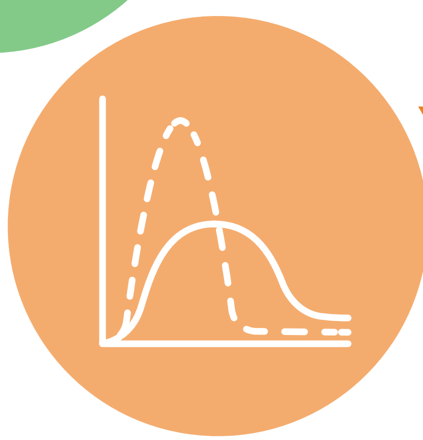
Green Stormwater Infrastructure Common Design Guidelines

FOR THE CAPITAL REGION

CAPTURE & SLOW

CLEAN & INFILTRATE



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APPENDICES AND SUPPLEMENTAL

Note: The appendixes and supplemental documents, will be periodically updated to keep up with advances in research and practice by adding additional GSI facility design guidelines appropriate for the region.

Forward

This resource was created at the request of the Capital Regional District's Integrated Watershed Management – Inter-Municipal Group. The purpose is to present a breadth of regionally appropriate design guidelines and considerations to build Green Stormwater Infrastructure (GSI) facilities on public, private and institutional lands. The primary audience of this resource is local governments and those qualified professionals, developers and building contractors considering or building GSI facilities. With permission from Metro Vancouver Regional District much of this document is based on Metro Vancouver's Stormwater Source Control Design Guidelines 2012 and has been modified and enhanced to be updated and regionally appropriate.

Disclaimer

The design guidelines contained in this resource are not to be used as design standards – before starting please check with the respective local government for design specifications, regulations and jurisdictional authority. These guidelines do not supersede any applicable laws, bylaws, criteria or regulations. At all times, the designer remains responsible for detailed design and satisfactory operation and performance and must meet all Federal, Provincial and Local government requirements.

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Acknowledgments

The technical design guidelines presented in the resource were written, or with permission modified and adapted, by **Opus International Consultants Limited**. **Kerr Wood Leidal Associates Ltd**. provided the technical drawings. **Colquitz Engineering** provided guidance with Part 1, Part 2 and Appendix A.

The CRD and the CRD's Integrated Watershed Management – Inter-Municipal Group would like to thank the following consultants and governments for granting permission to compile, adapt and modify their stormwater management documents for this collaborative document.

- Metro Vancouver - Stormwater Source Control Design Guidelines 2012, written by Lanarc Consultants Ltd., Kerr Wood Leidal Associates Ltd. & Goya Ngan, Landscape Architect.
- District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), technical aspects by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.
- City of Victoria, Rainwater Management Standards – Professional addition (June 2015)

Thank you to RBC Blue Water Project grant for in part funding the creation of this document.

RBC Blue Water Project™

Executive Summary

This resource presents a variety of regionally appropriate Green Stormwater Infrastructure (GSI) design guidelines and implementation considerations. GSI offers local governments an innovative stormwater management tool to help meet legislative responsibilities to protect natural receiving environments from impacts of stormwater, and can also be utilized as a climate change adaptation tool to protect property and infrastructure, while creating climate resiliency.

Working in conjunction with grey infrastructure, GSI can allow for replenishing of groundwater and interflow; reduction of property damage caused by flooding; protect waterways from storm events and summer low flows; protect aquatic habitat; and improve water quality in receiving environments.

GSI facilities are designed to:

Capture & Slow > the flow of stormwater by re-directing it to naturalized facilities with safe dispersion.

Clean & Infiltrate > stormwater runoff before it reaches the natural receiving environments.

Store & Convey > stormwater to minimize peak flows in heavy rain events and for safe conveyance in the piped and natural storm drain system.

Part 1 – Background – Solving Stormwater: Introduces the purpose and intended audience, along with GSI regional implementation considerations, drivers, principles, benefits, jurisdictional roles and tools.

Part 2 – GSI Application: Outlines the application of GSI via the design process, selection of the GSI drivers, and provides the rainfall targets required for proper sizing of a facility with other design resources to be considered.

Appendices and Supplementals: Numerous appendices make up the bulk of this document with design guidelines for a breadth of regionally appropriate GSI facilities for application on road-right-of-way, private, institutional and public properties. Each GSI design guideline presents design, siting, sizing, contaminant and runoff reduction, and maintenance considerations that are required for properly functioning facilities that work to clean, infiltrate or detain for the safe delayed or slowed conveyance of stormwater. The appendices also include a planting resource for vegetated GSI facilities and regional considerations for potential unintentional interactions with sanitary sewers.

The common design guidelines contained in this resource are not to be used as design standards.

Before starting, please check with the respective local government for design specifications, regulations and jurisdictional authority. The appendices will be periodically updated to keep up with advances in research and practice by adding additional GSI facility design guidelines appropriate for the region. The most up-to-date version of this document found at: www.crd.bc.ca/education/green-stormwater-infrastructure

Part 1 – Background – Solving Stormwater

1.0 Introduction

Solving stormwater is about better management of stormwater volume and quality. As the communities across the capital region continue to grow, densify and become more connected by roads, there is a mounting loss of forest and wetland, with impervious surfaces becoming a larger percentage of the land use cover. This has altered the natural hydrology of the watersheds and has a negative impact on the proper function and health of the fresh and marine aquatic systems that function as natural receiving environments of stormwater.

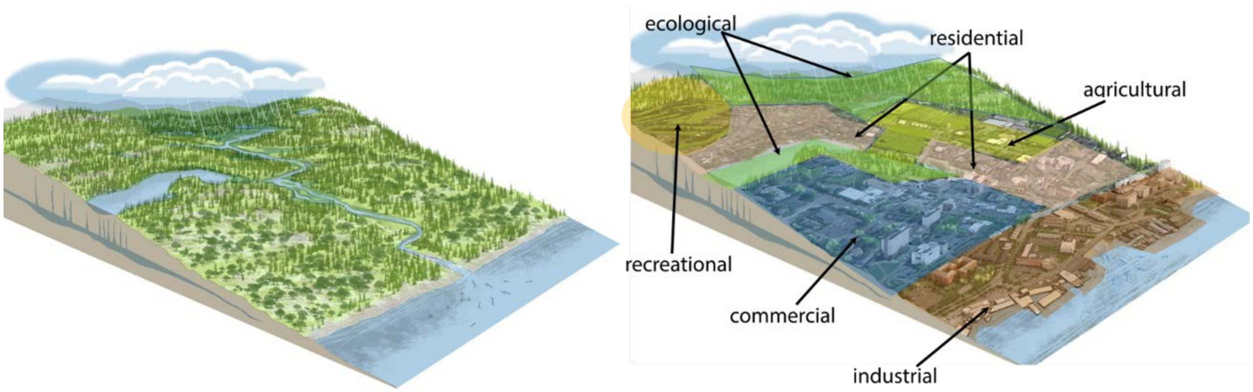

Figure 1 Natural Watershed vs. Developed Multi-Use Watershed

In addition, aging infrastructure and the impacts of climate change are expected to amplify the current stressors on stormwater drainage systems and overall watershed health and function. Because watersheds cross local government borders, how each respective community is designed has a direct effect on the health of shared waterways and marine environments through stormwater runoff quality, quantity and rate of discharge.

