (Peck & Kuhn, 2001).
- Canada does not have official green roof standards. Until such standards are published, the German FLL guidelines and test procedures represent the only comprehensive standards for green roof design, installation and maintenance. Green roofs, as extensions of the roofing system, should comply with the BC Building Code.

Extensive Green Roof Types

Extensive green roofs can be one of following designs:

- Multiple layer construction (Drawing 5A and 5B) - consists of either: i) a three-layer system including separate drainage course, filter layer and growing medium or; ii) a two layer system where the growing medium is sized to not require a filter between it and the underlying drainage layer. Extensive Green Roof may be installed over either a conventional or an inverted roof system.
- Single layer construction (Drawing 5B) - consists of a growing medium which includes the filter and drainage functions.

Design Guidelines

1. Start the design of the green roof at the same time as the design of the building or retrofit project, so that the structural load of the green roof can be balanced with the structural design of the building. From the outset, involve all design disciplines – structural, mechanical and electrical engineers, architects and landscape architects – and include roofing design professionals in a collaborative and optimization effort (Oberlander *et al.*, 2002).

2. Provide construction and maintenance access to extensive green roofs. Access through a 'man door' is preferable to access through a small roof hatch (Peck & Kuhn, 2001). Provide areas of storage for maintenance equipment. Review Workers Compensation Board requirements for safety of maintenance workers – can gardeners working near the edge of the roof use the same harness fastenings as window washers? (Oberlander *et al.*, 2002) Provide a

hose bib for manual watering during establishment if no automatic irrigation system is planned.

3. Roofs with less that 2% slope require special drainage construction so that no part of the growing medium is continuously saturated. As the slope increases, so does the rate of rainfall leaving the roof. This can be compensated for by using a medium with high water storage capacity. Roofs with over 20° require special precautions against sliding and shearing (FLL. 2002). If inverted roof systems are used with exterior insulation, good drainage needs to be provided to prevent continuous saturation of the insulation, and subsequent damage (Peck & Kuhn, 2001). With inverted roofs, the green roof components must allow moisture to move upwards from the insulation and to eventually evaporate (Krupka, 1992).

4. Provide plant free zones to facilitate access for inspections and maintenance and prevent plants from spreading moisture onto exposed structural components. They can also function as a measure against fire and wind-uplift. They should be at least 50 cm wide and located along the perimeter, all adjacent facades and covered expansion joints, and around each roof penetration.

Photo Credit: Lanarc Consultants Ltd.

Newly planted extensive green roof showing plant-free zones at drain and edges – White Rock Operations Building

5. Fire breaks of non-combustible material, such as gravel or concrete pavers, 50 cm wide, should be located every 40 m in all directions, and at all roof perimeter and roof penetrations (FLL, 2002). Other fire control options include use of sedums or other succulent plants that have a high water content, or a sprinkler irrigation system connected to the fire alarm (Peck & Kuhn, 2001).

6. There are several choices of waterproof membranes. Thermoplastic membranes, such as PVC (polyvinyl choride) or TPO (thermal polyolefin) using hot air fusion methods are commonly used for green roof applications. Elastomeric membranes like EPDM (ethylene-propylene rubber materials) have high tensile strength and are well-suited to large roof surfaces with fewer roof penetrations. Modified bitumen sheets are usually applied in two layers and are commonly available. Liquid-applied membranes are generally applied in two liquid layers with reinforcement in between. The quality is variable. A factor in choosing a waterproofing system is resistance to root penetration (see point 7 below).

7. Provide protection against root penetration of the waterproof membrane by either adding a root barrier or using a membrane that is itself resistant to root penetration

(more cost efficient). Resistance to root penetration is not being tested in Canada at time of writing[1]. Thermoplastic and elastomeric membranes in suitable thicknesses are usually resistant to root penetration. Roofing membranes, existing or new, which contain bitumen or other organic materials are susceptible to root penetration and micro-organic activity. These types of roofing membranes need to be separated from the growing medium by a continuous root barrier unless they contain an adequate root repelling chemical or copper foil (Ngan, 2003).

8. Chemically incompatible materials such as bitumen and PVC require a separation layer (FLL, 2002).

9. When the roofing membrane installation is complete, but prior to installing layers above the waterproof membrane, it should be tested by flooding and thorough inspection. Any leaks should be repaired prior to installing materials above the membrane (Ngan, 2003).

10. Install a protection layer to protect the waterproof membrane/root barrier from physical damage caused by construction activities, sharp drainage materials such as lava rock or broken expanded clay, and subsequent levels of stress placed on the roof (Ngan, 2003).

11. The drainage layer may be drain rock, but is often a lightweight composite such as lava, expanded clay pellets, expanded slate or crushed brick. If weight is a concern, rigid plastic materials that allow rapid lateral drainage may be used. The drainage layer may also function to store water and make it available to the vegetation during dry periods. The top of the drainage layer is normally separated from the growing medium by non-woven filter cloth.

[1] Check with the manufacturer to determine if the membrane is resistant to root penetration according to the German FLL Root Penetration Test, 2002.

Table 5-1: Weights of Common Building Materials (Oberlander *et al.,* 2002: 26)

Material	Kg/m³
Light weight concrete	1298-1622
Precast concrete	2108
Reinforced concrete	2433
Gravel	1946
Timber – hardwood (av.)	730
Timber –softwood (av.)	568
Sand (dry)	1460-1784
Sand (wet)	1784-2108
Water	1013
Light-weight growing medium (moist condition)	884-1121

12. Light weight growing medium is often a combination of pumice, lava rock, expanded clay or other lightweight absorbent filler, with a small amount of organic matter. The FLL recommends between 6 and 8% organic matter. When properly sized (see Figure 11), a mineral-based growing medium is able to retain stormwater as effectively as soil high in organic matter without the disadvantage of compacting and breaking down over time. For additional detailed information on the properties of green roof growing media, refer to the FLL guidelines(2002):

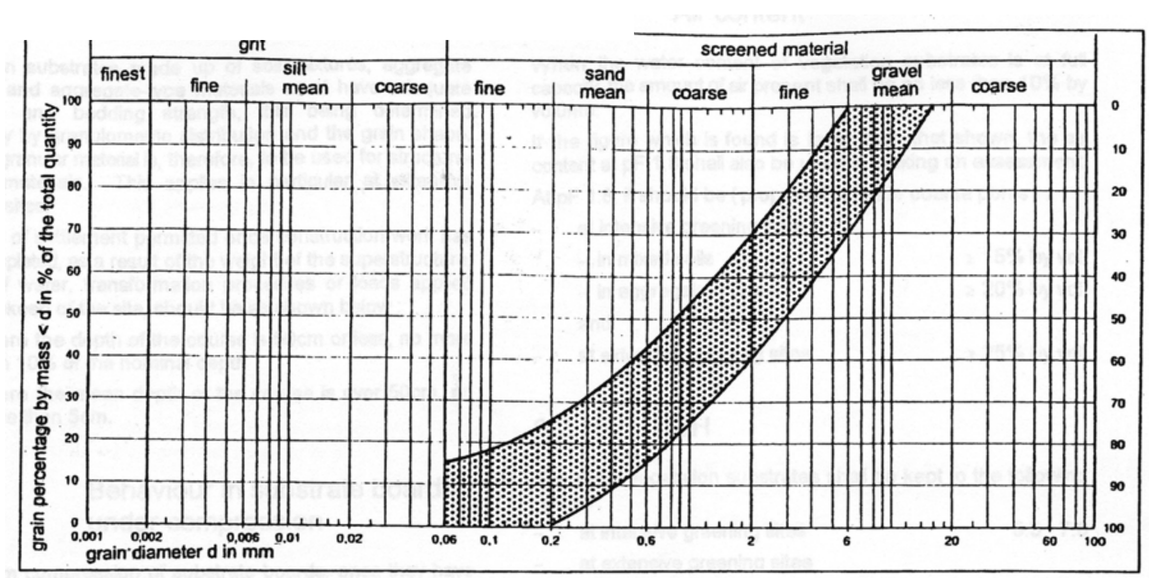


Figure 5-1: Particle (grain) size distribution range for substrates used in multiple layer extensive green roofs (FLL, 1995: 34)

13. In calculating structural loads, always design for the saturated weight of each material (Oberlander *et al.*, 2002). See Table 5-1 for weights of common building materials.

14. Light weight growing medium can be subject to wind erosion when dry. If planting is delayed through a dry weather season, provide a wind erosion control blanket over the growing medium.

15. Plant choices for extensive green roofs are limited to plants that can withstand the extremes of temperature, wind, and moisture condition on a roof. Typically, extensive green roofs use a variety of mosses, sedums, sempervivums, alliums, other bulbs and herbs, and grasses.

16. Avoid specifying or allowing volunteer plant materials with aggressive root systems (e.g. bamboo, couch grass, tree seedlings). Supply and install growing medium that is free of weeds (Ngan, 2003).

17. Design planting to respect microclimate and sun/aspect conditions. Collaborate with mechanical engineers on placement of exhaust vents, and design plantings accordingly (Oberlander *et al.*, 2002).

18. Avoid swaths of one species. The chances of creating a self-maintaining plant community are increased when a wide mix of species is used.

19. Planting methods include seeding, hydroseeding, spreading of sedum sprigs, planting of plugs or container plants, and installing pre-cultivated vegetation mats.

20. If automatic irrigation is required, low volume and rainwater reuse systems are preferred.

21. Provide intensive maintenance for the first two years after the plant installation – including watering in dry periods, removal of weeds, light fertilization with slow release complete fertilizers, and replacement of dead plants. It is recommended that the maintenance contract for the first 3-5 years be awarded to the same company that installed the green roof and that the service be included in the original bid price (Peck & Kuhn, 2001). Once established, a typical extensive green should require only one or two annual visits for weeding of undesired plants, clearing of plant-free zones and inspecting of drains and the membrane.

Photo Credit: Goya Ngan

Green roof test plots - Saskatoon

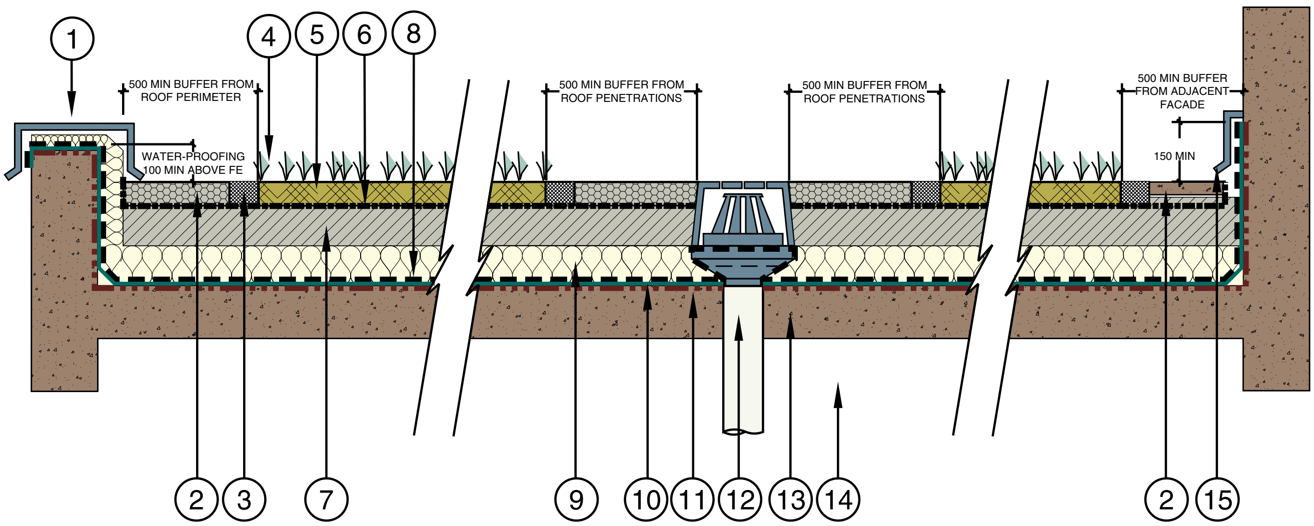
22. Installers should have experience with green roof systems. It may be preferable to have one company handle the entire project from roofing to planting to avoid scheduling conflicts and damage claims (Peck & Kuhn, 2001). If it is not possible, make a clear separation between the responsibilities of the roofing contractor and those of the green roof contractor (Krupka, 1992).

23. Although green roof membranes will last longer than others, leaks can still occur at flashings or through faulty worksmanship. Some companies are recommending an electronic leak detection system to pinpoint the exact location of water leaks, thus allowing easy repair (Peck & Kuhn, 2001).

24. Consider the environmental impact of each green roof material. How much energy was required to extract, manufacture and deliver the material? Is there a suitable material derived from local recycled products? What effect does the material have on water quality? How often must it be replaced? How will it be disposed of? Is it recyclable?

25. Several companies provide the GVRD with complete green roof service, and offer a range of long-term guarantees on the entire assembly. This type of comprehensive installation may be more expensive than comparable 'off the shelf' products not specifically designed for green roof use. The decision on risk management is with the owner (Peck & Kuhn, 2001).

1. WALL CAP FLASHING
2. DRAIN ROCK, PAVING SLAB, OR OTHER BUFFER EQUIVALENT
3. WOOD, STEEL OR CONCRETE CURB/EDGING (OPTIONAL)
4. PLANTING
5. GROWING MEDIUM
6. FILTER LAYER
7. DRAINAGE LAYER
8. PROTECTION LAYER AND ROOT BARRIER
9. THERMAL INSULATION
10. WATERPROOF MEMBRANE
11. VAPOUR BARRIER
12. AREA DRAIN
13. STRUCTURAL SLAB
14. BUILDING INTERIOR
15. WALL FLASHING



NOTE: UNLESS THE WATERPROOF MEMBRANE IS RESISTANT TO ROOT PENETRATION, A ROOT BARRIER IS REQUIRED BETWEEN THE PROTECTION LAYER AND WATERPROOF MEMBRANE. A SEPARATION LAYER MAY BE REQUIRED BETWEEN CHEMICALLY INCOMPATIBLE MATERIALS.

