Stormwater Source Control Design Guidelines 2005

Greater Vancouver Regional District

FINAL REPORT

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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 The Interim Report is superceded by this Final Version.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:

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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:

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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

Greater Vancouver Regional District

Stormwater Source Control Design Guidelines 2005

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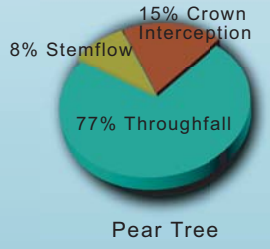
Goya Ngan
Landscape Architect

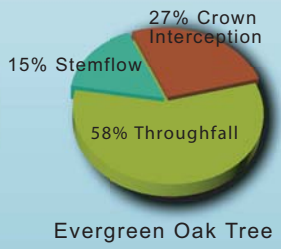
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

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



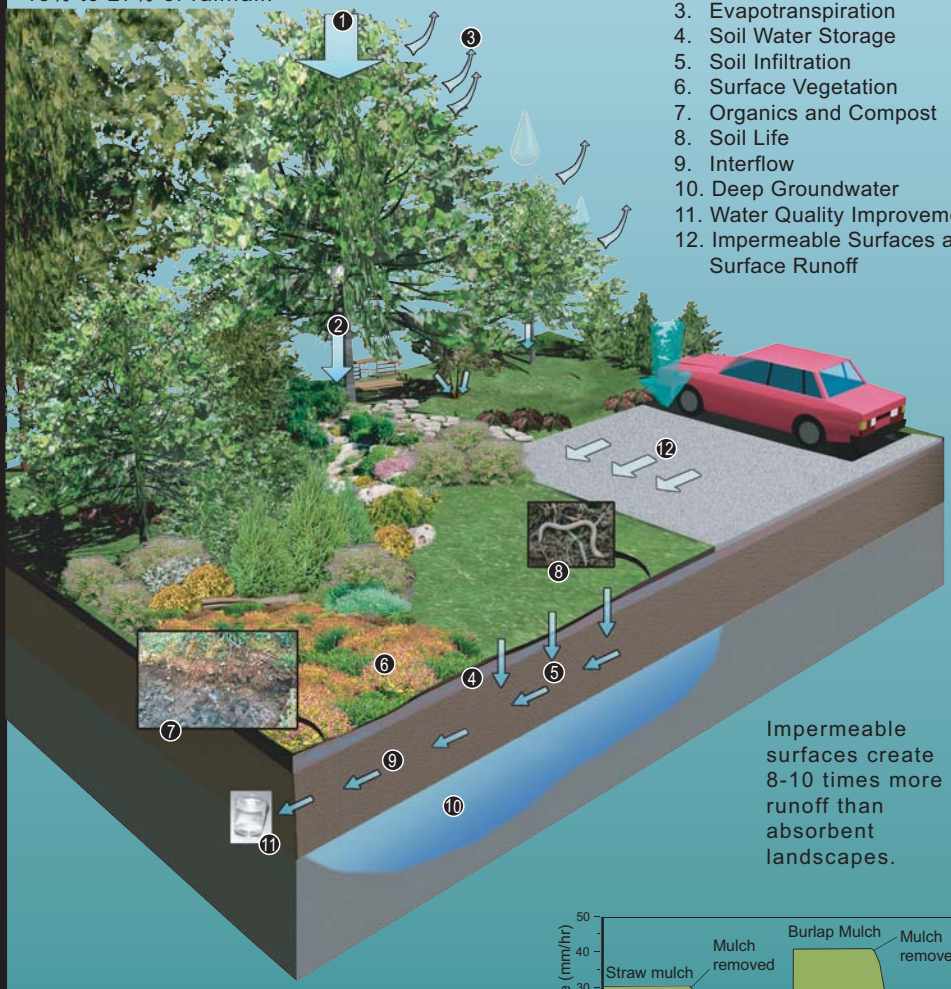
Evergreen Oak Tree

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

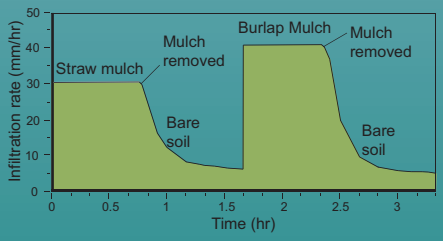
Winter tree canopies intercept 15% to 27% of rainfall.



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.

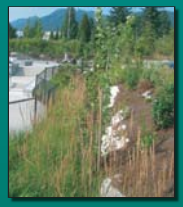


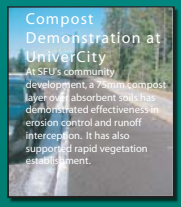
Influence of surface cover on infiltration rate of sandy loam

Absorbent Landscapes

Greater Vancouver Regional District

Stormwater Source Control Design Guidelines 2005





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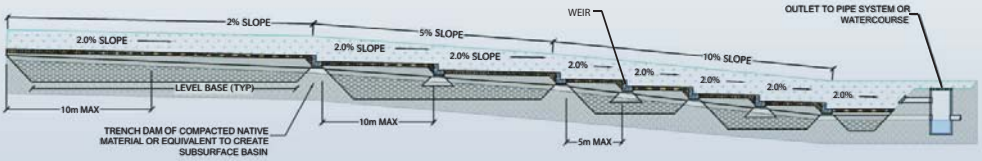
Goya Ngan
Landscape Architect

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

DESIGN PRINCIPLES

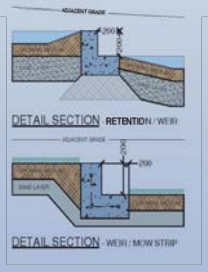
- Literature suggests swale areas of about 10-20% of upstream impervious area. For GVRD, calculate swale area by continuous flow modelling.
- Flow to the swale should be distributed sheet flow, travelling through a grassy filter area at the swale verges. Provide pre-treatment and erosion control to avoid 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.

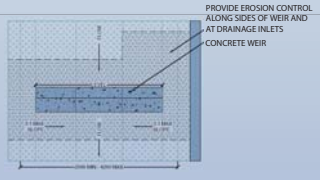


INFILTRATION SWALE

Not To Scale

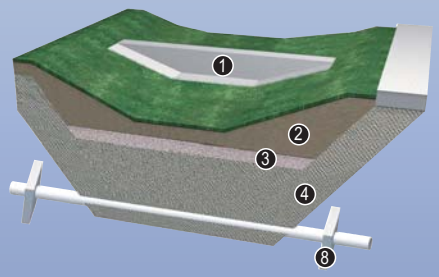
Longitudinal Profile





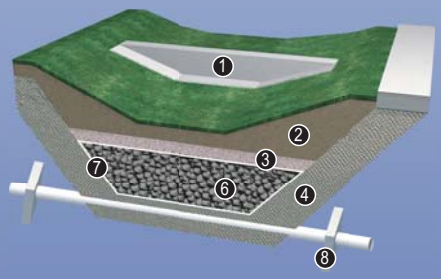
PLAN

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.



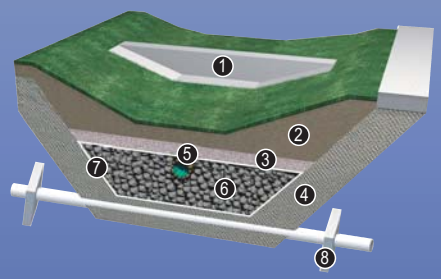
Full Infiltration

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

Stormwater Source Control Design Guidelines 2005

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Goya Ngan Landscape Architect

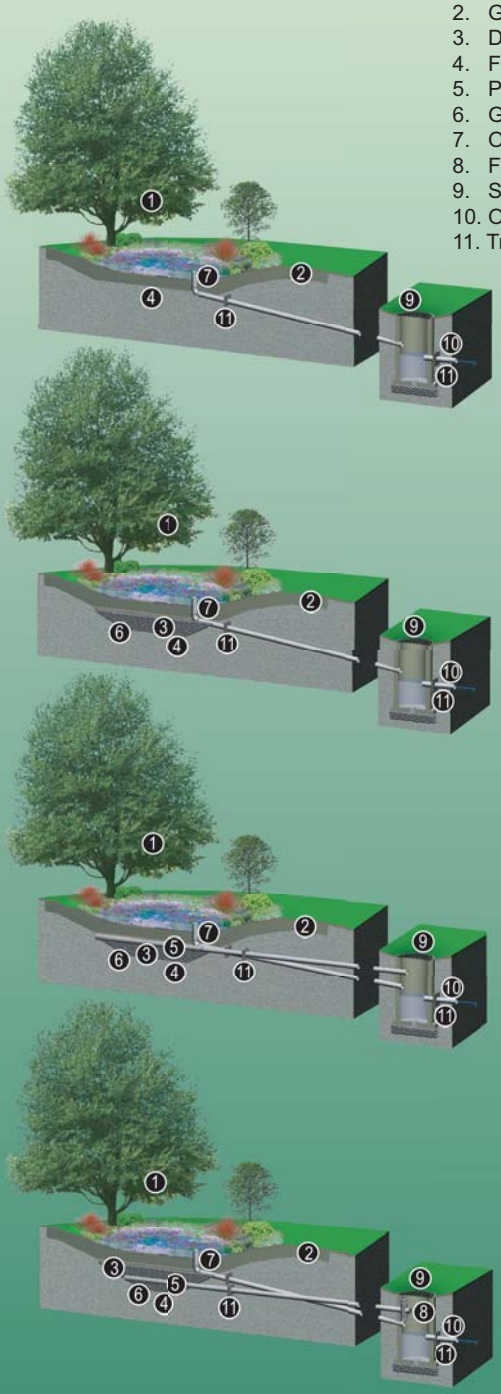
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

DESIGN PRINCIPLES

- 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

Greater Vancouver Regional District

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

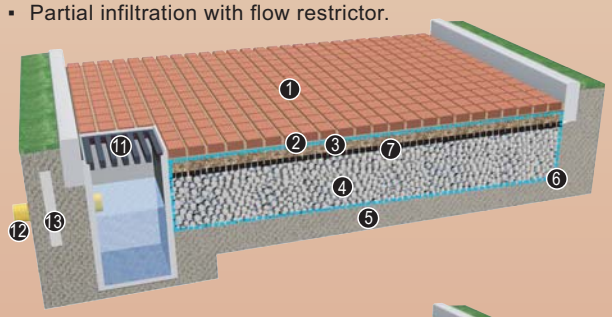
- Pervious paving is most suitable for low traffic areas – driveways, parking areas(maximum 1 - 2 vehicles per day per parking space), walkways, recreational vehicle pads, service roads, fire lanes.
- The ratio of impermeable surface area draining onto pervious pavement area should be 1.2:1 maximum.
- 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.

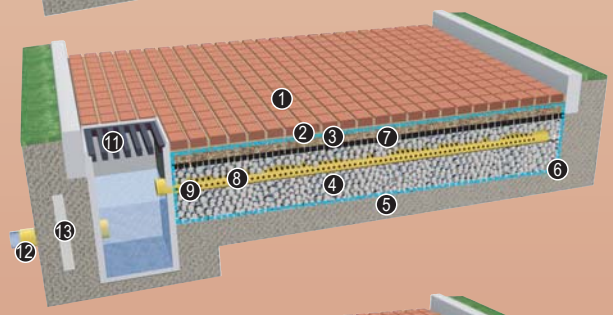
Pervious pavement designs may be one of three types:

- Full infiltration.
- Partial infiltration.
- Partial infiltration with flow restrictor.



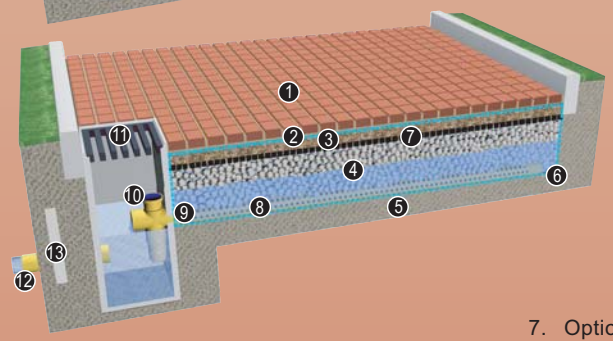
Full Infiltration

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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Goya Ngan
Landscape Architect

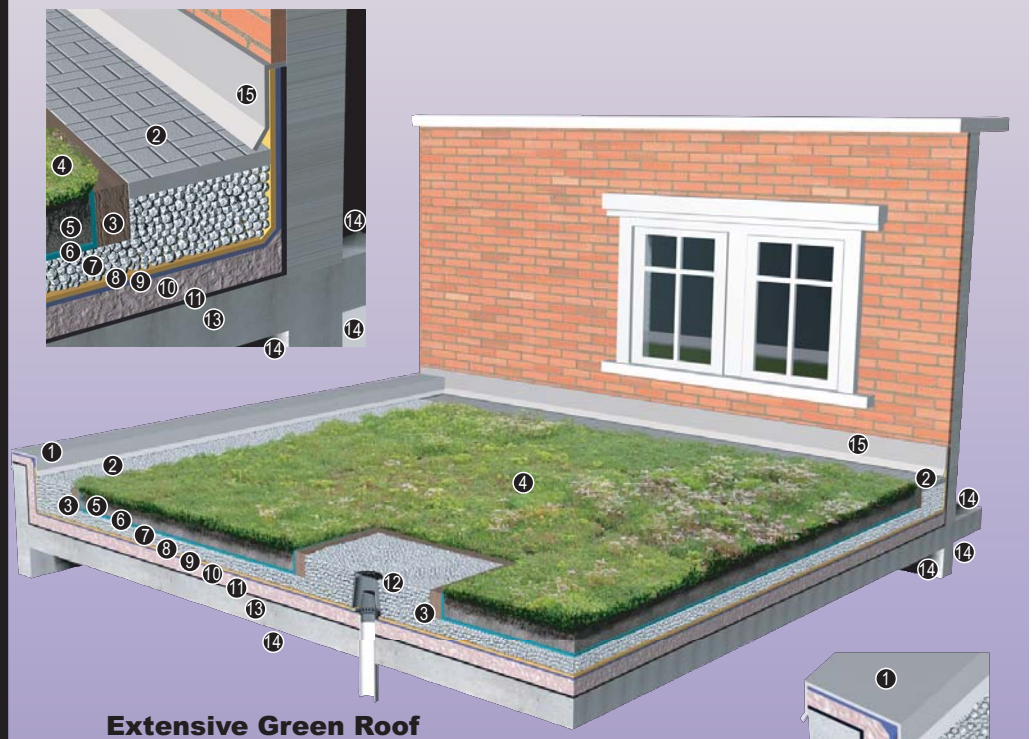
Detailed design guidelines can be found in the Design Guidelines 2005 report, available at www.gvrd.bc.ca

DESIGN PRINCIPLES

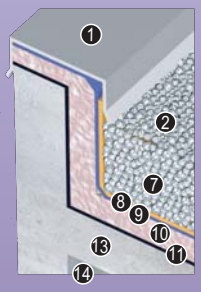
- Suitable for flat roofs and, with proper design, roofs of 20º (4:12 roof pitch) or less.
- Suitable for many rooftop situations – industrial, warehousing, commercial buildings, office complexes, hospitals, schools, institutional/ administrative buildings, residential and garages.
- Design a green roof 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 Benefits

- Reduced peak flows & stormwater volume
- Mitigation of urban heat island effect
- Insulation against heat loss and gain
- Extended roof membrane life
- Sound insulation and air filtration
- Urban habitat
- Aesthetics

Green Roof

Greater Vancouver Regional District

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Goya Ngan
Landscape Architect

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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.

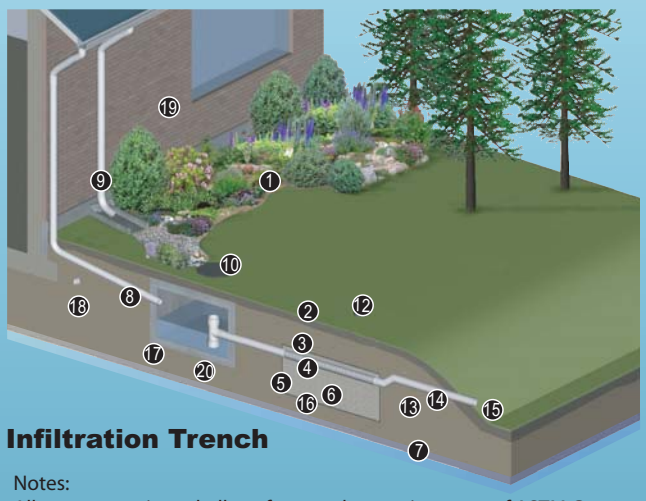
An **Infiltration Trench** System includes an inlet pipe or water source, catch basin sump, perforated distribution pipe, infiltration trench and overflow to the storm drainage system.

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:

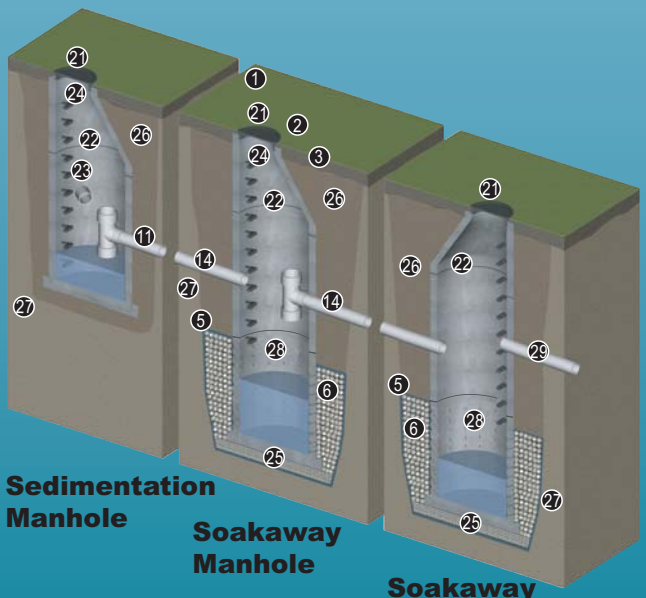
a) To avoid groundwater pollution, do not direct un-treated polluted runoff to Infiltration Trench or Shaft:
- Direct clean runoff (roof, non-automobile paving) to Infiltration Trench or Shaft.
- For polluted runoff (roads > 1000 vehicles / day, parking areas, other pollution sources), provide upstream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



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

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.

Infiltration Trench & Soakaways

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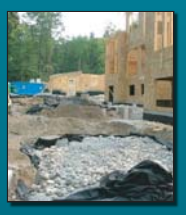

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RAINWATER SOURCE CONTROL

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.

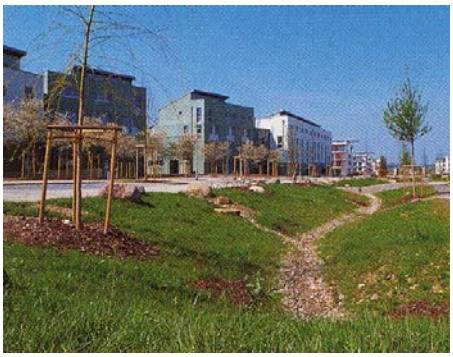
Photo Credit: Melbourne Water

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

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).

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.

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.

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).

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.

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.

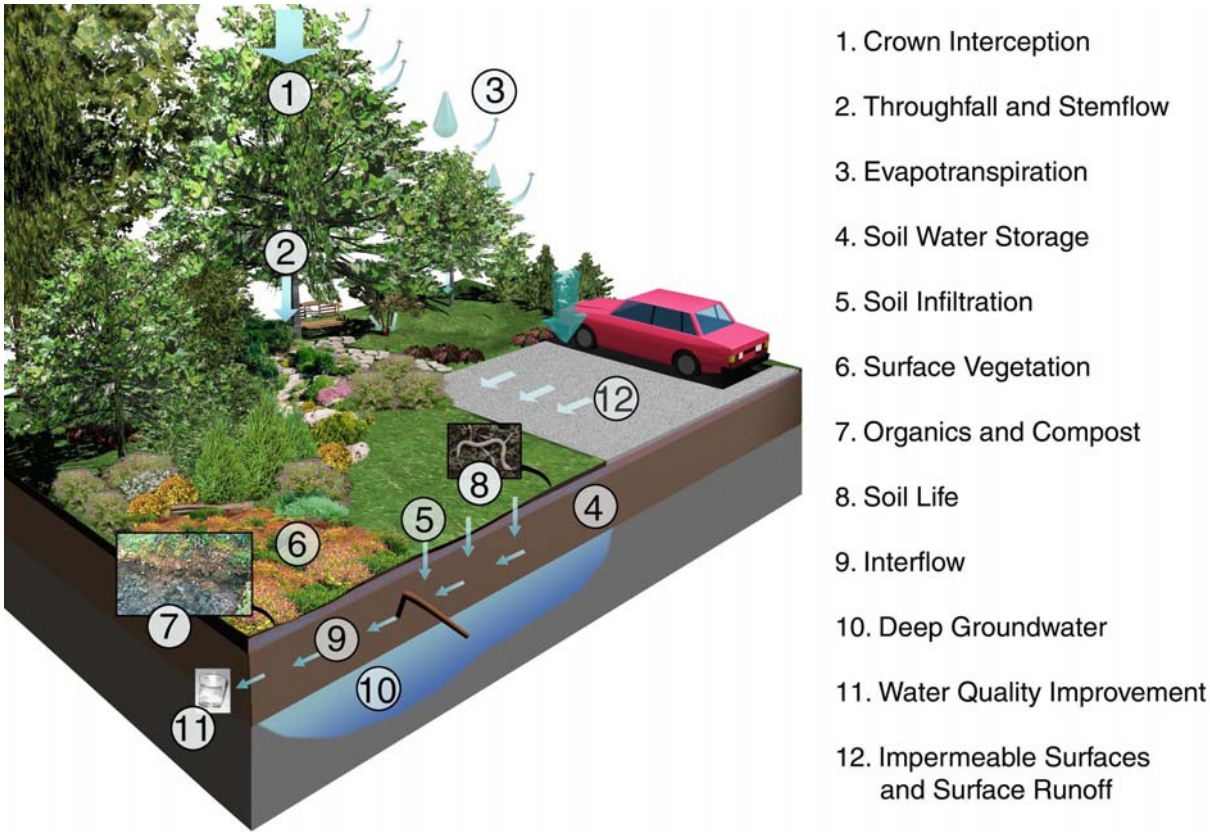


Figure 1-1 shows a schematic representation of the 12 stormwater variables of absorbent landscape discussed below. Keeping these variables in balance is the key to successful stormwater source control using absorbent landscape.

Winter Tree Canopies Intercept 15%-27% of Rainfall

1. Crown Interception

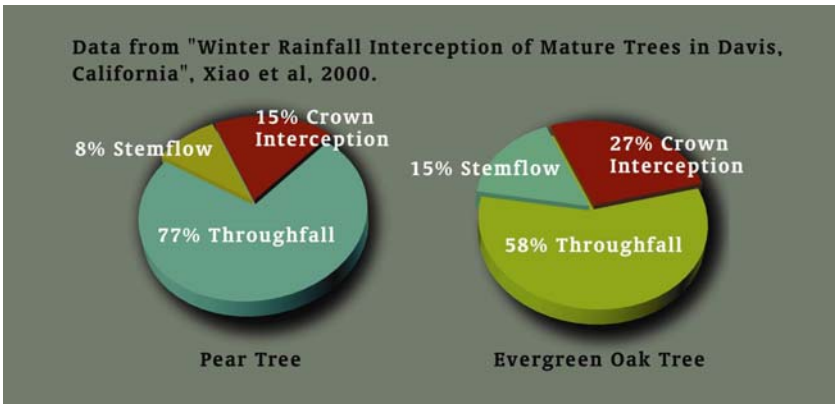


Figure 1-2: Interception, stemflow and throughfall data from California (Xiao *et al.*, 2000)

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).

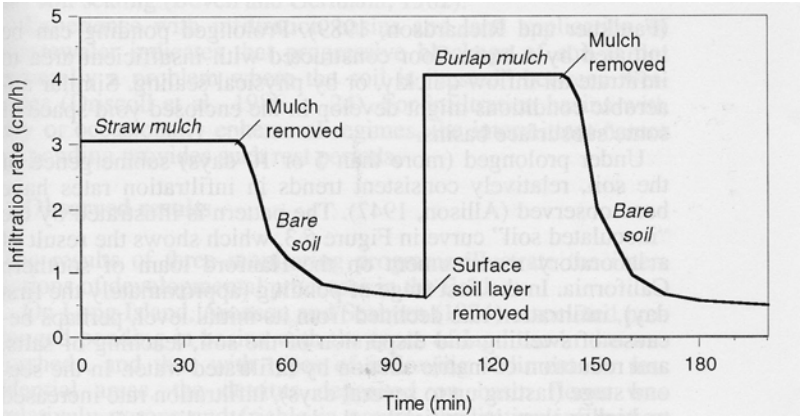


Figure 1-3: Infiltration rate of a sandy loam under continous water sprinkling at a rate in excess of intake with a series of 4 surface conditions (Ferguson, 1994: 191)

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

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.

Photo Credit: Lanarc Consultants Ltd.

Drainage from parking area to landscape.

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.

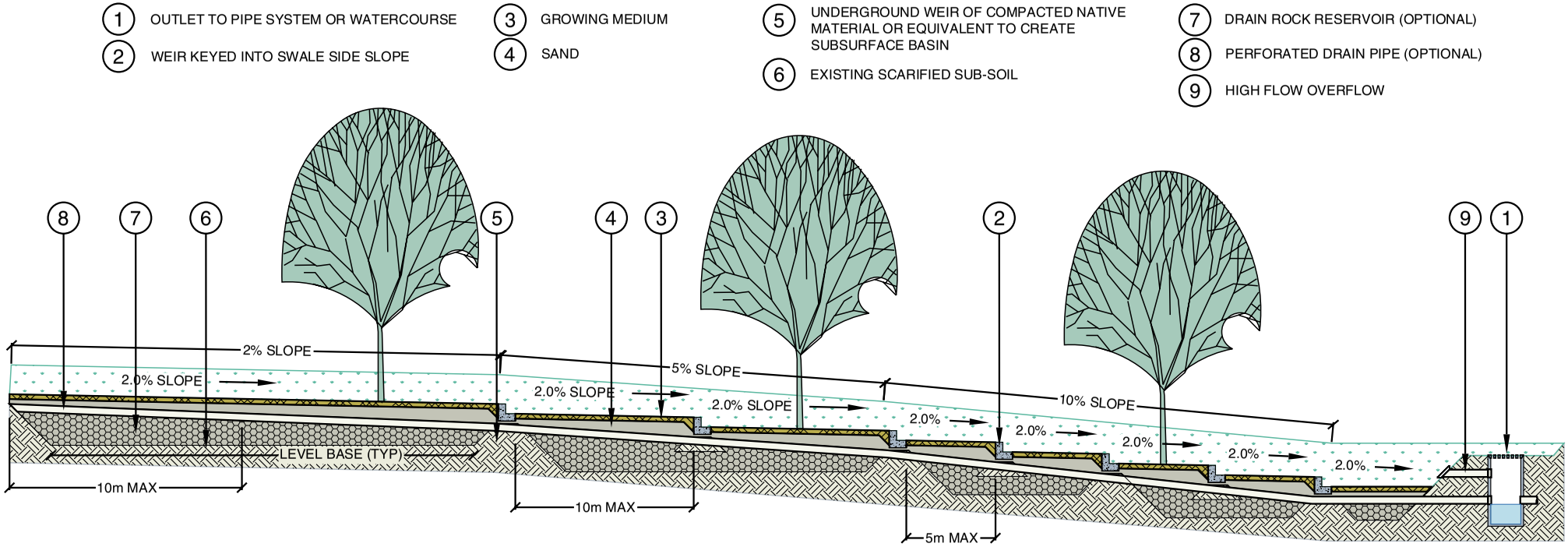
Guideline Specifications

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:

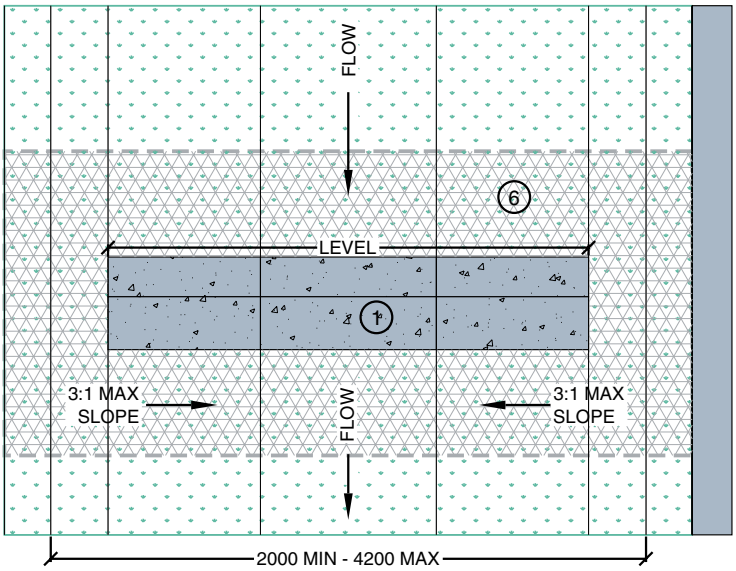
1. Isolate the swale site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300mm of material over the final subgrade of the swale until after all sediment-producing construction in the drainage area has 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.