This resource presents a wide selection of regionally applicable design guidelines for Green Stormwater Infrastructure (GSI) facilities that are suitable for road Right-Of-Ways (ROW), or on public, commercial, residential or institutional properties of various parcel sizes. GSI can be integrated as a retrofit, re-build or in new developments. Where appropriate, GSI facilities may be considered as standalone facilities, or as part of a treatment train system (sequence of multiple treatment facilities) integrated into a fully green or traditional grey storm drain system. It is the responsibility of the Qualified Professional (i.e., Professional Engineer, Professional Landscape Architect) to insure that techniques utilized are appropriate for a given situation.

1.1 About this Resource

GSI offers local governments an innovative stormwater management tool to better meet legislation to protect the aquatic receiving environment and human health from stormwater impacts, and prepare for the impacts of climate change. GSI facilities should be designed to address volume reduction (capture and slow), water quality (clean and infiltrate) and rate control (store and convey) design drivers, via proper sizing of GSI facilities. This resource showcases an array of regionally specific common design guidelines for GSI facilities.

The design guidelines for each facility in this resource identifies design, siting, sizing, contaminant and runoff reduction, and maintenance considerations required for properly functioning facilities that work to clean, infiltrate or detain for the safe delayed or slowed conveyance of stormwater.

Please refer to www.crd.bc.ca/education/green-stormwater-infrastructure for the most current version of each appendix, as dated on the front page.

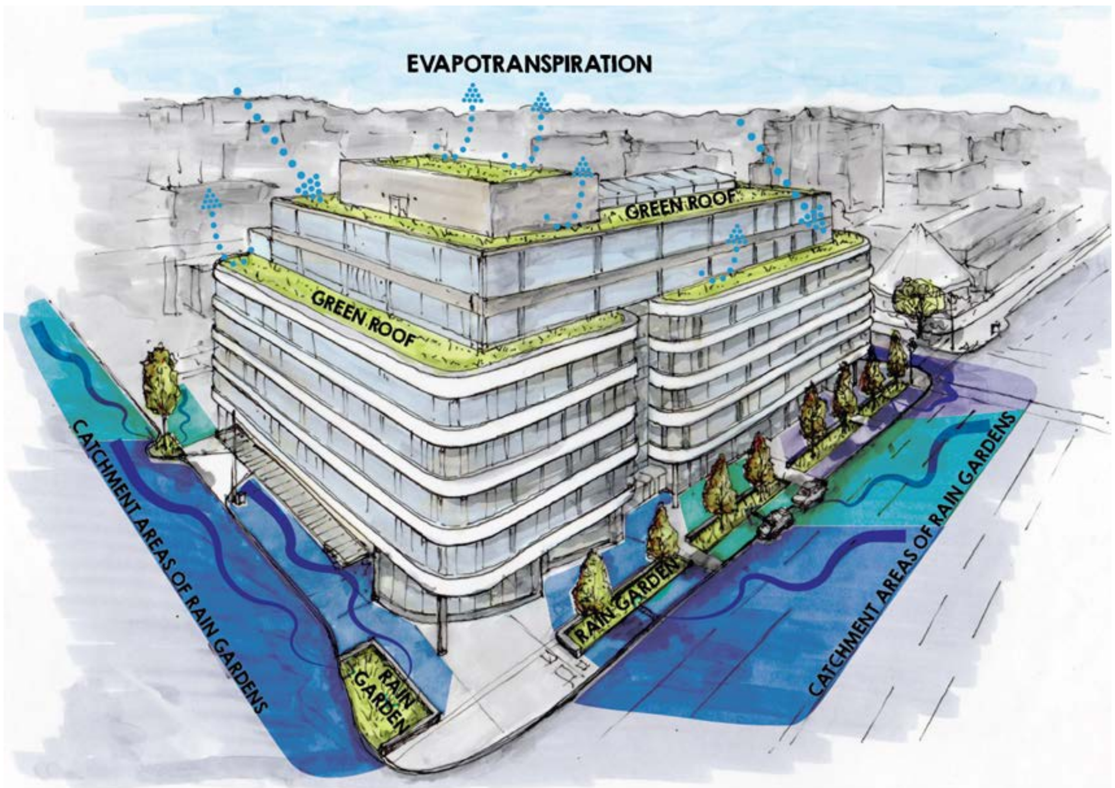

Figure 2 Illustration of GSI Implemented at the Atrium, Victoria, BC

1.2 Intended Audience

1.2.1 Primary Audience

1. Local Governments – involved in funding and making decisions about municipal infrastructure and stormwater management including: elected officials, municipal managers, planners, engineers, technical and maintenance staff, and community associations.
2. Qualified professionals, developers, building contractors and maintenance workers – involved in planning, designing, constructing and maintaining GSI facilities on public or private lands.

1.2.2 Secondary Audience

1. Commercial, Institutional & Multi-Residential property owners, managers and operations staff interested in GSI on their property – small to large properties, urban to rural parcels.
2. Residential Land Owners interested in GSI on their property – small to large properties, urban to rural parcels, interested in GSI on their property.

1.3 Solving Stormwater

How communities in the capital region develop and manage stormwater volume, rate and quality, has a direct effect on the ecological health and function of the region's shared watersheds, waterways and shorelines.

Whether at a property, neighbourhood, urban catchment or watershed scale, land development negatively alters the natural hydrological cycle. When trees, other natural vegetation and soils are replaced with storm drain pipes and impervious surfaces (rooftops, paved roads, parking lots and compacted and waterlogged soils), less rain infiltrates into the ground and more runs off becoming stormwater.