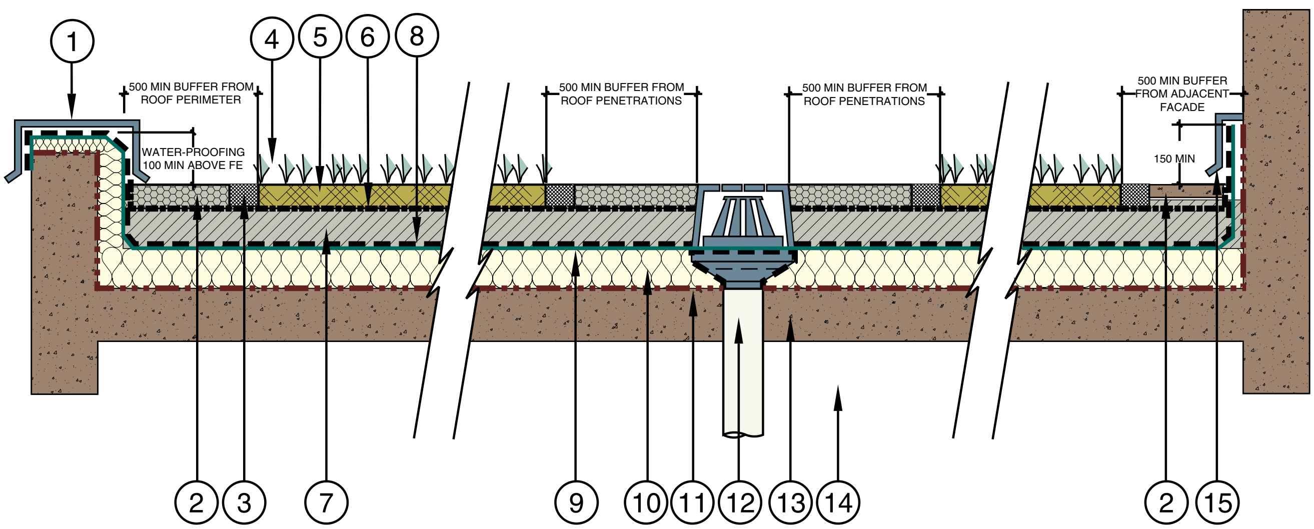
5
A

MULTIPLE LAYER EXTENSIVE GREEN ROOF

Not To Scale

Section

1 WALL CAP FLASHING
2 DRAIN ROCK, PAVING SLAB, OR OTHER BUFFER EQUIVALENT
3 WOOD, STEEL OR CONCRETE CURB/EDGING (OPTIONAL)
4 PLANTING
5 GROWING MEDIUM
6 FILTER LAYER
7 DRAINAGE LAYER
8 PROTECTION LAYER AND ROOT BARRIER
9 WATERPROOF MEMBRANE
10 THERMAL INSULATION
11 VAPOUR BARRIER
12 AREA DRAIN
13 STRUCTURAL SLAB
14 BUILDING INTERIOR
15 WALL FLASHING



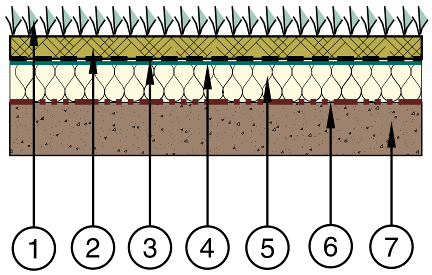
NOTE: UNLESS THE WATERPROOF MEMBRANE IS RESISTANT TO ROOT PENETRATION, A ROOT BARRIER IS REQUIRED BETWEEN THE PROTECTION LAYER AND WATERPROOF MEMBRANE. A SEPARATION LAYER MAY BE REQUIRED BETWEEN CHEMICALLY INCOMPATIBLE MATERIALS.

5 / B

MULTIPLE LAYER EXTENSIVE GREEN INVERTED ROOF

Not To Scale

Section



1 PLANTING
2 GROWING MEDIUM (SPECIAL COARSE COMPOSITION)
3 PROTECTION LAYER
4 WATERPROOF MEMBRANE
5 THERMAL INSULATION
6 VAPOUR BARRIER
7 STRUCTURAL SLAB

5
C

SINGLE LAYER EXTENSIVE GREEN ROOF

Not To Scale

Section

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Infiltration Trench & Soakaway Manhole

Description

An **Infiltration Trench** System includes an inlet pipe or water source, catch basin sump, perforated distribution pipe, infiltration trench and overflow to the storm drainage system. Although commonly in a linear trench shape, the same principles apply to underground drain rock infiltration devices of any shape (See Drawing 6D).

An **Soakaway Manhole** System includes an inlet pipe, a sedimentation manhole, and one or more Soakaway Manholes with connecting pipes (See Drawings 6A, 6B, 6C).

Other common terms used are *Infiltration Sump, Dry Well, or Infiltration Shaft*.

Photo Credit: Lanarc Consultants Ltd.

Perforated pipe over drain rock reservoir at infiltration trench under construction in Maple Ridge.

Photo Credit: Lanarc Consultants Ltd.

Same infiltration trench as above, before backfill, showing filter cloth wrap, and showing trench dam of native material between infiltration trench 'cells'.

Application

- Infiltration Trenches are often used to allow roof runoff to soak away into the ground. With water quality pre-treatment, they can be used for infiltration of other surface waters. Although ideally located under surface soils that will allow some evaporation, there are applications where an infiltration trench can be installed under pavement, provided that structural design of pavement is appropriate.
- Provision of underground overflow allows use of the technique in most soils, including clay with infiltration rates as low as 0.6mm/hr.
- Suitable for clean, unpolluted runoff from many development situations – residential areas, municipal office complexes, rooftop runoff, parks and greenspace, golf courses (Stephens *et al.*, 2002). Not suited for parking and heavy traffic roadway runoff unless there has been water quality pre-treatment to remove hydrocarbons and heavy metals.

Limitations

Use of Infiltration Trench or Soakaway Manhole will be limited by hydro-geotechnical conditions in much of GVRD.

- To avoid groundwater pollution, do not direct un-treated polluted runoff to Infiltration Trench or Soakaway Manhole:
  - Direct clean runoff (roof, non-automobile paving) to Infiltration Trench or Soakaway Manhole.

Photo Credit: Lanarc Consultants Ltd.

Infiltration facilities near urban structures should only be installed in neighbourhoods that have footing drains or other methods to protect basements from flooding.

- For polluted runoff (roads > 1000 vehicles / day, parking areas, other pollution sources), provide upstream source control for pollutant reduction prior to release to Infiltration Trench or Soakaway Manhole.

- Use Infiltration Trench or Soakaway Manhole only in areas with footing drains. If steep slopes or drinking water wells exist within 200m horizontally from the proposed Infiltration Trench or Soakaway Manhole, provide a hydro-geotechnical report to analyze site-specific risks and determine setbacks. Guidelines for setbacks to steep slopes are 60m from the tops of slopes more than 3m high and steeper than 2h:1v. Setbacks to drinking water wells should at least equal the BC Ministry of Health setback from well to septic field (30.5 m at time of writing).
- Minimum depth from base of drain rock reservoir to water table 600 mm.
- Identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this BMP. (Maryland Dept. Environmental Resources Program, 2000).
- Design should provide for drain rock reservoir to drain in 96 hours to allow aerobic conditions for water quality.

Design Guidelines

Infiltration Trench System:

1. Locate Infiltration Trench at least 3m from any building, 1.5m from property lines, and 6m from adjacent infiltration facilities (or as recommended by a geotechnical engineer).
2. If any surface water is to enter the system, provide pre-treatment erosion control to avoid sedimentation in the Infiltration Trench. Provide non-erodable material and sediment cleanout basins at point-source inlets (Maryland Dept. Environmental Resource Programs, 2001).
3. Provide vegetated erosion control along any surface water conveyance swales (e.g. between rain water leader and sump inlet). Swale planting is typically sodded lawn. Low volume swales can be finished with a combination of grasses, shrub, groundcover and tree planting to provide a 100% vegetated cover within 2 years of planting.
4. Sump: Concrete, plastic, or other non-degradable box with strength suitable to withstand surface loads. Provide a lid for periodic inspection and cleanout. Include a T-inlet pipe to trap oils, sediments and debris. Provide weep holes to dewater the sump, for mosquito management.

5. Infiltration Trench: installation of perforated distribution pipe and bottom of drainrock to be level. If more than one section of infiltration trench is required, design so that underground water is temporarily 'ponded' in each infiltration section, using underground weirs of undisturbed native material or constructed ditch blocks designed to create underground pooling in the reservoir sufficient for infiltration performance.
6. Infiltration Trench bottom width - 600mm minimum, 2400mm maximum.
7. Install the Infiltration Trench in native ground, and avoid over-compaction of the trench sides and bottom, which reduces infiltration.
8. Observation well for each Infiltration Trench (optional): vertical standpipe, with perforated sides, and locking lid, to allow the monitoring of water depth.
9. Size the Infiltration Trench or Soakaway Manhole system by continuous flow modelling. For single family areas, check with local governments to see if there are sizing guidelines for your watershed or neighbourhood.
10. A non-erodible outlet or spillway must be established to discharge overflow (Maryland Dept. Environmental Resource Programs, 2001).
11. Avoid utility or other crossings of the Infiltration Trench. Where utility trenches must be constructed crossing below the Infiltration Trench, install trench dams to avoid infiltration water following the utility trench.

Photo Credit: Lanarc Consultants Ltd.

Infiltration trench can be in any plan shape – the photo shows a rectangular 'soakaway' under construction at a single family subdivision in BC.

Soakaway Manhole System:

1. Provide a report from a geotechnical engineer including on-site test data of infiltration rates at the depth of the proposed infiltration. The bottom of the Soakaway Manhole shall be at least 600mm above the seasonal high water table or bedrock, or as recommended by the engineer.
2. Provide a sedimentation manhole, and a maximum of two Soakaway Manholes in series, unless otherwise approved. Minimum distance between Soakaway Manholes shall be 8m.
3. Provide an overflow from Soakaway Manhole to the storm drainage system or major storm flow path.
4. Size the Soakaway Manhole system by continuous flow modelling.

Photo Credit: Lanarc Consultants Ltd.

Infiltration trench with catch basin inlet at Silver Maples Subdivision in Maple Ridge, prior to surface cover with filter cloth and growing medium.

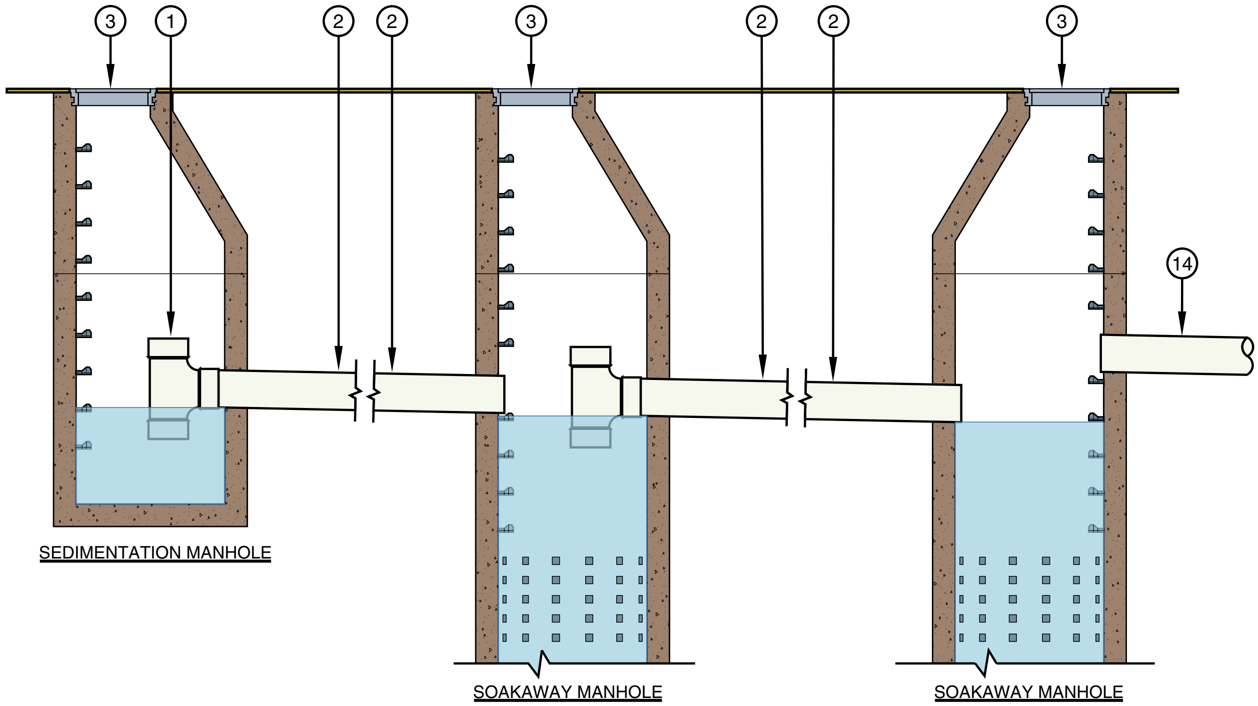
Guideline Specifications

Materials shall meet Master Municipal Construction Document 2000 requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, 75mm max, 38mm min, 40% porosity (Maryland Dept. Environmental Resource Programs, 2001).
2. Pipe: PVC, DR 35, 100 mm min. dia. with cleanouts.
3. Geosynthetics: as per Section 02498, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 02226.
5. Growing Medium over trench: As per Section 02921 Topsoil and Finish Grading, Table 2.
6. Seeding: to Section 02933 Seeding or 02934 Hydraulic Seeding (note – sodding will be required for erosion control in most swales, subject to the erosion control professionals decision).
7. Sodding: to Section 02938 Sodding.
8. All precast sections shall conform to the requirements of ASTM C 478.
9. Invert shall be level and smooth.
10. Soakaway Manhole barrel shall not be perforated within 1200mm of the cone.

Construction Practices shall meet Master Municipal Construction Document 2000 requirements, and:

1. Isolate the infiltration site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300mm of material over the final subgrade until after all sediment-producing construction in the drainage area has been completed (Maryland Dept. Environmental Resource Programs, 2001).
2. Prevent natural or fill soils from intermixing with the Infiltration Drain Rock. All contaminated stone aggregate must be removed and replaced (Maryland Dept. Environmental Resource Programs, 2001).
3. Infiltration Drain Rock shall be installed in 300mm lifts and compacted to eliminate voids between the geotextile and surrounding soils (Maryland Dept. Environmental Resource Programs, 2001).
4. Provide a min. of 150mm of 25mm or 19mm clean crushed rock under all pipes.

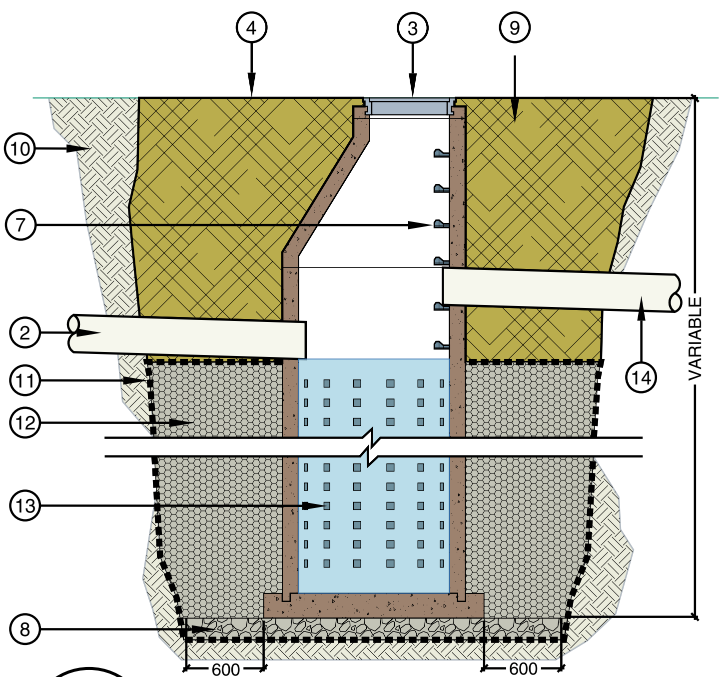


6 A SEDIMENTATION MANHOLE AND SOAKAWAY MANHOLES

Not To Scale

Section

NOTES:
ALL PRECAST SECTIONS SHALL CONFORM TO THE REQUIREMENTS OF ASTM C 478.
PROVIDE A MIN. OF 150mm OF 25mm OR 19mm CLEAN CRUSHED ROCK UNDER ALL PIPES.
INVERT SHALL BE LEVEL AND SMOOTH.
SUMP BARREL SHALL NOT BE PERFORATED WITHIN 1200mm OF THE CONE.