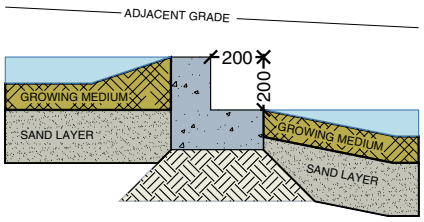
2/A INFILTRATION SWALE

Not To Scale

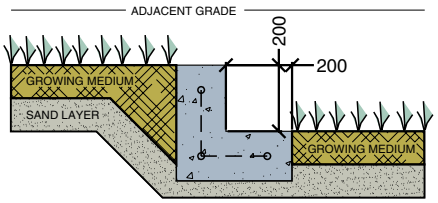
Longitudinal Profile



PLAN



DETAIL SECTION - WEIR WITH PONDING



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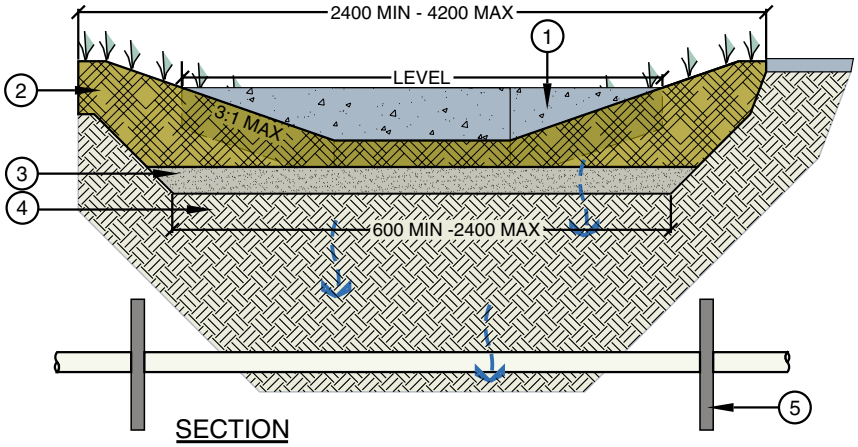


SECTION

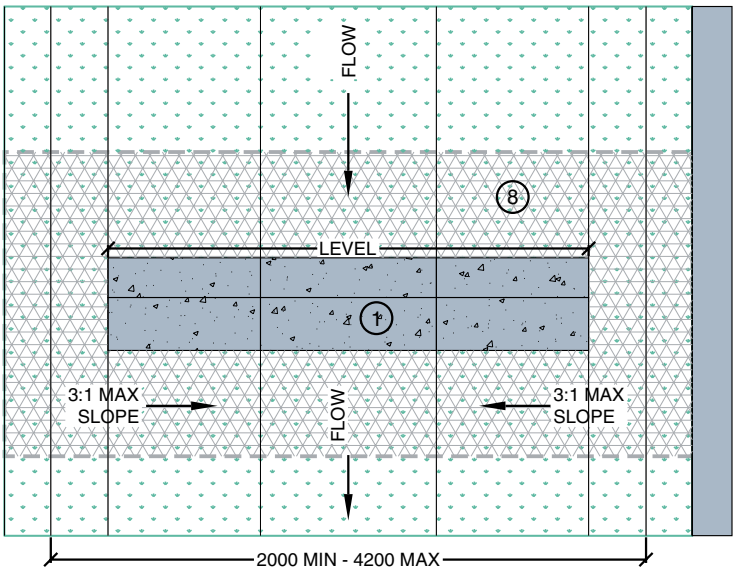
1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. TRENCH DAMS AT ALL UTILITY CROSSING
6. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND AT DRAINAGE INLETS

2/B

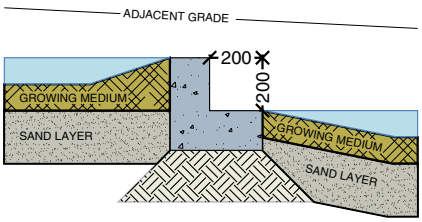
FULL INFILTRATION SWALE

Not To Scale

Plan / Section



PLAN



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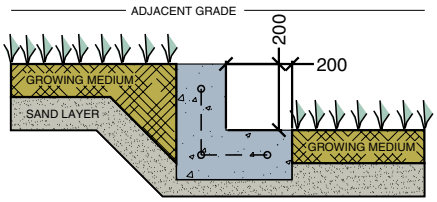

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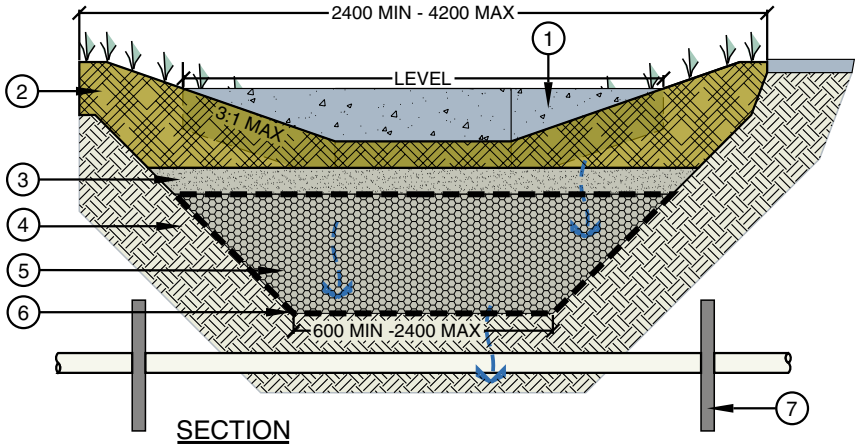


SECTION

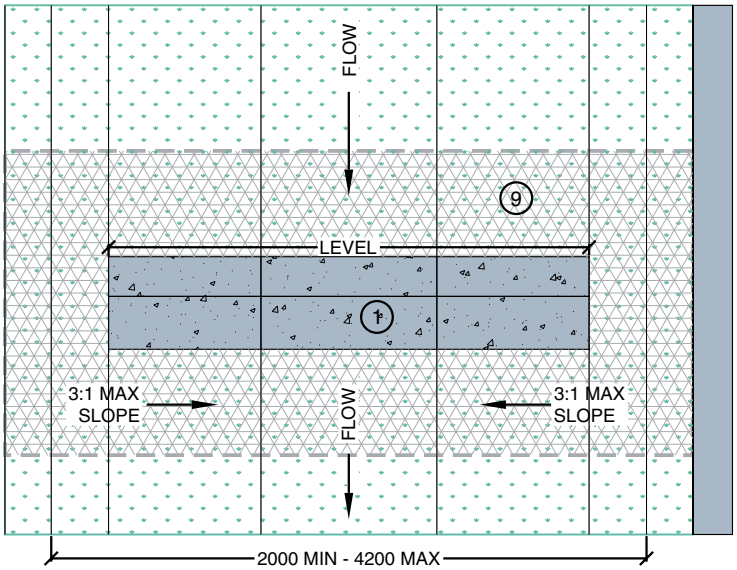
1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. DRAIN ROCK RESERVOIR
6. GEOTEXTILE FILTER ALONG ALL SIDES OF RESERVOIR
7. TRENCH DAMS AT ALL UTILITY CROSSINGS
8. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND AT DRAINAGE INLETS

2 / C

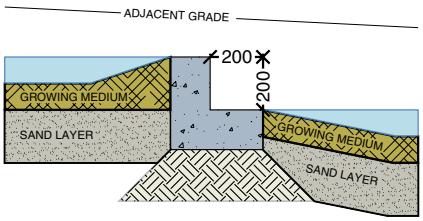
FULL INFILTRATION SWALE WITH RESERVOIR

Not To Scale

Plan / Section



PLAN



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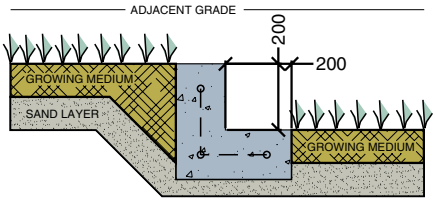

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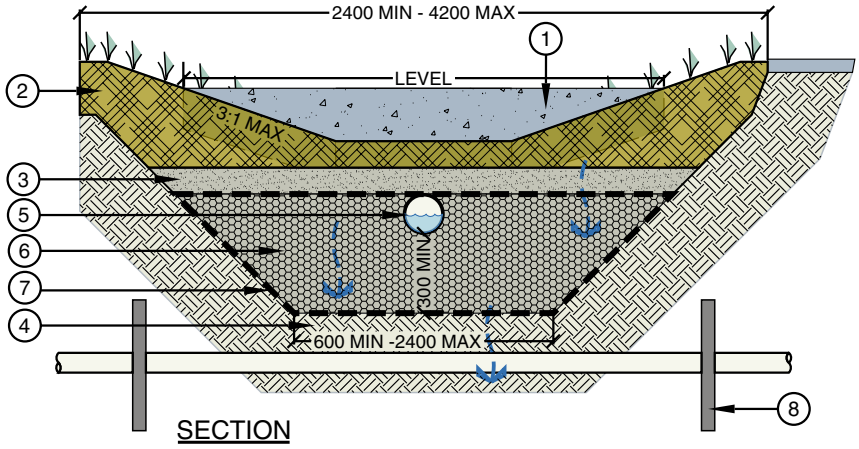


SECTION

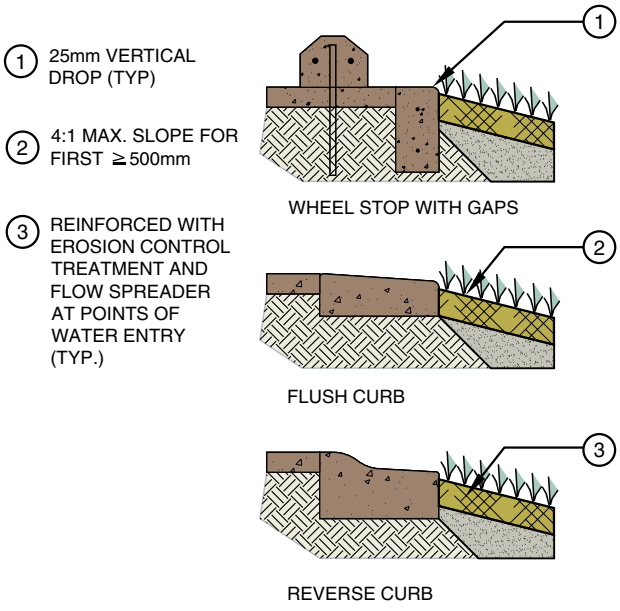
1. WEIR KEYED INTO SWALE SIDE SLOPE
2. GROWING MEDIUM
3. SAND
4. EXISTING SCARIFIED SUBSOIL
5. PERFORATED UNDERDRAIN (150mm DIA MIN.)
6. DRAIN ROCK RESERVOIR
7. GEOTEXTILE FILTER ALONG ALL SIDES OF RESERVOIR
8. TRENCH DAMS AT ALL UTILITY CROSSING
9. PROVIDE EROSION CONTROL ALONG ALL SIDES OF WEIR AND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

2 / D

PARTIAL INFILTRATION SWALE WITH RESERVOIR AND SUBDRAIN

Not To Scale

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:

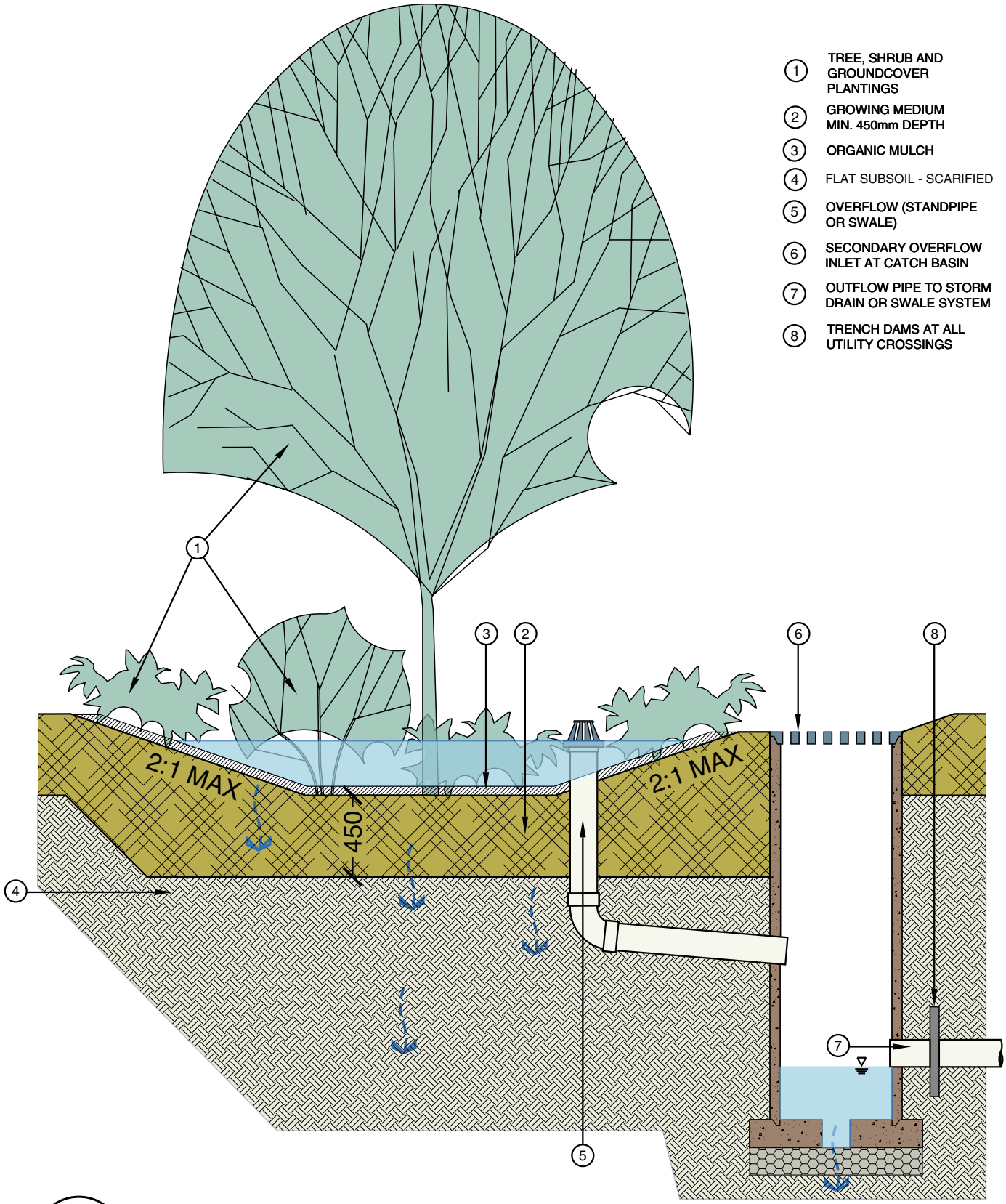
1. Infiltration Drain Rock: clean round stone or crushed rock, 75mm max, 38mm min, 40% porosity (Maryland Dept. Environmental Resource Programs, 2001).
2. Pipe: PVC, DR 35, 150 mm min. dia., with cleanouts.
3. Geosynthetics: as per Section 02498, select for filter criteria or from approved local government 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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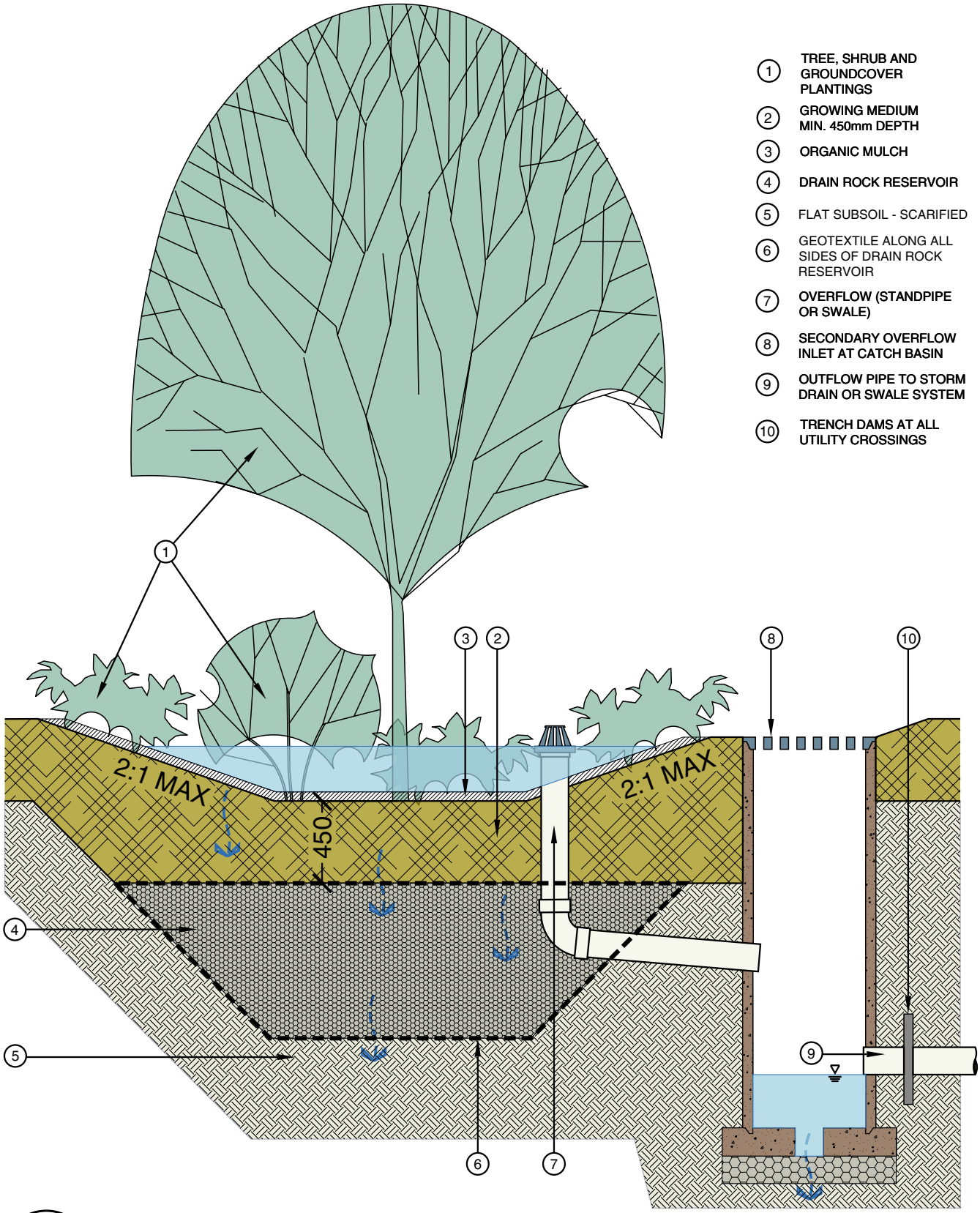
Section



3/B RAIN GARDEN - FULL INFILTRATION WITH RESERVOIR

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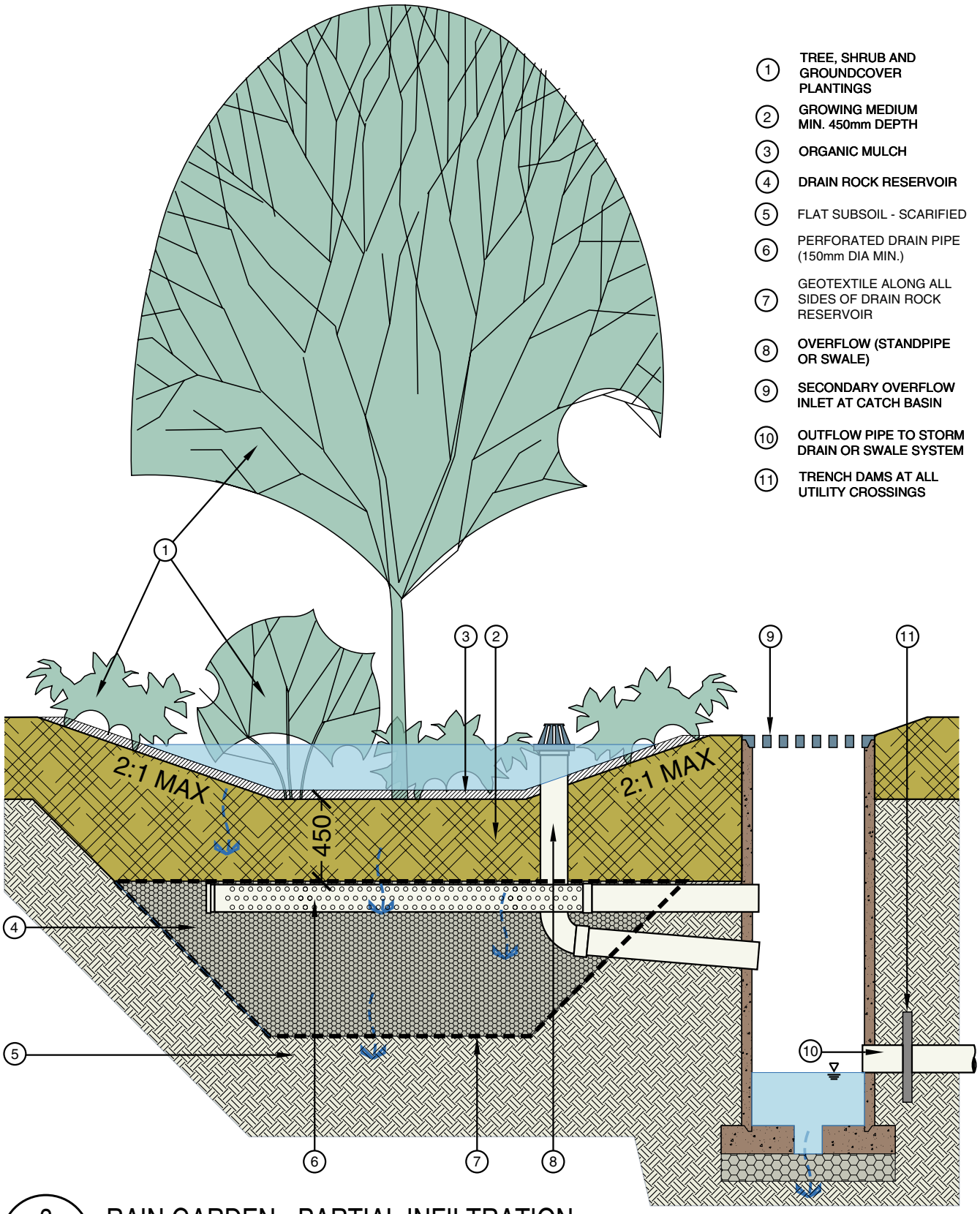
Section