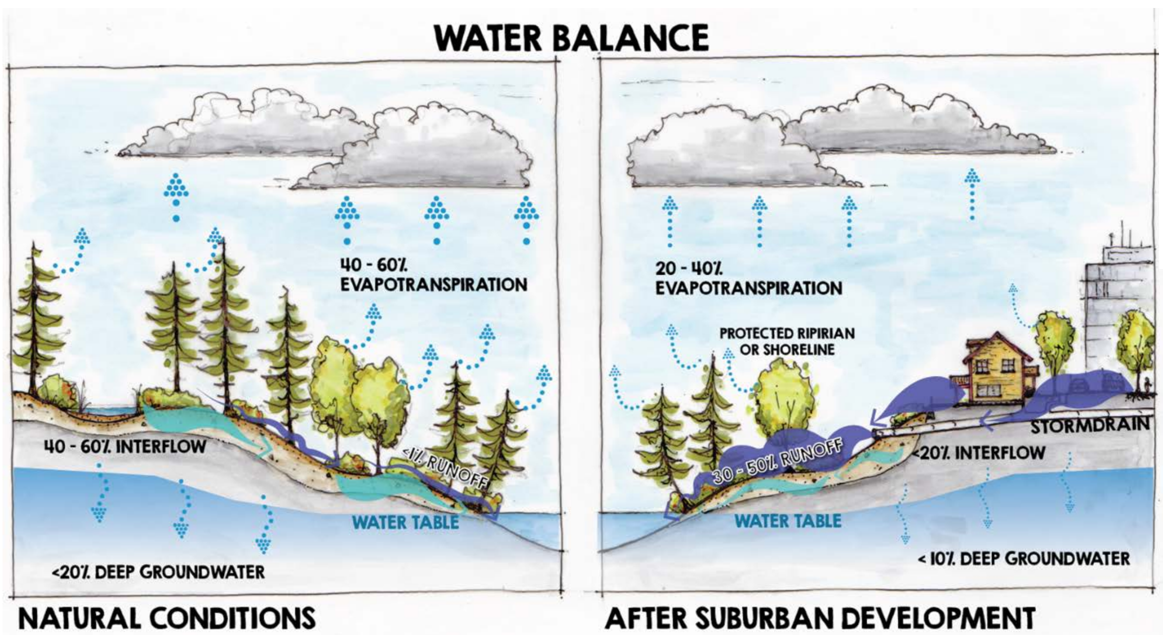

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Figure 3 Water Balance

This alteration of the hydrological cycle results in less water infiltrating into the landscape and too much stormwater too quickly being conveyed by storm drains directly into waterways and shorelines. The volume and speed and contaminants carried within the stormwater causes degradation of these natural receiving environments. The traditional grey (piped) infrastructure is designed to move stormwater off the impervious surfaces and away from the built environment as quickly as possible. Much of this piped (grey) system typically provides only minimal removal of contaminants captured by catch basin and oil/grit separators (when well maintained) throughout the catchments. Much less common are proprietary end-of-pipe stormwater treatment devices. Thus, most contaminants in stormwater are transported to the natural receiving environments, further impacting water quality for aquatic species and human recreational values.

1.4 What is Green Stormwater Infrastructure?

GSI facilities are designed to intercept, slow, treat and store stormwater runoff directed from impervious surfaces. By design, these facilities primarily work by mimicking natural (undeveloped) hydrology through bioretention (soil-water-plant interactions), infiltration or detention.

GSI facilities presented in this guidebook are generally smaller, decentralised, site-specific alternative stormwater management facilities for public lands such as parks and ROW, private, commercial and institutional lands in the ultra-urban to rural setting. Depending on the site-specific conditions and municipal requirements, these GSI facilities may or may not be required to be connected to the piped storm drainage system. Opportunistically, GSI may be designed for new development and retrofitted into existing or redevelopments.

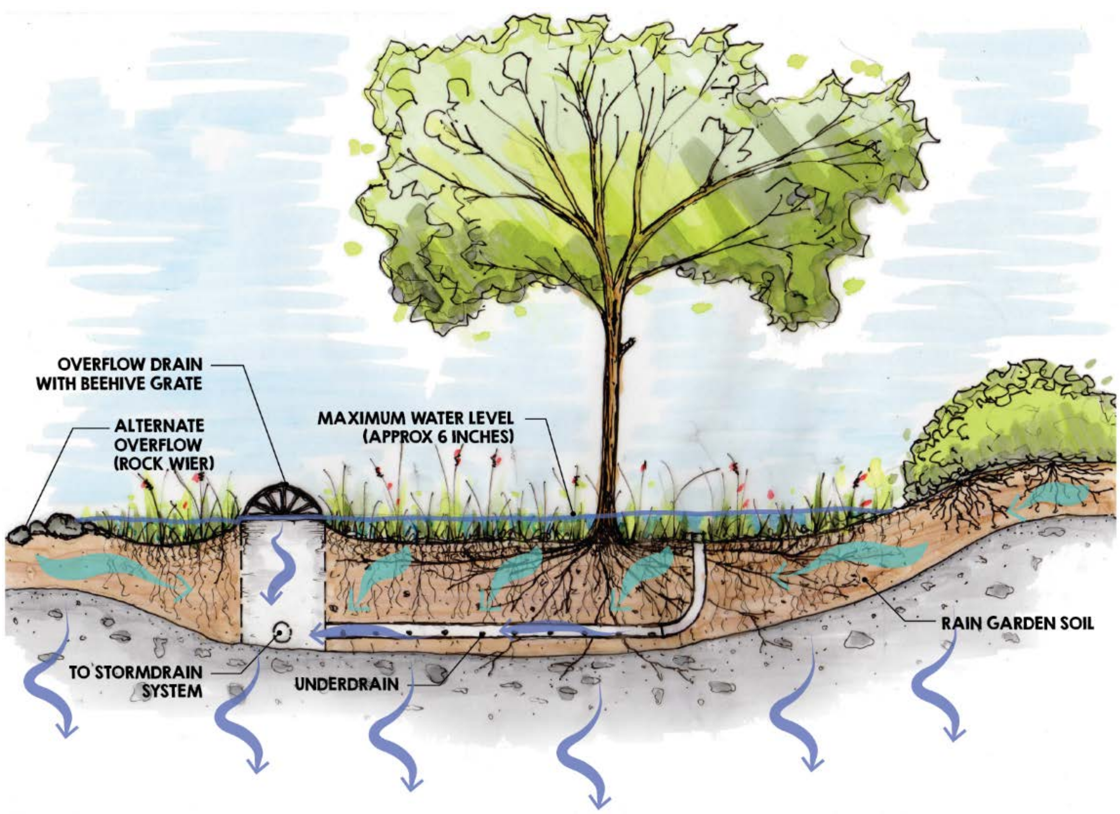

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Figure 4 Cross Section of a Rain Garden

1.5 Objectives of Green Stormwater Infrastructure

The objective of using GSI facilities as a part of a stormwater or integrated watershed management strategy is to effectively protect local watersheds, and ultimately the marine receiving environment, through reducing stormwater contamination and improving overall watershed function. GSI facilities strategically placed throughout communities and watersheds can effectively remove nutrients, pathogens and trace metals from stormwater, and reduce the volume, rate, duration and intensity of stormwater flows as close to the source as possible (i.e., where rain falls on impervious surfaces). Careful selection and placement of a GSI facility many have significant social, economic and environmental benefits.