6 B SOAKAWAY MANHOLE

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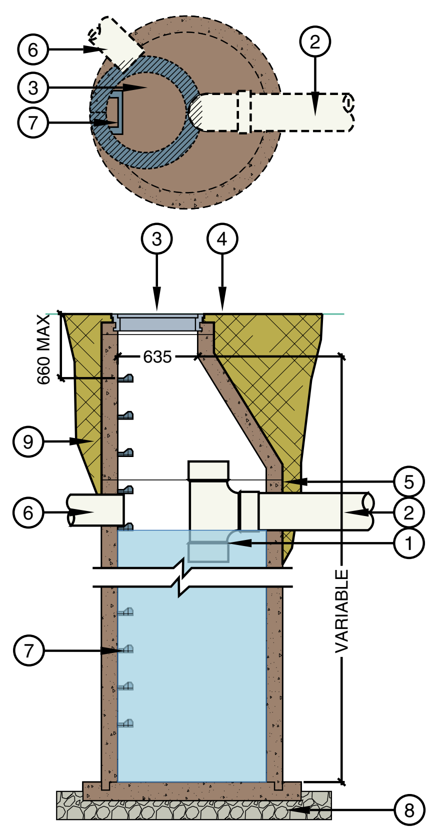

6 C SEDIMENTATION MANHOLE

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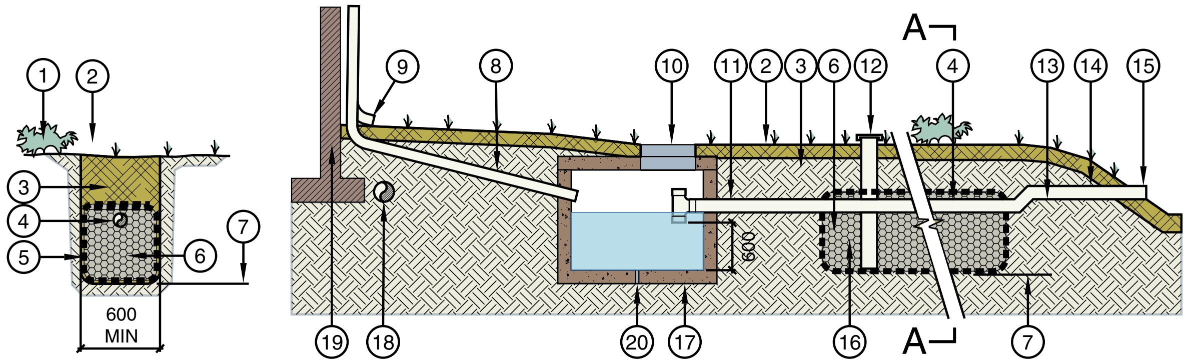
Section

1. PVC SOLID PIPE C/W INLET TEE
2. INTERCONNECTING PVC SOLID PIPE
3. STANDARD MANHOLE FRAME AND COVER
4. FINISH GRADE
5. SEAL JOINTS WITH CEMENT GROUT OR APPROVED MASTIC
6. STREET INLET CONNECTION
7. LADDER RUNG
8. 25mm CRUSH GRAVEL OR DRAIN ROCK BASE
9. NATIVE SOIL BACK FILL
10. UNDISTURBED GROUND
11. GEOTEXTILE BETWEEN DRAIN ROCK AND NATIVE SOIL
12. 50mm DRAIN ROCK
13. 1200mm PERFORATED BARREL (LANGLEY CONCRETE OR EQUAL)
14. OVERFLOW TO STORM DRAINAGE SYSTEM

1. GRASS OR OTHER PLANTING
2. FINISH GRADE
3. GROWING MEDIUM BACKFILL
4. 100mm DIA PVC DR28 PERFORATED PIPE
5. LIGHT NON-WOVEN GEOTEXTILE C/W MIN. 400mm LAPS
6. 50mm DRAIN ROCK OR ROCK OF EQUAL POROSITY
7. MAXIMUM GROUNDWATER ELEVATION
8. NON-POLLUTED DRAINAGE FROM BUILDING OR TERRACE
9. ALTERNATE SURFACE ROUTE - WITH SPLASH PAD AND VEGETATED SWALE TO CB
10. CB LID / ACCESS HATCH FOR CLEANOUT, INSPECTION AND INFLOW / OVERFLOW FROM SUMP
11. 100mm DIA PVC SOLID PIPE C/W INLET TEE
12. OBSERVATION WELL (OPTIONAL)
13. INVERT TO TOP OF INFILTRATION PIPE (APPROX.)
14. 100mm DIA PVC SOLID PIPE
15. DISCHARGE TO STORM DRAINAGE SYSTEM. ENSURE DRAINAGE DOES NOT IMPACT NEIGHBOURING USES. DIRECT DISCHARGE TO ROAD RIGHT-OF-WAY IF NECESSARY
16. INFILTRATION TRENCH WITH LEVEL BOTTOM
17. CATCH BASIN
18. BUILDING FOOTING DRAIN (NOT CONNECTED TO INFILTRATION FACILITY)
19. BUILDING
20. 50mm DIA MIN. DRAIN HOLE



SECTION A-A

SECTION FROM WATER SOURCE TO INFILTRATION TRENCH

6
D

INFILTRATION TRENCH

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Section

DESIGN, CONSTRUCTION AND MAINTENANCE PROCESS

For Stormwater Source Controls

The Stormwater Source Control Design Process

Just as rainfall hits all areas of a development site, the design of stormwater source controls should be integrated with the entire development concept. This chapter outlines a design process for stormwater source control practices - identifying key steps and their arrangement in a typical development process.

Table F1: Stormwater Source Control Design Process

Design Stage	*Objective*
Design Targets *for stormwater source controls*	Identify the senior and local government requirements for stormwater source control, and the related design targets or criteria.
Site Analysis *for stormwater source controls*	Gather critical data: rainfall patterns, existing vegetation cover, infiltration constraints, soils mapping and infiltration tests.
Development Concepts *that integrate stormwater source controls*	Integrate stormwater source controls into the development concept: what mix and sizing of techniques fit with the site and the land use?. Develop Stormwater Management Plan Concept.
Detail Design *of stormwater source controls*	Design and size source controls. Create technical details in plan, cross section and profile. Incorporate stormwater source controls in construction and maintenance specs.
Construction Staging *of stormwater source controls*	Schedule the installation of stormwater source controls to avoid problems with disturbance and sedimentation during construction.
Field Review & Monitoring *of stormwater source controls*	Provide critical field inspections to ensure performance. Use post-construction monitoring and adaptive management to reduce costs.

Do include stormwater source control designers in your design team from the earliest stage of the design development. This will ensure that stormwater source controls are integrated into the development in the most cost effective way.

Don't treat stormwater source controls as a last minute, after everything else is decided, extra. This will lead to more difficult or expensive design solutions, greater land requirements, and will create significant redundancy and revisions in design effort.

The key disciplines involved in source control design are civil engineers, geotechnical engineers, and landscape architects. A team approach is encouraged to ensure that the facilities are designed properly and perform as intended, and are aesthetically pleasing and suitable for the subject community.

Design Targets for Stormwater Source Controls

Fisheries and Oceans Canada

The *Urban Stormwater Guidelines and Best Management Practices for Protection of Fish and Fish Habitat, 2001* from Fisheries and Oceans Canada (DFO) stipulates a three-fold stormwater criteria:

Table F2: DFO Stormwater Guidelines

Objective	Target
Volume Reduction	Retain the 6-month/24-hour post-development volume from impervious areas on-site and infiltrate to ground. If infiltration is not possible, the rate-of-discharge from volume reduction Best Management Practices (BMPs) will be equal to the calculated release rate of an infiltration system.
Water Quality	Collect and treat the volume of the 24-hour precipitation event equalling 90% of the total rainfall from impervious areas with suitable BMPs.
Detention or Rate Control	Reduce post-development flows (volume, shape and peak instantaneous rates) to pre-development levels for the 6-month/24-hour, 2-year/24-hour, and 5 year/24-hour precipitation events.
Notes: Flood conveyance events are not addressed in the DFO guidelines, but are stipulated by municipalities.	

Source controls address volume reduction and water quality aspects of the guidelines, and therefore should be designed to capture and hold on-site the 6-month, 24-hour post-development flow volume. An analysis of rainfall data from a number of GVRD climate stations shows that the 6-month, 24-hour event ranged from 67% to 76% of the 2-year, 24-hour event volume, with an average of 72%. This result is consistent with other regional results (Washington State, 2001) and can be used in the absence of site specific data.

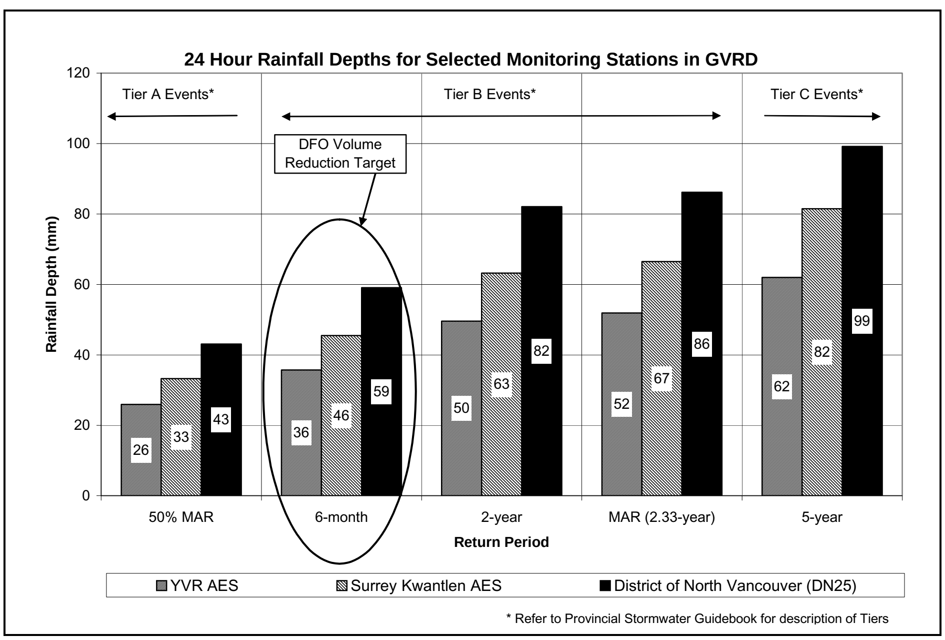


Figure F1: Typical 24 Hour Rainfall Depths in the GVRD

Province of BC

The Ministry of Water, Air, and Land Protection released *Stormwater Planning: A Guidebook for British Columbia* in 2002; the stormwater guidelines are summarized as follows.

Table F3: Stormwater Criteria from Provincial Stormwater Guidebook

Objective	Target
Runoff Volume Reduction and Water Quality Control	Capture 0 to 50% of the MAR [1] (90% of the rainfall volume in a typical year) at the source (building lots and streets) and infiltrate, evaporate, or reuse it.
Runoff Rate Reduction	Store 50% to 100% of MAR runoff and release at a rate that approximates the natural forested condition. Decrease the erosive impact of the large storm events.
Peak Flow Conveyance	Ensure that the drainage system is able to convey extreme storm events (up to 100-yr. return period) with only minimal damage to public and private property.
Notes: 1. MAR is Mean Annual Rainfall Event (i.e. approximates the 2-year 24-hour storm event – refer to Guidebook)	

The selection of which criteria (DFO or Province of BC) is the decision of the designer. However, as DFO approval is often required in the GVRD, it is recommended that the DFO guidelines be apllied for design of stormwater source controls.

Local Governments in GVRD

Municipalities are undertaking Integrated Stormwater Management Plans (ISMPs) on a watershed basis. The ISMPs meet community needs and allow development and re-development to occur, while preserving watershed health as a whole. ISMPs may allow for tradeoffs so that impacts in one area within a watershed can be offset by gains in other areas, thereby meeting the ISMP principle of no net loss of watershed health as a whole.

Developed ISMPs may stipulate alternate stormwater targets to the ones outlined by DFO and MWALP. For instance, this can be a result of increased targets in areas with good infiltration capability soils and decreased targets in steep slope areas with poor soils.

Site Analysis for Stormwater Source Controls

Limitations and Precautions to Implementing Source Controls

The implementation of source controls is prohibited in hazardous areas of potential slope instability. Source controls encourage infiltration that saturate soils and further reduce the stability of these hazardous slopes. Adequate setbacks from the top of these slopes should be delineated by a qualified geotechnical engineer.

As with all drainage works, source controls should be designed to ensure that facility overflows and interflows drain to the municipal minor/major drainage system or natural drainage path, and do not discharge to or through adjacent sites. Emergency overflows should be designed as a part of all source controls.

It is also important to consider the impacts of groundwater contamination and the presence and potential influences on existing water wells in the vicinity. A hydrogeologist should confirm that infiltrated water does not put groundwater resources at risk.

Rainfall Data

Rainfall data can be obtained from representative climate stations closest to the subject site. Three types of rainfall data are used in the analysis and design of source controls:

- Numerical values taken from the intensity-duration-frequency (IDF) curves to determine rainfall depth. This rainfall depth can be used in simplistic calculations to roughly determine the rainfall-runoff capture volume for the subject site.
- Hourly rainfall data for a typical year from the period of record. This is used in the hydrologic computer modelling in the sizing of source controls.
- IDF curves are also used to determine extreme flows that would occur during flood events (e.g. 10-year or 100-year events). Source controls must provide adequate overflows to accommodate large events. Flood events are quantified using the Rational Method or using design storm events in hydrologic computer modelling.

Existing Vegetation Cover on the Development Site

Trees and vegetation have been shown to intercept significant amounts of annual rainfall:

- 15% interception by leafless deciduous trees (Xiao *et al*, 2000), relative to a typical year.
- 27-28% interception by evergreen trees (Xiao *et al*, 2000) (Johnston, 1990).

In addition to their canopy interception, trees and vegetation provide significant evapo-transpiration – removing water from the soils, and thereby freeing up soil pore space to accept and store infiltrated rainwater.

Erosion control is also provided in a most effective way by surface vegetation. Leaving surface vegetation in place until development proceeds at UniverCity in Burnaby has provided 100% erosion control on individual parcels (Reid, 2004).

Initial site investigations for development projects should map the existing vegetation, and consider its role prior, during and after construction. Development strategies that have been successful in maintaining, or delaying removal of, vegetation are listed in the Vegetation Management Checklist on the facing page.

Designers should summarize, on a site analysis drawing, the opportunities and constraints presented by existing vegetation. Make this information available to all members of the design and approvals team.