3/C RAIN GARDEN - PARTIAL INFILTRATION

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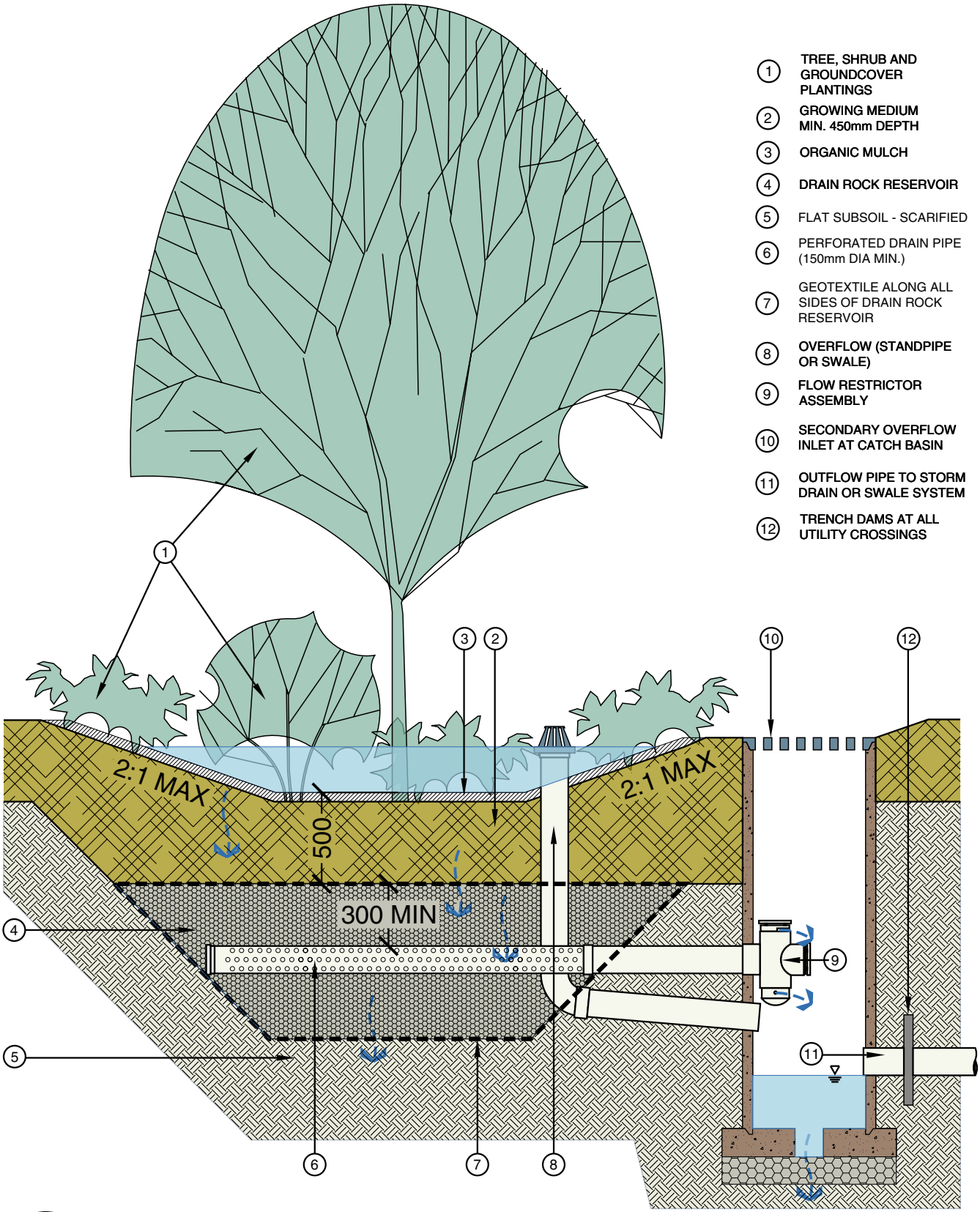
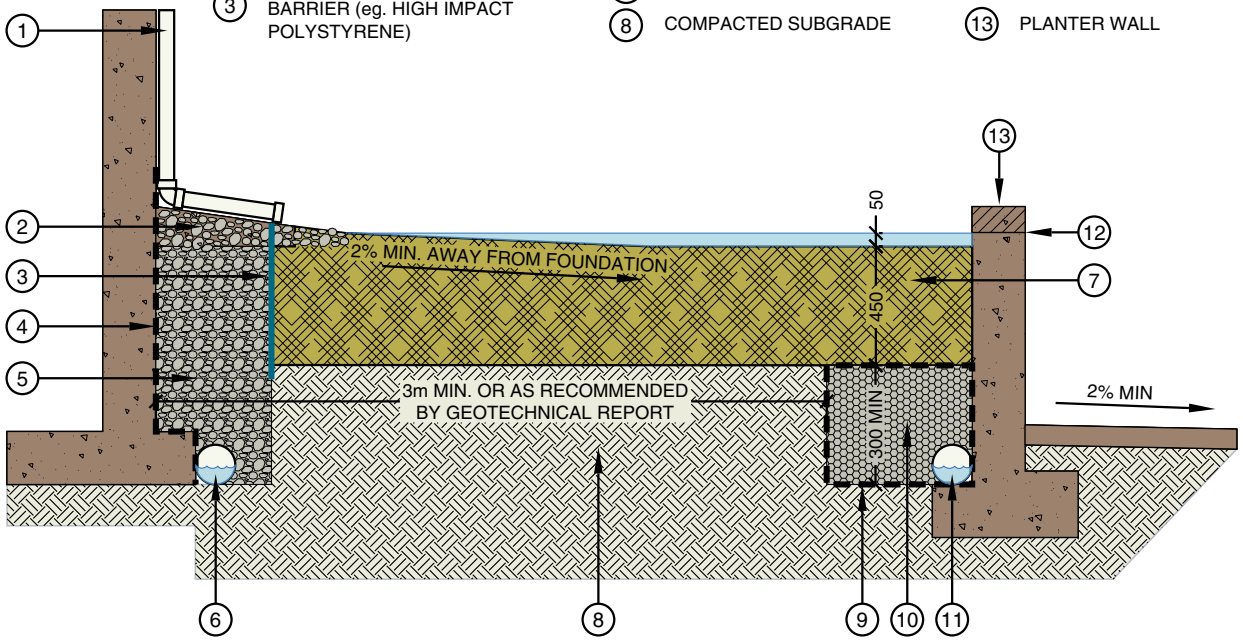


3/D RAIN GARDEN - PARTIAL INFILTRATION WITH FLOW RESTRICTOR

Not To Scale

Section

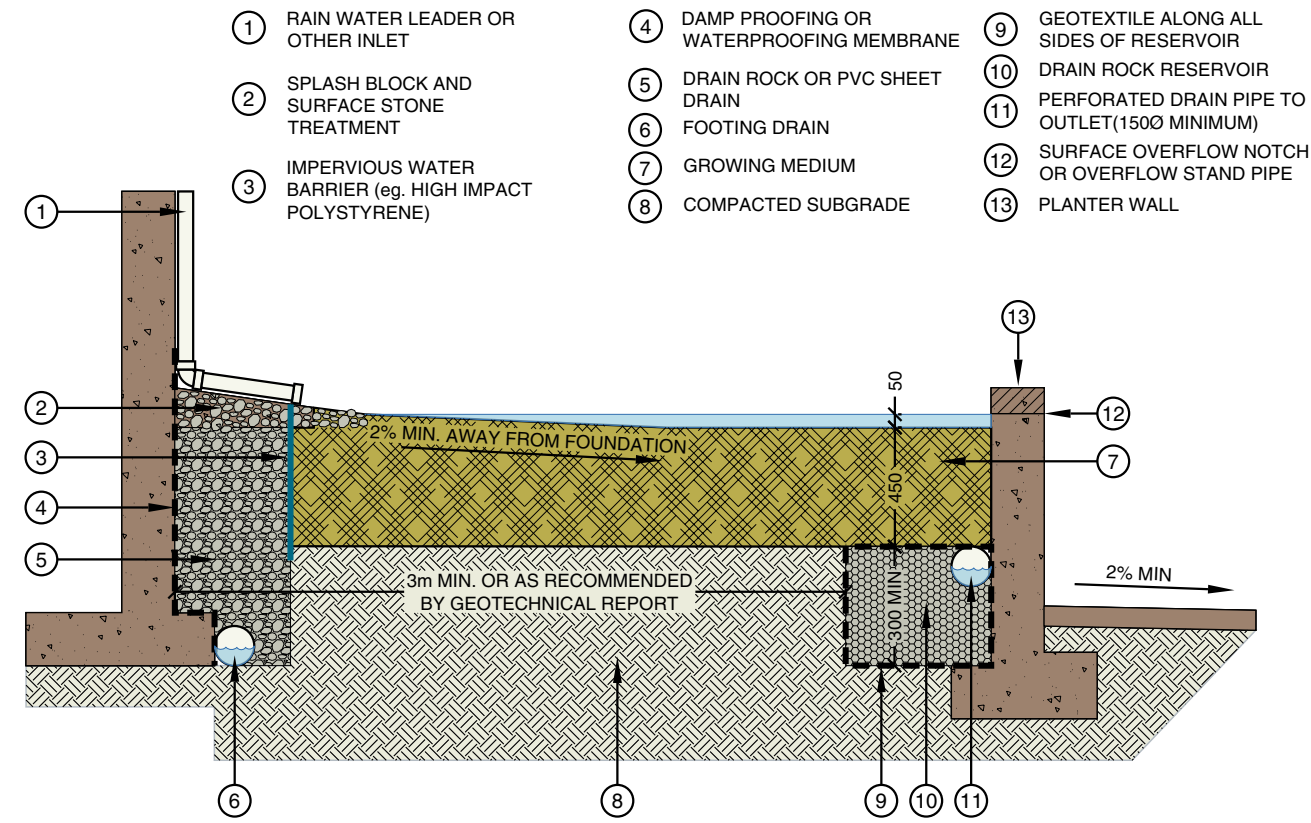
1. RAIN WATER LEADER OR OTHER INLET
2. SPLASH BLOCK AND SURFACE STONE TREATMENT
3. IMPERVIOUS WATER BARRIER (eg. HIGH IMPACT POLYSTYRENE)
4. DAMP PROOFING OR WATERPROOFING MEMBRANE
5. DRAIN ROCK OR PVC SHEET DRAIN
6. FOOTING DRAIN
7. GROWING MEDIUM
8. COMPACTED SUBGRADE
9. GEOTEXTILE ALONG ALL SIDES 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/E FLOW THROUGH PLANTER

Not To Scale

Section



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)

Photo Credit: Lanarc Consultants Ltd.

Plastic grid pavers in parking, White Rock Operations Centre.

Photo Credit: Lanarc Consultants Ltd.

Plastic grid paver detail

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).

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.

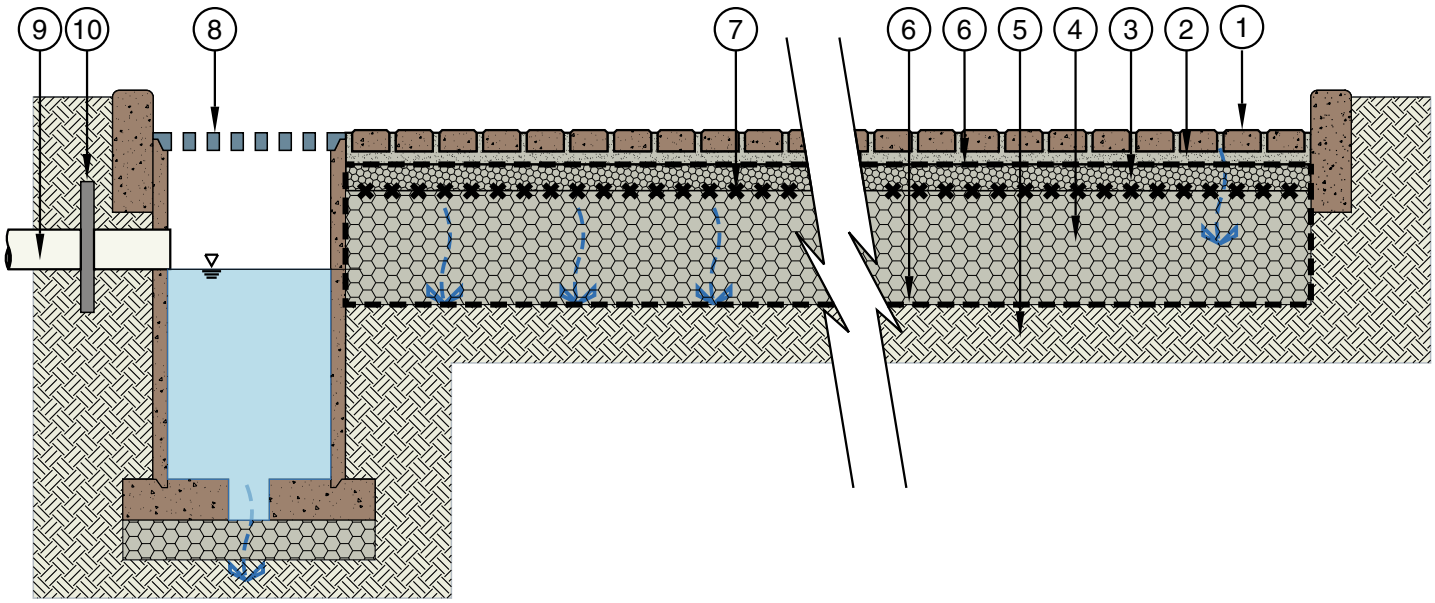
Photo Credit: Lanarc Consultants

Pervious unit paving with aggregate joints at bike rack.

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).

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

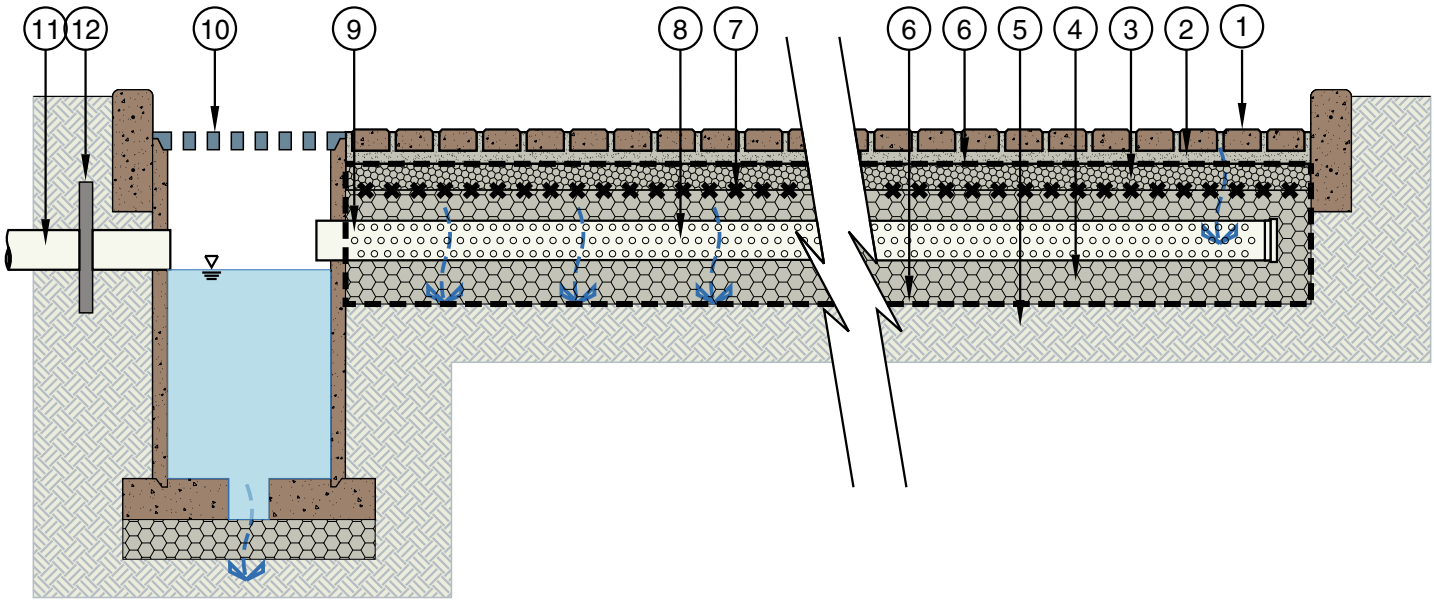


4/A PERVIOUS PAVING - FULL INFILTRATION

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

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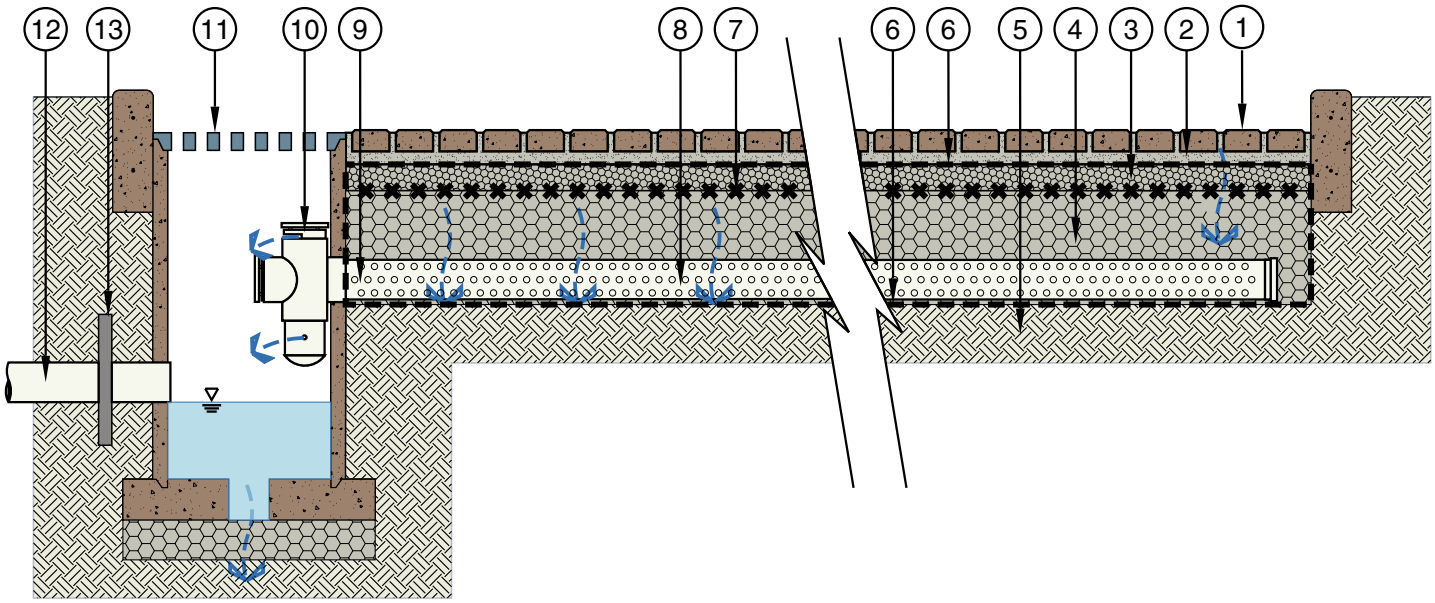
Section

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

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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.

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

Photo Credit: Lanarc Consultants Ltd.

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

(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/m^3
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):

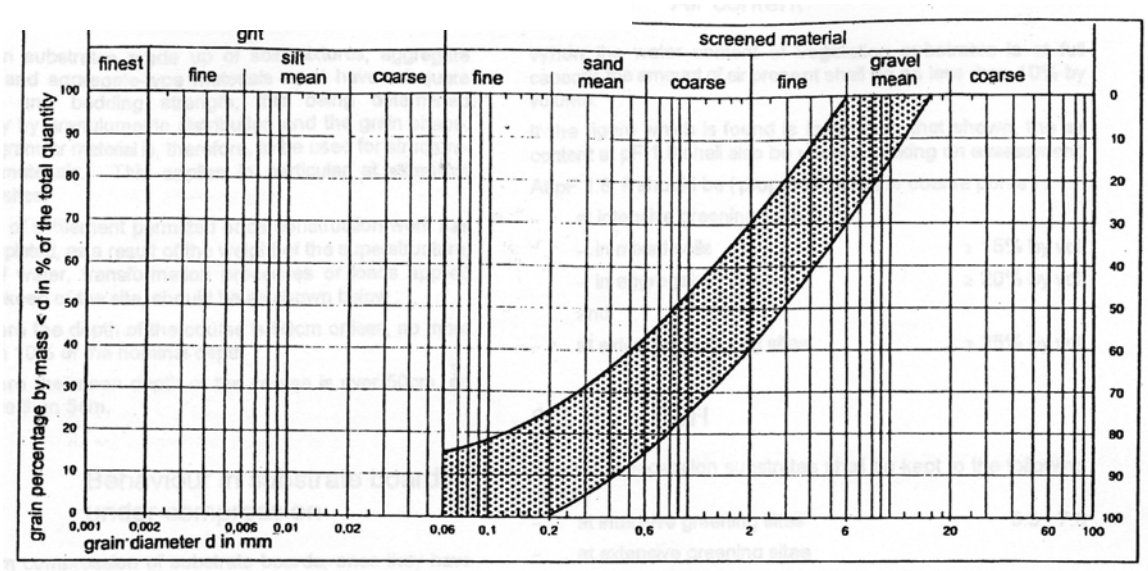


Figure 5-1: Particle (grain) size distribution range for substrates used in multiple layer extensive green roofs (FLL, 1995: 34)

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

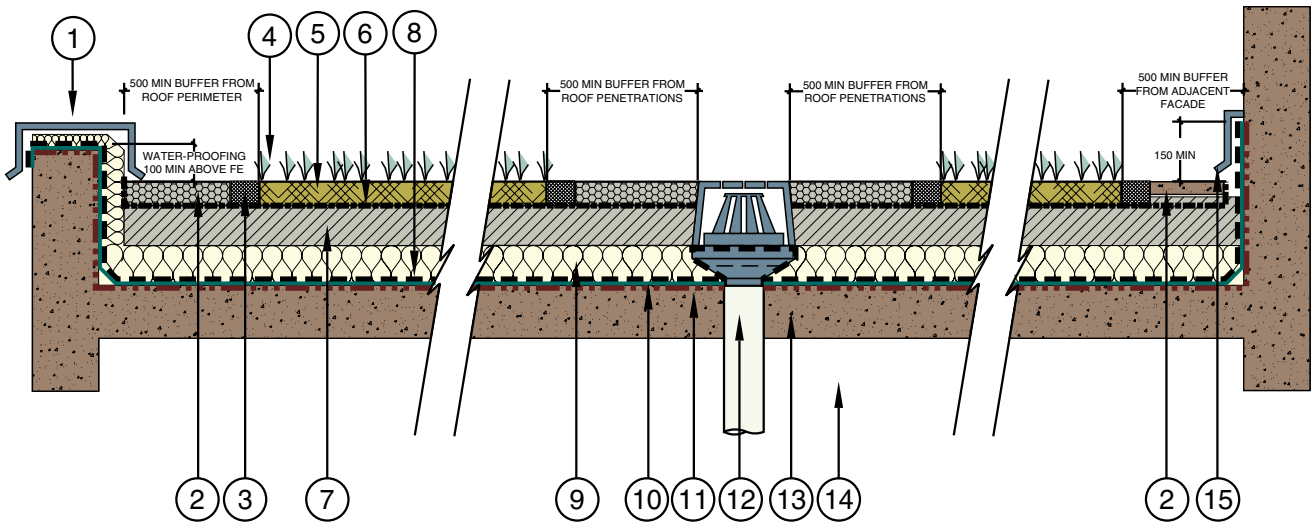
22. Installers should have experience with green roof systems. It may be preferable to have one company handle the entire project from roofing to planting to avoid scheduling conflicts and damage claims (Peck & Kuhn, 2001). If it is not possible, make a clear separation between the responsibilities of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



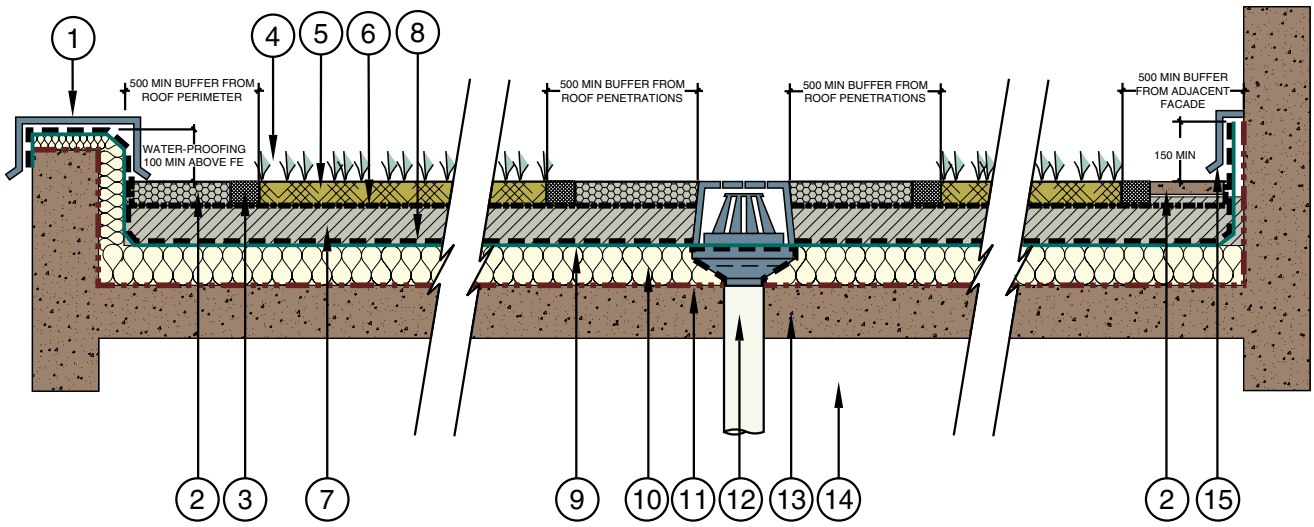
NOTE: UNLESS THE WATERPROOF MEMBRANE IS RESISTANT TO ROOT PENETRATION, A ROOT BARRIER IS REQUIRED BETWEEN THE PROTECTION LAYER AND WATERPROOF MEMBRANE. A SEPARATION LAYER MAY BE REQUIRED BETWEEN CHEMICALLY INCOMPATIBLE MATERIALS.

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

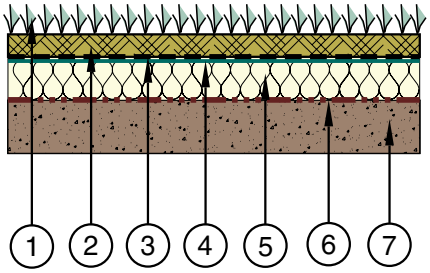


NOTE: UNLESS THE WATERPROOF MEMBRANE IS RESISTANT TO ROOT PENETRATION, A ROOT BARRIER IS REQUIRED BETWEEN THE PROTECTION LAYER AND WATERPROOF MEMBRANE. A SEPARATION LAYER MAY BE REQUIRED BETWEEN CHEMICALLY INCOMPATIBLE MATERIALS.

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

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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.

  - 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.

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.

- 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.

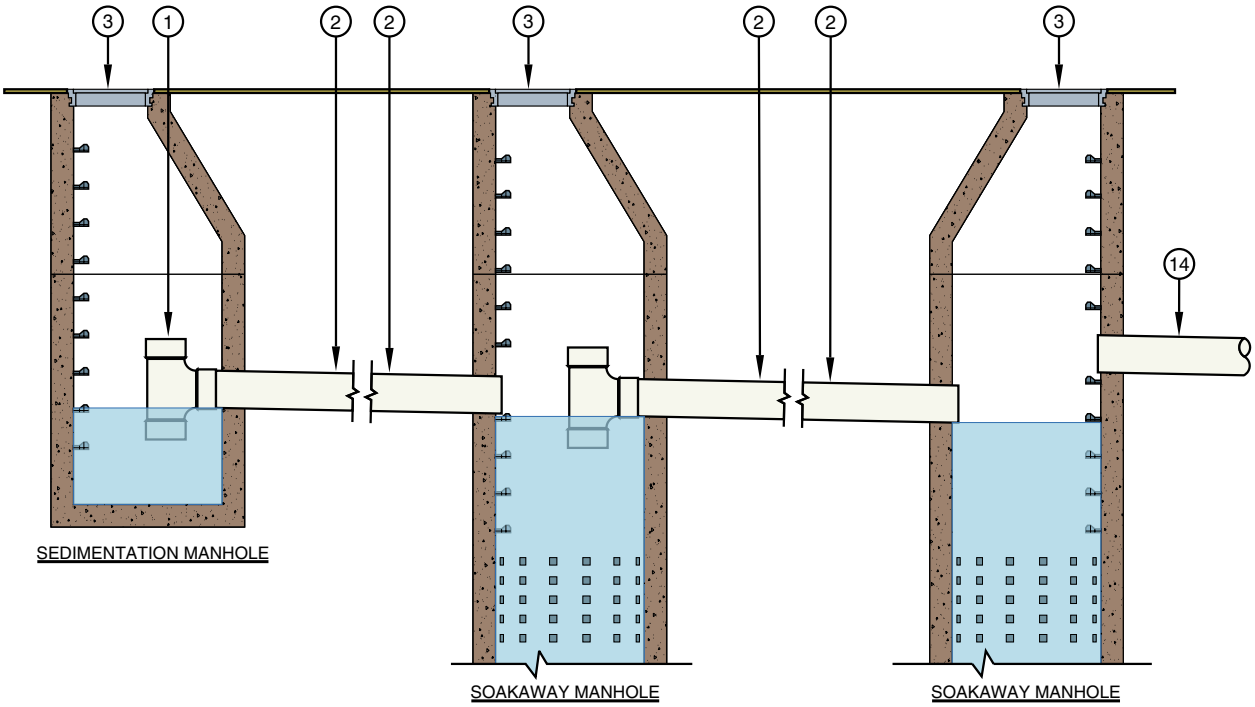
Guideline Specifications

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

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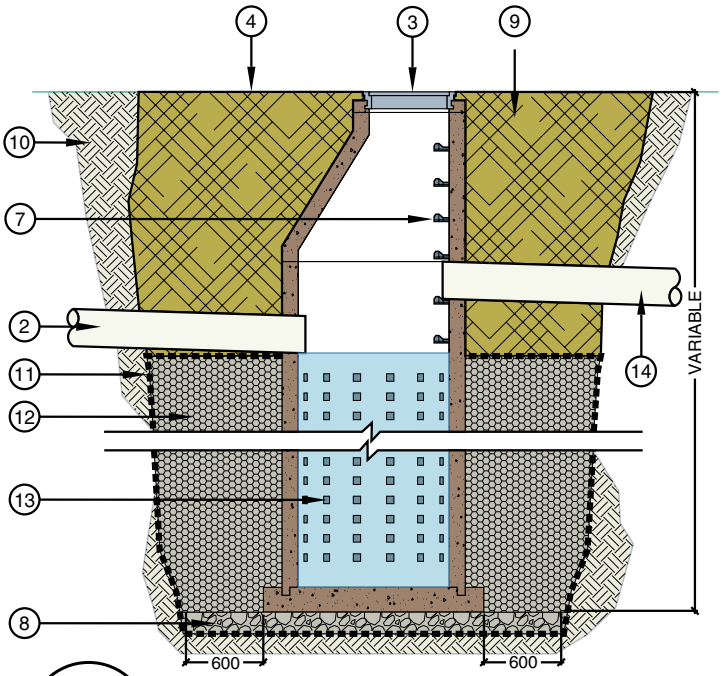
NOTES:
ALL PRECAST SECTIONS SHALL CONFORM TO THE REQUIREMENTS OF ASTM C 478.
PROVIDE A MIN. OF 150mm OF 25mm OR 19mm CLEAN CRUSHED ROCK UNDER ALL PIPES.
INVERT SHALL BE LEVEL AND SMOOTH.
SUMP BARREL SHALL NOT BE PERFORATED WITHIN 1200mm OF THE CONE.