1.6 Design Drivers of Green Stormwater Infrastructure

On a site-by-site, neighbourhood or watershed scale, GSI aims to address the impacts of stormwater by better managing stormwater where it is being generated. Working in conjunction with, or an alternative to, grey infrastructure, GSI can provide green space, allow for reduction in potential property damage caused by flooding, protection of waterways and aquatic habitat from high flow storm events and seasonal low flows, and replenish groundwater. GSI drivers can help address stormwater stressors on both the natural environment and grey infrastructure through site-specific design.

GSI facilities are designed to:

Capture & Slow the flow of stormwater by re-directing it into naturalized facilities with safe dispersion;

Clean & Infiltrate stormwater runoff before it reaches natural receiving environments; and

Store & Convey stormwater to minimize peak flows in heavy rain events and for safe conveyance in the piped and natural storm drain system.

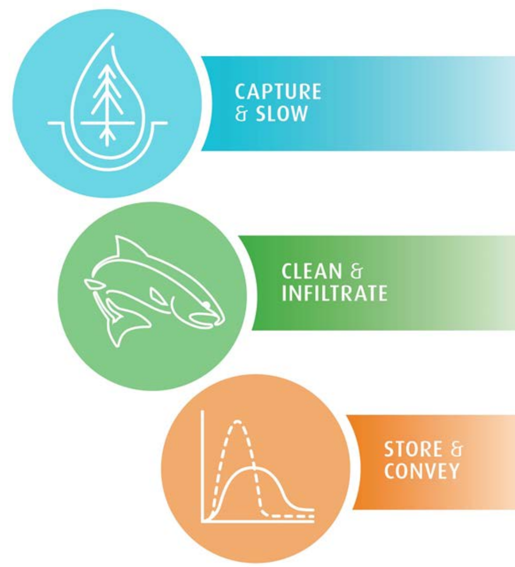

Figure 5 GSI Design Drivers

1.7 Principles for Effective Planning of GSI Facilities

1. Mimics Natural Hydrology
2. Integrates Facility into Overall Site Design
3. Provides Reliable Pollutant Removal Performance
4. Manageable Maintenance
5. Attractive Community Amenity
6. Delivers Multiple Community Benefits
7. Provides Learning Opportunity for Future Improvement
8. Recognizes Accumulative Environmental Benefits
9. Reduces Infrastructure Costs
10. Acceptable Life Cycle

1.8 Benefits of GSI

- Reduce water quality guidelines exceedances
- Reduce levels of contaminants
- Reduce risk of erosion in receiving environments
- Increase protection of sensitive aquatic ecosystems
- Reduce sewer overflows
- Increase climate change resilience
- Expand green amenities
- Increase protection of human health
- Reduce flood risk
- Cost effective when opportunistically implemented
- Visually raises awareness of stormwater

1.9 Land Use Cover

Percentage of land use cover, such as forest/trees, agriculture, open green spaces and impervious surfaces in a watershed is a good indicator of the health and function of the watershed and aquatic environments. Regional land use cover data (http://hat.bc.ca/our-blog/urban-forest-stewardship-initiative) indicates that the region is trending towards a continued increase in impervious cover and a decrease in forest cover, at all scales - regional, municipal, watershed, urban catchment, neighbourhood and property scale. Without GSI, the result of development will be an increase in peak runoff rates and a decrease in the ecological health of watercourses. Learn more at:

https://www.crd.bc.ca/education/our-environment/watersheds/watershed-maps-flow-diagrams/watershed-land-cover-maps.