Vegetation Management Checklist

- ❑ Leave existing vegetation in place during the planning and approvals stages. Pre-clearing vegetation results in increased costs for temporary revegetation and erosion control, at the same time as increasing runoff and sedimentation unnecessarily.
- ❑ Clear the site in stages as development proceeds. For instance, for larger developments, clear only road and utility corridors during each phase of subdivision, leaving the development parcels vegetated until they are sold, designed, approved and ready for construction.
- ❑ Identify areas where vegetation can permanently remain in the development. These may be areas of steep slope, stream riparian or wetland areas, wildlife or greenway corridors, specimen trees or other site areas with site constraints.
- ❑ Protect the soils under vegetation to be retained during construction. It is critical to their stormwater performance that these areas not be disturbed or compacted by equipment or storage during construction. Temporary fencing is likely required.
- ❑ In stormwater calculations, consider the contribution that leave areas of existing vegetation and soils make to stormwater capture targets. These areas will count as pervious area.
- ❑ Consider the possibility for some stormwater management techniques to make use of tree leave areas for stormwater capture. For example, parking areas may be graded toward leave areas of existing vegetation, encouraging both filtration and infiltration of surface water. Roof drainage could also be directed towards forested leave areas, provided the drainage is dispersed before entering the leave area. Only sheet flow is permitted, not concentrated flow that can be erosive and have higher concentrations of pollutants. Sheet discharge should be restricted to limited impervious areas only where the leave area is owned by the subject site owner and not the property of others. Calculations should be undertaken to ensure the leave area can "capture" the target runoff volume. Infiltration trenches or swales can encourage infiltration just uphill from leave areas, so that shallow groundwater interflow occurs through the leave area. Although root zones should not be disturbed, development schemes have included the addition of drain rock / compost / soil check dams to create vernal infiltration pools in leave areas.

Constraints to Infiltration Techniques

All sites in the GVRD can incorporate some form of stormwater source control, even though in some poor drainage soil or site conditions the choices will be limited to constructed solutions like green roof, flow through planters or infiltration techniques with flow restrictors.

The most cost and space effective techniques will be those that rely on significant infiltration into site soils. To determine if infiltration based source controls are advisable on the development site, professional geotechnical engineers and designers should identify site or neighbourhood features that may act as constraints.

The Infiltration Constraint Checklist below provides a partial list of constraints to the use of infiltration that should be mapped to determine if they would affect a site design.

Infiltration Constraint Checklist

- ❑ Drinking Water Wells: Infiltration should be separated from drinking water wells, against both surface water intrusion and ground water pollution. Standards for separation may vary by municipality, soil conditions, and well operation, but should, at a minimum, equate the separation required between septic fields and drinking water wells by BC Ministry of Health. At time of writing, this separation was a minimum of 30.5 m horizontally.
- ❑ Land Uses that are Pollutant Hot Spots: Infiltration should not be undertaken from land uses that present a high risk of groundwater pollution e.g. automobile service yards, wrecking yards, sites storing industrial chemicals or wastes, unless appropriate pretreatment is included.
- ❑ Contaminated Soils: Sites that have previously contaminated soils will need geotechnical analysis to determine if they can be remediated, and if they are suitable for infiltration once remediated.
- ❑ Seasonally High Water Table: For infiltration to be effective, the bottom of the infiltration facility should be at least 600 mm above seasonally high water table. Site test holes and mapping should be completed if areas of high water table are indicated.

- Shallow Bedrock: Infiltration may be constrained by shallow bedrock, or by cemented layers in soils. The infiltration facility bottom should be at least 600mm above monolithic, unfractured bedrock. Note, however, that many types of bedrock including fractured sandstone are highly pervious and suitable for infiltration. Some other types of bedrock e.g. karst limestone are excessively permeable, and infiltration directed at them may need careful pretreatment for water quality. Some cemented layers in soils are underlain by highly permeable strata, and facilities can be designed to remove pollutants from surface water and then infiltrate it to these deeper permeable soils.
- Steep Slopes: Existing or proposed steep slopes can be a constraint to infiltration. Designers must consider the stability of the slope, and the interaction of deep and shallow groundwater interflow on the stability of the slope. Infiltration designs within 30m of steep slopes, or that direct surface or groundwater at a steep slope area are prohibited unless reviewed and deemed acceptable by engineers with experience in geotechnical engineering.
- Unstable Soils: The stability of soils for foundation conditions or against mass slumping may be affected by infiltration. If expandable clays are present on a site, geotechnical advice should be sought on setbacks from infiltration facilities to foundations – 3-5m setback distances are common. Other unstable soils, such as peat or organic muck, may be affected by increased water content related to infiltration, and geotechnical advice should be sought.
- Riparian Area or other Protected Habitat: Infiltration techniques that require excavation are commonly restricted in areas of protected habitat. However, non-invasive techniques that provide drain/soil/compost check dams to create vernal pools, or facilities outside the protected area that allow treated runoff to distribute and slowly flow through the protected area are appropriate.

Soils Mapping and Infiltration Testing

General soils mapping for the Lower Mainland area can be found on:

- GeoMap Vancouver, Geological Map of the Vancouver Metropolitan Area, Geological Survey of Canada Open File 3511, 1998.
- 1:50,000 surficial geology mapping, Geological Survey of Canada, 1980.
- Municipalities also may have soil mapping.

These maps provide generalized information only, and are appropriate for planning level studies only. Site specific soils and infiltration information should be obtained by a geotechnical engineer at the design phase.

On-site infiltration testing at the elevation of the proposed infiltration facility is required. The BC Environment Percolation Test Requirements recommend using the double ring infiltrometer testing methodology. Infiltration rates should be reported in mm/hr.

A correction factor can be applied to the determined infiltration rate to allow for average soil variability, degree of long-term facility maintenance, and total suspended sediments reduction through pretreatment. Selection of a correction factor is based on the judgement of the designer. A factor of 2 is commonly used for infiltration; however, for facilities designed for stormwater source control (volume reduction and water quality treatment) where emergency overflows are provided, it is recommended that no correction factor be applied.

Integrated Stormwater Management Plans

Municipalities in the GVRD are active in creating Integrated Stormwater Management Plans (ISMPs). These are typically created at a watershed scale, and identify objectives and proposed techniques for flood control and fish habitat protection. Many ISMPs will create source control targets and strategies for a watershed or parts of watersheds.

Large-scale developments may also create Stormwater Management Plans that identify, in more detail, the role of stormwater source control for a development. Stormwater Management Plans may set 'rainfall capture targets' for roads and development parcels, to set out the amount of rainfall that should be captured on a development site, either by infiltration, evaporation, or re-use. Both Design Targets and ISMPs should be reviewed prior to development planning.

Development Concepts that Integrate Stormwater Source Controls

Identify Candidate Stormwater Source Controls

Every development and site combination merit a customized solution for stormwater source controls. However, Table F4 illustrates the typical relationship between source controls and site / land use combinations at the parcel or street level.

Table F4: Typical Source Control Applications

Development Type	*Absorbent Landscape*	*Infiltration Swale*	*Rain Garden*	*Pervious Paving*	*Infiltration Trench or Shaft*	*Green Roof*
Park / Open Space *may include parking / buildings*	X	X	X	X	X	X
Low Volume Road *with roadside landscape or medians*	X	X	X		X	
Surface Parking *on-street or off-street w/ islands*	X	X	X	X	X	
Single Family / Low Density *30 – 50% building coverage**	X	X	X	X	X	X
High Density / Industria/ Commercial/Institutional *50 – 90% building coverage**	X	X	X	X	X	X
Ultra High Density *>90% building coverage**						X

*In Table F4, the building coverage figures refer to the percent of building footprint covering the site. This should not be confused with % impervious area, or FSR (floor site ratio).

Stormwater Treatment Chains

Designers are encouraged to think about combinations of stormwater source controls. A 'Stormwater Treatment Chain' is a series of source controls that are arranged in series.

The diagrams in Figure F1 illustrate alternative concepts for stormwater source controls on a development parcel.

- The Treatment Chain on the left relies equally on Green Roof, Rain Gardens, and Soakaway Manhole to each capture 33% of its on-site rainfall capture target. This concept may apply to a medium density development that has a balance of rooftop and landscape area.
- The Treatment Chain on the right has Green Roof take up 60% of its rainfall capture volume, and 30% in Rain Garden, with less reliance on Soakaway Manhole. This may be necessary on a high density development with limited landscape area.

Conceptually, the diagrams show these elements in series on the site. Rainfall would move from Green Roof to Rain Garden to Soakaway Manhole to Overflow.

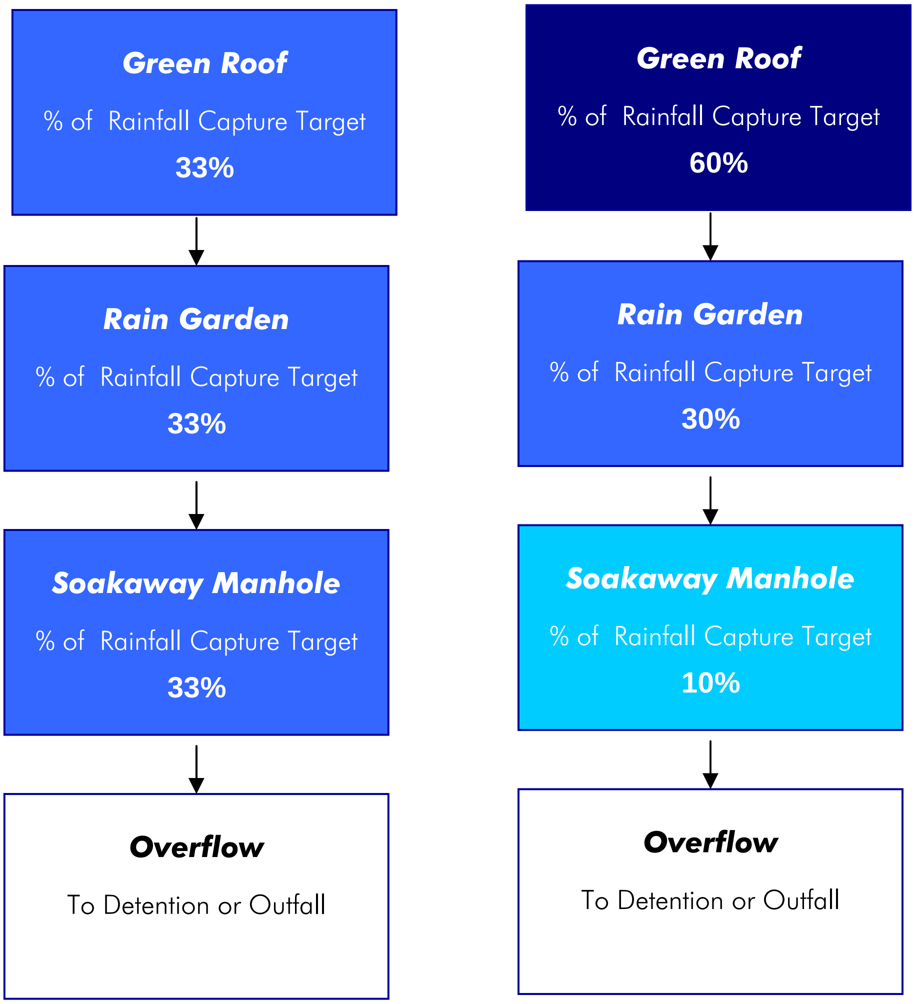


Figure F2: Alternative Stormwater Treatment Chain for High Density Development

Parallel sequences of treatment chains are also possible.

The diagrams in Figure F2 show one alternative for parallel stormwater source controls that is typical of Low to Medium Density development.

Two treatment chains are shown in parallel:

- On the left, an area of impervious paving such as road or travelled lane drains to pervious paving in parking areas or walkways. This pervious paving overflows to infiltration swales, which have an overflow to the major storm flow path.
- On the right, building rooftop without green roof drains to storage devices such as cisterns or shallow surface storage area such as pools over the rain gardens. Drainage from this storage flows at a low but continuous rate into rain gardens or other infiltration system. This slow release rate of rainwater takes the most advantage of limited infiltration rates in soils, by distributing infiltration in time. The Rain Gardens have an overflow to the major storm flow path.

On-parcel stormwater source controls must be designed with an awareness of the role of neighbourhood detention ponds, and regional flow paths for major storm events.

On-parcel or on-street stormwater source controls should always be designed with an overflow to the major flow path.

Rainwater re-use is a technique that can also be explored to act as a part of a stormwater source control chain. Many projects have used rainwater to flush toilets, for laundry purposes, or for landscape irrigation. Un-polluted roof drainage is ideal for these purposes.

Designers are encouraged to describe the path of rainwater hitting the site through stormwater source controls to outfall early in the development concept stage. Communication of this concept to all members of the design team, and to approval authorities, will allow creative synergy and integration of the source controls into overall design.

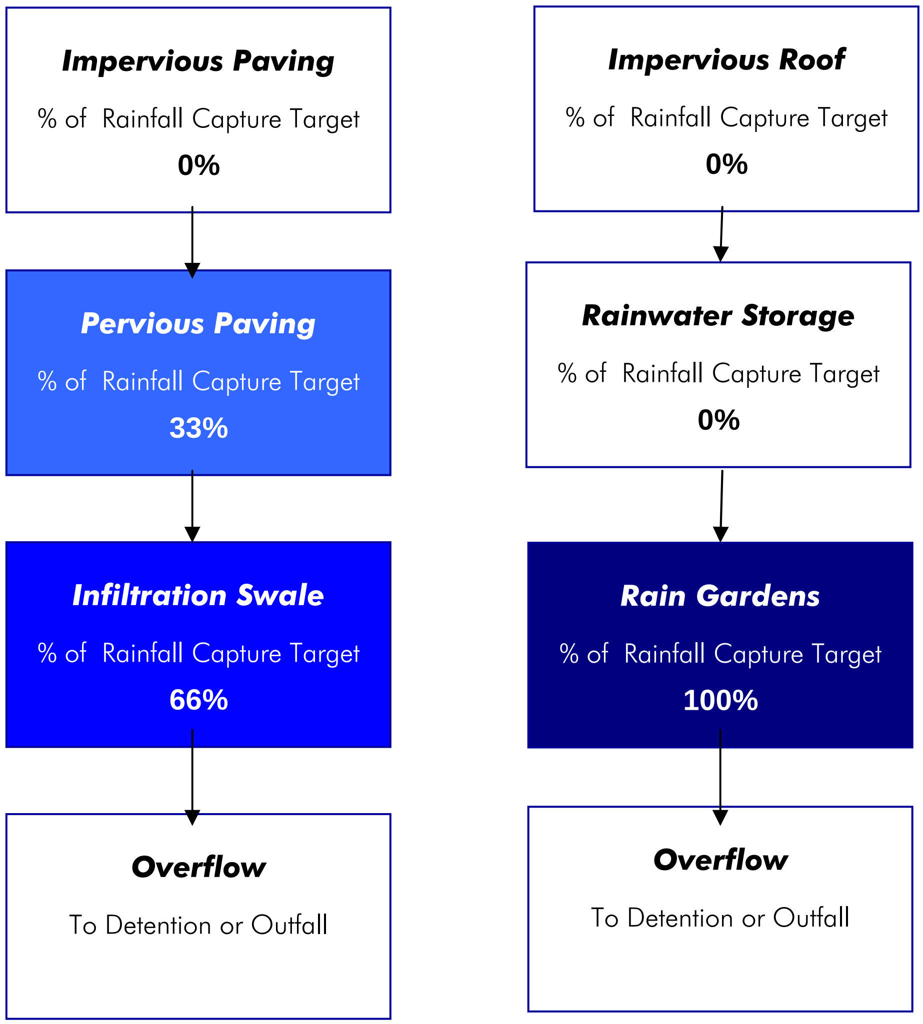


Figure F3: Alternative Stormwater Treatment Chain for Low Density Development

Conceptual Sizing and Space Allocation for Stormwater Source Controls

Prior to a conceptual Stormwater Source Control Treatment Chain being finalized, it is important to identify, at the concept level, the approximate size and location for stormwater source controls.