6 B SOAKAWAY MANHOLE

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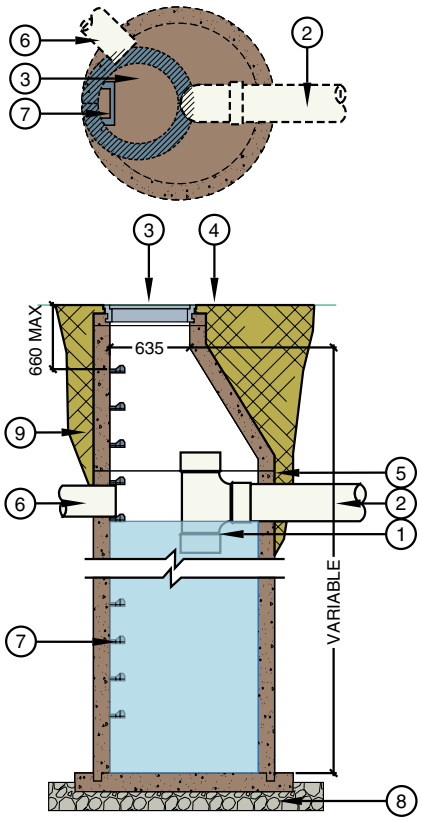

6 C SEDIMENTATION MANHOLE

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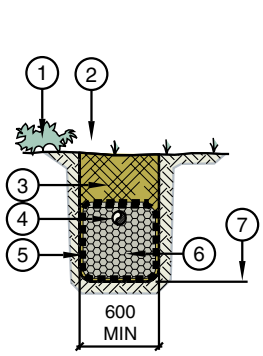
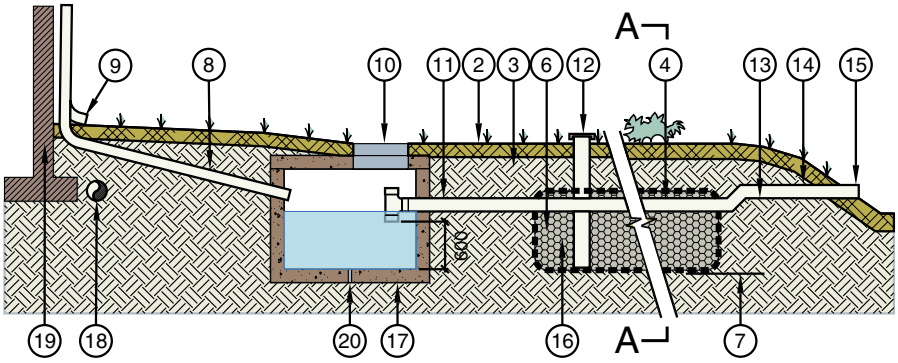
1. PVC SOLID PIPE C/W INLET TEE
2. INTERCONNECTING PVC SOLID PIPE
3. STANDARD MANHOLE FRAME AND COVER
4. FINISH GRADE
5. SEAL JOINTS WITH CEMENT GROUT OR APPROVED MASTIC
6. STREET INLET CONNECTION
7. LADDER RUNG
8. 25mm CRUSH GRAVEL OR DRAIN ROCK BASE
9. NATIVE SOIL BACK FILL
10. UNDISTURBED GROUND
11. 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

6D

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.

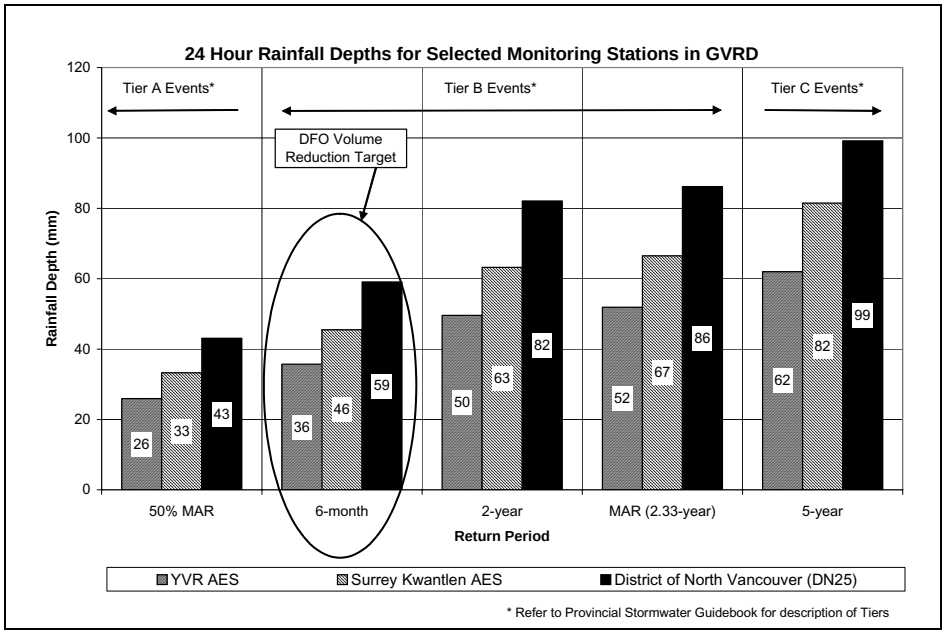


Figure F1: Typical 24 Hour Rainfall Depths in the GVRD

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.

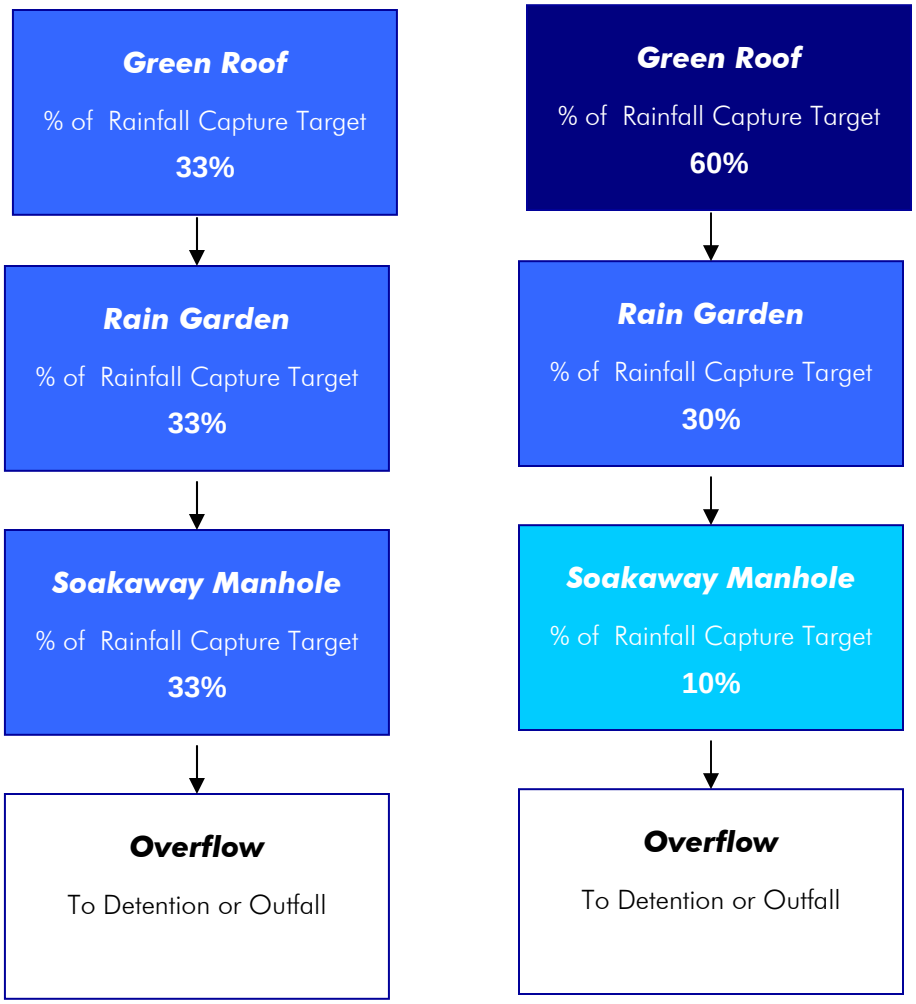


Figure F2: Alternative Stormwater Treatment Chain for High Density Development

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.

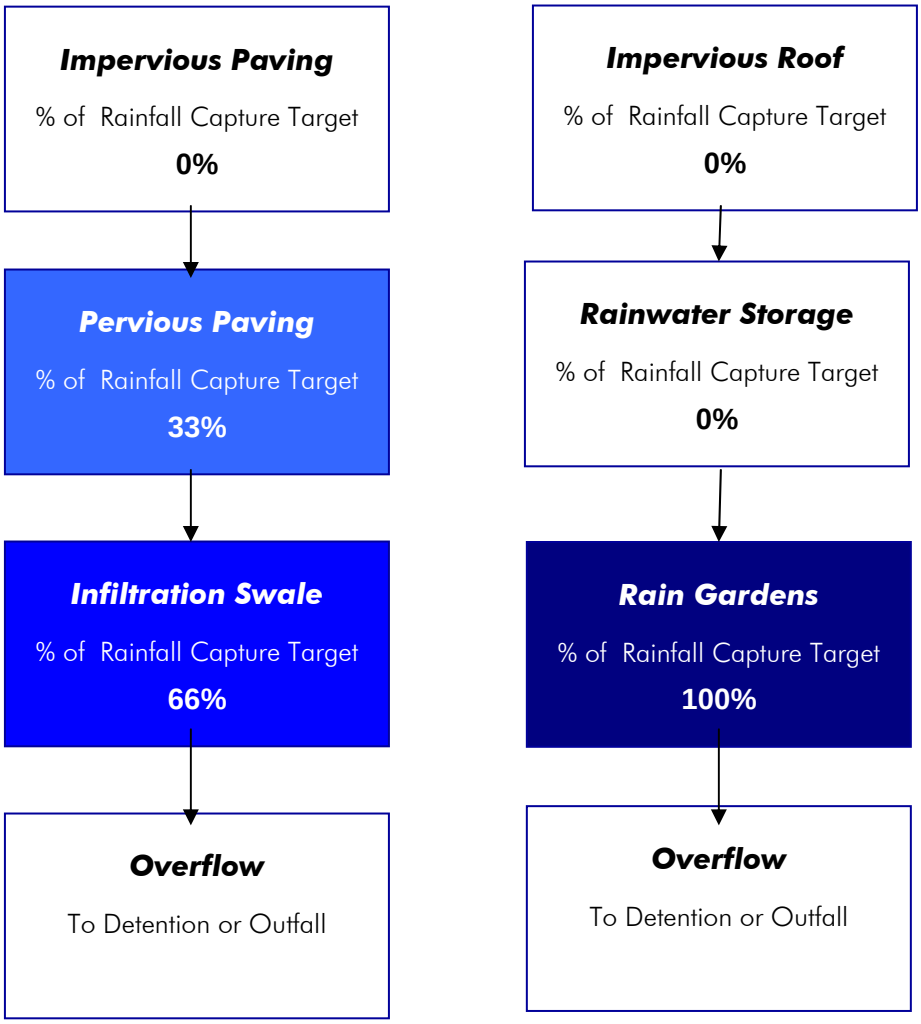


Figure F3: Alternative Stormwater Treatment Chain for Low Density Development

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

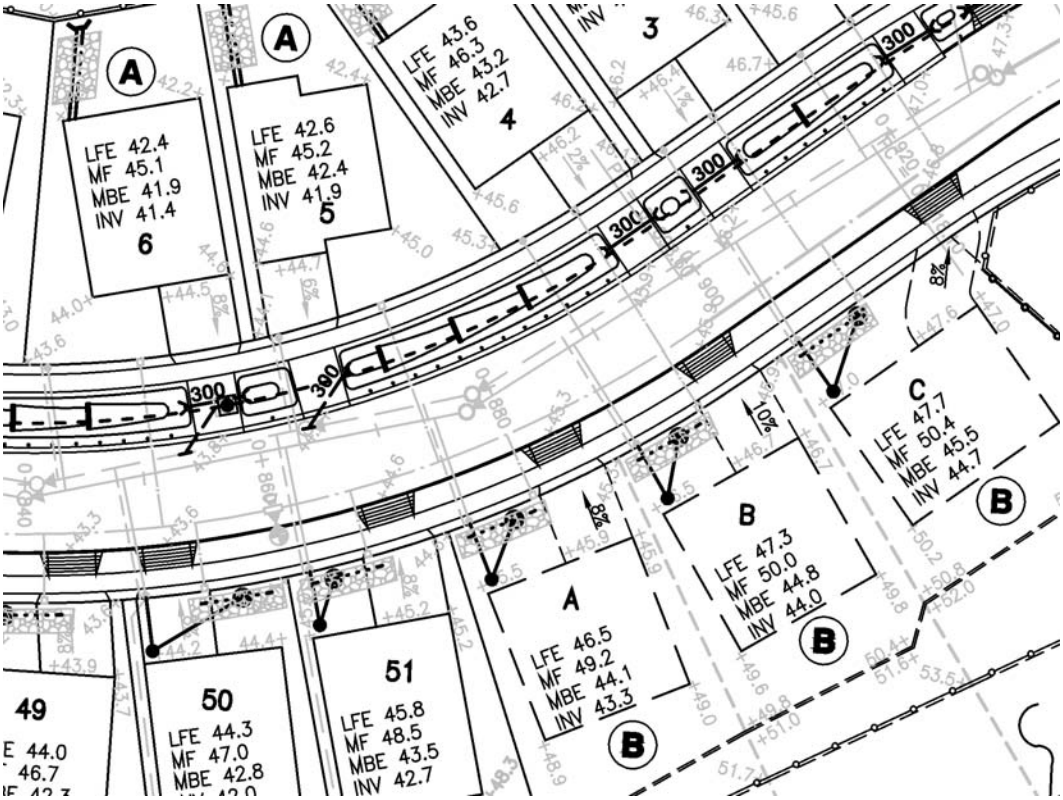
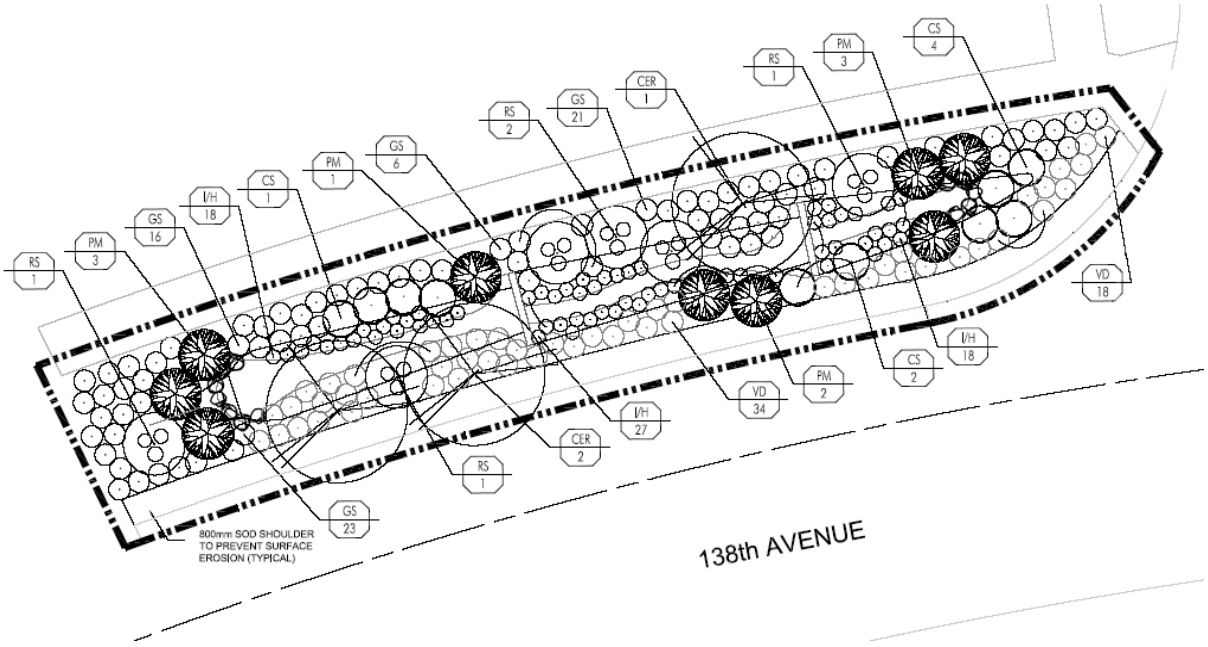


Figure F5: Example of Landscape Plan (Silver Ridge – Lanarc Consultants Ltd.)



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

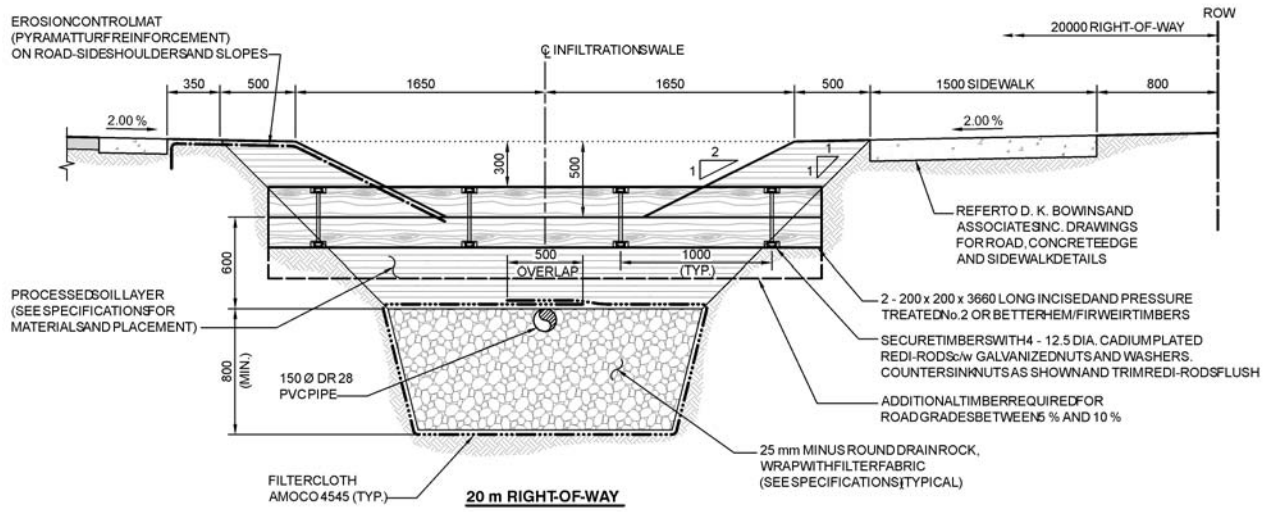
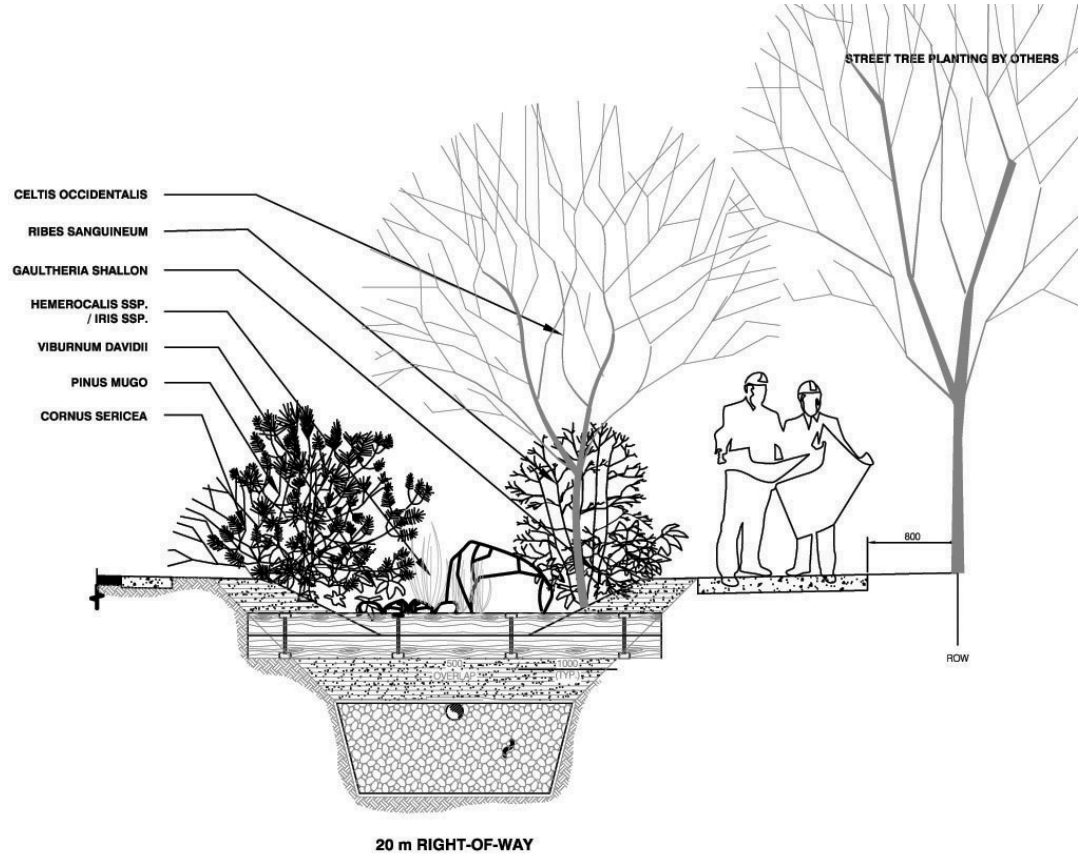


Figure F7: Example of Landscape Cross Section Detail (Silver Ridge – Lanarc Consultants Ltd.)



Profile Details

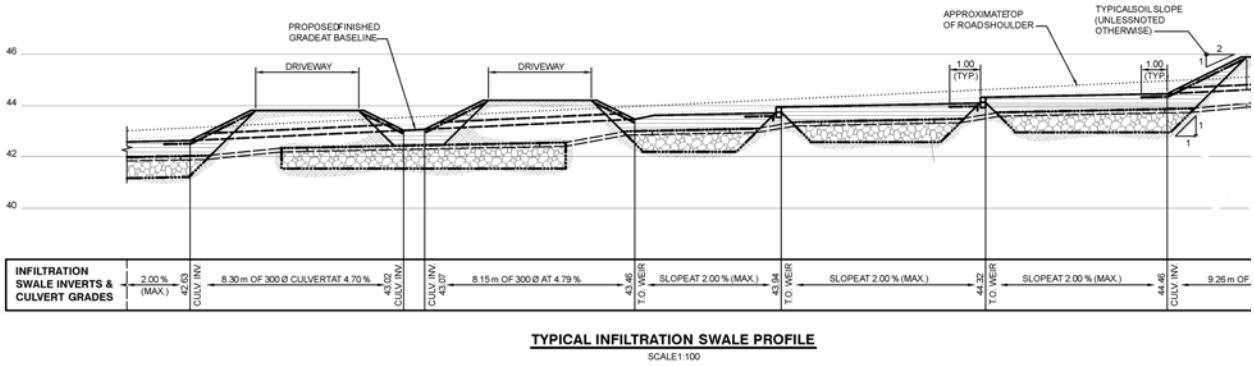
Profile details (one or more views) for Stormwater Source Controls should show the features listed in the Profile Checklist, as appropriate to the design.

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.