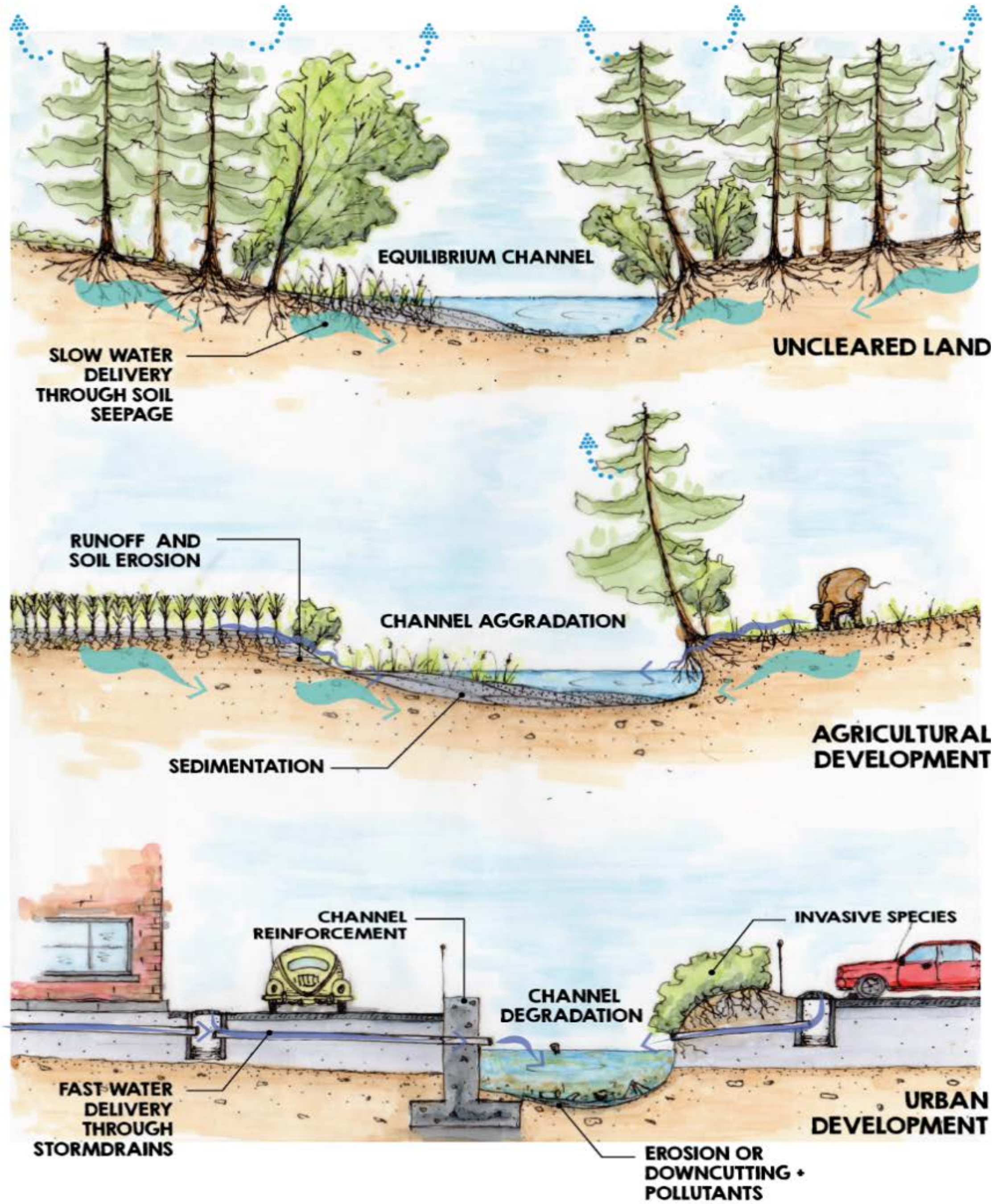

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Figure 6 Impacts of Land Use Cover On a Watershed and Creek

1.10 Climate Change Impacts and Adaptation

In April 2017, the CRD released 2 key resources to assist the numerous stakeholders across the region to prepare for climate change:

- *Taking Action on Climate Change Capital Regional District - Regional Climate Action Strategy*[1], is a region-wide strategic planning document that recognizes the importance of our region's natural environment and the necessity of taking strategic action on climate change to strengthen the resilience of our region as we face uncertainty and;
- *Climate Projections for the Capital Region* (April 2017)[2], is a data-rich technical document with high-resolution regional projections to understand the details of how the region's climate may change by the 2050s and 2080s. The report indicates that climate change is expected to bring increased rainfall volume, frequency and intensity throughout the fall, winter and spring. In the summer, there is an expected decrease in rain with longer duration of dry spells and hotter temperatures. These climate projections will most likely amplify current stressors on the traditional storm drain system and the natural receiving environment. GSI that utilize these projected climate changes can best be implemented opportunistically at site, catchment and watershed scale, as part of a cost effect climate adaptation strategy for stormwater infrastructure that also protects the natural environment from the impacts of stormwater. Appendix A, Table 1 provides regionally specific rainfall capture target amounts required when sizing typical GSI facilities.

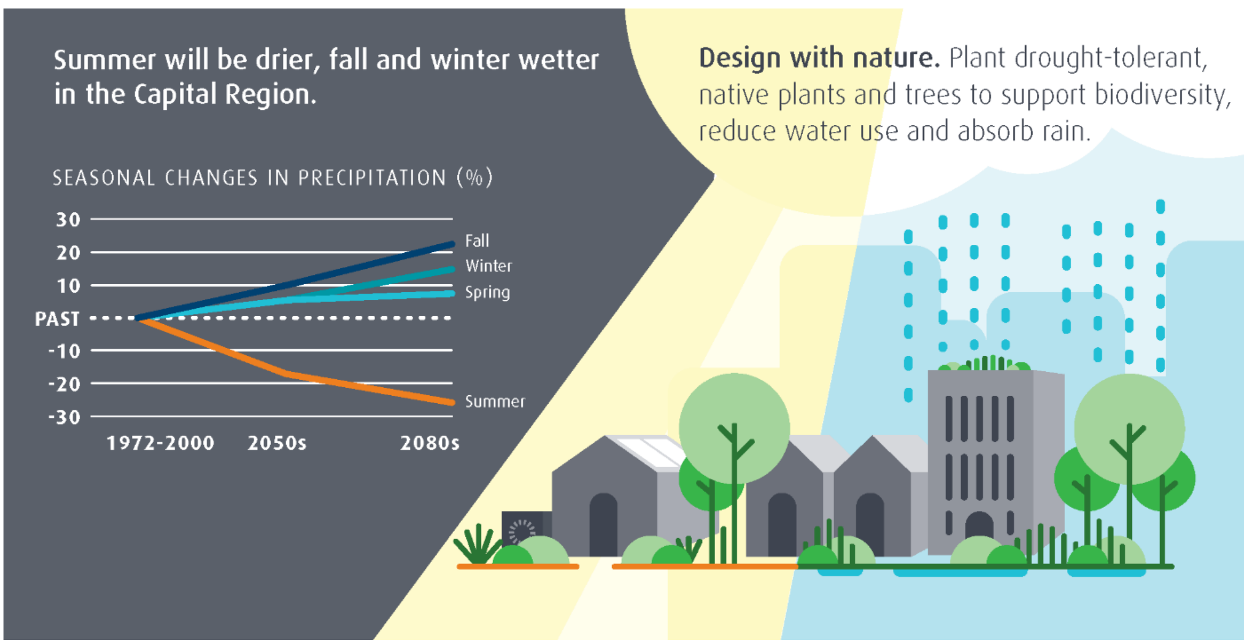

Figure 7 Season Rainfall Projection Illustration

[1] https://www.crd.bc.ca/project/climate-action

[2] https://www.crd.bc.ca/about/data/climate-change

1.11 Stormwater Monitoring

Many common contaminants in stormwater are non-point source pollution from deposits on impervious surfaces and the land, such as metals, nutrients, hydrocarbons, soils and bacteria. These contaminants are transported in stormwater from impervious areas into the storm drain system to natural water bodies and shorelines. A summary of typical stormwater sourced contaminants in freshwater and marine receiving environments are summarized in Table 1.

The CRD's Environmental Protection Division works alongside local governments and Island Health Authority to plan, promote and coordinate the management of stormwater quality with the goal to minimize the impacts from stormwater on the natural receiving environment. Program staff monitor, identify and track the sources of contamination in stormwater, creeks, lakes, harbours and the ocean through bacterial and chemical sampling to ensure that provincial water quality guidelines are met for sensitive aquatic ecosystems and recreational use. In the summer, Island Health Authority monitors public beaches for bacterial contamination. GSI implementation and evaluation is an important tool in contaminant reduction.