The amount of space required for stormwater source controls is a direct function of:

- The volume and intensity of rainfall hitting the site, and the associated rainfall capture target.
- The amount of impervious area on the site.
- The area of infiltration surface on the site.
- The rate of infiltration into the infiltration surface.
- The amount of rainfall storage that can be provided to temporarily hold water until it can infiltrate into the ground.

To prepare a gross initial approximation of the space needed for stormwater source control, try the following steps:

1. Disturbed pervious areas should be replaced with adequate soil layers to capture the rainfall target. The target is calculated by taking 72% of the 2-year, 24-hour rainfall depth from the nearest climate station IDF curve. Determine the required soil layer depth for absorbent landscapes by assuming a reasonable void space in the soil layer. E.g. Surrey Kwantlen Park climate station 2-year, 24-hour rainfall depth = 54.5 mm. 72% of 54.5 = 39 mm. Soil layer required with 0.2 void space = 200 mm.
2. Calculate the impervious area of the site. Minimize this number by providing absorbent landscape, pervious paving, or by hydraulic disconnects – where small impervious surfaces drain into large absorbent landscapes (size soil layer to accommodate impervious runoff), thereby not creating runoff.
3. Using the rainfall capture target, calculate the volume of rainfall that must be infiltrated or reused on the site, in cubic metres (impervious area x rainfall capture target). (e.g. Surrey Kwantlen Park rainfall target is 39 mm x impervious area = capture volume.)
4. Determine surface area, soil layer depth, and rock reservoir depth (if needed) required for selected source controls to achieve the capture volume target. Account for infiltration using the on-site tested infiltration rate

multiplied by 24 hours, volume storage in the source control soil layer and rock reservoir (if used) void spaces.

5. Investigate feasibility of selected source controls with the site plan.

Table F5 summarizes rainfall capture targets (72% of the 2-year, 24-hour event based on DFO guidelines) for a few local municipalities.

Table F5: Typical Rainfall Capture Targets

Rainfall Capture Targets	
Climate Station	Rainfall Capture Target
North Vancouver Lynn Creek (upper elevations)	86 mm
North Vancouver Municipal Hall (lower elevations)	58 mm
West Vancouver CS (upper elevations)	81 mm
West Vancouver Municipal Hall (lower elevations)	56 mm
Maple Ridge Reservoir	65 mm
Langley Lochiel	46 mm
Surrey Kwantlen Park	39 mm
White Rock STP	37 mm
Vancouver Airport	36 mm

The above process provides only a rudimentary approximation of source control sizing. However, the process is useful to generate concepts that are suitable for detailed investigation. For accurate sizing of stormwater source controls, it is necessary to complete a continuous flow model – these models calculate the water levels in a source control facility using site development data and continuous rainfall data from historic weather records.

Optimizing the Space Needs and Sizing of Stormwater Source Controls

The fine-tuning of space needs and sizing of stormwater source controls is an iterative process. Designers use computer-based modelling to test how a tentative solution will work given historic rain data. Several scenarios can be tested, and the best scenario selected for detailing.

Several computer modelling tools are candidates for sizing source controls in Coastal British Columbia. The Water Balance Model for BC is introduced below, and newer versions of SWMM that can model disconnected surfaces can be considered.

Water Balance Model for BC

The Water Balance Model for BC (WBM) has been developed jointly by an Inter Governmental Partnership that includes federal, provincial and local government representatives, as well as consultants and industry partners.

The model can be accessed on a free trail basis at www.waterbalance.ca. Users can register and use the model. But scenarios are purged from the server database after 7 days. For those wishing to use the model on an ongoing basis an annual subscription account is available.

The WBM is designed for larger scale land use simulations, allowing users to model the impacts of land use planning decisions and stormwater source controls at a watershed or basin scale. The WBM can also be applied at a site scale for source control facility sizing.

The WBM is not calibrated, and its results are not guaranteed to be accurate. In its disclaimer statement the WBM stresses that it is intended to be used as a planning-level decision support tool, and that the interpretation and application of scenario modeling results are the sole responsibility of individual users of the Water Balance Model for BC.

Input fields in the Water Balance Model include:

- Rainfall Data - several regional databases of hourly rainfall data are pre-installed. Custom data may be added.
- Soil Characteristics - users need to input hydraulic properties of soils including its: saturated hydraulic conductivity, maximum water content, field capacity, wilting point, and soil water half life – these can be obtained from literature values.
- Land Use and Impervious Area Calculations - users input percentages or areas that characterize their site or development.

- Proposed Stormwater Source Controls - users may select from Absorbent Landscape, Infiltration Swale, Rain Garden, Infiltration Trench, Pervious Paving and Green Roof, and input the size and general characteristics of these practices.

Output from the Water Balance Model includes:

- Proportion of Annual Rainfall that is infiltrated, evaporated, or becomes surface runoff or drainflow from subdrains.
- Hydrograph showing the annual runoff pattern.
- Water level fluctuations within stormwater source controls.

Limitations of the Water Balance Model include:

- It is not yet calibrated with field test data.
- Surface flow is not modelled within the WBM. That is, infiltration swales and rain gardens are assumed to be flat, so that surface ponding will remain up to the allowable depth that is input by the user, until such time as the surface pond can infiltrate. This could result in standing surface water for an unacceptably long period in winter months in parts of the GVRD. Users should review the water level output, and consider use of Source Controls with Reservoir (and perhaps Subdrain) if surface water ponding durations are too high.
- Groundwater flow is also not modelled in the WBM. Site conditions where groundwater flow or interflow enter the stormwater source control from upstream are not considered. Designers should be aware that such groundwater flow may reduce the available infiltration capacity of a proposed stormwater source control.

SWMM

The SWMM model (RUNOFF and HYDRAULICS Blocks) was originallly developed in 1971 by the US Environmental Protection Agency (EPA). Since that time the model has been updated numerous times and now incorporates modelling of disconnected surfaces required for Source Control modelling. Several versions of SWMM are available on the market from different software suppliers, as well as directly from the EPA as a public domain version.

The SWMM software is capable of carrying out hydrologic and hydraulic simulation and features:

- industry-standard SWMM analysis engine that is well-proven.
- capability for both event (design and/or real storms) and continuous (multi-event, multi-year) modeling.
- block modules that allow for expansion to fully dynamic backwater analysis (HYDRAULICS block) and water quality modeling (TRANSPORT block).

Because the SWMM model includes a groundwater routine, it provides a complete water balance calculation allowing source control facilities to be sized. The physically-based model parameters provide greater confidence in extending model results beyond those contained in flow monitoring data set (i.e. to lower or higher return periods).

The inputs required for the model include:

- rainfall data
- evaporation rate data
- soil parameters
- catchment characteristics such as area, impervious percentage, overland flow length, and slope

Most source controls can be modeled using the groundwater and soil parameters. Because SWMM includes a hydraulic model, additional parameters can be entered to size and test conveyance systems and/or detention facilities. Additional parameters include pipe sizes or open channel cross sections, conduit inverts, roughness values, storage versus elevation relationships, weir, orifice, and pump data, and variable downstream water level boundaries (recorded stage or tidal).

Outputs from the SWMM model include:

- catchment runoff flow rates
- shallow groundwater or interflow flow rates
- evaporation volumes
- water levels in conduits or detention ponds
- soil moisture and groundwater table elevation
- statistical summaries on water balance for model run duration

The SWMM model can be used for site, subdivision and watershed level analysis. Using previously-established general parameters will give reasonable results with further improvements possible by calibrating a limited set of variables to site specific observations.

Strategies to Deal with Limited Infiltration Rates

There are a wide variety of soil conditions in the GVRD, and infiltration rates will vary considerably. Depending on soil conditions, various designs of full or partial infiltration source controls are appropriate. Table F6 provides general guidance on the match between source control type and infiltration rate. Use these as guidelines, not rules.

Table F6: Tentative Match: Source Control Type to Soil Infiltration Rate

Soil Infiltration Rate tested at the site of proposed infiltration.	*Full Infiltration*	*Full Infiltration with Reservoir*	*Partial Infiltration with Reservoir and Subdrain*	*Partial Infiltration with Flow Restrictor*
>30 mm/hr.	X	?	?	
15-30 mm/hr.	?	X	?	
1-15 mm/hr.		?	X	
<1 mm/hr.			X	X

When infiltration rates are high - greater than 30mm/hr., such as in sand soils – full infiltration designs should be pursued. Full infiltration provides the highest water quality treatment of all options, and is the least expensive source control to construct.

In soils which have moderate infiltration rates – 15-30mm/hr., such as in sandy loam soils – the addition of a drain rock reservoir under a soil layer provides underground storage. This system removes water from the surface, and ponds it in the reservoir until it can be infiltrated by the subsoils.

In soils with low infiltration rates – 1-15 mm/hr., such as silt loams - the addition of a subdrain at the top of the drain rock reservoir removes water to the downstream storm drainage system when the reservoir fills up. This design provides opportunities for infiltration, while minimizing surface ponding. This type of design is also advantageous for planting of trees and other non-aquatic plants in the soils above the subdrain, as the subdrain keeps roots from being saturated for excessive periods.

In soils with very low infiltration rates – less than 1 mm/hr., such as compact till –infiltration still occurs. An infiltration rate of 1mm/hour is 24mm/day, which would absorb a significant portion of annual rainfall. However, when rainfall is relatively continuous in winter months, the reservoir in these designs may remain full between rain events, with rainfall-runoff moving directly to drainflow through the subdrain. To provide additional storage, and a controlled release rate, a flow control structure can be added to the subdrain. The small orifice on the flow control structure provides a gradual decanting of the storage above the drain pipe. In this sense, the technique operates like a miniature detention pond. However, the path of the rainfall-runoff through the soil medium provides excellent filtration and water quality improvement.

Strategies to Deal with Limited Space

Land is a significant cost in the GVRD. A key advantage of integrating Stormwater Source Controls into the overall design of a project is to avoid requirements for additional land.

Strategies to minimize the requirement for extra land for stormwater source control are listed in the Source Control Strategies for Limited Space Checklist.

Source Control Strategies for Limited Space Checklist

- ❑ Use required landscape areas as stormwater source control – make concave landscape areas at the site periphery and in parking lot islands and courtyards, rather than berms.
- ❑ Consider that even formal, rectilinear urban planters can be designed as rain gardens.
- ❑ Design roadside boulevards and medians as infiltration areas.
- ❑ Infiltrate into tree wells and structural soils. The use of structural soils for tree planting in paved areas is a well established technique. Drainage of small paved areas into these structural soils should be considered where the infiltration rate of the subsoils will allow the removal of the water within 24 hours, or where adequate under drainage is provided.
- ❑ Increase the depth and organic matter content of landscape soils. Soil stores up to 20% of its volume in water. Greater soil depth allows the storage of additional surface runoff. Sufficient organic matter maintains soil percolation rates.
- ❑ Create hydraulic disconnects – that is, drain small paved areas into absorbent landscape rather than to the storm drain system. A good example is draining sidewalks to boulevard rather than directly to curb and gutter. Another example is allowing small roof areas to drain from roof leaders to the surface of absorbent landscape. If these hydraulic disconnects are properly designed, the 'disconnected' impervious surface is effectively pervious, and can be eliminated from calculation of impervious area.
- ❑ Install pervious paving. Pervious paving of several types is highly suitable for pedestrian areas, overflow parking, and main parking areas.
- ❑ Place infiltration trench or soakaway manhole under paved areas. For example, the drain rock reservoir under infiltration swales can extend under driveways, thus increasing the infiltration area.

- Allow surface storage. Temporary ponding on the surface of infiltration swales or rain gardens is approximately 3x more efficient than underground storage in a drain rock reservoir.
- Provide underground storage. Temporary storage of rainfall, and slow release into infiltrating soils, can greatly increase the effectiveness of limited infiltration capacity or area. Underground storage can be by concrete cistern, welded plastic pipes, or by several proprietary brands of underground infiltration structure (e.g. Infiltrator Chamber, Rainstore, Atlantis Cells, etc.).
- Install green roof, either intensive or extensive, to provide rainfall capture above buildings and parkades.
- Consider rainwater re-use, for flushing toilets, irrigation and/or laundry uses. This technique is common in Australia and Europe.

Detail Design of Stormwater Source Controls

Plan Details

Plan details (one or more views) for Stormwater Source Controls should show the features listed in the Plan Detail Checklist, as appropriate to the design.

Plan Detail Checklist

- ❑ Extent of impervious surface.
- ❑ Outline of Stormwater Source Control.
- ❑ Edge treatment at the Stormwater Source Control e.g. drop curb, flush curb, bollards, border, etc.
- ❑ Piping and drainage diagrams, sizes and slopes.
- ❑ Utility crossings and seepage cutoff details.
- ❑ Spot elevations, slope arrows and/or contours to show grading design, including pipe inverts, catch basin elevations, breaks in grade.
- ❑ Proposed weir locations, other features.
- ❑ Extent of proposed growing medium installation.
- ❑ Extent of proposed drain rock reservoir installation.
- ❑ Erosion control and runoff dispersion features at steep slopes and inlet points.
- ❑ Planting plan showing trees, shrubs, ground covers, and use of grasses as applicable.
- ❑ Watering or irrigation plan showing provisions for establishment watering.

Figure F4: Example of Engineering Plan (Silver Ridge – KWL Associates Ltd.)