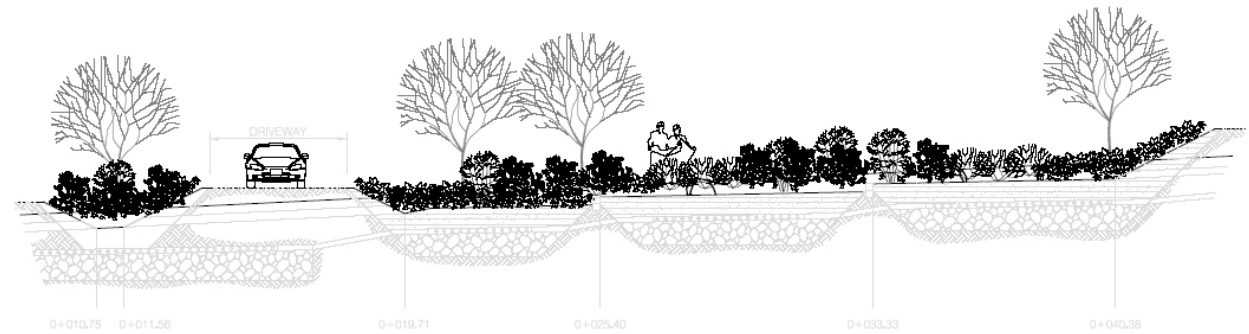
Figure F8: Example of Engineering Profile (Silver Ridge – KWL Associates Limited)

Roadside Infiltration Swale with Reservoir and Subdrain



TYPICAL INFILTRATION SWALE PROFILE
SCALE 1:100

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



TYPICAL SWALE PLANTING
SCALE 1:100
Profile

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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Key Contacts

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US	Eugene, City of	Paul Klope	construction and specifications for street edge alternatives, porous pavement	City of Eugene, 244 E. Broadway St., Eugene, OR 97401	??	paul.w.klope@cl.eugene.or.us
US	Oregon, University of, Center for Housing Innovation Neighborhoods Lab	Ron Kellett and Cynthia Girling	green neighbrhoods, stormwater master planning and design, best management practices, urban forestry	5250 University of Oregon Eugene, Oregon	503-346-3647	kellett@darkwing.uoregon.edu
US	Oregon, Urban Watershed Institute	April Hildner	Urban Watershed Issues, PNW	Urban Watershed Institute, 19600 S. Molalla Ave., Oregon City, OR 97045	??	aprilhildner@home.com
US	Portland Metropolitan area	Kelley Webb	green streets project, trees for green streets, wildlife crossings, stormwater best management practices, street design	Metro Portland, 600 NE Grand Avenue, Portland, OR 97232	503-797-1894	webbk@metro.dst.or.us

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US	Portland, City of	Steve Fancher	Development Engineering / Stormwater Manual	City of Portland, Bureau of Environmental Services, 1120 SW 5th Ave., Room 1100, Portland, OR 97204	(503) 823-7126	stevef@bes.ci.portland.or.us
US	Portland, City of	Tom Liptan	green roof	City of Portland, Bureau of Environmental Services 1120 SW 5th Avenue Room 1100 Portland, Oregon 97204-1972		toml@bes.ci.portland.or.us
US	Seattle, City of	John Arnesen	SEA project manager	Seattle Public Utilities, 710 Second Street., Suite 660, Seattle, WA 98104-9712	??	john.arneson@ci.seattle.wa.us
US	Seattle, City of	Tracy Chollak	SEA drainage design engineer	Seattle Public Utilities, 710 Second Street., Suite 660, Seattle, WA 98104-9712	??	tracy.chollak@ci.seattle.wa.us
US	Washington State University	Curtis Hinman	Economic and Hydrologic Analysis of Low Impact Development	Extension Faculty, Puget Sound Water Quality Field Agent, WSU, 3049 S 36th St., Suite 300, Tacoma, WA 98409	??	chinman@wsu.edu
US	Washington, Univ. of and Western Wash. Univ.	Chris May	relationships between development and habitat impacts	16700 Seminole Rd., Poulsbo, WA 98370	??	may@apl.washinton.edu

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Australia Dept. of Environment and Heritage.	2002	Introduction to Urban Stormwater Management in Australia. Commonwealth of Australia. 103 p.		http://www.deh.gov.au/coasts/publications/stormwater/	Australia	AU001
B.C. Society of Landscape Architects and B.C. Landscape and Nursery Association.	2001	* BC Landscape Standard 6th Edition. Vancouver. 132 p.	absorptive landscapes		Canada	CA001

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Oberlander, C.H., E. Whitelaw and E. Matsuzaki.	2002	* Introductory Manual for Green Roofs - Version 1.1. For Public Works and Government Services Canada. 32 p.	green roof		Canada	
Olympia, City of.	1995	Impervious Surface Reduction Study. Olympia Community Planning and Development Department, Olympia, Washington. 81 p		http://depts.washington.edu/cwws/Research/Reports/ipds.pdf	USA	
Peck, S.	2002	* Green Roofs for Healthy Cities Opens its Doors. The Green Roof Insfrastructure Monitor 4(2): 1-12	green roof	http://www.greenroofs.ca	USA	
Peck, S. and M. Kuhn.	2001	* Design Guidelines for Green Roofs. For Ontario Assoc of Architects and CMHC. 22 p.	green roof	http://www.cmhc-schl.gc.ca/en/imquaf/himu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=32570	Canada	
Pentec Environmental.	2000	* BMP - Permeable Interlocking Concrete Pavement. Paper for Mutual Materials. 17 p. +figures.	Permeable paving		USA	
Phillips, A.	2003	** City of Tucson Water Harvesting Guidance Manual. For City of Tucson, Dept. of Transportation, Stormwater Section. 35 p.	underground infiltration structures	http://www.ci.tucson.az.us/planning/whm.pdf	USA	US016
Portland Metro (Washington)	2002	** Green Streets: Innovative Solutions for Stormwater and Stream Crossings (also: Trees for Green Streets and Creating Liveable Streets)	absorptive landscapes, permeable paving, swales, underground devices	http://www.metro-region.org/	USA	US011
Portland, City of, Environmental Services.	?	* Protect Our Rivers - Disconnect Your Downspouts. 10 p.	underground infiltration structures	http://www.cleanrivers-pdx.org/	USA	UK008

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Pratt, C., S. Wilson and P.Cooper.	2001	* Source control using constructed pervious surfaces – hydraulic, structural and water quality performance issues. CIRIA C582. London. 152 p.	permeable paving	http://www.ciria.org/suds/publications.htm	UK	UK004
Pratt, C.J.	2001	* Sustainable Urban Drainage – a Review of Published Material on the Performance of Various SUD Devices. Coventry University. For UK Environment Agency. 25 p.	permeable paving, swales, infiltration devices	Miscellaneous references collection; http://www.ciria.org/suds/pdf/suds_review_jan02.pdf	UK	UK007
Priesnitz, W.	2003	* How Green is your Roof? Natural Life Magazine #87. 3 p.	Green roof	http://www.life.ca/nl/87/roof.html	US	
Puget Sound Action Team	2003	Natural Approaches to Stormwater Management – low impact development in Puget Sound.	absorptive landscapes, permeable paving, bioretention, green roofs	http://www.psat.wa.gov/Publications/LID_studies/LID_approaches.htm	USA	US012
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Rollings, R.S.and M.P. Rollings.	1999	* SF-RIMATM - A Permeable Paving Stone System. SF Concrete Technology Inc. 27 p.	Permeable paving		USA	
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Schueler, T.	1987	Controlling Urban Runoff: A Practical Manual for Planning and Designing BMPs. For Washington Metropolitan Water Resource Planning Board.	permeable paving, swales, underground devices		USA	US008
Scottish Environment Protection Agency.	2004	* Permeable Car Parks eat oil. 2 p.	Permeable paving	http://www.sepa.org.uk/guidance/urban-drainage/oil.htm	UK	

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Smith, David	2001	*Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance. 2nd Ed. International Concrete Pavement Institute (ICPI). 42 p.	permeable paving	http://www.icpi.org	USA	US017
Soprema Inc.	2000	* Environap Modified Bitumen Geomembranes. Waterproofing Structures and Environmental Projects. 16 p.	green roof		Canada	
Soprema Inc.	1998	* Green Roof Systems/Soprema 02909. 15 p.	green roof		Canada	
Stabilizer Solutions Inc.	2003	* Stabilizer Ballyard Products - offering innovations in field materials and maintenance. 6 p.	absorptive landscapes		USA	
Stadtentwasserung Hannover.	2001?	* Water Concept Kronsberg: part of the EXPO Project "Ecological Optimization Kronsberg". 34 p.	Case studies and application of source controls	Miscellaneous resources collection	Germany	GE006
Stephens, K., P. Graham and D. Reid.	2002	** Stormwater Planning: A Guidebook for British Columbia. B.C. Ministry of Water, Land and Air Protection (MWLAP). 200 p (approx.)	absorbent landscapes, water balance, infiltration structures, bioretention, green roof, adaptive management	http://wlapwww.gov.bc.ca/epd/epdpa/mpp/stormwater/stormwater.html	Canada	CA002
Stormwater Managers' Resource Centre	2003	** Stormwater Design Manual Toolbox - website	swales, bioretention, underground devices	http://www.stormwatercenter.net	USA	US015
Tosomeen, C.	1999	* Summary of porous concrete sidewalk. City of Olympia. 2 p.	Permeable paving		USA	
Tyler, R.	2003?	* Wake up and Smell the Compost! 8 p.	absorptive landscapes		USA	
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Urban Water Resources Centre, University of South Australia.	?	Porous Pavement Parking Bays at Kirkcaldy Ave., Charles Sturt	Permeable paving	http://www.unisa.edu.au/uwrc/project.htm	Australia	
Urban Water Resources Centre, University of South Australia.	2003	Stormwater management problems and the source control philosophy.	Website	http://www.unisa.edu.au/uwrc/project.htm	Australia	
Vaes, G. and J. Berlamont.	2002	* Design rules and impact assessment for source control measures based on continuous long term simulations. Water Science & Technology 45(7): 21-29.		http://www.iwaponline.com/wst/04507/wst045070021.htm	Belgium	
Viklander, M., M. Backstrom, m. Forster and D. Thevenot.	2003	* Urban Stormwater Source Control Strategy within DayWater Project (FP 5 RTD): General Feature and Specific Issues in Cold Climate. 1st Int. Conf. Urban Drainage and Highway Runoff in Cold Climate 25-27 Marck 2003, Sweden. 11 p.	green roof		USA	
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Ward, A. and S. Trimble.	2003	Environmental Hydrology, 2nd Ed. Lewis Publishers, Florida. 475 p.	absorbent landscapes		USA	
Washington State Dept. of Ecology.	2003	Stormwater Management for Eastern Washington DRAFT.		http://www.ecy.wa.gov/programs/wq/stormwater/eastern_manual/index.html	USA	
Washington State Dept. of Ecology.	2001	**Stormwater Management for Western Washington –Volume V –Runoff Treatment BMPs. Publication No.99-15.	permeable paving, swales, underground devices	http://www.ecy.wa.gov/biblio/9915.html	USA	US009

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Xiao, Q., E. McPherson, S. Ustin, M. Grismer and J. Simpson.	2000	* Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrol. Process 14: 763-784.	absorbent landscapes, evaporation, interception		USA

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APPENDIX A
Jurisdiction Summaries

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Washington State

Stormwater Management - status

Key Drivers

- **Minimizing flooding.**
- **Salmon protection** - legal and moral imperative to avoid, mitigate and/or restore salmon habitat in the midst of urban growth.
- **Protection of local streams and rivers** for fish habitat but also drinking water and recreation.
- **Federal and state regulations** for water quality and protection of salmon habitat, including the *1987 Clean Water Act Amendment*, and the *Endangered Species Act* and National Marine Fisheries Service policies on salmon habitat. These statutes effectively require state and local governments to implement a stormwater management program.
- **Pollution reduction** with pollutants of concern including suspended solids, heavy metals, nutrients, bacteria and viruses, organics including hydrocarbons, floatable debris, and increased temperature. Many streams have total maximum daily loads (TMDLs) of pollutants established by senior government law.

Standards and Policy

Federal Clean Water Act – This Act requires the chemical, physical and biological integrity of the Nation's waters be maintained. Under this Act, the U.S. Environmental Protection Agency has established National Pollutant Discharge Elimination System (NPDES) Stormwater Regulations, which establish stormwater permitting requirements and identify state agencies and local governments that are subject to those requirements. Under Phase I and II of these regulations, most cities and counties in the state are required to apply for these permits and meet minimum measures for stormwater programs laid out in federal regulations. City and county governments are guided by the Washington State Stormwater Management Manuals for meeting those requirements.

Federal Endangered Species Act – This Act requires the maintenance or restoration of "properly functioning condition" in habitats of specified endangered species. The listing of Pacific salmon and steelhead as threatened species under this Act has had profound effects on urban runoff and stormwater management in order to maintain or restore flows and riparian habitats of streams in and around settled areas.

State Water Pollution Control Act – Under this Act, discharges to state waters shall not cause pollution, defined as an alteration of the physical, chemical or biological properties of State waters that would impair beneficial uses. This requires the use of "all known available and reasonable methods to prevent and control pollution" (given the acronym AKART) and BMPs approved by the State – see "Stormwater Management Manual".

Stormwater Management Manual for Western Washington - In Washington, several guidance manuals have been prepared, used, and updated to address state, regional and local requirements. The State Department of Ecology published the Stormwater Management Manual for Western Washington in August 2001 as an update to a predecessor manual prepared in 1992. The Manual is a guidance document that provides local governments, State and Federal agencies, developers and project proponents with a set of stormwater management practices. If these practices are implemented correctly, they should result in compliance with existing regulatory requirements for stormwater.

The Manual was recently reviewed by the State's Independent Science Panel (ISP) at the Governor's Salmon Recovery Office. The ISP was created by the Legislature in 1998 to provide scientific review and oversight, and help ensure that sound science is used in Washington's salmon, steelhead, and trout recovery efforts. The Panel's conclusions can be viewed at http://www.ecy.wa.gov/programs/wq/stormwater/#review.

A Stormwater Management Manual for Eastern Washington is nearing completion after extensive review of a draft.

Local Government Manuals and Policies - Several county and city governments have established their own manuals for stormwater management, as well as watershed planning programs, to meet state and federal regulations; e.g., King County Surface Water Design Manual, Thurston County Drainage Design and Erosion Control Manual, Seattle's Stormwater, Grading, and Drainage Control Code, etc.

Key Concepts and Use of Source Controls

Source control

In Washington State, the term "source control" refers to measures to control pollution and prevent contamination of stormwater for all discharges or new development at a source. It incorporates structural measures to prevent contact with stormwater through physical separation or careful management of activities that are known sources of pollution. It also includes operational source controls are those which require modified or additional behavioural practices, such as sweeping a parking lot or maintaining special equipment on site, such as spill response equipment.

Flow control, runoff treatment

Infiltration is commonly associated with the terms "flow control" (to reduce surface runoff volumes through such devices as infiltration trenches or basins) and "runoff treatment" (to manage stormwater quality through such devices as sand filters and bioswales). Stormwater management in Washington, however, has traditionally focused on detention and 'end of pipe' solutions over on-site infiltration, likely due in part to the predominance of clay soils and till with low permeability in coastal urban areas.

However, permeable pavements have been studied and applied on trial bases in the State; e.g., work at the Centre for Water and Watershed Studies, University of Washington (Brattleboro and Booth, 2004); and the City of Olympia's Impervious Surface Reduction Study (1995).

Low Impact Development (LID)

With respect to stormwater management in the Pacific Northwest, LID refers to practices and designs that aim to preserve 'natural' characteristics of a healthy watershed, these being:

- Retention or restoration of 65% of natural forest cover.
- No (or minimal) drainage collection system – minimizing impervious area and all stormwater to be infiltrated or evapotranspired.
- Protection broad riparian buffers of undisturbed native vegetation.[1]

Some authors prefer the term "zero" impact development as not compromising the goal of 'zero" runoff.

[1] Droscher and Holz, 2003

Documented Costs and Benefits

Horner, 2003 and Horner, Lim and Burges 2002 (see reference list) provide analyses of costs and benefits of the S.E.A. Streets and Cascade projects.

Case Studies

S.E.A. Streets, Seattle

The Street Edge Alternatives (S.E.A.) project was designed to demonstrate residential street design alternatives that benefit the environment and reduce the impact of surface runoff. Initiated by the City of Seattle's Public Utilities department, the project integrates drainage, roadway and landscape design elements to reduce the impact of urban development on natural hydrological systems. Residents of 30 streets in the Pipers Creek watershed were informed of the project, and based on resident interest and petitioning, one block was selected for the initial pilot. The road was narrowed and made curvilinear; and swales and rain gardens built between the road and properties. The aim was to reduce the runoff rate of surface drainage as well as create an attractive right of way that slowed traffic and encouraged pedestrians. Homeowner support was critical to ensure long-term maintenance of the landscape features.

The project prevented the discharge of all dry season flow and 98% of the wet season runoff, reducing discharge to Pipers Creek in the wet months by 4.7 relative to estimates for a conventional street design.[2] The project cost US$850,000. This included a more extensive design and communication budget as the first project of its kind. Extension of this street form is expected to be competitive with traditional street improvements.

http://www.cityofseattle.net/util/SEAstreets/default.htm

Viewlands Cascade, Seattle

Seattle Public Utilities replaced a narrow, partially culverted ditch along four blocks of NW 110th Street with a series of wide, stair-stepped natural pools designed to slow damaging stormwater flows, reduce flooding, and trap pollutants before they reach Piper's Creek. Stormwater flow from approximately 21 acres (8.5 ha) is to be managed through this infrastructure. Relative to estimates for the ditch, the new channel reduces runoff discharge to the Creek in the wet months by a factor of three.[3]

http://www.cityofseattle.net/util/NaturalSystems/cascade.htm

Permeable parking lot demonstration study

This study, carried out by the Centre for Water and Watershed Studies at the University of Washington, examined the long-term effectiveness of permeable pavement as an alternative to traditional impervious asphalt pavement in a parking area. Four commercially available permeable pavement systems were installed in 1996 in a parking lot at a King County Public Works facility, and evaluated after six years of daily parking usage for structural durability, ability to infiltrate precipitation, and impacts on infiltrate water quality. All four permeable pavement systems showed no major signs of wear. Virtually all rainwater infiltrated through the permeable pavements, with almost no surface runoff. The infiltrated water had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area. Motor oil was detected in 89% of samples from the asphalt runoff but not in any water sample infiltrated through the permeable pavement. Neither lead nor diesel fuel were detected in any sample.

http://depts.washington.edu/cwws/Research/Reports/permeableparking.pdf

[2] Horner, 2003.

[3] *Ibid.*

Reference Documents

Brattebo, B.O. and D.B. Booth. 2004(anticipated). Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. Centre for Water and Watershed Studies Department of Civil and Environmental Engineering, University of Washington. 15 p. http://depts.washington.edu/cwws/Research/Reports/permeableparking.pdf

Olympia, City of. 1995. Impervious Surface Reduction Study. Olympia Community Planning and Development Department, Olympia, Washington. 81 p. http://depts.washington.edu/cwws/Research/Reports/ipds.pdf

Droscher, T. and T.W. Holz. 2003. In the Absence of Standards Low Impact Development Might Equate to High Impact Development. Paper, 13 p.

Horner, R.R. 2003. Stormwater Runoff Flow Control Benefits of Urban Drainage System Reconstruction According to Natural Principles. Paper. 10 p.

Horner, R.R., H.Lim and S.J. Burges. 2002. Hydrologic monitoring of the Seattle Ultra-Urban Stormwater Management Projects. University of Washington Water Resources Series Technical Report no. 170. 31 p.

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Oregon

Stormwater Management - status

Key Drivers

- **Meeting requirements of federal law** for water quality and protection of salmon habitat,, which in effect require local governments to implement a stormwater management program. These include the *1977 Clean Water Act Amendment*, and the *Endangered Species Act* and National Marine Fisheries Service policies on salmon habitat.
- **Flood and flow control** - intended to protect downstream properties, infrastructure, and resources from the increases in stormwater runoff peak rates and volumes resulting from development.
- **Eroding stream channels** caused by increased impervious surfaces associated with development.
- **Pollution levels and temperature of stormwater runoff** that is transported from impervious areas to streams and rivers. Pollutants of concern including suspended solids, heavy metals, nutrients, bacteria and viruses, organics including hydrocarbons, floatable debris, and increased temperature. Many streams have total maximum daily loads (TMDLs) of pollutants established by senior government law.
- **Protection of local streams and rivers for a great number of uses**, including fish and wildlife habitat, recreation and drinking water.
- **Combined sewers** in some parts of older cities, with the need to avoid minimize stormwater flows into these systems.
- **Groundwater recharge.**

Standards and Policy

Federal Clean Water Act - Attention to pollution caused by stormwater began rising in the 1980's, with a key federal law being enacted with an amendment in 1987 to the *Clean Water Act.* The amended act required cities to apply for the same type of NPDES (National Pollutant Discharge Elimination System) permits for their municipal 'separate' storm sewers as they would for regular outfalls from sanitary or combined sewage systems. Implementation of these regulations have been staged, with most cities being required to comply by 1996.[4].

Federal Endangered Species Act - Recent listing of the Pacific salmon and steelhead species as threatened under the *Endangered Species Act* (ESA) will have an unprecedented impact on urban areas. Under the Act, the National Marine Fisheries Service (NMFS) has designated critical habitat for salmon and steelhead that includes all freshwater and estuarine areas, and their adjacent riparian areas. In effect the NMFS has become a key approval authority over many aspects of urban development administered by local and state efforts. [5]

Local Government Requirements[6] - The City of Portland has a citywide pollution reduction requirement for all new or redevelopment projects with over 500 ft^2 (46 m^2) of impervious development footprint area. The City also requires flow control on most development that drains to tributary streams. Detention standards are to limit 2-year post-development peak runoff rate to one-half of the 2-year pre-development

[4] Metro, Green Streets: Innovative Solutions for Stormwater and Stream Crossings, 2002

[5] Metro, Green Streets: Innovative Solutions for Stormwater and Stream Crossings, 2002

[6] City of Portland, Stormwater Management Manual, 2002

peak rate, 5-year post to 5-year pre, 10-year post to 10-year pre, and 25-year post to 25-year pre peak runoff rate. Surface retention facilities must be used to the maximum extent practicable in Portland. Exceptions include cases of soil or slope constraints, contaminated soils, or special space constraints. The City also requires that stormwater draining from private property be managed on on site in privately maintained facilities, unless special circumstances apply.

Key Concepts and Use of Source Controls

Both the City of Portland and the Metro Regional Government have extensive documentation in support of stormwater source controls. Portland's Stormwater Management Manual[7] includes design and maintenance guidelines for the following practices.

Simplified Approach for Stormwater Management

An approach has been adopted in the City of Portland that allows users to design areas with less than 1395 m^2 of impervious development by selecting from a menu of BMPs and sizing them for their project using a simple form – see attached. Generalized assumptions were used that may result in conservative sizing for some development sites, and users have the option to follow a performance approach by submitting detailed engineering calculations. Larger projects must follow a performance approach, using detailed engineering calculations.

Figure A-1: Simplified Approach for Stormwater Management

Form SIM: Simplified Approach for Stormwater Management

The city has produced this form to assist with a quick and simple approach to manage stormwater quality, flow rate, and volume on projects. Facilities sized with this form are presumed to comply with stormwater quality and flow control requirements.

New or Redeveloped Impervious Site Area 2500 **Box 1**

INSTRUCTIONS

1. Enter square footage of new or redeveloped impervious site area in Box 1 at the top of this form.
2. Select impervious area reduction techniques from rows 1-3 to reduce the site's resulting stormwater management requirement. Tree credit can be calculated using the tree credit worksheet on the next page.
3. Select desired stormwater management facilities from rows 4-12. In Column 1, enter the square footage of impervious area that each facility will manage.
4. Multiply each impervious area from Column 1 by the corresponding sizing factor in Column 2, and enter the result in Column 3. This is the facility surface area needed to manage runoff from the impervious area.
5. Total Column 1 (Rows 1-12) and enter the resulting "Impervious Area Managed" in Box 2.
6. Subtract Box 2 from Box 1 and enter the result in Box 3. If this number is less than 500 square feet, stormwater quality and quantity requirements have been met. Submit this form with the application for permit.
7. If Box 3 is greater than 500 square feet, add square footage or facilities to Column 1 and recalculate, or use additional facilities from Chapter 3.0 of the Stormwater Management Manual to manage stormwater from these remaining surfaces.

	Column 1	Column 2	Column 3	
Impervious Area Reduction Technique	**Impervious Area Managed = Facility Surface Area**			
1) Eco-Roof	sf			
2) Contained Planter Box	sf			
3) Tree Credit (See Next Page)	400 sf			

Note: Porous Pavement areas do not need to be included in Box 1

Stormwater Management Facility	**Impervious Area Managed**		**Sizing Factor**		**Facility Surface Area**	**Unit**
4) Infiltration Planter Box	sf	x	0.06	=		sf
5) Flow-Through Planter Box	sf	x	0.06	=		sf
6) Vegetated Swale	2000 sf	x	0.09	=	180	sf
7) Grassy Swale	sf	x	0.1	=		sf
8) Vegetated Filter Strip	sf	x	0.2	=		sf
9) Vegetated Infil. Basin	sf	x	0.09	=		sf
10) Sand Filter	sf	x	0.06	=		sf
11) East Side Soakage Trench	sf	x	0.06	=		sf
12) West Side Soakage Trench	sf	x	0.08	=		sf

Total Impervious Area Managed 2400 **Box 2**

Box 1 - Box 2 100 **Box 3**

Stormwater Management Manual Page E-2

Eco-Roof / Roof Garden

The City of Portland uses the term Eco-Roof to describe extensive green roof, and Roof Garden for intensive green roof.

The City has been a leader in promoting the use of eco-roof with growing medium depths between 50mm and 150mm, and has been actively

[7] City of Portland, Stormwater Management Manual, 2002

involved in several pilot projects. An eco-roof density bonus option is provided in the Central City:

- Where the total area of eco-roof is at least 10 percent but less than 30 percent of the building's footprint, each square foot of eco-roof earns one square foot of additional floor area.
- Where the total area of eco-roof is at least 30 percent but less than 60 percent of the building's footprint, each square foot of eco-roof earns two square feet of additional floor area.
- Where the total area of eco-roof is at least 60 percent of the building's footprint, each square foot of eco-roof earns three square feet of additional floor area.

The City defines Roof Gardens as landscape areas over slab with growing medium depths of 200mm or more. Both Eco-roof and Roof Gardens are treated as pervious area in the City's stormwater management calculations.

Porous Pavement

The City also allows areas of porous pavement to be treated as pervious area in stormwater management calculations. Alternative surface treatments over reservoir base course recognized include porous asphalt, porous concrete, and composite surfacing with permeable joints, including brick, cobble, crushed aggregate, natural stone, turf block and unit pavers.

Contained Planter Box

Planting boxes with a minimum soil depth of 300 mm and surface planting of trees, shrubs or groundcover are credited as being pervious, even though they are placed over and drain to impervious surfaces.

Tree Credits

In Portland, Tree Credits are provided in stormwater calculations in recognition of the flow control and pollution reduction benefits of urban trees. Credits are applied as follows:

- New evergreen tree over 1.8 m height within 9 m of impervious surface provides a credit against 19 m^2 of impervious area.
- New deciduous tree over 50 mm calliper within 9 m of impervious surface provides a credit against 9.5 m^2 of impervious area.
- Existing preserved canopy of trees over100 mm calliper outside environmental zones provides a credit against impervious surface of 50% of the qualifying leave area .

Tree credits cannot exceed 25% of impervious area for sites with greater than 465 m^2 impervious area.

Infiltration Planter Box

Infiltration planter boxes are designed to allow runoff to filter through the planter soils and then infiltrate into native soils. The planter is sized to accept runoff or roof drainage and temporarily store the water in a reservoir on top of the soil. The planter is designed with a minimum depth of 450 mm of growing medium, over an infiltration trench of drain rock. Overflow is provided. Special approval and attention to wall waterproofing and foundation drainage is provided if the planter is closer than 3 m to an adjacent building.

Flow-Through Planter Box

The flow through planter box is similar to the infiltration planter box, except that its base is sealed, and subdrainage is provided by a perforated pipe in a layer of drain rock. With proper waterproofing, this BMP is suitable for use adjacent to or on a building.

Vegetated Swale

Vegetated swales are long narrow concave facilities planted with trees, shrubs, grasses and ground cover. A common application is landscape areas within parking lots. Growing medium depth is 450 mm minimum, 3:1 max. side slopes, longitudinal grade 6% maximum with 75 – 125 mm high check dams at 3.65 m intervals. Vegetated swales of between 1.5 and 3.65 m width are allowed in all soil types, and do not require a bypass for larger storms provided that they drain a maximum of 1395 m^2 impervious area and an overflow is provided.

Grassy Swale

Similar to a vegetated swale, the grassy swale is surfaced with a dense grass mix. Growing medium depth is 300 mm minimum, side slopes 4:1 max, longitudinal slope between 1% and 5%.

Vegetated Filter Strip

Vegetated filter strips are gently sloping areas used to filter, slow and infiltrate stormwater. Stormwater enters the filter as sheet flow from an impervious surface, or is converted to sheet flow using a flow spreader. Portland restricts use of filter strips to impervious areas smaller than 93 m^2. Minimum width is 3 m, slope less than 5% or less than 10% is check dams are provided at 1.5 m intervals. Minimum depth of growing medium is 450 mm. Designers are encouraged to plant a variety of trees, shrubs, ground covers and grasses, and to integrate these areas into the landscape design.

Vegetated Infiltration Basin

Vegetated infiltration basins (or bioretention or rain gardens) work by holding runoff in the basin and allowing pollutants to settle out as water infiltrates into the soils below. Infiltration basins are appropriate for soils with a minimum infiltration rate of 50 mm/hour. Storage depth may vary from 300 to 450 mm, side slopes 3:1 max. Growing medium depth 450 mm. A safety overflow is required. Design and planting may be formal or informal in character, and plantings should be suitable for periodic inundation. Setbacks are 3 m from building foundations, 1.5 m from property line. Infiltration areas are to be clearly marked and protected from construction traffic.