CRD annual stormwater quality monitoring reports can be found at:

https://www.crd.bc.ca/about/document-library/Documents/annual-reports/environmental-protection/integrated-watershed-management

The CRD stormwater monitoring program uses the following water quality guidelines:

Sensitive Ecosystem Health Water Quality

British Columbia Ambient Water Quality Guidelines are developed to promote healthy ecosystems and protect human health. Water quality guidelines are science-based levels of physical, biological and chemical parameters for the protection of water uses such as aquatic life, wildlife, agriculture, drinking water and recreation. Learn more at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines

Canadian Water Quality Guidelines for the Protection of Aquatic Life provides science-based goals for the quality of aquatic ecosystems. These water quality guidelines are intended to provide protection of freshwater and marine life from anthropogenic stressors such as chemical inputs or changes to physical components (e.g., pH, temperature, and turbidity). Learn more at:
http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/

Recreational Water Quality

British Columbia Recreational Water Quality for Human Health provides science-based goals for the quality of recreational waters used for exercise, play and relaxation to protect people's physical exposure to pathogens and contaminants. Health authorities may sample the water quality of recreational beaches or create reports on recreational water quality concerns to help inform them of any public health risks. At their discretion, they may decide to close beaches, issue public advisories or post warning signs based on these sampling results until the water samples indicate that it is safe to resume swimming in these waters. Learn more at:

http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/recreational-water-quality

Water Quality Objectives

British Columbia Water Quality Objectives are used to manage fresh and marine water quality. Water quality objectives may be developed for specific water bodies to protect water uses in that watershed. Attainment monitoring is used to determine if water quality objectives are being met. Learn more at:

http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-objectives

Flow Monitoring

Several permanent and temporary flow monitoring stations have been installed on creeks throughout the capital region's core area. Once these stations have been installed for sufficient time to develop flow trends, the data will be interpreted and made available upon request.

Table 1 Typical Stormwater Contaminants in Natural Receiving Environments

Contaminant	Parameter Monitored by CRD staff	Typical Source
Solids	Total suspended solids (TSS) Turbidity	sand, silt, soils, decomposing organics, garbage/trash, cooking oil and grease
Bacteria	Fecal coliform *Escherichia coli* (*E. coli*) *Enterococcus*	Cross contamination from domestic sewage system, wild, farm and domestic animal waste, plant or soil material
Metals	Arsenic (total) Aluminum (total and dissolved) Cadmium (total) Chromium (total) Copper (total) Iron (total) Lead (total) Nickel (total) Zinc (total)	Vehicle parts and fluids, industrial waste, domestic waste, naturally occurring and leaching from soils, mineral leaching from metals exposed to weather
Nutrients	Total phosphorus Orthophosphate Nitrate (NO3) Nitrate plus nitrite (NO3 + NO2) Nitrite (NO2)	Fertilizers, farm-animal waste, faulty septic systems, vegetation decomposition
Physical	Temperature Conductivity Salinity Dissolved Oxygen pH	Indicates changes in land-based activities
Organics	Polycyclic aromatic hydrocarbons (PAH)	Combustion engines, petroleum based products, wood stoves

1.12 Jurisdictional Responsibilities for Protection of Stormwater Quality

GSI offers local governments an innovative stormwater management tool to help meet their responsibilities to protect natural receiving environments from impacts of stormwater, and can also be utilized as a climate change adaptation tool to protect property and infrastructure, while creating climate resiliency.

1.12.1 Key Federal and Provincial Legislation

The jurisdictions involved in protection of stormwater quality, either directly or indirectly, include all municipalities, districts, electoral areas, the Capital Regional District, Island Health Authority, the BC Ministry of Transportation and Infrastructure, the BC Ministry of Forests, Natural Resource Operations and Rural Development, the BC Ministry of Environment and the Department of Fisheries and Oceans Canada (DFO). These agencies set guidelines and administer protection of groundwater and surface water for proper ecological function, protection of water quality for the environment, sensitive ecosystem habitat and public health recreational contact.

Table 2 Key Federal and Provincial Legislation Related to Stormwater Management Impacts

Key Federal and Provincial Legislation	Section relevant to stormwater management impacts
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Check with the respective local governments for local bylaws which meets or beats the below regulations.	
Fisheries Act (Federal R.S.C., 1985, c. F-14 – updated 2012)	
Fisheries Protection and Pollution Prevention	35 – Serious harm to fish 36 – Deposit of deleterious substance prohibited 37 – Minister may require plans and specifications if a person carries on or proposes to carry on any work, undertaking or activity that results or is likely to result in serious harm to fish or in the deposit of a deleterious substance in water frequented by fish, ecological significant areas etc. 38 – Duty to notify
Regulations	43 – 1) The Governor in Council may make regulations for carrying out the purposes and provisions of this Act and in particular, but without restricting the generality of the foregoing, may make regulations: (b) respecting the conservation and protection of fish; (h) respecting the obstruction and pollution of any waters frequented by fish; (i) respecting the conservation and protection of spawning grounds; (n) establishing a list of aquatic invasive species; (o) respecting the control of aquatic invasive species, including regulations respecting the prevention of the spread of such species, etc.
Riparian Areas Protection Act **(BC – updated 2014)**	
	2-11, 36 Repealed 12 – Provincial directives on streamside protection 13 – Regulation-making authority

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Key Federal and Provincial Legislation	Section relevant to stormwater management impacts
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Check with the respective local governments for local bylaws which meets or beats the below regulations.	
Riparian Areas Protection Act Riparian Areas Regulation (B.C. Reg. 376/2004– updated 2014)	
	2 – Purposes of this regulation (a) to establish directives to protect riparian areas from development so that the areas can provide natural features, functions and conditions that support fish life processes, and (b) to facilitate an intergovernmental cooperation agreement between the ministry, Fisheries and Oceans Canada and the Union of British Columbia Municipalities including the ability for individual intergovernmental cooperation agreements with local governments. 3 – Application – this regulation applies within the geographic boundaries of the CRD. 4 – Assessment reports required before development 5 – Development of strategies for monitoring, enforcement and education 6 – Use of local government powers for protection and enhancement of areas 7 – Preparation of assessment report by qualified environmental professional 8 – Transitional – "former regulation" means the Streamside Protection Regulation, B.C. Reg. 10/2001
Water Sustainability Act (BC – new 2016)	
Part 2 — Licensing, Diversion and Use of Water	11 – Changes in and about a stream 15 – Environmental flow needs 16 – Mitigation measures 17 – Sensitive streams mitigation 22 – Precedence of rights 26 – Amendment or substitution of authorization, change approval or permit 30 – Beneficial use 39 – Water reservations
Part 3 — Protecting Water Resources	43 – Water objectives 46 – Prohibition on introducing foreign matter into stream 47 – Remediation orders in relation to foreign matter in stream