Roadside Infiltration Swale

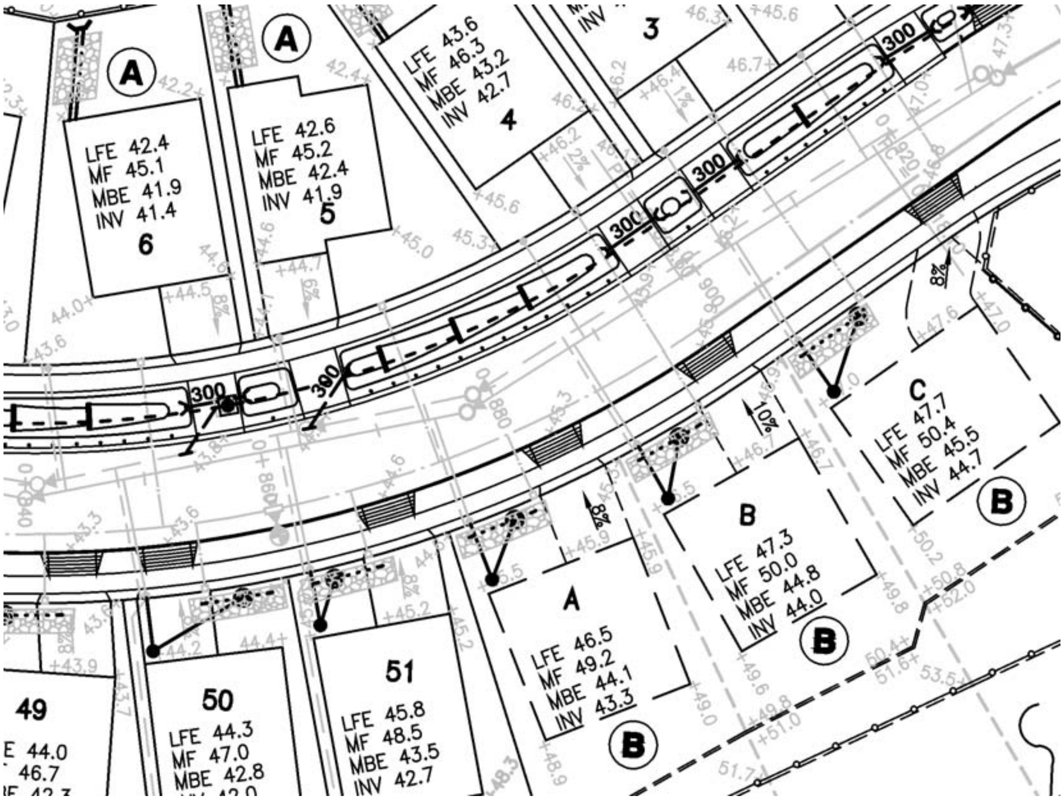
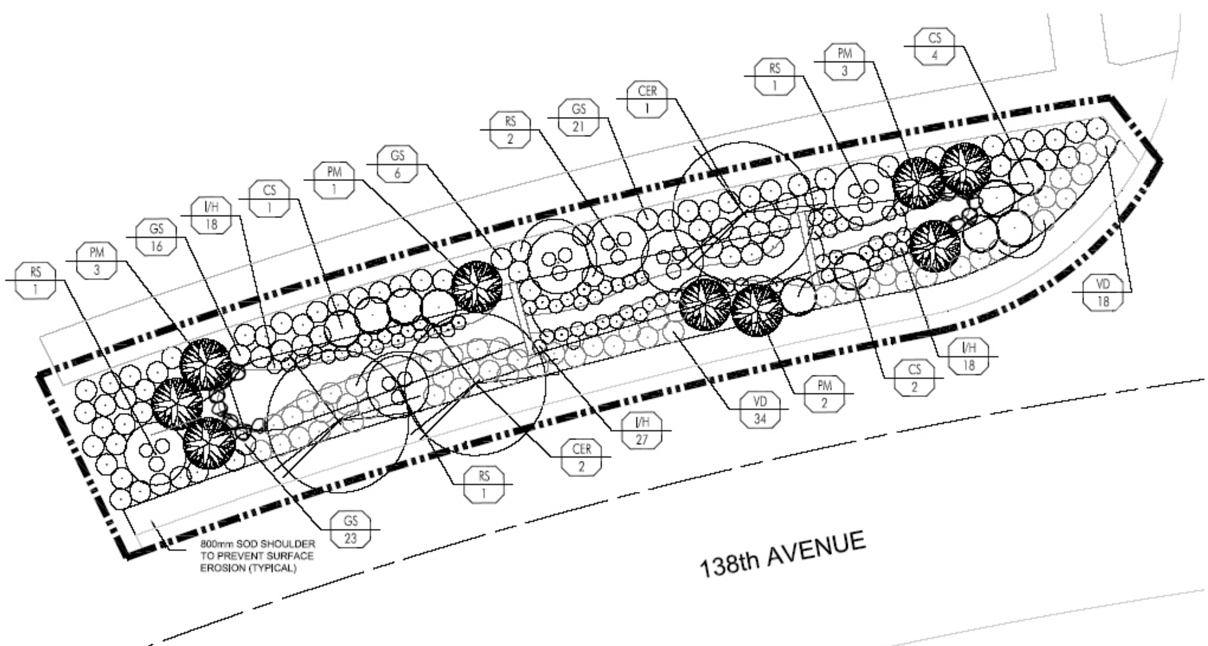


Figure F5: Example of Landscape Plan (Silver Ridge – Lanarc Consultants Ltd.)



Cross Section Details

Cross Section details (one or more views) for Stormwater Source Controls should show the features listed in the Cross Section Checklist, as appropriate to the design.

Cross Section Checklist

- ❑ Surface grades.
- ❑ Paving and base course layers, if included in design.
- ❑ Extent of proposed growing medium installation, layering of growing medium types.
- ❑ Extent of proposed drain rock reservoir installation.
- ❑ Piping and drainage locations in relation to growing medium and reservoir.
- ❑ Erosion control and runoff dispersion features at steep slopes and inlet points.
- ❑ Edge treatment at the Stormwater Source Control e.g. drop curb, flush curb, bollards, border, etc.
- ❑ Front view of proposed weirs.
- ❑ Typical cross section of planting and mulching treatment.
- ❑ Specialty materials for Green Roof, such as lightweight soils, root barrier, drainage layer.

Figure F6: Example of Engineering Cross Section Detail (Silver Ridge – KWL Associates Limited)

Roadside Infiltration Swale with Reservoir and Subdrain

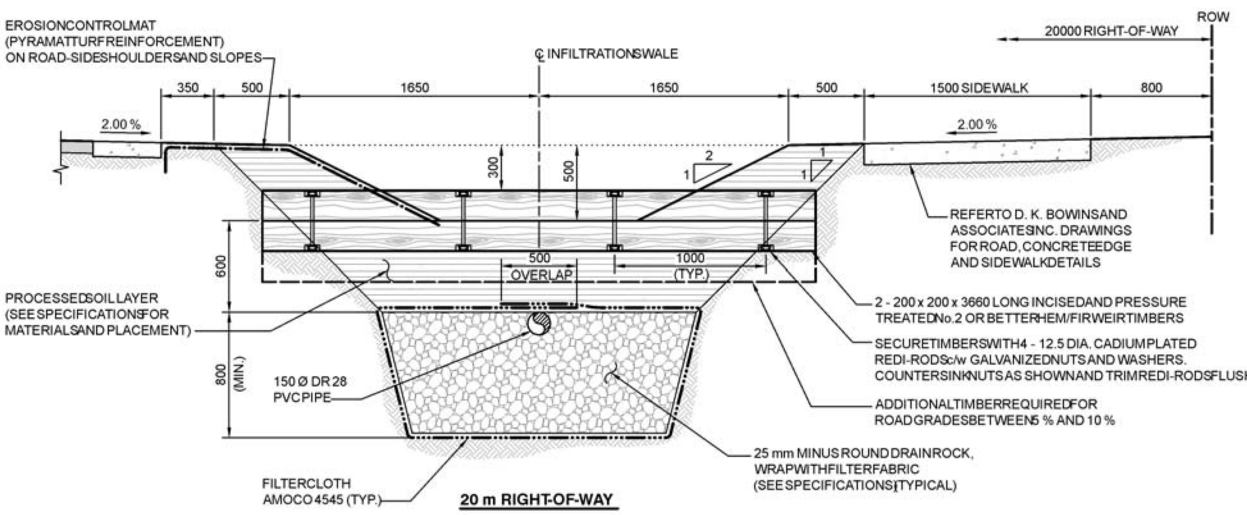
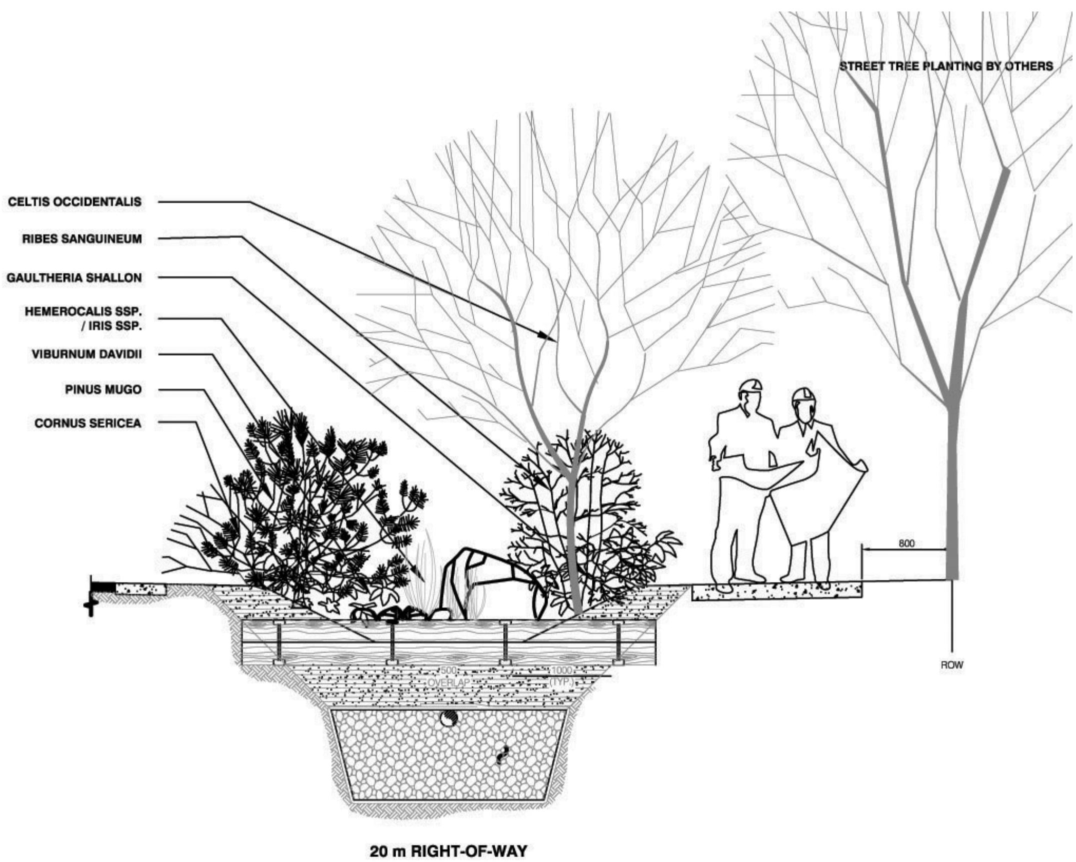


Figure F7: Example of Landscape Cross Section Detail (Silver Ridge – Lanarc Consultants Ltd.)



Profile Details

Profile details (one or more views) for Stormwater Source Controls should show the features listed in the Profile Checklist, as appropriate to the design.

Profile Checklist

- ❑ Surface grades.
- ❑ Extent of proposed growing medium installation.
- ❑ Extent of proposed drain rock reservoir or drainage layer installation (top, and level bottom).
- ❑ Undisturbed native or check dam details between discrete reservoir or infiltration trench cells.
- ❑ Piping locations in relation to soil and reservoir, pipe gradients.
- ❑ Side view of proposed weirs.

Figure F8: Example of Engineering Profile (Silver Ridge – KWL Associates Limited)

Roadside Infiltration Swale with Reservoir and Subdrain

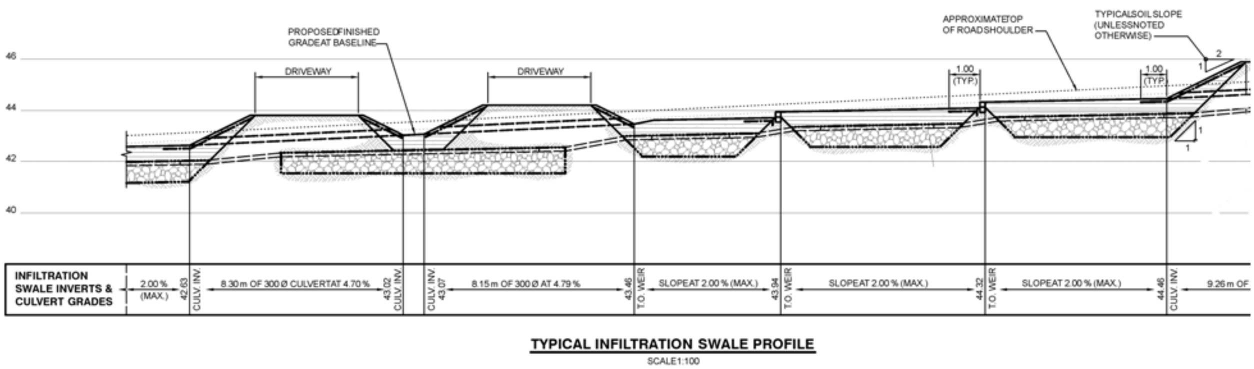
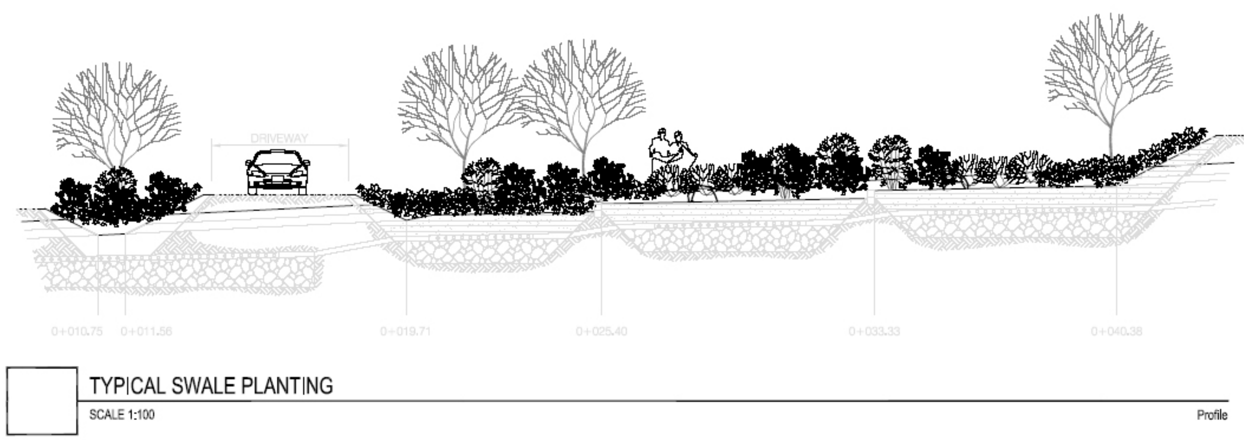


Figure F9: Example of Landscape Profile (Silver Ridge – Lanarc Consultants Ltd.)



Construction and Establishment Maintenance Specifications

Specifications for Construction should include either references to accepted standards or customized clauses on the topics listed in the Specifications Checklist.

Specifications Checklist

- ❑ Construction staging guidelines, and request for Contractor's Construction Plan to avoid disturbance, compaction or sedimentation of infiltration areas.
- ❑ Growing medium materials, amendments mixing, installation and maintenance for the establishment period.
- ❑ Reservoir and drainage materials, installation and maintenance during construction.
- ❑ Geotextile materials, installation and maintenance during construction.
- ❑ Erosion control materials, installation and maintenance during construction.
- ❑ Plants and planting materials, installation and establishment maintenance.
- ❑ Seeding and sodding materials, installation and establishment maintenance.
- ❑ Watering or Irrigation materials, installation and establishment maintenance.
- ❑ Specialty materials for Green Roof, such as lightweight soils, root barrier, drainage layer.

Long-Term Maintenance Arrangements

Like any other development, Stormwater Source Controls rely on appropriate maintenance for their longevity and performance. Where Stormwater Source Controls are situated on private land, local governments may place maintenance agreements or covenants in place to ensure appropriate long term maintenance. Key ingredients of these include the items in the Maintenance Checklist.

Maintenance Checklist

- ❑ Maintain surface drainage paths to lawn basins;
- ❑ Keep lawn basin grates clear of debris to ensure proper drainage;
- ❑ Clean lawn basin sumps on an annual basis (preferably in November) to remove organic debris collected in the sump;
- ❑ Conduct an annual inspection of the lawn basin, building footing drain sump and overflow outlet piping for proper function; clean interconnecting piping if required;
- ❑ Regularly cut, aerate and fertilize the lawn.