Sand Filter

Sand filters may be one of two types – those with an impervious bottom, or those with over pervious soils that allow filtered water to soak into the ground. Sand shall have a minimum infiltration rate of 127 mm/hr., and the facility should drain within 3 hours after a storm event.

Soakage Trench

A soakage or 'infiltration' trench is a shallow trench in permeable soil that is backfilled with sand and coarse stone and lined with filter fabric. The trench surface may be covered with grating, stone, sand or a grassed cover with a surface inlet.

Soakage trenches are not accepted in soils with a tested infiltration rate of less than 50 mm per hour, or areas with less than 1.2 m from bottom of trench to impervious layer. Drawdown time shall not exceed 10 hours. Setbacks to slopes apply. Pretreatment by catch basin is recommended. Observation wells are required. An overflow path is also mandatory. For two areas in Portland, the City provides a standard design and required length of soakage trench per 93 m^2 of impervious surface.

Stormwater Disposal through Dry-Wells and Sumps

In areas of suitable soils, Portland allows use of private drywells to dispose of stormwater through infiltration. Public infiltration sump systems using perforated concrete manhole-like structures extending

9 m into suitable soils are used to drain public rights of way. Thorough infiltration testing and engineering design is required for public facilities, sized for the 10 year design storm, with a safety factor of 2. Water quality treatment is required prior to injecting stormwater into the drywells or sumps. Public systems require use of a sedimentation manhole upstream of sump systems.

The Oregon Department of Environmental Quality has identified drywells, sumps and soakage trenches as "Class V Injection Wells' under the federal Underground Injection Control Program. These facilities must be classified as "exempt" – roof runoff only, or authorized by rule or permit. Site controls and treatment are required before disposing stormwater into them.

Case Studies

Buckman Terrace Apartments, Portland

Buckman Terrace Apartments, at 303 NE 16th Ave. in Portland, is an excellent example of a market apartment complex that has implemented a wide range of stormwater source controls. The site, on two sides of a street, has used the following BMPs:

- Vegetated infiltration basins (formal layout)
- Roof drainage to flow through planter boxes with overflow
- Infiltration trench
- Extensive green roof, both grass and sedum types
- Small areas of pervious unit paving
- Tree credit in the adjacent street
- The site is not connected to a storm sewer system

Other projects

Hamilton Apartments, 1212 SW Clay St., Portland: extensive green roof retrofit on an existing building.

Hawthorne Ridge Subdivision, SE 162nd S. of Foster, Portland: vegetated swales.

Oregon Museum of Science and Industry, 1945 SE Water Ave., Portland: vegetated swales in parking areas.

BES Water Pollution Control Laboratory, 6543 N. Burlington, Portland: vegetated swales, infiltration basin, and stormwater pond.

Reed College, SE 28th Ave., Portland: grassy swales.

Cascade Station, NE Airport Way & I-205, Portland: sand filters in formal park setting.

Reference Documents

Portland, City of. 2002. Stormwater Management Manual Revision #2. http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm

(Portland) Metro. 2002. Green Streets: Innovative Solutions for Stormwater and Stream Crossings. http://www.metro-region.org/ (also: Trees for Green Streets and Creating Liveable Streets)

Australia

Stormwater Management Status

Australia is among the driest continents, and managing scarce water resources is perceived as fundamental to supporting its population and protecting the country's unique ecosystems.

Key Drivers

- **Minimizing flooding.**
- **Pollution control.**
- **Retention-based** versus detention-based stormwater management (see "Key Concepts" below).
- **Harvesting stormwater** (see "Key Concepts" below).
- **Protecting downstream water bodies**, and protecting habitat and aesthetic values.
- **Provide recreational opportunities** - e.g., "multiple use drainage corridors".

Standards and Policy

- ***National Strategy for Ecological Sustainable Development*** - aims to develop water management policies based on an integrated approach to water resources, including total catchment management, public participation and water allocations.[8]
- ***Water Sensitive Urban Design (WSUD)*** – when applied to stormwater management, modifies the traditional "hard" engineering approach to stormwater management by focusing on runoff sources (source controls) and particularly tools to contain and reuse water within urban residential, commercial and industrial areas. Equivalent to SUDS (Sustainable Urban Drainage Systems) used in Europe, and LID (low impact development) used in the U.S. and Canada. See further discussion under "Key Concepts" (below).
- ***Living Cities Urban Stormwater Initiative*** – an intergovernmental (federal, state, territorial, local) program that focuses countrywide on urban stormwater management.
- ***National Water Quality Management Strategy*** - adopted by the Council of Australian Governments representing the Commonwealth, State, Territory and local governments, it focuses on regionally-based "integrated catchment management" (ICM).
- ***Council of Australian Governments strategic framework for water reforms*** - promotes innovation in stormwater storage and reuse as a supplement to existing water services, and the potential to eliminate the need for future new water supply dams.[9]

Key Concepts and Use of Source Controls

Source vs. interception approaches

Source control approaches are defined to include planning and other activities that are consistent with WSUD, including: minimizing soil loss during development; locating sewer surcharge points to reduce discharges and minimize impacts; minimizing impervious surface area; street sweeping, litter trapping and pit cleaning, using storage and reuse facilities such as rainwater tanks; and public education.

[8] Environment Australia, p.17

[9] Environment Australia, p.29

Many of the measures defined in this study as part of source controls may be referred to as "interception" approaches: vegetated floodways, filters in sumps and storm inlets, filtration devices (sand filters), bioretention and infiltration systems such as swales, as well as detention ponds and wetlands.[10]

Stormwater "Treatment Trains"

This term refers to the use of BMPs in sequence to: a) control pollutants at source, b) minimize stormwater pollution by in-transit measures, and c) as a last resort, manage effects in receiving waters.

Water Sensitive Urban Design (WSUD)

"WSUD makes the entire stormwater treatment network part of the urban fabric via multiple use corridors and BMP treatment trains… It maximizes infiltration and on-site storage, treatment and reuse and utilises natural runoff channels where appropriate."[11] Retention-based technology is promoted as the basis for WSUD when it comes to stormwater management.[12]

Stormwater Retention (or retention-based stormwater management)

On-site stormwater retention (OSR) is the logical next step in the progress of detention/ retention technology.[13] The primary goal of detention has been peak flow reduction, with surface runoff ultimately carried off site. OSR, on the other hand, focuses on managing overall stormwater volume to mimic natural flows, by draining water to soil (rather than piped drainage systems) or in some cases, to underground aquifers for later re-use.

Three primary goals of retention-based stormwater management are:[14]

- Reduce storm runoff in terms of both peak flow and volume;
- Minimize pollution conveyance to downstream receiving waters; and
- Harvest and use stormwater to replace mains water, mostly for non-drinking uses.

Retention measures include enlarged roof gutters (“Rainsavers”), rainwater tanks, in-ground filtration devices and dry ponds.

The use of retention techniques in different soil types is a focus of considerable attention, especially in the expansive clay soils that predominate in many Australian cities. Retention system design has focused on determining “emptying” or drain time – the time taken for a filled, inground retention device to empty. Overflow drainage is achieved by a bore to an aquifer, or by slow drainage to a street drainage path or waterway.

Stormwater Harvesting

Coupled with retention, there is also strong emphasis on stormwater capture, treatment and re-use (“stormwater harvesting”) for a variety of purposes – from garden watering and irrigation, to toilet flushing and laundry, to industrial and commercial applications. "Stormwater can become a major alternative to damming more rivers to ensure water supply."[15]

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[10] Environment Australia, p. 24

[11] Environment Australia, p.53

[12] Argue, 2002b

[13] [13]

[14] Argue, 2002b

[15] Environment Australia. 2002. *Introduction to Urban Stormwater Management in Australia.* Commonwealth of Australia. p.16

Stormwater harvesting can take the form of:

- Roof runoff collected in rainwater tanks, for domestic use (e.g., hot water supplies, toilet flushing).
- "Leaky" devices, such as shallow wells and gravel-filled trenches, that maintain soil moisture and promote vegetation growth.
- Recharge, and even water quality improvement, of aquifers with cleansed water for retrieval in irrigation and commercial uses, or as "environmental flows" (percolation to local streams).

Urban stormwater and treated wastewater are increasingly recognized as important economic resources, but are not yet widely used to augment supplies in expanding urban areas. Recent research and demonstration projects (see case studies) have shown that these resources can be exploited in a cost effective and environmentally sensitive manner in new development, and that water reclamation can reduce potable water demand by as much as 50%. Only 3% of stormwater is reused in Australia's urban areas, compared to 11% of municipal wastewater. [16]

Aquifer Storage and Recovery (ASR)

ASR involves the harvesting of surplus stormwater and temporarily storing it in a suitable aquifer and retrieving it for potable, irrigation or industrial applications. "ASR provides a viable alternative to reservoirs in areas where land values and evaporation rates are high [or] catchment areas are intensively developed… Artificial recharge of aquifers using infiltration basins has been practised for many years where soils are permeable and aquifers are unconfined"[17]

Research and development has focused on the injection, storage and recovery of stormwater and treated domestic water into shallow, unconfined and deep confined aquifer systems using injection wells and infiltration trench methods. Usually the input water is pre-treated in a wetland.

Confined aquifers are generally a stable and predictable environment for storage. Monitoring is an integral part of recharge operation. It is normal for each site to have several observation wells and for injected waters and ground waters to be sampled regularly. The longest operating site for stormwater recharge into an aquifer is at Mount Gambier, South Australia, which has been recharging the groundwater via drainage wells for over 100 years.[18]

Documented Costs and Benefits

- "In field testing, the use of rainwater tanks for household garden watering and toilet flushing reduced the stormwater export from a Canberra catchment by 20%.[19]
- "In Sydney, the storage gutter system [Rainsaver - Australia patent] saves 27% of the potable water supply to an average household, and when used in a new building construction is cost neutral."[20]
- "Research by the University of Newcastle has shown that rainwater tanks when used with toilets, garden irrigation and hot water use, reduce the reliance upon mains supply by up to 65%."[21]

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[16] Australia Environment, p.33

[17] Australia Environment, p.85

[18] Australia Environment, p.85-86

[19] Australia Environment, p.83 quoting McAlister, Tony. 1999. Stormwater reuse: a balanced assessment. In *Stormwater 2000: the green with the gold - Conference Proceedings 26-28 April 1999,* ed. J.A. Wood. Stormwater Industry Association.

[20] Australia Environment, p.83

[21] Australia Environment, p.84 referring to Figtree Place project, see case studies.

- Figtree Place (see Case Studies): Rainwater collected on site reduces mains water consumption by the residential portion by 54%, and total mains water consumption by all site uses by 77%. Stormwater runoff has been almost completely eliminated and the quality of water from the aquifer is suitable for open space irrigation.[22]

Case Studies

Figtree Place, City of Newcastle, NSW

This project, opened in 1998, was designed by the University of South Australia and commissioned by the Office of Community Housing with funding by the national "Building Better Cities" program. Roof runoff from 27 inner city residences is stored in sub-surface raintanks and used for hot water and toilet flushing. Raintank overflows and surface flows pass into a grassed infiltration zone for aquifer recharge. Some of the recharged water is extracted and used for on-site irrigation and for an adjacent bus-washing facility. Performance monitoring is conducted in partnership by the University of Newcastle and Newcastle City Council.

http://www.unisa.edu.au/uwrc/ham.htm

http://www.eng.newcastle.edu.au/~cegak/Coombes/FIGTREE%20LAST21.htm

Parfitt Square

Residential, public reserve and road runoff from a 1.6 ha catchment are retained within a small reserve and underground aquifer system. The aquifer water will be used for irrigation of the on-site “reserve” (park) during summer. A variety of runoff treatment methods are used, including sediment traps, a gravel-based subsurface-flow wetland, infiltration swale, filter trench and geotextile-screened bore inlet.
http://www.unisa.edu.au/water/Prototypes/Parfitt_Square.html

Parafield Airport

This pilot project applies stormwater capture, treatment in bird-proofed reed bed ponds, and re-use directly or injection into underground aquifers for storage. Water is used in a wool processing operation and other users in the Salisbury area. The project’s objectives included reducing nutrient pollution of Barker Inlet and reducing water extraction from the River Murray by 1 billion litres/year.
http://www.itenviro.com.au/Projects/AirportEnvOfficer.htm

Inkerman Oasis, Port Phillip Bay - St. Kilda, Melbourne, Victoria.

Integrated Eco-Villages designed a system to recycle stormwater and greywater using an aeration tank and wetlands in a 236-unit housing development. Reuse of first flush stormwater will reduce potable water use in the development by up to 45% and prevent nearly 7 tonnes of nitrogen and phosphates entering Port Phillip Bay each year.

http://www.melbournewater.com.au/content/library/wsud/case_studies/inkerman_oasis.pdf

New Brompton Estate Redevelopment, City of Charles Sturt

Roof runoff from 15 residences pass to ‘pipe upstands’ to trap sediment, then passes into an underground gravel-filled trench. Clean runoff is collected and conveyed via a bore to an aquifer 30 m below ground.

[22] City of Newcastle, Stormwater Trust and University of Newcastle. Figtree Place: a case study in Water Sensitive Urban Development. brochure - date unknown.

Overflow in large storms passes to a street drainage system. Water is pumped in summer to irrigate a central reserve (park).

http://www.unisa.edu.au/uwrc/brompton.htm

Elizabeth Church Carpark, City of Marion

Winter storm runoff from 1300 sq.m. of carpark, 1600 sq.m. of tennis courts and some roof area is cleansed by various on-site means, and conveyed to a bore an then to an aquifer at 45 m depth. In summer, water is pumped from the bore to irrigation networks located around the carpark and a local reserve (park). http://www.unisa.edu.au/uwrc/church.htm

Andrews Farm, Northern Adelaide Plains, South Australia

A pilot study that injects passively treated stormwater in a brackish aquifer to improve water quality to irrigation standards. Stormwater is captured in 3 detention basins then pumped to an aquifer injection well. Clogging has occurred but has been overcome by periodic redevelopment of the injection well. Capital costs: AUD$80,000; operating costs AUD$0.15 per kL (mains water costs AUD$0.90/kL); monitoring costs AUD$2000 per year.

http://www.eidn.com.au/aquifer.html

http://www.clw.csiro.au/publications/technical2002/tr17-02.pdf

Reference Documents

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Argue, J.R. 2002b. WSUD and stormwater management in urban catchments: basic concepts and examples. 23 p.

Australia Dept. of the Environment and Heritage. 2002. *Introduction to Urban Stormwater Management in Australia.* Commonwealth of Australia. 103 p.

Melbourne Water (State of Victoria). Water Sensitive Urban Design – website: http://wsud.melbournewater.com.au/

Urban Water Resources Centre, University of South Australia. Stormwater management problems and the source control philosophy - website. http://www.unisa.edu.au/uwrc/project.htm

Europe

European Collaborations

Before summarizing the activities of individual European countries, several collaborative programs are worth noting.

DayWater

DayWater is a new European Union project involving partners from 8 different countries as well as various scientific experts and end-users. The aim of the DayWater project is to build a prototype for a decision support system devoted to urban stormwater pollution source control. Innovative aspects include decision making processes, urban policies evolution, BMP assessment and source modelling.

DayWater Co-ordination:
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Working Group on Source Control for Stormwater Management (SOCOMA)

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The objective of the Working Group is to facilitate the development of source control techniques through research, experimentation and information. The group organized a session on "urban water and society" for the Novatech Conference in 2004 (see next section), and is .facilitating the collection, reporting and analysis of water quantity and quality measurements from BMP projects. A Junior Workshop will be organised in Germany in order to develop exchanges between young researchers.

The Group is also preparing a list of source control manuals; the contact is Sylvie Barraud (barraud@urgc-hu.insa-lyon.fr).

Novatech Conferences

These conferences are triennial international meetings on innovative technologies in urban drainage intended for researchers, service providers and technicians. During these conferences, an international community of specialists in urban drainage meets to review state-of-the-art knowledge and exchange practical experiences concerning technical solutions and innovative strategies. Novatech conferences combine presentations dealing with case studies with presentations on scientific approaches contributing to the improvement of the technology. It is also a unique opportunity for practitioners and researchers to meet and share their experiences without any language barrier, thanks to simultaneous English-French translations.

Proceedings from the 2001 Conference are available at http://www.iwapublishing.com//template.cfm?name=isbn1843394138

NOVATECH'2004, the 5th international conference on sustainable techniques and strategies in urban water management, is scheduled for June 6 - 10, 2004 in Lyon, France - http://www.graie.org/novatech/a_index.htm.

United Kingdom

Stormwater management - status

Key drivers

- **Sustainability agendas -** Following from the 1992 UN Earth Summit at Rio de Janerio, the UK updated a national strategy for sustainable development in 1999, and the Local Government Management Board published *Local Agenda 21 A framework for local sustainability*. Local authorities are implementing their own Agenda 21 strategies.
- **Sustainable Urban Drainage Systems (SUDS)** are surface water drainage systems in the UK that take account of quantity, quality and amenity issues. SUDS are more sustainable than conventional systems, because they:
    - manage runoff flow rates, reducing the impacts of urbanization on flooding;
    - protect or enhance water quality;
    - are sympathetic to the environmental setting and the needs of the local community;
    - provide a habitat for wildlife in urban watercourses;
    - encourage natural groundwater recharge (where appropriate).[23]
- **Amenity Considerations of Drainage Systems –** issues affected by the way surface water is managed include the landscape, land use, wildlife habitats, land values, recreation opportunities and water resources. Opportunity costs, perceptions of risk and construction impact should also be considered. All these environmental and community issues have been gathered together under the heading amenity.[24]

Standards and Policy

Sustainable urban drainage techniques were not widely practiced in the UK when legislation was passed and so are not dealt with explicitly.

Key approval authorities include the local authority planner, the national Environment Agency, as well as in some cases a sewerage undertaker, building control representative and highways authority representative. Landowners have duties to manage runoff within their own site, local authorities are responsible for the prevention and control of local flooding, whilst the Environment Agency has a general supervisory role in relation to flood defence and land drainage and for the quality of controlled waters.

Uncontaminated surface water discharges do not require a consent from the Environment Agency. This is also true for runoff from residential areas and car parks drained with SUDS. Approvals are required for water quality that may threaten groundwater and flow quantity for some land uses and some watercourses.[25]

The National Rivers Authority has formulated a policy for groundwater protection, and location of infiltration devices is affected by this policy. There is evolving policy and practice in the UK concerning ongoing ownership and maintenance of infiltration systems.[26]

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[23] CIRIA, Sustainable Urban Drainage Systems, Design Manual for England and Wales, 2000

[24] CIRIA, Sustainable Urban Drainage Systems, Design Manual for England and Wales, 2000

[25] CIRIA, Sustainable Urban Drainage Systems, Design Manual for England and Wales, 2000

[26] Bettess, CIRIA, Infiltration Drainage – Manual of Good Practice,1996

Key Concepts and Use of Source Controls

The *SUDS Design Manual for England and Wales*[27] encourages the following stormwater course control practices.

Prevention

Techniques include minimizing paved areas, rainwater recycling, minimizing directly connected areas, pavement cleanliness and other pollution source controls, education, road sweeping, repairing sewer cross connections, and pollutant containment to protect against industrial incidents.

Surface Water Management Train

Source controls are recognized as one part of a surface water management train, which also includes site and regional control, and related conveyance and discharge systems.[28]

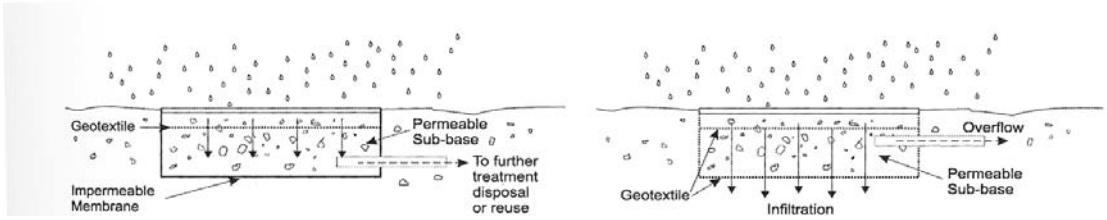
Pervious Surfaces

In addition to the SUDS Manual, CIRIA and the Environment Agency have published a comprehensive manual 'Source Control Using Constructed Pervious Surfaces'[29]. UK definitions distinguish between two types of pervious surfaces:

- **Porous surfacing** infiltrates water across the entire surface of the material forming the surface, for example grass and gravel surfaces, porous concrete and porous asphalt;
- **Permeable surfacing** is formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration through the pattern of voids, for example concrete block paving.

A full range of pervious surfaces is supported, including open textured soil or granular material, geosynthetic gravel/grass protection systems, small porous elemental surfacing blocks, continuous laid porous material, large elemental surfacing blocks, small elemental surfacing blocks, and continuous laid permeable material. Two types of pavement substructure are also recognized:

Figure A-2: Outflow Options



The Manual provides comprehensive information on:

- hydraulic design of pervious surfaces, including impacts of maintenance practices;

[27] CIRIA, Sustainable Urban Drainage Systems, Design Manual for England and Wales, 2000

[28] Pratt, Wilson, Cooper, CIRIA, Source Control Using Constructed Pervious Surfaces, 2002

[29] Pratt, Wilson, Cooper, CIRIA, Source Control Using Constructed Pervious Surfaces, 2002

- structural design of pavements and base courses, including reservoir base courses and notes on winter behaviour, concluding that frost heave of the pavement surface is not an issue due to the large percentage of voids in the subbase;
- and water quality performance issues. In a related reference, Pratt (1999) has reported on testing of hydrocarbons associated with a construction of permeable unit pavers over geotextile over open graded reservoir base course. The geotextile in the upper layers of construction was found to retain 60-90 per cent of the oil entering the construction, with some 99 per cent of the oil being trapped in the construction as a whole over a four year period. In a laboratory experiment, the degradation of the stored oil was monitored and found to take one-two years. It was estimated that it would take more than 100 years to saturate this type of pervious construction with oil, even at an inflow concentration of 1800 mg/L. Oil saturation of the pavement, therefore, was not seen as a problem. A key element of water quality performance in pervious pavements is the location of a geotextile close to the surface of the structure. This also protects the sub-base below the geotextile from potential plugging, so that any infiltration blocking is restrict to only surface layers, which can be more easily lifted and reinstated, especially in unit paving systems.

Filter Strips

Filter strips are areas of vegetated land through which runoff is directed, and may be in any vegetated form, from grass verge to shrub area. Pollutant trapping efficiency is also affected by the characteristics of the vegetation – its height, stiffness and density. Generally the strip should be designed so regular flow rates are below 0.3 m/s to encourage settlement, whilst larger storms should be below 1.5 m/s to prevent erosion. For best performance, cross slopes should not exceed 1 in 20, and widths should be between 6 m and 15 m.

Swales

Swales are linear grassed drainage features in which surface water can be stored, conveyed or infiltrated. Locating swales at the end of piped systems is not recommended, due to the high local flowrates and risk of erosion. Longitudinal bottom slope should be as level as possible, and ideally no greater than 1 in 50 (2%). Check dams can be added to reduce slopes to this level. If the swale is being used primarily for extended detention or infiltration, it should drain the relevant design volume completely within two days. This prevents waterlogging and keeps the grass cover in good condition. Swales with a slope in excess of 1 in 17 (6%) will not be effective for infiltration. In general, depth of flow should not exceed 0.1 m, and vegetation height in the swale should exceed depth of flow. Width of swale should generally not exceed 3.0 m to discourage formation of gullies.

Soakaways and Infiltration Trenches

Soakaways is a UK term for techniques in America commonly called drywells, sumps, or infiltration trenches. Two types of soakaway in UK are common:

- a rubble or stone filled pit.
- a precast concrete ring unit or brick chamber.

Soakaways and infiltration trenches should be restricted where they may adversely affect groundwater, in ground where the water table reaches the bottom of the device at any time of the year, or within 5m of buildings or under a road.

Infiltration devices should be kept as shallow as possible to maximize the length of the flowpath to the water table. For stone filled soakaways, design guidelines suggest a pretreatment catch basin with sump, and then connecting the inlet pipe to the soakaway to a vertical inspection tube (e.g. a 225 mm perforated pipe) with a surface cover. Debris may be removed periodically from the base of the inspection tube.

Filter Drains

A filter drain is similar to a french drain – a perforated or porous pipe in a trench surrounded with filter material. Filter drains have been used extensively for road and car park developments, where they have been constructed in the verge and median strip. The traditional purpose of the filter drain is to intercept surface water on the verge or median strip, preventing water from entering the pavement construction formation. Filter drains have also been reported to be effective in removal of suspended solids (85%), total lead (83%), total zinc (81%) and oil (estimated at around 70%) on an annual basis. Filter drains remove the need for catch basins. Filter drains and infiltration trenches share many characteristics. One difference is that infiltration trenches discharge laterally into the surrounding soil whilst the flow in filter drains is along the length of the device to an outfall. Filter drains can be used in the base of swales, providing extra storage and attenuation.

Infiltration Basins

Infiltration basins store surface water runoff and allow it to gradually infiltrate through the soil of the basin floor. An emergency overflow can be provided. Infiltration basins may take any shape. Guidelines for infiltration basins are similar to those for grassed swales.

Documented Costs and Benefits

Infiltration Drainage: Manual of Good Practice[30] includes a section on appraisal of costs. It is clear that infiltration practices can sometimes offer significant economies over positive (conventional) drainage systems. Often this is related to requirements for upsizing of downstream drainage facilities. Appraisal of costs needs to consider the 'whole life' costs of the system. These include the future operating, maintenance and replacement costs over a specified design life.

Measurement of environmental benefits is often difficult to express in cash terms. A related issue is the question of who pays and who benefits – the site owner/developer vs. the sewerage authority vs. the community at large.

Table A-1: Example: Comparative present values of drainage system options

Scheme	Present Values – 5% Discount Rate, Period of analysis 60 years			
	Capital	Replacement	Maintenance	Total PV
Positive system with drop shaft	£228 447		£ 1 900	£230 339
Positive system without drop shaft	£124 770		£ 1 900	£126 662
Positive system on-site cost only	£ 55 058		£ 1 900	£ 56 950
Soakaway scheme	£ 51 869	£ 5 020	£18 929	£ 75 818

CIRIA Report 156

The attached table 4.3 provides a comparison of capital costs of a positive vs. infiltration drainage system at a housing scheme in East Anglia. Although this project has unusual off-site drainage costs including a major drop shaft, it can be seen that the soakaway system is still less in terms of comparing on-site capital costs only. Once replacement and maintenance costs are calculated to present value, including an assumption that the soakaways may have a 30 year life as opposed to a 60 year design life for positive

[30] Bettess, CIRIA, Infiltration Drainage – Manual of Good Practice,1996

drainage components, it can be seen that the soakaway scheme still has the best overall performance when off-site costs are considered.

However, the issue raised is who pays for replacement and maintenance? In this case, the adopting authority was reluctant to accept a soakaway system for fear of the future replacement and maintenance costs. There was not a financial vehicle to allow the developer to fund this future cost.

The fundamental questions, therefore, are whether the environmental and community benefits of an infiltration scheme, combined with the reduced cost to the developer, should override the financial concern of the approving agency, and whether and how the long term maintenance or replacement costs are funded by the community.

Case Studies[31]

Sports Centre, Bognor Regis, Sussex: car park with pervious surfaces over weak subgrades

National Air Traffic Services, Edinburgh: car park with a permeable concrete block surface over impermeable clay. Hydraulic and water quality performance was monitored.