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Key Federal and Provincial Legislation	Section relevant to stormwater management impacts
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Check with the respective local governments for local bylaws which meets or beats the below regulations.	
	59 – Prohibition on introducing foreign matter into well 60 – Remediation orders in relation to foreign matter in well Division 4 — Water Sustainability Plans (64-85) Division 5 — Temporary Protection Orders (86-88)
Part 6 — Regulations (124-136)	126 – Regulations respecting administration and governance 127 – Regulations respecting licensing, diversion and use of water and related matters 128 – Regulations respecting sensitive streams 129 – Regulations respecting streams and stream protection 130 – Regulations respecting groundwater and groundwater works 131 – Regulations respecting measuring, testing and reporting 132 – Regulations respecting water sustainability plans
Part 8 — Consequential and Related Amendments	See various
Water Sustainability Act Water Sustainability Regulation (B.C. Reg. 36/2016)	
Division 2 — Sensitive Streams	17 – Sensitive streams designated 18 – Applications respecting sensitive streams 19 – Mitigation requirements 20 – Mitigation measures 21 – Compensatory mitigation measures
Division 4 — Exemptions from Section 6 (1) of Act	31 – Exemption — corridor drainage 32 – Exemption — local government drainage works 33 – Exemption — agricultural drainage

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Key Federal and Provincial Legislation	Section relevant to stormwater management impacts
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Check with the respective local governments for local bylaws which meets or beats the below regulations.	
	34 – Exemption — building perimeter drainage 35 – Exemption — wells 35.1 – Diversion and use of water for firefighting
Part 3 — Changes in and about a Stream	37 – Authority to make changes in and about a stream 38 – Notice to habitat officer 39 – Authorized changes 40 – Limitation on making authorized changes under this Part 41 – Obligations of persons making authorized changes under this Part 42 – Failure to comply with this Part when making authorized change 43 – Protection of water quality 44 – Protection of aquatic ecosystem 45 – Protection of other water users

1.12.2 Local Government Regulatory Tools, Authority and Responsibilities

As watersheds cross jurisdictional borders it is important that upstream and downstream communities work together to minimize the ecological, health, social and financial impacts of stormwater. It is the local governments or respective jurisdictions (e.g., provincial ministries) that own, operate and maintain the storm drain systems that carry stormwater from roads, public or private to the nearest waterway. Within First Nation communities it is a responsibility of the Band Council, in cooperation with Indigenous and Northern Affairs Canada (INAC) and Health Canada, to build and manage stormwater infrastructure and protect receiving environments from the impacts of stormwater. These jurisdictions are responsible for the management of stormwater runoff and to meet the requirements of federal and provincial legislation related to stormwater impacts.

The regulatory tools, authority and responsibility of stormwater management in British Columbia occurs at the municipal level under authority of the Provincial Local Government Act (LGA). Under authority of the LGA, the local governments and the CRD have Liquid Waste Management Plans (LWMP) or area based stormwater quality bylaws or service agreements. These LWMP and bylaws set out a cooperative framework to protect the aquatic ecosystems and public health from the impact of stormwater through stormwater quality monitoring, education, engagement and enhancement. Across the capital region, there are also unique cooperative initiatives between First Nations, neighbouring local governments and the CRD for the management and protection of watersheds and shorelines.

The LGA contains development planning, servicing, financing and approval provisions applicable to stormwater management (e.g., enacting bylaws that encourage more natural drainage or implementation of GSI). Table 3 outline sections of the LGA that can be utilized by local governments as tools to implement GSI and other stormwater management activities.

Table 3 Tools Available Under the LGA for Implementation of GSI and Other Stormwater Management Initiatives

Relevant Sections of the BC Local Government Act Revised 2015	Tools available under the LGA for Implementation of GSI
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Where applicable, check with the respective local governments for enacted local bylaws.	
Part 9: Regional Districts: Specific Service Powers Drainage	Division 3 — Drainage, Sewerage and Related Matters 306 – Special drainage and sewerage authority May, by bylaw, (a) regulate and prohibit the design and installation of drainage works provided by persons other than the regional district, and (b) require owners of real property to connect their buildings and structures to the appropriate drain connections in the manner specified in the bylaw. 306-313 – Defines special drainage authority including: watercourse may be included in drainage system; works for controlling drainage; watercourse agreements between adjoining municipalities or land owners; requirements respecting drainage works and; appropriation of stream channel or bed. 314 – authority subject to *Water Sustainability Act* Division 7 — Other Specific Service Powers 327 – If the regional district provides a service in relation to the control of the deposit and removal of soil and the control of the deposit of other materials, it may regulate removal and deposit of soil or other material on any land in the regional district or in any area of the regional district.
Soil and Fill	The Soil Conservation Act gives local government permitting authority for soil removal and placing of fill. Continued on next page

Relevant Sections of the BC Local Government Act Revised 2015	Tools available under the LGA for Implementation of GSI
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Where applicable, check with the respective local governments for enacted local bylaws.	
Part 10- Regional Districts: Service Structure and Establishing Bylaws	The CRD, on behalf of the participants, provide area based stormwater quality monitoring, watershed based initiatives and education. These services are provided for under: Liquid Waste Management Plans (LWMP) Stormwater Quality Management Establishing Bylaws Harbours Environmental Action Service Establishing Bylaw
Part 13: Regional Growth Strategy	426, 428, 429 – Provides for goal statements that promote human settlement that is socially, economically and environmentally healthy and that makes efficient use of public facilities and services, land, water and other resources. Including reducing water pollution and protecting the quality and quantity of ground and surface waters.
Part 14: Planning and Land Use Management Official Community Plans (OCP) Development Approval	**Division 4 — Official Community Plans (OCP)** 473 – Content and process must include statements on the restrictions on the use of land that is subject to hazardous conditions or that is environmentally sensitive to development, and the approximate location and phasing of any major road, sewer and water systems. 474 – Policy Statement that may be included may include policies relating to the preservation, protection, restoration and enhancement of the natural environment, its ecosystems and biological diversity. **Division 6 – Development Approval Information Requirements** 484-487 – by bylaw, may make requirements for development approval information regarding potential impacts of a proposed development on local infrastructure and the natural environment of the area affected. Continued on next page