Regular maintenance is required to ensure proper drainage function and a healthy landscape.

Construction Staging of Stormwater Source Controls

Natural soils generally have infiltration capabilities. Most infiltration problems are created during construction - commonly associated with disturbance, compaction and sedimentation of proposed infiltration areas. Operations of grading and building construction are highly disruptive, with much competition for space on a construction site, leading to most of the site being compacted. Rainfall during the construction period can also readily erode exposed soils, and transport fine sediment to proposed infiltration areas, creating a surface crust that impedes infiltration.

Successful strategies that have been used to avoid disturbance, compaction and sedimentation of infiltration areas are listed in the Construction Staging Checklist.

Construction Staging Checklist

- ❑ Provide temporary fencing during construction if proposed infiltration areas are in areas of natural vegetation, and require that vegetation remain in place.
- ❑ Ensure effective erosion control practices are in place during the construction period. If fine sediments are deposited on infiltration areas by accident, remove the surface crust prior to opening the infiltration facility.
- ❑ If possible, have stormwater outfalls bypass the proposed infiltration area during construction.
- ❑ Do not place erosion control sediment traps in infiltration areas. Only if absolutely necessary, build erosion control sediment traps above infiltration areas, protecting the infiltration soils with temporary cover of plastic, sand, or other mechanism that will capture all surface sediments without compacting the infiltration area, and that can be removed prior to opening the infiltration facility.
- ❑ When infiltration facilities involve the excavation of native material, consider staging infiltration area excavation until after all adjacent construction is complete. Building trades will disturb and compact the native surface soils, but when they are removed for the final infiltration facility construction, the compaction will also be removed.
- ❑ For infiltration facilities that involve excavation, ensure that the bottom and sides of infiltration excavations are scarified to remove glazing and improve infiltration.
- ❑ When infiltration facilities involve installation of growing medium, ensure that layers of growing medium are tilled so that a transition of soil texture occurs. Do not compact between layers. Layers of different soil texture or compaction can create perched water tables.
- ❑ Unvegetated infiltration areas that are subjected to heavy rainfall will set up a surface crust – even in sand. Although only a new millimetres thick, the surface crust will impede infiltration. Any infiltration area, or growing medium, that is left open to heavy rainfall, must be scarified prior to adding additional layers or opening for infiltration use.
- ❑ Cultivate in organic matter to the surface of growing medium infiltration areas. The organic matter and associated soil life will increase soil infiltration.
- ❑ Avoid the intrusion of road sands and construction traffic sediment into infiltration facilities, and pervious paving in particular. Provide regular street sweeping of roads as a part of the erosion control system. After construction , pervious paving should also be maintained by dry sweeping at least twice annually.

Field Review & Monitoring of Stormwater Source Controls

Required Field Reviews

Critical field reviews during construction include those in the Field Review Checklist.

Field Review Checklist

- ❑ Protection of proposed infiltration areas from disturbance, compaction and sedimentation.
- ❑ Scarification of subgrade.
- ❑ Filter cloth and rock reservoir installation, including rejection of contaminated drain rock and inspection of filter cloth overlap.
- ❑ Pipe, drainage utilities, structures and bedding.
- ❑ Laboratory testing of growing medium components, for texture, fertility and amendment requirements.
- ❑ Growing medium installation and depth. Scarification of growing medium surfaces after heavy rainfall and prior to installation of subsequent layers.
- ❑ Plant material review at the nursery or assembly point prior to planting.
- ❑ Irrigation piping and bedding, hydrostatic testing, operational performance.
- ❑ Plant material and surface mulch installation.
- ❑ Substantial and Final Performance.
- ❑ Periodic Establishment Maintenance Review.
- ❑ Review at end of Maintenance Period and Warranty Period.
- ❑ Provide record drawings.

Post-Construction Environmental Monitoring Strategies

The objective of post-construction monitoring is to measure the performance of the source controls. The results are interpreted to determine if the stormwater capture targets were met, and provide real data of performance and effectiveness to municipalities, practitioners, and developers for the adaptive management process. The results can be used both locally and regionally to refine source control designs and/or recommend additional environmental protection measures if needed.

Post-construction monitoring can consist of rainfall, groundwater levels, and flow downstream of the constructed source control. Flow can be compared with the identified stormwater target.

In large, multi-phase developments, post construction monitoring can provide data for adaptive management for later phases. In some cases, requirements for stormwater source controls may be reduced because monitoring indicates targets are being exceeded.

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CANDIDATE PLANT LIST

Candidate Plant List

Design plantings to respect the wet, dry or moist soil zones of the stormwater facilities. The following plants are recommended for stormwater source control facilities. Most plants listed are native. Non-native street trees are identified as such.

The ‘Availability’ column in the tables has 3 codes which represent general plant availability as listed in the BC Landscape and Nursery Association website

(www.canadanursery.com)in 2004:

- A available at 3 or more nurseries in BC.
- B available at 2 nurseries in BC.
- C available at 1 nursery in BC.

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
WET SITES						
TREES						
Acer rubra	Red Maple	Broadleaf Deciduous Tree	Full Sun /Part Shade	25m	Wet/Moist	A
Nyssa sylvatica	Black Gum	Broadleaf Deciduous Tree	Full Sun /Part Shade	20m	Wet/Moist	A
Quercus palustris	Pin Oak	Broadleaf Deciduous Tree	Full Sun	20m	Wet/Moist	A
Quercus rubra	Red Oak	Broadleaf Deciduous Tree	Full Sun	25m	Wet/Moist	A
Salix lucida Ssp. Lasiandra	Pacific Willow	Deciduous Tree or Shrub	Full Sun /Part Shade	12m	Wet	A
Salix scouleriana	Scouler's Willow	Deciduous Tree or Shrub	Full Sun /Part Shade	2-12m	Wet	A
Salix sitchensis	Sitka Willow	Deciduous Tree or Shrub	Full Sun /Part Shade	1-8m	Wet	A
SHRUBS						
Cornus stolonifera (sericea)	Red Osier Dogwood	Broadleaf Deciduous Shrub	Full Sun	1-6m	Wet/Moist	A
Ledum groenlandicum	Labrador Tea	Broadleaf Evergreen Shrub	Full Sun	0.5-1.5m	Wet	C
Myrica gale	Sweet gale	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1.5m	Wet	B
Spirea douglasii	Douglas Spirea (Hardhack)	Broadleaf Deciduous Shrub	Full Sun	2m	Wet	A
HERBACEOUS PERENNIALS						
Carex lyngbyei	Lyngby's Sedge	Herbaceous Perennial	Full Sun	0.3-1.5m	Wet	B
Carex obnupta	Slough Sedge	Herbaceous Perennial	Full Sun	1-1.5m	Wet	B
Carex rostrata	Beaked Sedge	Herbaceous Perennial	Full Sun	0.3-1.5m	Wet	A
Scirpus microcarpus	Small-flowered Bullrush	Herbaceous Perennial	Full Sun /Part Shade	1-1.5m	Wet	B
AQUATIC PLANTS						
Lysichiton americanum	Skunk Cabbage	Herbaceous Perennial	Part Shade / Shade	0.30-0.90m	Wet/Submerged	C
Nuphar luteum Ssp. Polysepalum	Pond Lily	Aquatic	Full Sun	0.15-5m long	Wet/Submerged	C
Sparganium angustifolium	Narrow-leaved Bur-reed	Herbaceous Perennial	Part Shade / Shade	0.20-1m long	Wet/Submerged	C

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
MOIST SITES						
TREES						
Acer rubra	Red Maple	Broadleaf Deciduous Tree	Full Sun /Part Shade	25m	Wet/Moist	A
Acer saccharinum	Silver Maple	Broadleaf Deciduous Tree	Full Sun	35m	Moist	A
Cercis canadensis	Redbud	Broadleaf Deciduous Tree	Full Sun /Part Shade	8m	Moist	A
Gleditsia triacanthos	Honeylocust	Broadleaf Deciduous Tree	Full Sun	30m	Moist	A
Liriodendron tulipifera	Tulip Tree	Broadleaf Deciduous Tree	Full Sun	35m	Moist	A
Malus fusca	Pacific Crabapple	Broadleaf Deciduous Tree	Full Sun	13m	Moist	B
Nyssa sylvatica	Black Gum	Broadleaf Deciduous Tree	Full Sun /Part Shade	20m	Wet/Moist	A
Picea sitchensis	Sitka Spruce	Coniferous Evergreen	Full Sun /Part Shade	70m	Moist	B
Pinus contorta var. contorta	Shore Pine	Coniferous Evergreen	Full Sun	20-30m	Moist	B
Pinus monticola	Western White Pine	Coniferous Evergreen	Full Sun	40m	Moist	C
Populus balsamifera Ssp. Trichocarpa	Balck Cottonwood	Broadleaf Deciduous Tree	Full Sun /Part Shade	50m	Moist	B
Populus tremuloides	Trembling Aspen	Broadleaf Deciduous Tree	Full Sun /Part Shade	25m	Moist	B
Prunus emarginata	Bitter Cherry	Broadleaf Deciduous Tree	Full Sun /Part Shade	2-15m	Moist	B
Pseudotsuga menziesii	Douglas Fir	Coniferous Evergreen	Full Sun	80m	Moist	B
Quercus palustris	Pin Oak	Broadleaf Deciduous Tree	Full Sun	20m	Wet/Moist	A
Quercus rubra	Red Oak	Broadleaf Deciduous Tree	Full Sun	25m	Wet/Moist	A
Rhamnus purshiana	Cascara	Broadleaf Deciduous Tree	Shade	10m	Moist	B
Taxus brevifolia	Pacific Yew	Coniferous Evergreen	Shade	5-15m	Moist	C
Thuja Plicata	Western Red Cedar	Coniferous Evergreen	Part Shade / Shade	60m	Moist	A
Tsuga heterophylla	Western Hemlock	Coniferous Evergreen	Shade	60m	Moist	A
SHRUBS						
Juniperus communis	Common Juniper	Broadleaf Evergreen Shrub	Full Sun	1m	Moist	C
Lonicera involucrata	Black Twinberry	Broadleaf Deciduous Shrub	Shade	0.5-3m	Moist	B
Menziesia ferruginea	False Azalea	Broadleaf Deciduous Shrub	Full Sun /Part Shade	3m	Moist	C
Oemleria cerasiformis	Indian Plum	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1.5-5m	Moist	A
Oplopanax horridus	Devil's Club	Broadleaf Herbacious Shrub	Part Shade / Shade	1-3m	Moist	C
Philadelphus lewisii var. gordonianus	Mock Orange	Broadleaf Deciduous Shrub	Full Sun	3m	Moist	B
Physocarpus capitatus	Pacific Niniebark	Broadleaf Deciduous Shrub	Shade	4m	Moist	A
Rhododendron albiflorum	White Flowered Rhododendron	Broadleaf Deciduous Shrub	Full Sun /Part Shade	2.5m	Moist	C
Rhododendron macrophyllum	Pacific Rhododendron	Broadleaf Evergreen Shrub	Shade	2-8m	Moist	B
Ribes bracteosum	Stink Current	Broadleaf Evergreen Shrub	Part Shade / Shade	3m	Moist	C
Ribes lacustre	Black Gooseberry	Broadleaf Evergreen Shrub	Full Sun /Part Shade	0.5-2m	Moist	C
Ribes laxiflorum	Trailing Black Current	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1m	Moist	C
Rosa gymnocarpa	Baldhip Rose	Broadleaf Deciduous Shrub	Full Sun	1.5m	Moist	A

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
Rosa nutkana	Nootka Rose	Broadleaf Deciduous Shrub	Full Sun	3m	Moist	A
Rosa pisocarpa	Swamp Rose	Broadleaf Deciduous Shrub	Part Shade	1.5m	Moist	A
Rubus spectabilis	Salmonberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	4m	Moist	A
Salix scouleriana	Scouler's Willow	Broadleaf Deciduous Tree or Shrub	Full Sun /Part Shade	2-12m	Moist	A
Salix sitchensis	Sitka Willow	Broadleaf Deciduous Tree or Shrub	Full Sun /Part Shade	1-8m	Moist	A
Sambucus caerulea	Blue Elderberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	6m	Moist	B
Sambucus racemosa	Red Elderberry	Broadleaf Deciduous Shrub	Part Shade	6m	Moist	A
Sherpherdia canadensis	Soapberry	Broadleaf Deciduous Shrub	Full Sun	1-2m	Moist	B
Sorbus sitchensis	Sitka Mountain Ash	Broadleaf Deciduous Shrub	Full Sun /Part Shade	4m	Moist	B
Symphocarpus albus	Snowberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	0.5-2m	Moist	A
Vaccinium alaskaense	Alaska Blueberry	Broadleaf Deciduous Shrub	Full Sun	2m	Moist	C
Vaccinium membranaceum	Black Huckleberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1.5m	Moist	C
Vaccinium ovalifolium	Oval-leaved Blueberry	Broadleaf Deciduous Shrub	Full Sun	2m	Moist	C
Vaccinium ovatum	Evergreen Huckleberry	Broadleaf Evergreen Shrub	Full Sun /Part Shade	2-3m	Moist	A
Vaccinium parvifolium	Red Huckleberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1.2-3m	Moist	B
Viburnum edule	Highbush Cranberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	0.5-3.5m	Moist	C
Herbaceous Perrenials Grouncovers and Ferns						
Achlys triphylla	Vanilla-leaf	Herbaceous Perennial	Full Sun /Part Shade	0.1-0.3m	Moist	C
Adiantum pedatum	Maidenhair Fern	Fern	Shade	0.3-0.5m	Moist	A
Aquilegia formosa	Red Columbine	Herbaceous Perennial	Full Sun /Part Shade	1m	Moist	B
Aruncus dioicus	Goat's Beard	Herbaceous Perennial	Full Sun /Part Shade	1-2m	Moist	C
Asarum caudatum	Wild Ginger	Herbaceous Perennial	Full Sun /Part Shade	0.05-0.2m	Moist	B
Athrium felix-femina	Lady Fern	Fern	Part Shade / Shade	2m	Moist	A
Cammasia leitchtinii	Great Camas	Herbaceous Perennial	Part Shade	0.7m	Moist	C
Cammasia quamash	Common Camas	Herbaceous Perennial	Part Shade	0.7m	Moist	B
Carex deweyana	Dewey's Sedge	Herbaceous Perennial	Full Sun /Part Shade	0.2-1.2m	Wet/Moist	C
Carex obnupta	Slough Sedge	Herbaceous Perennial	Part Shade	0.6-1.5m	Wet/Moist	B
Carex stipata	Sawbeak Sedge	Herbaceous Perennial	Part Shade	0.25-1m	Wet/Moist	C
Clintonia uniflora	Queen's cup	Herbaceous Perennial	Part Shade / Shade	0.2m	Moist	C
Cornus canadensis	Bunchberry	Deciduous Groundcover	Shade	0.2m	Moist	A
Dicentra formosa	Pacific Bleeding Heart	Herbaceous Perennial	Shade	0.5m	Moist	C
Disporum hookeri	Hooker's fairybell	Herbaceous Perennial	Shade	1m	Moist	C
Dodecatheon Ssp.	Shooting Star	Herbaceous Perennial	Part Shade / Shade	0.1-0.5m	Moist	C
Dryopteris expansa	Spiny Wood Fern	Fern	Part Shade / Shade	1m	Moist	C
Empetrum nigrum	Crowberry	Evergreen Groundcover	Shade	0.2m	Moist	C
Erythonium oregonium	White Fawn Lily	Herbaceous Perennial	Full Sun /Part Shade	0.3m	Moist	C