Royal Bank of Scotland, Edinburgh: car park extension of permeable concrete block surface adjacent to coventional impermeable paving. The system is tanked with an impermeable geomembrane, and the reservoir base course is drained by perforated pipes. Water quality performance results, including hydrocarbons, showed all parameters low when compared to runoff found from conventional roads, and are below levels required for drinking water.

Tesco, Wokinham: car park: porous asphalt over reservoir base course over sealed geomembrane due to high water table. Relative small size aggregate (10mm) in the porous asphalt has been subject to localized plugging and use in future of 20mm aggregate is suggested.

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Pratt, C., S. Wilson and P.Cooper. 2001. *Source control using constructed pervious surfaces – hydraulic, structural and water quality performance issues.* CIRIA C582. London. 152 p. http://www.ciria.org/suds/publications.htm

Pratt, C.J. 2001. Sustainable Urban Drainage – a Review of Published Material on the Performance of Various SUD Devises. Coventry University. Prepared for the Environment Agency. 25 p.

[31] Pratt, Wilson, Cooper, CIRIA, Source Control Using Constructed Pervious Surfaces, 2002

Germany

Stormwater Management - status

Key Drivers

- **Increased impervious surface** leading to saturated sewer networks and water treatment facilities.
- **Minimizing flooding.**
- **Sinking groundwater levels** in urban areas and the need for groundwater recharge.
- **Environmental awareness and sustainable development goals**. Many German cities have an active Local Agenda 21 program initiated by the Rio declaration in 1992.
- **Federal and state laws** for nature, water and soil protection. Under these laws, interventions in undeveloped areas must be avoided, minimised or compensated for area lost. Green roofs are an example of a recognised compensation measure. The water act in North Rhine Westphalia requires that infiltration be considered before conveyance into the public sewer system.
- **European directives.**
- **Disconnection** of stormwater from the sewer system. In the Emscher region, the Emscher River authority expects to disconnect 15% of stormwater from the sewer system in the next 15 years[32].
- **Rainwater as a valuable urban amenity** that can be used to enhance aesthetic values, to improve microclimate, as a play element for children and it can be re-used for various functions, such as irrigation and flushing toilets.
- **Nature compensation** – measures such as green roofs are recognised as means of compensating for nature lost to development.

Standards and Policy

In terms of source control, much experience has been gained in North Rhine Westphalia where factors such as a high population (18 million), high industrial density and associated pollution problems, have provided the stimulus for early research and application of source control measures. This jurisdiction learned that sustainable stormwater management requires many parallel actions (technical, political, legal) to support the change from a conventional approach. The development of technical standards and incentive-based policies has brought source control into frequent use throughout Germany.

Technical Standards - The key technical standards are the *ATV-A138* design rules for infiltration systems and the *FLL guidelines* for green roofs. These are particularly useful since they bring together all the national standards and norms into single practical publications.

State and Local Government requirements - Most state or municipal jurisdictions provide a wide range of manuals, brochures and information on sustainable stormwater management. Some states like North Rhine Westphalia have an advisory group assigned to answer technical, political and legal questions and provide municipalities with tools necessary to implement source control policy. Various river authorities such as the Emschergenossenschaft take a leading role in promoting source controls and making technical information available. Some cities, like Dortmund, are preparing special maps to assist in designing source controls which include information about the infiltration rate of soils and average high groundwater levels.

[32] Raasch, Ulrike. Pers. comm. 01.09.03

***Stormwater Fees* (*Regenwassergebühr*) –** The "polluter-pay principle" is practiced extensively for stormwater discharge. Property owners with impervious surfaces pay for the discharge of stormwater runoff into the public system, whereas owners with source control measures qualify for a discount. The effect of this policy is far-reaching. To save costs, owners prefer to be disconnected from the sewer system as much as possible, if not completely.

Since Bonn started in 1970, most if not all large German cities have gone from a single discharge fee (sanitary and stormwater combined) to a split fee system. With the split system, the sanitary fees are determined by drinking water consumption and stormwater fees are determined by the area of impervious surface connected to the public sewer system (regardless of whether it is combined or separated).

As an example, Berlin charges 1.90 €/m³ ($2.85) for drinking water and 1.30 €/m² ($1.95) per year for stormwater discharge. Owners qualify for a reduction in the annual stormwater runoff fees if they reduce impervious surface. How the reduction is calculated varies. Usually, the reduction is based roughly on the runoff coefficient of the surfacing. Green roofs typically qualify for a reduction of about 50%, depending on the thickness of substrate. If the runoff for the whole property is completely disconnected from the sewer system, then the annual fee is not charged at all. If source controls are used but emergency overflow is discharged in the public sewer, then a calculation is made of the volume and the owner charged accordingly.

Direct subsidies - these provide another financial incentive for source control. Funds for subsidies are derived from taxes on industrial and commercial water polluters. An example is the "Initiative for Ecological and Sustainable Water Management", a 320 million € (480 million $) program in North Rhine Westphalia. Funding is derived from a water pollution tax imposed on industrial and commercial property owners. The aim of the program is to improve the quality of rivers and bodies of water. The program financially supports projects that remove impervious surface (15 €/m² - $22.50), and install infiltration systems (15 €/m²), green roofs (15 €/m²) and rainwater storage systems (1,500 €/system - $2,250.00). From 1998 to 2002, North Rhine Westphalia subsidized 600,000 m² of green roofs.[33] The program targets projects in existing urban areas.

Local regulations for new development - In addition to financial incentives, stormwater source controls are being anchored into the local regulations of new development plans. Generally, the municipality will require that the least amount of stormwater possible be discharged into the public sewer. In areas with saturated networks and lack of funding for drainage infrastructure, the planning regulations may simply forbid an increase in stormwater loading. Stormwater source control policy is more effective on new developments because the spatial requirements of source control systems can be designed into the infrastructure plan from the start.

Demonstration projects – "Seeing is believing" - Many successful projects are held up as models to demonstrate that source control works. Almost two decades of experience with source control has made designers more and more comfortable with the technology.

Key Concepts and Source Controls in Use

Some local terms for stormwater source control: *dezentralen Versickerungsanlagen, Naturnahe Regenwasserbewirtschaftung, Regenwasserversickerung, nachhaltiges Entwässerungskonzept...*

Surface Infiltration

Surface infiltration (*Flächenversickerung*) includes permeable paving, lawn and planted areas, and green roofs. Surface infiltration is the first choice for a source control measure. Permeable paving is

[33] Christof Mainz. EFB-FBB Gründach Symposium 2003 proceedings.

frequently used for parking lots, parking along streets and pedestrian areas. Grid pavers and unit pavers are very commonly used. Two specific types of paving that are relatively unknown in the Vancouver region are crushed stone surfaces (*wassergebundene Decke*) and load-bearing lawns with a gravel base (*Schotterrasen*), often used for emergency vehicle access. Porous pavement (*Drainpflaster*) is used but costs more. Porous asphalt has been used on the Autobahn A2 and is apparently a pleasure to drive on in the rain because the water drains immediately and there is no spray from vehicles ahead.

Extensive green roof in Stuttgart

Photo: Goya Ngan

German experience with green roofs (*Dachbegrünung*) over the past 30 years has provided the base for modern green roof technology. Green roofs are installed in about 1 in 7 of all new and retrofitted flat roofs in the country[34]. In 2001 this translated into 13.5 million m². In Berlin, where many developments require them, 30% of all new flat roofs are greened[35].

The effectiveness of a green roof at reducing stormwater runoff depends on the thickness of the layers penetrable by plant roots, characteristics of the substrates, slope and aspect. Generally, thicker roofs are more water retentive. Typical extensive green roofs retain and evaporate 50% of the rainwater.

Conveyance of stormwater from a roof

Source: Naturnaher Umgang mit Regenwasser, Bavaria

The advantage of green roofs is that they do not require extra space and regional infiltration rates are irrelevant. Research has been conducted on green roof materials, which shows that water quality from green roof runoff can be equal to that of the tap water. The key is in keeping humus content down. Although, people are not yet drinking it, the water is being used for irrigation, putting out fires, toilet flushing and certain washing applications.

Permeable surfaces are also used to infiltrate water from adjacent impervious surfaces. If the impervious surface is not adjacent to the source control, surface conveyance systems are used which can have much aesthetic value in the landscape.

Swale Infiltration

Swales or shallow basins (*Muldenversickerung*) are employed where there is adequate space. They can be combined with a trench if space is limited. Experience has shown that the swale must not be wet for long periods of time (more than 2 days) as this is when fine sediment can adversely affect the permeability of the swale. During dry periods, flora and fauna in the soil restore the permeability. A five year-old study at Veitshöchheim has found that vegetation swales can retain 30% more water than grass swales[36]. So far the use of vegetation in swales is motivated more by aesthetics than functionality. Swales

[34] Hämmerle, Fritz. "Grün wächst" in *DDH Das Dachdecker-Handwerk Heft 14/02*. pp.22-24

[35] Podium discussion in proceedings from *Infoforum Regenmanagement, Berlin 2000*. p.80

[36] Eppel, Jürgen. "Versickerungsfactor Pflanze" in *Stadt + Grün*, 8/2003. pp. 14-18

are the most common source controls (not counting surface infiltration) in the Emscher region because they are simple to implement and maintain[37].

Trench Infiltration

Infiltration trenches (*Rigolenversickerung*) require less space than swales and can cut through impermeable soil layers to more permeable material for infiltration. They may be designed with a perforated pipe to improve distribution of water and the possibility of a delayed overflow drain. They are commonly used with pre-treatment systems to infiltrate stormwater runoff from adjacent parking areas and driveways. Trenches must be horizontal (no slope) for proper infiltration.

Shaft Infiltration

Shaft infiltration (*Versickerungsschacht*) consists of a manhole-like shaft with infiltration holes on the side and an open bottom. It is typically used where space is limited and where the infiltration rate of the soil is poor. The critical design factor is the average high groundwater level, and the ATV has determined the minimum distance between this level and the bottom of the infiltration shaft. Shaft infiltration is the last choice for source control as it is associated with the highest risk to groundwater. Shafts are not commonly used in the Emscher region because they are costly to install and are not covered by the state subsidy program.

Networked Infiltration

A number of systems have been designed to collect stormwater in large-scale developments using a network of source control measures. A commonly used system is one combining swales and trenches (*Mulden-Rigolen-System*). Water is collected from adjacent surfaces into a grassy swale where it either flows downstream over check dams and eventually into a catch basin, or seeps through a pre-treatment soil layer into an infiltration trench. From there the water infiltrates into the ground or into the drainpipe. The pipe leads to the same catch basin at the end of the grassy swale and from here the water can overflow into the next trench and so on until it arrives at the outfall. Flow attenuation is as effective as a conventional system except that the volume of water discharged at the outfall is significantly reduced and has been pre-treated. Like a conventional system, overflow occurs based on the selected return time. Continuous long-term simulations are used in the calculations.

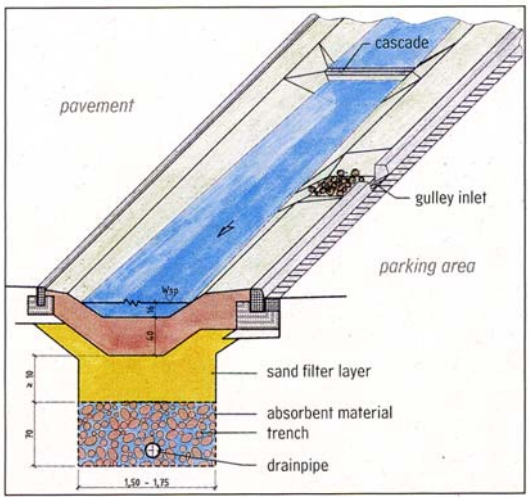

Figure A-3: Cross-section - swale-trench system

Source: Water Concept Kronsberg

The technique has been in use for over ten years, usually in "sustainable" communities with integrated stormwater concepts. It is important to include swale-trench systems early in the planning phases of a development so that spatial requirements are taken into consideration.

The application of this technique in existing urban areas is more complicated, as it can be difficult to integrate both aesthetically and functionally. The landscape architect, Gabriele Kiefer, suggests that in central urban settings like Berlin, more emphasis should be placed on pervious paving such as mineral

[37] Raasch, Ulrike. Pers. comm. 30.09.03

surfaces and on elements designed to collect surface water rather than on swale-trench systems[38]. In short, designers need the freedom to choose from the range of source control measures that which best suits not only the physical site, but also the function and look.

Documented Costs and Benefits

A cost analysis was conducted for the industrial park "Warstein-Belecke" in North Rhine Westphalia (see bar graph)[39]. Three variations were analysed: the swale-trench system, the separated sewer system (*Trennsystem*) and the combined sewer system (*Mischsystem*). The initial investment is shown in blue, reinvestment in red, operating costs in yellow and the project's monetary value in light blue.

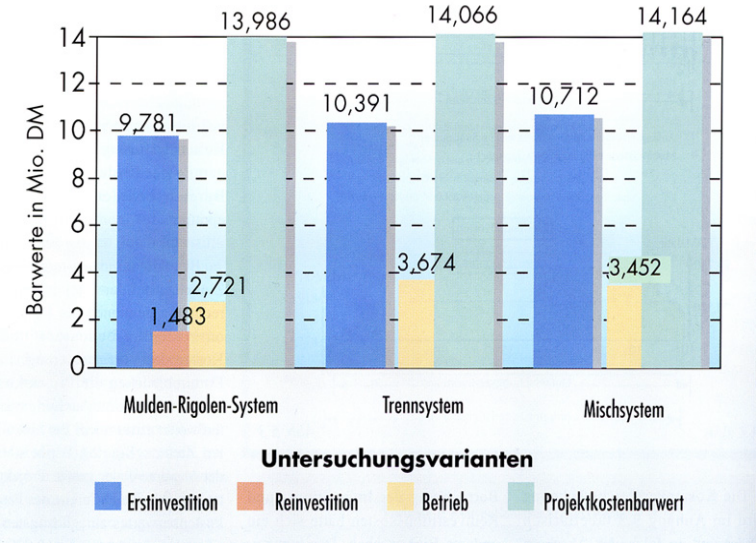

Figure A-4: Comparison of investment costs and project value

Source: Naturnahe Regenwasserbewirtschaftung: zukunftsfähige Wasserwirtschat in Industrie- und Gewerbegebieten, NRW

The costs were based on pipe infrastructure lasting 70 years, basin structures lasting 70 years, swale-trench systems lasting 35 years and pre-treatment systems lasting 35 years. It is important to bear in mind that a swale-trench system does not require a conventional system as backup for emergency overflow.

In financial terms, the overall costs after 70 years are very similar for all three systems. Therefore, ecological benefits of the swale-trench system come at no extra cost.

There have been numerous cost-benefit analyses for green roofs. A detailed analysis by Bernd Krupka for North Rhine Westphalia compares the costs of a gravel roof, a three-layer extensive green roof and a single-layer extensive green roof over a period of 40 years[40]. A key factor in the calculation is the annual stormwater fee. When the calculation includes it, both types of green roof are markedly less expensive than the gravel roof. When the annual stormwater fees are not included in the calculation, the costs are more similar and minor distinctions can skew the results one way or another.

Case Studies

Kronsberg, Hanover

Kronsberg is a well-documented sustainable community of 6000 residential units, which was showcased during Expo 2000 in Hanover. Because there was a limitation on the volume of stormwater that could be received in the reservoir downstream, the planners opted to use a swale-trench system to drain the streets and sidewalks[39]. To test the system, they executed a full-sized simulation which allowed some of the early design flaws to be addressed. During a true rainfall event that measured 36 mm of rain in barely one hour

[38] Kiefer, Gabriele. "Niederschlagswasserbewirtschaftung und Landschaftsarchitektur: Vom Regen in die …?" in proceedings from *Infoforum Regenmanagement, Berlin 2000*. pp. 70-72

[39] Stadtentwässerung Hannover. *Water Concept Kronsberg.*

[40] Krupka, Bernd. *Extensive Dachbegrünung: Praxisempfehlungen und Kostenbetrachtungen.* Landesinstitut für Bauwesen des Landes NRW, Aachen. 2001.

(one in 69 year storm), all 16 systems then in operation functioned perfectly. Compared to the conventional system, the volume of stormwater at outfall is about 10 times less. The system cost more than a conventional one to build but this is likely offset by the ecological and social benefits. In the future, there will also be about 30% savings in annual stormwater fees to property owners.

http://www.hannover.de/deutsch/wohnen/planen/oemobakr.htm

Other projects

Landschaftspark Duisburg-Nord, landscape park on former industrial site

DaimlerChrysler, Potsdamerplatz in Berlin, commercial urban centre with green roofs (4 ha), re-use of roof water (3500m³) and urban bodies of water (1.2 ha)

Adlershof Science- and Technology park in Berlin, 420 ha development on former airport site

Universität Ulm, university campus

Neue Messe Freiburg, exhibition grounds on former airport site

Dahlwitz-Hoppegarten near Berlin, industrial park

Rummelsburger Bucht in Berlin, riverside residential development

Schüngelberg-Siedlung in Gelsenkirchen, residential development

Bertelsdorfer Höhe in Coburg, residential development

Aachen, "ecological city of the future"

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Richtlinie für die Planung, Ausführung und Pflege von Dachbegrünung, Forschungsgesellschaft Landschaftsentwicklung und Landschaftsbau e.V. (FLL), Bonn. 2002. 95 p.

Geiger, W and H Dreiseitl. *Neue Wege für das Regenwasser. Handbuch zum Rückhalt und zur Versickerung von Regenwasser in Baugebieten*. Oldenbourg Industrieverlag, München. 2001. 303 p.

France

Stormwater Management - status

Key Drivers

- **Increased impervious surface** leading to saturated sewer networks and water treatment facilities
- **Minimizing flooding**.
- **Pollution control.** identifying stormwater pollution from urban areas and roadways, function of specific treatment systems, stormwater source control in reservoir structures.
- **Groundwater recharge.**
- **European directives.**
- **Compensation** for the impact of stormwater runoff.
- **Integration of source controls in the landscape**. Landscape design and programming of space must accompany the hydraulic design. By making stormwater management visible rather than hiding it underground, a greater sensitivity towards the environment and thus ecological awareness is anticipated.
- **Evolution of mentalities** away from "everything to the sewer" towards what sometimes appears like a return to past techniques.

Standards and Policy

"La ville est son assainissement" is a national guideline document resulting from a European directive from 1991 regarding urban wastewater covering the principles, methods and tools for integrated urban stormwater management. It states that the first principle for stormwater management is to limit to the strict necessity, the area of impervious surface. The second principle is to limit the volume discharged into the public sewer system by way of re-use systems, source controls or open channels. Some key points are: the design of source controls should not be done independently of urban design or transportation design; the measures can be combined with other landscape functions, such as small squares, parking areas and playgrounds; the techniques should be visible to guarantee good maintenance and attract public attention to the presence of water.

The first projects with source control in France were implemented in Bordeaux. Bordeaux is situated at the confluence of the Garonne River and the Gironde estuary. The topography of the area, with its low-lying centre and surrounding hills, makes it susceptible to flooding. In addition, Bordeaux is relatively spread out; the proportion of streets and impervious surface to population is more than 3 times that of Lyon. Catastrophic flooding in 1982 (81 mm in 1 hour followed 2 days later by 44 mm in 54 minutes) raised the problems of urbanization to the forefront of public awareness. The Communauté Urbaine de Bordeaux, an assembly of 27 municipalities responsible for transferring experience on water management to the member municipalities, decided to address the problem and finances were made available to develop solutions to compensate for the impact of urban runoff.

The first source control systems, built between 1983 and 1987, were designed according to quantitative aspects (volume and discharge) alone. A critical evaluation found that they were unsatisfactory due to their poor integration in the landscape and lack of maintenance. The technical guidelines from 1998, **"***Les solutions compensatoires d'assainissement pluvial,"* include information on selection, design and maintenance of source control measures, as well as how to secure responsibility for maintenance.

The Communauté Urbaine de Lyon is also active with source control. An important driver is groundwater recharge of an aquifer area to the east of the city valuable as a potable water source. With an increase in urbanization, the area would receive less runoff and the concentration of nitrates from surrounding agricultural land would increase as the water table dropped. Infiltration of urban stormwater is being incorporated into the planning for new developments in the area. The Communauté Urbaine refers to "La ville et son assainissement" for the design of infiltration systems.

Although source control techniques are recognized in France, their application depends on the local authorities. Other notable jurisdictions that use source controls are Rennes, Strasbourg and Douai. Douai, in the north of France, has a sustainable stormwater management program (ADOPTA) which publishes technical bulletins on the internet for various source controls.

L'Agence de l'Eau Seine Normandie (AESN) is the agency responsible for water and drainage in the Paris area. Schéma Directeur d'Aménagement et de Gestion des Eaux (SDAGE) is responsible for the 6 drainage basins in France and the overall objectives. These objectives are based on European water directives.

The French Public Works Research Laboratory (LCPC) is researching alternative stormwater management and pollution and treatment of stormwater, in particular reservoir base structures.

Key Concepts and Source Controls in Use

Some local terms for stormwater source controls: *contrôle à la source des eaux pluviales, solutions compensatoires d'assainissement pluvial, techniques alternatives,* and *approche intégrée de l'assainissement.*

Reservoir structures

Reservoir structures (*structures réservoirs*) are systems which retain and store stormwater in permeable base materials. This can be achieved by direct infiltration through a porous pavement, by runoff on impervious surfaces followed by adjacent infiltration into the reservoir structure and by runoff on impervious surfaces followed by adjacent injection into the reservoir structure. Porous pavement (*chaussées poreuses*) includes porous asphalt, porous hydraulic concrete, prefabricated porous concrete pavers and alveolar products (thermoplastic materials with 'bee hive' structure sometimes covered with a permeable geotextile).

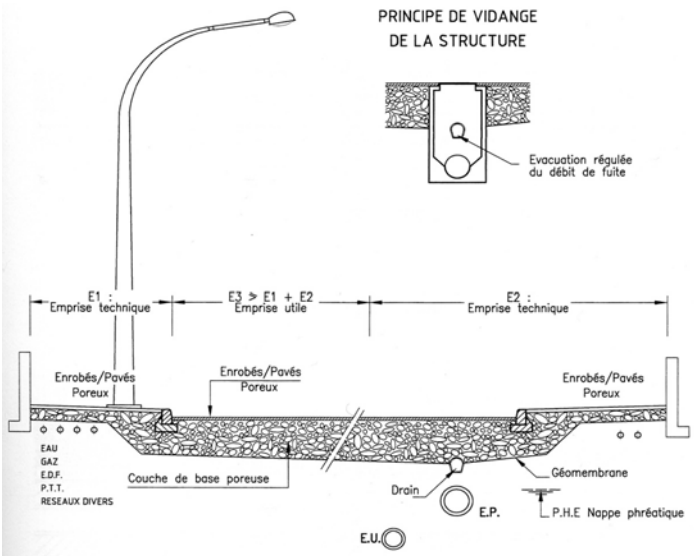

Figure A-5: Street with porous pavement and reservoir structure

Source: Les solutions compensatoires d'assainissement pluvial, Communauté Urbaine de Bordeaux

Porous pavement

The Communauté Urbaine de Bordeaux has been using porous pavement since 1986 and this, in conjunction with the studies at LCPC, has afforded valuable experience with the technique. Interestingly, porous pavements are also being examined as a measure to reduce urban traffic noise.

Regular maintenance is required for the continued permeability of porous pavement. A high-pressure rotating water jet in combination with a vacuum has been effective at restoring the original porosity of the material. Porous pavement is not recommended in the following cases: streets of housing developments with phased or unspecified construction periods because of the sediment build-up before and during construction of individual lots, truck parking areas because the pavement causes shredding and fine dust which can plug the pavement pores, and in stockpiling areas.

In Lyon, porous pavement has been used in 3 instances[41]. The municipal works department did not have the machinery necessary to maintain the systems. As a result, the pavement plugged and the technique fell out of favour with the municipality.

Swales

In France, swales (*noues*) are desirable source control measures because they integrate well in the landscape and with other functions, in addition to sensitizing the public to the issue of stormwater management by direct visual means. The early projects in Bordeaux showed that without adequate maintenances, swales can quickly turn into cesspools. Their gentle slope allows them to be mowed without difficulty, but it is important to have a maintenance contract in place. In Lyon, swales are starting to be used in new developments. There is often a conflict with sidewalks when space is limited. Ditches are the ancient form of swales and some effort is being made to save them from being replaced with underground pipes.

Figure A-6: Networked swale system

Source: Les solutions compensatoires d'assainissement pluvial, Communauté Urbaine de Bordeaux

Infiltration Trenches

Infiltration trenches (*tranchées drainantes)* regulate the stormwater runoff typically collected from paved areas and roofs. They are either built directly below the surface or with a pre-treatment soil layer usually combined with a planted or grassy swale. Being buried, they have been easily integrated into projects around Lyon.

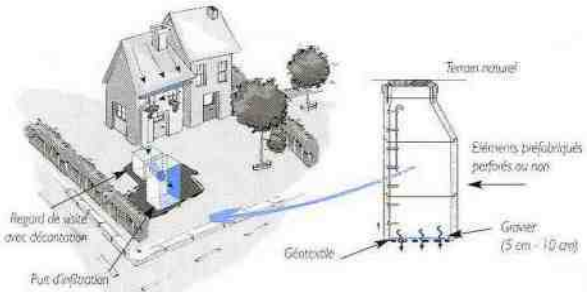

Figure A-7: Shaft Infiltration

Source: ADOPTA

Well and Shaft Infiltration

[41] Sibeud, Elisabeth. Pers. comm. 30.09.03

The City of Douai sustainable stormwater management program (ADOPTA) recommends using infiltration shafts (*puit d'infiltration*) to receive runoff from roofs. Undesirable materials are trapped and the water infiltrates through the bottom of the shaft. The sand or gravel filtration layer and geotextile need to be regularly replaced. Attention must be paid to the groundwater level. In Lyon, there are between 2000 and 3000 infiltration wells but their implementation today is disappearing for two reasons: 1) the wells frequently become blocked and are associated with sanitary sewer contamination; 2) new transportation projects now include early consultation with the Communauté Urbaine which allows more elaborate drainage systems (swales, trenches) to be incorporated from the concept stage[42].

Gravel Roofs and Green Roofs

Gravel roofs (*toitures terrasses*) are composed of a waterproof membrane covered in fine gravel. They provide temporary water retention. Maintenance consists of two annual visits to ensure the drains are unobstructed and to remove vegetation. Green roofs (*toitures végétalisées*) are rarely used in France. Architects are afraid of the real or perceived risks that green roofs will cause leaks and cause loading problems[41]. Manufacturers are worried that root penetration will affect their product guarantees. As a result extra root barriers are almost always used.

Documented Costs and Benefits

A brief cost analysis was done for the Porte des Alpes project near Lyon[43]. The site constraints were a saturated sewer system and poor infiltration capability of the soils. The options were as follows:

1) Build a conveyance system to discharge the stormwater into the nearest body of water (the Rhone 6000 meters away). Estimated cost = over 15 million € or $24.7 million.
2) Build an antenna conveyance system to discharge the stormwater into a newly built outlet 1700 meters away. The facility also receives sanitary sewer which would periodically overflow and pollute the Rhone. Estimated cost = about 2.3 million€ ($3.8 million)
3) Infiltrate the water in the permeable area to the east of the project which is the natural destination of existing stormwater from the zone. Estimated cost = 0.8 million € (about $1.28 million)

The third option was chosen, however, there is not enough data to estimate operating costs. The plan to integrate source control with other functions also translates into cost savings and meant that outside financing could be sought for it. The retention lakes are an added selling feature of the development.