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
Fragaria vesca	Woodland Strawberry	Deciduous Groundcover	Part Shade / Shade	0.2m	Moist	B
Goodyera oblongifolia	Rattlesnake Plantain	Herbaceous Perennial	Shade	0.4m	Moist	C
Gymnocarpum dryopteris	Oak Fern	Fern	Part Shade / Shade	0.4m	Moist	C
Heuchera micrantha	Small-flower Alumroot	Herbaceous Perennial	Shade	0.1-0.4	Moist	C
Juncus effusus	Common Rush	Herbaceous Perennial	Full Sun	0.3-1m	Wet/Moist	A
Juncus tenuis	Slender Rush	Herbaceous Perennial	Full Sun	0.15-0.70	Wet/Moist	C
Linnaea borealis	Twinflower	Deciduous Groundcover	Full Sun /Part Shade	0.1m	Moist	B
Maianthemum dilatatum	False lily-of-the-valley	Herbaceous Perennial	Shade	0.1-0.4	Moist	B
Mitella breweri	Brewer's mitrewort	Herbaceous Perennial	Shade	0.2-0.4m	Moist	C
Polystichum munitum	Sword Fern	Fern	Part Shade / Shade	1.5m	Moist	A
Pteridium aquilinum	Bracken Fern	Fern	Part Shade / Shade	3m	Moist	C
Scirpus microcarpus	Small-fuited Bullrush	Herbaceous Perennial	Full Sun /Part Shade	1.5m	Moist	B
Smilacina stellata	Star Flowered Soloman's Seal	Herbaceous Perennial	Part Shade / Shade	0.3-1m	Moist	B
Tellima grandiflora	Fringecup	Deciduous Groundcover	Full Sun /Part Shade	0.4-0.8m	Moist	C
Trillium Ovatum	Western Trillium	Herbaceous Perennial	Part Shade / Shade	0.4m	Moist	C
Viola glabella	Yellow Wood Violet	Herbaceous Perennial	Part Shade / Shade	0.5m	Moist	C
Viola sempervirens	Trailing Yellow Violet	Herbaceous Perennial	Shade	.08m	Moist	C

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
DRY SITES						
TREES						
Alnus rubra	Red Alder	Broadleaf Deciduous Tree	Full Sun	25m	Dry	A
Prunus emarginata	Bitter Cherry	Broadleaf Deciduous Tree	Full Sun	2-15m	Dry	B
Quercus garryana	Garry Oak	Broadleaf Deciduous Tree	Full Sun	25m	Dry	B
Pseudotsuga menzesii	Douglas Fir	Coniferous Evergreen	Full Sun /Part Shade	70m	Dry	B
Pinus poderosa	Ponderosa Pine	Coniferous Evergreen	Full Sun	35m	Dry	B
SHRUBS						
Amelanchier alnifolia	Western Serviceberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1-5m	Dry	A
Holodiscus discolor	Oceanspray	Broadleaf Deciduous Shrub	Full Sun /Part Shade	4m	Dry	A
Ribes sanguineum	Red-flowering Current	Broadleaf Deciduous Shrub	Full Sun /Part Shade	1-3m	Dry	A
Rosa gymnocarpa	Baldhip Rose	Broadleaf Deciduous Shrub	Full Sun	1.5m	Dry	A
Rubus parviflorus	Thimbleberry	Broadleaf Deciduous Shrub	Part Shade	0.5-3m	Dry	A
Sambucus racemosa	Red Elderberry	Broadleaf Deciduous Shrub	Part Shade	6m	Dry	A
Gaultheria shallon	Salal	Broadleaf Evergreen Shrub	Part Shade / Shade	0.2-0.5m	Dry	A
Mahonia Aquifolium	Tall Oregon Grape	Broadleaf Evergreen Shrub	Full Sun /Part Shade	0.9-3m	Dry	A
Mahonia nervosa	Cascade Oregon Grape	Broadleaf Evergreen Shrub	Full Sun /Part Shade	0.6m	Dry	A
Symphocarpus albus	Snowberry	Broadleaf Deciduous Shrub	Full Sun /Part Shade	0.5-2m	Dry	A
Herbaceous Perrenials Grouncovers and Ferns						
Achillea millefolium	Yarrow	Herbaceous Perennial	Full Sun /Part Shade	0.5-1m	Dry	C
Arctostaphylos uva-ursi	Kinnikinnick	Broadleaf Evergreen Goundcover	Full Sun /Part Shade	0.20m	Dry	A
Elymus glaucus	Blue Wildrye	Herbaceous Perennial	Full Sun	0.5-1.5m	Dry	C
Fragaria vesca	Wood Strawberry	Herbaceous Perennial	Part Shade	0.25m	Dry	A
Lupinus bicolor	Two Color Lupine	Herbaceous Perennial	Full Sun	0.1-0.45m	Dry	C
Lupinus latifolius	Broadleaf Lupine	Herbaceous Perennial	Full Sun	0.1-0.45m	Dry	C
Lupinus polyphyllus	Large-Leafed Lupine	Herbaceous Perennial	Full Sun	0.1-0.45m	Dry	C
Mahonia repens	Creeping Oregon Grape	Broadleaf Evergreen Groundcover	Full Sun /Part Shade	0.30m	Dry	A
Pteridium aquilinum	Bracken Fern	Fern	Part Shade / Shade	3m	Dry	C
Solidago canadensis	Canada Goldenrod	Herbaceous Perennial	Full Sun	0.40-1.5m	Dry	C

Latin Name / Botanical name	Common Name	Type	Light Condition	Typical Size / Spacing	Application	Availability
NON-NATIVE TREES						
Gleditsia triacanthos	Honeylocust	Broadleaf Deciduous Tree	Full Sun	30m	Moist	A
Acer rubra	Red Maple	Broadleaf Deciduous Tree	Full Sun /Part Shade	25m	Wet/Moist	A
Quercus rubra	Red Oak	Broadleaf Deciduous Tree	Full Sun	25m	Wet/Moist	A
Liriodendron tulipifera	Tulip Tree	Broadleaf Deciduous Tree	Full Sun	35m	Moist	A
Quercus palustris	Pin Oak	Broadleaf Deciduous Tree	Full Sun	20m	Wet/Moist	A
Cercis canadensis	Redbud	Broadleaf Deciduous Tree	Full Sun /Part Shade	8m	Moist	A
Nyssa sylvatica	Black Gum	Broadleaf Deciduous Tree	Full Sun /Part Shade	20m	Wet/Moist	A
Acer saccharinum	Silver Maple	Broadleaf Deciduous Tree	Full Sun	35m	Moist	A

Glossary

Absorbent Landscape – a combination of surface soil structure, surface plants and/or organic matter that is highly permeable and supports high infiltration and evapotranspiration capacity. Absorbent landscapes help to store, infiltrate, evaporate and cleanse surface runoff. "To optimize infiltration, the surface soil layer should have high organic content (10-25%)… A range of soil and vegetation characteristics is acceptable depending on whether the area is to be covered by lawn, shrubs or trees" (B.C. MWLAP, 2002: 7-9). To establish absorbent landscapes, recommended minimum depths of growing medium range from 150 mm (6") for lawn areas, 300 mm (12") for ground covers, 450 mm (18") for shrubs respectively, and 600 mm (24") for tree planting areas. These depths are modified according to the depth and drainage capacity of the subgrade.

Dry wells - sub-surface reservoirs made from graded rock or large diameter pipes set on end over a base of washed rock, typically used to receive runoff from roof downspouts (GVRD, 1999: 4-73).

Evapotranspiration – the combination of water transpired (or breathed) from vegetation and evaporated from the soil and plant surfaces (Ward and Trimble, 2003).

Exfiltration – the movement (usually downward) of water out of one soil layer and into another soil layer or into a drainage structure.

French drain - a small, underground trench filled with a layer of open-graded gravel, designed to accept surface and shallow groundwater and to drain it away from a building or area that is prone to surface water build up and/or flooding. It may include a perforated drain pipe at the bottom of the gravel layer to convey overflow waters to a drainage system.

Filter drain – similar to a french drain, a small, underground trench filled with a layer of open-graded gravel, designed to accept surface and shallow groundwater. However, a filter drain is common used as a water quality treatment, placed at roadside or in roadway medians. Runoff passing through the rock is detained and has coarse sediments removed. Filter drains also commonly include a perforated drain pipe at the bottom of the gravel layer to convey of overflow waters to a drainage system.

Filter strips – (also known as vegetated filter strips or biofilters) broad vegetated areas along the edges of impervious surfaces (such as roadways) that intercept and direct stormwater flows over the vegetated surface before the flows can become substantially concentrated. The vegetated surface can range from turf to forest. Filter strips are intended to promote even sheet flow over a gently sloped vegetated ground surface, thereby directing stormwater broadly into a swale or similar conveyance structure. Some infiltration may occur, as well as some attenuation of peak runoff rates for flood control and streambank erosion protection. Contaminant removal mechanisms are similar to those for grassed channels. (GVRD, 1999: 4-60)

Green Roof – a vegetation-supporting roof cover aimed at reducing the volume and rate of runoff from a rooftop. Additional benefits include improved thermal efficiency (enhanced building heating in winter and cooling in summer), sound attenuation, extended service life of the underlying waterproofing system, improved air quality and urban 'greening'. Green roofs can be:

- *extensive* – soil depths are shallow, typically 20-200 mm, and support mosses, grasses and sedums. They are characterized by their low weight, low per unit capital cost and lower maintenance.
- *intensive* – soil depths are greater than 200 mm and able to support larger vegetation (shrubs, small trees, etc.) that have higher maintenance requirements.

Green roof designs are a functional enhancement to a "roof garden" where the latter may be largely a series of freestanding planters and paving installed primarily for aesthetic or 'living space' purposes with little emphasis on source control.

Hydraulic conductivity – the ability of soil to transmit water under a unit hydraulic gradient. Hydraulic conductivity is often equated to *permeability* and is a function of soil suction and soil water content. Fine-grained soils tend to have lower hydraulic conductivity than coarse grained soils (Ward and Trimble, 2003).

Infiltration – the downward entry of water through a soil surface and into the soil (Ward and Trimble, 2003).

Interflow – water that infiltrates into the soil and moves laterally through the upper soil layers until it returns to the surface, often as a stream (Ward and Trimble, 2003).

Loam – a rich soil consisting of sand and clay and decaying organic matter.

Permeability – the ease with which a liquid penetrates or passes through a layer of soil or porous medium; can also be referred to as perviousness.

Permeable / Pervious / Porous pavement or paving – (these terms are often used interchangeably in the literature) a hardened surface that allows water to percolate through to underlying sub-base soils, or to a reservoir where water is stored and either exfiltrated to the underlying subgrade or removed by a subdrain. The surface component can be:

- Porous asphalt or concrete, where fines are not included in the mix, providing a high void ratio that allows water to pass through.
- A structural load-bearing matrix made of concrete or plastic with large voids that are filled with a permeable material – usually gravel or soil; the latter often have grass.
- Permeable unit pavers made of impervious concrete blocks with gapped joints that allow water to percolate between the pavers; also called "modular pavement" or "pervious interlocking concrete pavement".

Qualified professional - an applied scientist or technologist specializing in a relevant science or technology, including but not limited to agrology, forestry, biology, engineering, geomorphology, geology, hydrology, hydrogeology or landscape architecture. Qualified professionals should be registered with their applicable professional organization, and acting under that association's code of ethics and subject to disciplinary action by that association. Qualified professionals should demonstrate suitable education, experience, accreditation and knowledge relevant to the particular matter, such that they can be reasonably relied on to provide sound advice within their area of expertise.

Rain garden (Bioretention) - a concave landscape area where runoff from roofs or paving is retained temporarily to allow infiltration into deep constructed soils below; designed to have the aesthetic appeal of a garden, as opposed to a purely functional appearance. Plantings may include trees, shrubs, groundcovers, rushes, sedges, grasses and turf. On subsoils with low infiltration rates, rain gardens usually have an underlying drain rock reservoir and perforated drain. Typically designed as a 'standalone' facility to serve a small area, new designs are putting rain gardens in series along linear areas like roads with weirs and surface conveyance similar to infiltration swales (dry swale with underdrain).

Soakaway - a hole in the ground filled with rubble and coarse stone to which a small-scale drainage pipe (such as a roof downspout) conveys rainwater. To allow rainwater to "soak away", the soil in which the soakaway is placed must have good drainage properties.

Subsurface Infiltration Structure – any type of underground structure designed to receive water from the surface by infiltration (e.g., through porous paving) or conveyance (e.g., via a swale with drain outlet) and temporarily retain it to allow gradual exfiltration of the water into the underlying structural or native subsoil. They may be individual, isolated structures (e.g., rock pit, *soakaway*, *dry well*, sump, plastic void structures, perforated or "leaky" tank or catch basin, drain rock blanket) or linear (french drains, underdrains, plastic void chambers, underground infiltration trenches). They are frequently combined with surface structures such as swales, rain gardens or porous paving.

Swale – a linear depression or wide, shallow channel used to collect, infiltrate, treat and convey stormwater. A variety of types of swales and related terms are identified in the literature:

- *Grassed swale* – lined with grass, named presumably to differentiate from a rock or concrete lined swale; considered as typically dry between storms. The grass acts to decrease stormwater flow velocities; reduce peak flow rates, reduce flooding and erosion, and promote infiltration, thereby reducing the overall runoff volume. Removal of contaminants can be accomplished through filtration of suspended solids by plant stems, adsorption to soil particles and plants, infiltration, and some biological action. (GVRD, 1999: 4-52).
- *Vegetated swale* – a variant on the grassed swale that is more densely vegetated or landscaped with plants other than grass. The same attenuating, infiltration and contaminant removal characteristics apply.
- *Wet swale* – grassed or vegetation swale with standing water between storms, due to high groundwater levels or high base flow; alternatively, may be purposely designed with check dams that store water in shallow ponding areas. Check dams help to reduce flow velocity, promote infiltration and evapotranspiration, enhance settling of particulates and contaminant removal. Wet swales are planted with water tolerant or wetland plant species, with turf on the side slopes.
- *Bioswale* – a term to collectively refer to grassed, vegetated or wet swales.
- *Dry Swale with Underdrain, Bioretention swale*, *Infiltration swale* – a shallow grassed channel designed to enhance infiltration by containing check dams or weirs to create shallow ponds of stormwater and promote infiltration through an augmented soil bed to an underground drain rock reservoir and ultimately into underlying soils. A

perforated drain placed near the top of the drain rock reservoir provides an underground overflow. The surface swale and weir structures also convey larger storms (overflows) to a surface outlet. German literature refers to a *Swale/Trench Element,* and adds an outlet control structure to detain stormwater in the drain rock reservoir and soils, releasing the water either through infiltration or through small outlet orifices at the control structure.

Treatment Chain – the application of a series of physical stormwater best management practices to achieve managed hydrology and water quality . Often used to treat contaminated runoff, the chain (or train) may incorporate chambers or units that first slow water and remove large particulates, followed by a unit to allow settling out of finer particulates, and a third "finishing" unit to remove dissolved compounds. (See GVRD, 1999: 4-108, Western Australia Water and Rivers Commission, 1998: 3 or Argue, 2002 for further details and examples.)

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