Case Studies

Porte des Alpes in St. Priest near Lyon

This 230 ha sustainable development project is the largest for the Communauté Urbaine de Lyon. It will have 250 homes, a large technology park and a commercial centre. The constraints that led to an integrated stormwater approach were a saturated combined sewer network downstream, poor infiltration rate of the existing soils and environmental requirements to conserve the groundwater. Swales, infiltration trenches and retention lakes were used and backed up, in case of heavy rainfall, by soccer fields. 90% of the water systems are on public property and open to public use. There will be monitoring of groundwater, infiltration area soil, lake ecology and lake purification. The lessons learned included collaborating with landscape architects early on, providing multi-functional systems for quality public

[42] Chapgier, J, E Sibeud and J C Varnier. *La mise en œuvre d'une politique d'infiltration des eaux pluviales à l'échelle d'une agglomération : L'est du Grand Lyon.* Service études de la direction de l'eau, Communauté urbaine de Lyon.

[43] Grand Lyon, Direction de l'Eau. *Demand d'autorisation au titre de la loi sur l'eau.* July 1998.

open spaces, fostering a "water culture" with communication to ensure system sustainability, involving various actors at the design stage, and having a single management cell to define responsibilities of those concerned.

www.grandlyon.com/projets/

Other projects

Commercial centre near Chemillé, 1.5 ha parking with porous pavement on a sloping site

la rue de la Classerie in Rezé, porous pavement with reservoir base

Leclerc in Saint Medard en Jalles, 12 ha parking with reservoir base structure

Reference Documents

La ville et son assainissement : principes méthodes et outils pour une meilleure intégration dans le cycle de l'eau. Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques (CERTU). 2003.

Les solutions compensatoires d'assainissement pluvial. Communauté Urbaine de Bordeaux. 1998.

Raimbault, G., H. Andrieu, E. Berthier, C. Joannis and M. Legret. *Rainwater infiltration through urban surfaces: from impermeable surfacing to reservoir-structures.* Bulletin des laboratoires des Ponts et Chaussées, n° 238, May-June 2002, pp.39-50.

Netherlands

Stormwater Management- status

Key drivers

- **High groundwater levels**
- **Minimizing flooding: "**retain-store-drain" (*vasthouden-bergen-afvoeren*) are considered to be the three-steps to prevent flooding.
- **Pollution control**
- **Increased impervious surface** from expanding urbanization and **greenhouses** leading to saturated sewer networks and water treatment facilities
- **Climate change** leading to higher water levels and more precipitation
- **Groundwater depletion** affecting endangered species
- **EU Water Framework Directive**
- **Water Policy for the 21st Century**
- **Harmonisation between water policy and spatial policy:** Decisions about water need to be well-integrated in spatial planning and this requires an early integration of the water concept in the overall planning.
- **Disconnection of impervious surfaces from the sewerage system**. The national objective is to disconnect 60% of stormwater in new developments and 20% in existing built-up areas[44].
- **Target Ground and Surface Water Regime (GGOR).** Groundwater and surface water form a dynamic system. The Dutch are in the process of finding the appropriate targets to ensure a balance between extraction and replenishment of groundwater (i.e. sustainable use).

Policy and Standards

The Netherlands is particularly susceptible to changes in water levels because of the low-lying nature of their land. As a result, the government has had to seriously consider the impact of climate change with respect to water policy and its effect on spatial planning of water. The Netherlands Commission on Integrated Water Management 2003 annual report demonstrates that in a short time, the Dutch have been able to develop clear national objectives on the subject of source control. A history of joint action in the

3.1 Indication of the space required to retain and store water

	2015	2050
Retaining water	360,000 ha	430,000 ha
Storing water	32,000 ha	72,500 ha

Indication of the space required to retain water

	2015	2050
Additional open water	5,050 ha	12,388 ha
Retaining under or above ground	280,000 ha	387,000 ha
Separating rainwater drainage from the municipal sewage system in paved areas in urbanised regions	86,00 ha	24,000 ha

Rough estimate of the total costs of the possible solutions (in euro)

	2015	2050
Retain-store-drain	7.5 billion	15.3 billion
Amount of which targeting urbanised areas	3.5 billion	7.4 billion
Water quality	637 million	731 million

Source: partial catchment area visions

Table A-2: Space required to retain and store water

Source: Water in Focus 2003

[44] *Water in Focus 2003. Annual report on water management in the Netherlands.* Netherlands Commission on Integrated Water Management.

battle against water has allowed consensus-based policy to be implemented without much difficulty.

The Commission has as an operational objective to separate 60% of stormwater from the sewer system in new developments and 20% in existing built-up areas[44]. Excess water is infiltrated directly into the ground, discharged to surface waters or utilized as grey water for domestic use. The targets are generally being met in new developments, with already more than 2000 ha of paved surface in urban areas currently separated from the sewage system. The experience in existing built-up areas is less positive because of technical difficulties in separating the drainage. In 2002, only 5% of paved surfaces were disconnected.

Municipal governments (71%) are undertaking activities to encourage the separation of stormwater from the sewer system. Nearly all water boards offer subsidies as incentives for separation efforts. They range from 0.91 € to 5.00 €/m^2[44].

The Water Tests Manual (*Handreiking Watertoets*) attempts to harmonize water policy and spatial planning. The regulations will come into effect November 1, 2003. It is a bureaucratic instrument that will strengthen communication between developers, municipal planners and local water boards. Essentially, future developments will need to accommodate more space for open water. Specifically there will be provisions that any development only be permitted if the hydraulic consequences are approved by the local water board. This is in addition to environmental impact statements. Measurements depend on the situation but in most cases the standard is to compensate built-up areas with 10% open water area.

The main source control guidelines are contained in the water section of the National Sustainable Urban Design Package. They are not prescriptive guidelines, but should provide enough information to allow designers to choose appropriate solutions respectful of the particular site conditions. Groundwater levels and soil type play an important role in deciding what type of system to use. The package is intended for town planners, citizens, governments, architects, civil engineers and others.

Key Concepts and Source Controls in Use

Permeable Paving

The usual assortment of permeable paving (*doorlatende verharding*) is used. Interestingly, temporary storage of water on streets is recommended to reduce peak flows. Bicycle paths and sidewalks, on the other hand, should not get flooded.

Trench and Pipe Infiltration

Infiltration trenches are especially useful to keep ground dry in winter. As a general rule, for every square meter of disconnected impervious surface, 0.1 square meters of infiltration trench is suitable[45]. A perforated drain pipe increases infiltration capabilities. A cavity at the end prevents sediment from collecting in the pipe.

Green Roofs

Green roofs (*vegetatiedaken, groendaken*) are recognized for their efficient ability to reduce and slow down runoff, as well as positive effects on urban microclimate.

Constructed Wetlands

Constructed wetlands are built for their pre-treatment and aesthetic values. The longer the water stays in it, the better the water quality. Dry wetlands (*droog moeras*) are also used.

[45] *Nationaal Pakket Duurzame Stedebouw*. Nationaal Dubocentrum, Utrecht. 1999.

Wadis

A "wadi" (Arab for "valley" or "dry bed of a river") functions much like a broad swale. They are covered with humus and may be planted with grass or other vegetation, such as reeds and rushes. During heavy rainfall, normally only 3 or 4 times per year, the wadi fills with water and then dries up after about 24 hours. By filtering through a humus layer, the water is pre-treated before it enters the deeper ground and eventually the groundwater. The system can be either point, linear or flat-shaped and combined with other functions. The infiltration rate of the soil can be improved by adding expanded clay granules. A typical wadi is a few meters wide by about one meter deep. If space is limited, the system can be made deeper.

A wadi after a heavy rainfall

Credit: Mr. Dubbeling

Eeuwkanten

"Eeuwkanten" are low-lying stretches of land along a watercourse, which are flooded in times of high water. The use of eeuwkanten dates from several centuries ago (probably the middle-ages) and is recently re-discovered. In combination with check dams and planted with grass and reeds they not only store water in wet periods when the drainage capacity is reduced, but also clean it. They can be used to purify roof water before it is discharged into surface waters.

This plan shows how eeuwkanten were integrated into a water concept plan of the Auvergne Polder. A polder is an area of land that has been reclaimed from the sea. A certain percentage of the area was required to be open water, for which "eeuwkanten' qualify, in order for the development permit to be granted.

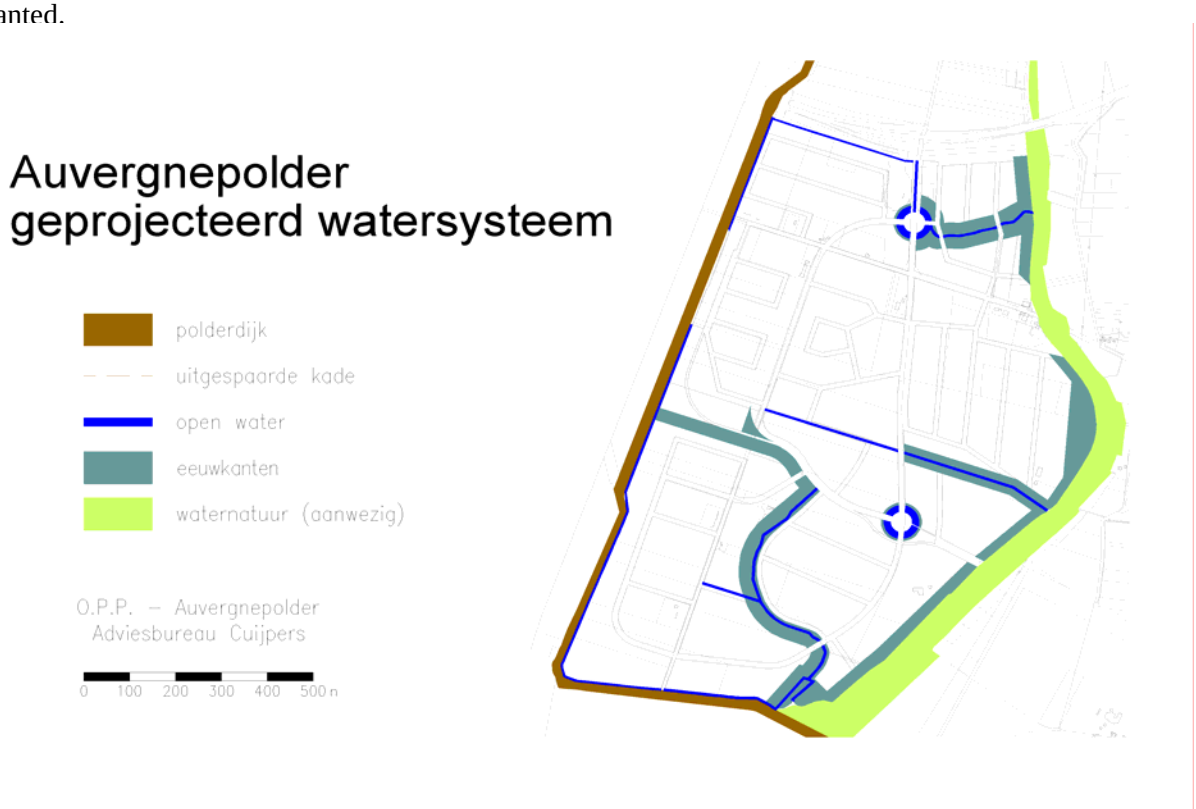

Figure A-8: Reconstructed and new eeuwkanten, part of the new water-system in a projected industrial estate

Credit: Adviesbureau Cuijpers

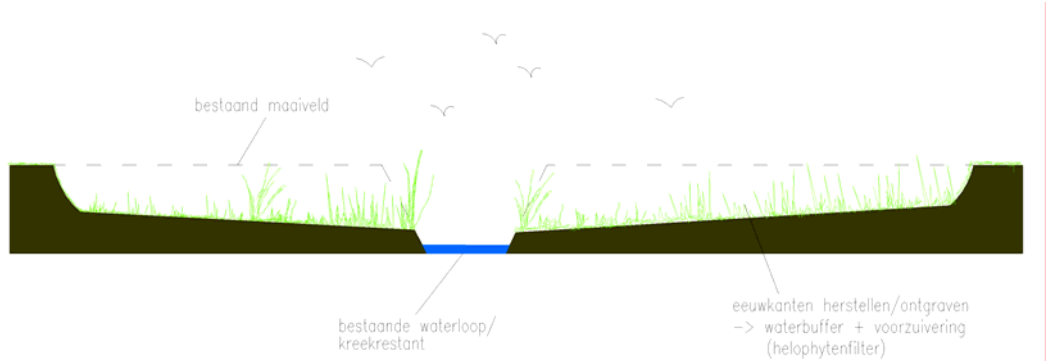

Figure A-9: Section of a watercourse with eeuwkanten in Auvergne Polder

Credit: Adviesbureau Cuijpers

Case Studies

Leidsche Rijn

Leidsche Rijn is a large-scale development in Utrecht which will eventually have 30,000 homes, a population of 90,000 and 40,000 people working in the area. Rainwater is considered too precious to send down the drain and into the sewer system. As much of this water as possible is held in the soil by way of wadis. Permeable paving materials are used and excess water is drained towards the wadis. Roof water is also conveyed to the wadis. Polluted stormwater from busy streets, large parking lots, car washing places and dog toilets is drained via the public sewer system where, after purification, it flows into the Amsterdam Rijnkanaal.

http://www2.utrecht.nl/smartsite.dws?id=15527&mw=1097&w=18;86;59&p=13409;13353&parFrom=13353&infFrom=13353

Other projects

Vijfhoek in Deventer, 4600 homes on 150 ha, groundwater recharge

Gelderland, greenhouse construction near drinking water source, emphasis on surface water quality, 250 ha added to the existing 250 ha

Auvergne Polder, 300 ha agricultural land converted to industrial estate

Leidschenveen in Leidschendam, 7000 homes

Roomburg in Leiden, 1000 homes

Eschmarke VINEX location in Enschede, 5300 homes, European protected species were threatened, wadi system

Haveneilanden en Rietlanden, Ijburg in Amsterdam, district

Oikos District in Eschmarke, 600 homes

Ruwenbos in Enschede, 400 homes

Hilversum Nieuw Oost, 750 homes

Wateringse Veld in the Hague, 8000 homes and 22 ha industrial estate

Amersfoort in Nieuwland, 5000 homes, 70 ha industrial estate

Reference Documents

Nationaal Pakket Duurzame Stedebouw. (National Sustainable Design Package) Nationaal Dubocentrum, Utrecht. 1999.

Handreiking Watertoets: Waarborg voor water in ruimtelijke plannen en besluiten. (Water Tests Manual) Dutch Ministry of Traffic and Water Control. 2003

Water in Focus 2003. Annual report on water management in the Netherlands. Netherlands Commission on Integrated Water Management.

B e l g i u m

Stormwater management status

Key drivers:

- **Increased impervious surface** leading to saturated sewer networks and water treatment facilities
- **Minimizing flooding.**
- **Pollution control.**
- **Disconnecting impervious surfaces from the sewer network.**
- **Storing water on site for re-use.**
- **Subsidy programs.**

Standards and Policy

There are no national guidelines for source control because environmental issues are regionalised.

The 1996 Flemish Guidelines on urban drainage emphasise source control measures in order to reduce the peak runoff from urban areas during wet weather conditions. The keyword is "disconnecting" impervious areas from the combined sewer system. For example, they prescribe that for new large impervious areas (starting from 0.1 ha) the downstream flow must be limited.

The Flanders Environmental Agency has published water guidelines for architects entitled "A Handbook for Sustainable Water Use in and around Private Dwellings." The guidelines are based largely on research conducted at the University of Leuven. They address the issue of how long antecedent periods of rainfall influence the design. In particular they include modelling techniques using continuous long-term simulation to determine optimum source control design. Green roofs are included as a source control measure.

Some municipalities offer subsidies for the installation of source controls. For example, the City of Mortsel pays 3.75 € / m² ($5.60) for the construction of green roofs up to a maximum of 743.68 € ($1,110); and 50% of construction costs for an infiltration system up to a maximum of 309.87 € ($465) in existing built-up areas and 247.89 € ($370) in new development areas. Most subsidies stipulate how effective the system must be, i.e. buffervolume or volume of stormwater for a certain area.

Key Concepts and Source Controls in Use

Green Roofs

Green roofs (*vegetatiedaken, groendaken*) are recognized in Belgium as important source control measures. Construction techniques generally follow those used in Germany. The focus of stormwater management aspects of green roofs has concentrated on flat roofs, even though the technology now exists to build them on steep roofs.

Because runoff studies are dependant on local climatic conditions such as total rainfall, rainfall distribution, temperature, etc, it is difficult to calculate the water retention in other locations with different total rainfall and rainfall distributions from the testing site. Research is being conducted at the University of Leuven to develop a water balance model for extensive green roofs which would simulate the water balance for various types of green roofs and climatic conditions. It will take into account slope and orientation, as well as climatic conditions, such as distribution and intensity of rainfall, and solar radiation. Initial results indicate that the evaporation rate is strongly influenced by the slope and

orientation of the green roof. This demonstrates the need to consider slope and orientation as essential parameters in the water balance model.

Infiltration Systems

Infiltration systems (*infiltratievoorziening)* include all the source controls which attempt to infiltrate stormwater into the ground. A range of basins, swales, trenches, wells and combinations thereof are used. Ditches are being re-evaluated for their infiltration function.

Reference Documents

Waterwegwijzer voor architecten: Een handleiding voor duurzaam watergebruik in en om de particuliere woning. Vlaamse milieumaatschappij.

Vaes, G. and J. Berlamont. 2002. "Design rules and impact assessment for source control measures based on continuous long term simulations" in Water Science & Technology 45(7): 21-29.

The impervious asphalt road drains into a concave infiltration swale fronting a residential garden.
Credit: Vlaamse Milieumaatschappij

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.
Credit: Vlaamse Milieumaatschappij

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APPENDIX B
Criteria for Source Control Selection

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Criteria for Source Control Selection

Priority Selection Process

There are a myriad of techniques and variations in use around the world for stormwater source controls. Table B - 1 lists forty-two of the most commonly used techniques. Many of these are variants within a general class of best management practices.

In order to focus the research for this project, it was necessary to select priorities among the many techniques. Table B - 1 shows a scoring system that compares the forty-two candidate techniques against a set of selection criteria. Each candidate technique is given a score from one to ten that is based on judgement concerning how well the technique satisfies the criteria.

This scoring is specific to the situation in the GVRD. All of these techniques have an appropriate use – this selection of priorities is for the purposes of focussing research only, and is not intended to steer readers away from using any of these best management practices where their application is appropriate.

Selection Criteria

The fifteen selection criteria used in Table B - 1 are introduced below:

1. **Promotes stormwater detention / disposal** – looks for source controls that reduces peak runoff rates by delaying the release of stormwater into receiving waters.
2. **Promotes stormwater retention through infiltration** – includes those techniques that return rainwater and runoff to soils, thereby returning some of the stormwater to natural flow paths.
3. **Promotes stormwater retention through evapotranspiration** – are techniques that deliver stormwater to living plant materials – trees, shrubs, forbs and grasses – where roots take up stormwater to leaves, and where through-leaf and surface evaporation are functional.
4. **Provides improvements / avoids risks to stormwater quality** – involves techniques that provide a filtration function, e.g. flowing through sand or soil materials.
5. **Facilitates stormwater reuse** – are practices that store rainwater and reuse it for such things as irrigation, toilet flushing, laundry, etc.
6. **Widely applicable in a variety of soil conditions in the GVRD** – the GVRD has soils that range from till with very limited infiltration capability, to sandy, free draining soils. Techniques that are adaptable to most soils conditions achieve a higher score.
7. **Proven practice and performance in other jurisdictions** – looks for practices that have been constructed and operated for years with good success. If the literature has stated reservations about performance, the technique is provided a lower score.
8. **Proven technical detailing available** – practices that have technical analysis and construction details in the literature rate a higher score than those that are more conceptual.

9. **Proven specifications available** – the availability of test specifications for materials and practices creates a higher level of certainty – and a higher score.
10. **Not widely used in GVRD at present** – if a technique was already in general use in the GVRD, there may not be a need for research and training support for its use, and it therefore would receive a lower score.
11. **Relatively low risk of failure in the GVRD** – source controls that include components like redundant or overflow systems likely involve less risk in those areas of the GVRD subject to high rainfall and poor soils. Such techniques would warrant a higher score.
12. **Relatively low cost /expertise requirements** – techniques that are cost effective in land, construction and maintenance aspects rate higher. Similarly, techniques that do not require rare or expensive expertise for design or supervision are more attractive.
13. **Anticipated in Water Balance Model / other design tools** – the Water Balance Model is an internet-based modelling tool for stormwater source controls in British Columbia. It has anticipated several types of source control (and not others). Source controls that cannot currently be modelled by the Water Balance Model or other available continuous simulation programs are less attractive.
14. **Existing or high likelihood of demonstration projects** – those practices which have either already be successfully constructed, or which will quite likely be constructed immediately score higher.
15. **Not well documented by local industries or organizations** – techniques that are applicable to GVRD, and perhaps constructed but not well documented, are higher priorities for research and publication, and would score higher.

Recommended Priorities

The analysis in Table B - 1 has led to the selection of the following priorities for this project, listed in general order of priority:

- Absorbent Landscapes
- Infiltration Swales
- Bioretention Facilities
- Pervious Pavement
- Extensive Green Roof
- Infiltration Structures

The focus of the research is on the higher-scoring variants within these broad categories.

Of note, Deep Well Infiltration fell low on the priority list. Although it is used successfully in dry climates of Australia and in the southern US – with a focus in many cases on water reuse - there are concerns about injection of untreated stormwater into aquifers. It is important, therefore, that there be clear understanding and broad implementation of techniques that effectively treat water quality (e.g. soil infiltration based techniques), so that these techniques can be used as a pre-treatment of stormwater prior to deep well infiltration. For these reasons, study of deep well infiltration is a last priority at this time for the GVRD research.

Table B-1 Criteria for Selection of Priority Stormwater Source Controls

Source Control Class	Absorbent Landscape					Bioretention Facilities						Vegetated Swales						Pervious Paving										
Candidate BMPs	Absorbent Soil Properties in landscape install's	Increased Soil Depth	Compost Amended Soil	Subgrade Tilling	Surface Planting – trees, shrubs, grasses	Rain Gardens w/o underdrain	Rain Gardens w/ underdrain	Rain gardens w/ lining/underdrain	Linear Sequence of Rain Gardens	Infiltration Planter	Flow-Through Planter	Grass Swale w/o underdrain	Grass Swale w underdrain	Grass Swale w/ lining / underdrain	Swale Variants with Shrubs/Trees	Swale Variants with Check Dams	Swale Variants with Wetland Plants	Pervious Unit Paving w/ infiltration	Pervious Unit Paving w/ liner/underdrain	Porous Asphalt (unlined)	Porous Concrete (unlined)	Concrete Grid Pavers (unlined)	Plastic Grid Pavers w/ Grass (unlined)	Plastic Grid Pavers w/ Gravel(unlined)	Cobble Paving (unlined)	Aggregrate Paving (unlined)	Stone Paving (unlined)	Brick Paving (unlined)
Selection Criteria																												
1. Promotes stormwater detention / disposal	10	10	10	10	10	10	10	10	10	10	10	2	5	2	5	5	5	10	10	10	10	10	10	10	10	10	10	10
2. Promotes stormwater retention through infiltration	10	10	10	10	10	10	10	0	10	10	10	5	5	2	5	8	5	10	0	10	10	10	10	10	10	10	10	10
3. Promotes stormwater retention through evapotranspiration	10	10	10	5	10	10	10	10	10	10	10	5	5	5	8	8	5	5	5	5	5	5	5	5	5	5	5	5
4. Provides improvements/ avoids risks to stormwater quality	10	10	10	10	10	10	10	10	10	10	10	5	5	5	5	8	5	9	8	8	8	8	8	8	8	8	8	8
5. Facilitates stormwater reuse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
6. Widely applicable in a variety of soil conditions in GVRD	10	10	10	10	10	5	8	10	5	5	10	5	5	5	5	5	5	5	10	5	5	5	5	5	5	5	5	5
7. Proven practice and performance in other jurisdictions	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	8	8	8	8	8	8	8	8	8	8
8. Proven technical detailing available	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9. Proven specifications available	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10. Not widely used in GVRD at present	5	10	10	10	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
11. Relatively low risk of failure in GVRD	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	9	5	5	8	8	9	9	9	7	7
12. Relatively low cost / expertise requirements	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	10	8	5	5	5	5	5	5	5	7	7	5	5
13. Anticipated in Water Balance Model / other design tools	10	10	10	0	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
14. Existing or high likelihood of local demonstration projects	10	10	10	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15. Not well documented by local industries or organizations	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Total Score (up to 10 points per criterion=150 max.)	135	140	140	120	130	135	138	130	135	135	140	112	115	109	116	124	113	120	120	116	116	119	119	120	122	122	118	118

Criteria for Selection of Priority Stormwater Source Controls (cont'd)

Source Control Class	**Infiltration Structures**										**Extensive Green Roof**								**Deep Well Infiltration**									
Candidate BMPs	Infiltration Dry Well (Soakaway)	Precast Concrete Infiltration Chamber	Plastic Infiltration Chamber – Geocellular	Plastic Infiltration Chamber – Infiltrator	Plastic Infiltration Chamber – Perf. Pipe	Plastic Infiltration Chamber – RWL Systems	Infiltration Trench - Surface Inlet	Infiltration Trench - Manhole Inlet	Infiltration Blanket	Filter Drain	Flat Roof	Sloped Roof							Stormwater Dispolsal to Deep Grouwater	Stormwater Storage/Reuse in Aquifer								
Selection Criteria																												
1. Promotes stormwater detention / disposal	7	8	10	10	10	9	7	7	7	7	7	7							10	10								
2. Promotes stormwater retention through infiltration	10	10	10	10	10	10	10	10	10	10	7	7							10	10								
3. Promotes stormwater retention through evapotranspiration	3	3	3	3	3	3	5	3	3	3	10	10							0	0								
4. Provides improvements/ avoids risks to stormwater quality	2	2	2	2	2	10	2	2	2	2	9	9							0	0								
5. Facilitates stormwater reuse	0	0	5	0	0	0	0	0	0	0	0	0							0	10								
6. Widely applicable in a variety of soil conditions in GVRD	5	5	5	5	5	5	5	5	5	5	10	10							5	5								
7. Proven practice and performance in other jurisdictions	8	8	8	8	8	8	8	8	8	8	10	10							8	5								
8. Proven technical detailing available	10	10	10	10	10	10	10	10	10	10	10	10							8	8								
9. Proven specifications available	10	10	10	10	10	10	10	10	10	10	10	10							8	8								
10. Not widely used in GVRD at present	10	10	10	10	10	10	10	10	10	10	10	10							10	10								
11. Relatively low risk of failure in GVRD	5	5	5	5	5	5	5	5	5	5	7	7							5	3								
12. Relatively low cost / expertise requirements	8	8	8	8	8	8	9	9	9	9	4	4							5	3								
13. Anticipated in Water Balance Model / other design tools	10	5	5	5	5	5	10	10	10	10	10	10							0	0								
14. Existing or high likelihood of local demonstration projects	10	10	10	10	10	10	10	10	8	8	10	10							5	3								
15. Not well documented by local industries or organizations	8	8	8	8	8	8	8	8	8	8	8	8							10	10								
Total Score (up to 10 points per criterion=150 max.)	106	102	109	104	104	111	109	107	105	105	122	122							84	85								