Relevant Sections of the [BC Local Government Act](#) Revised 2015	Tools available under the LGA for Implementation of GSI
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Where applicable, check with the respective local governments for enacted local bylaws.	
Development Permits	**Division 7 – Development Permits** 488-491 – by bylaw, may designate areas for protection of the natural environment, ecosystems and biological diversity, development from hazardous conditions and protection of farming. Establishment of objectives for the form and character of intensive residential, commercial, industrial or multi-family residential development. This may include requirements and conditions or sets standards within designated development permit area.
Other Permits and Permit Matters	**Division 10 – Other Permits and Permit Matters** 500 – by bylaw, may require tree cutting permits in relation to areas affected by flooding or other hazards
Drainage Collection Systems for Subdivision and Development	**Division 11 — Subdivision and Development: Requirements and Related Matters** 506-510 – by bylaw, may require, regulate and prescribe standards for a drainage collection system or a drainage disposal system be provided, located and constructed in accordance with the standards established in the bylaw. Requirements for excess or extended services means a provision may be requested of developer to provide park land or portion of the costs of the drainage system that will serve land other than the land being subdivided or developed may be required. 506-508 – requires that a drainage collection or management system be provided, located and constructed for subdivisions in accordance with standards established in a bylaw.
Runoff control requirements	523 – by bylaw, may (1) require that an owner of land who carries out construction of a paved area or roof area, manage and provide for the ongoing disposal of surface runoff and stormwater in accordance with the requirements of a bylaw, (2) establish the maximum percentage of the area of land that can be covered by impermeable material and, (3) make different provisions for different zones, uses, areas, sizes of impervious surfaces, terrain, surface water or groundwater conditions. Continued on next page

Relevant Sections of the BC Local Government Act Revised 2015	Tools available under the LGA for Implementation of GSI
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Where applicable, check with the respective local governments for enacted local bylaws.	
Flood Plains Areas	524 – by bylaw, may designate the land as a flood plain, specify the flood level for the flood plain, and the setback from a watercourse, body of water, etc.
Landscaping	527 – by bylaw, may require, set standards for and regulate the provision of screening or landscaping for preserving, protecting, restoring and enhancing the natural environment, and/or preventing hazardous conditions.
Farming Areas	514 – Land Title Act, and Agricultural Land Commission Act regulates subdivision of lands and minimum parcel size. 552 – local governments, with approval of the Minister of Agriculture and Lands, make bylaws with respect to farm operations, however, this section does not expressly provide for stormwater management. Other relevant Provincial Acts: Farm Practices Protection (Right to Farm) Act Water Sustainability Act
Drainage Service Delivery and Cost Recovery	559 sets out the general requirements under which local governments may charge DCCs which enables local governments to providing, constructing, altering or expanding drainage to service, directly or indirectly, the development for which the charge is being imposed. 570 – Municipal development works agreements with private developers, including works such as drainage.
Part 16 — Municipal Provisions Drainage Works	**Division 4 — Municipal Irrigation Services and Drainage Works** 639 – District/municipal drainage works: District/municipality may collect the water from any highway by means of drains or ditches, and convey the water to, and discharge the water in, the most convenient natural waterway or watercourse. When proposing to construct drains or ditches must publish in a newspaper once a week for 4 consecutive weeks. All claims for damages or compensation arising out of the construction, maintenance, operation or use of the works must be filed with the municipality within 1 month from the date of the 4th publication of the notice. Continued on next page

Relevant Sections of the [BC Local Government Act](#) Revised 2015	Tools available under the LGA for Implementation of GSI
This table is for quick reference only and may not be exhaustive. Refer to original legislation. Where applicable, check with the respective local governments for enacted local bylaws.	
Part 18: Legal Proceedings in Relation to Local Governments and Other Authorities Drainage Works	735 – indicates that there is a 6-month statute of limitations in which to lay claim to any damages form the works done. 736 – states that notice must be delivered to the municipality in writing within 2 month from the date on which the damage was sustained. 744 – Immunity in relation to certain nuisance actions, a municipality or regional district, is not liable in any action based on nuisance if the damages arise, directly or indirectly, out of the breakdown or malfunction of a water or drainage facility or system.

Part 2 – Green Stormwater Infrastructure – Application

2.0 GSI Design Drivers

Solving stormwater is about managing stormwater volume and quality from a site to watershed scale.

GSI may be designed for new development and retrofitted into existing or redevelopments. Working in conjunction with, or an alternative for, grey infrastructure, GSI can allow for replenishing of groundwater and interflow, reduction of property damage caused by flooding, protect waterways from storm events and summer low flows, protect aquatic habitat and improve water quality in receiving environments.

GSI facilities are designed to:

Capture & Slow > the flow of stormwater by re-directing it to naturalized facilities with safe dispersion.

Clean & Infiltrate > stormwater runoff before it reaches natural receiving environments.

Store & Convey > stormwater to minimize peak flows in heavy rain events and for safe conveyance in the piped and natural storm drain system.

2.1 GSI Design Process

In any new development, redevelopment or retrofit project on public, private, commercial or institutional lands the design of GSI should be considered as an integrated component early in the design process. This section outlines a design process for GSI facilities – identifying key steps and their arrangement in a typical development process from early planning through to field reviews and monitoring.

The attached appendices present design guidelines with more specific details of design considerations and process for the respective GSI facility.

Table 4 GSI Design Process

Design Stage	Objective
1. Pre-design/early stages of any construction, development, or re-development	Find synergies and save money in public or private new, redevelopment or retrofit projects (i.e., private redevelopment installing a GSI on the ROW, integrating bike lanes with GSI facilities). Determine what documentation and process is required from start to finish.
2. Planning & Stormwater Related Requirements for Site	Identify requirements (respective local government) of a local bylaw or guidelines for design are applicable (i.e., limits to percentage of impervious area or pre-/post-stormwater flow, qualified professional input or design, GSI-related design targets or criteria, etc.) or stormwater management plans for the watershed or catchment area, or as required by jurisdiction (i.e., oil grit separator may be required by your local municipal stormwater bylaw).
3. A. Drivers for GSI B. Stormwater Capture Targets for Site C. Simplified Sizing Approach for GSI facilities	How could implementation of GSI assist in achieving better stormwater management at a site, catchment, watershed and receiving environment scale? Prioritize the 3 drivers for GSI specific to the site. **> Slow – Reduce piped volume with safe dispersion** **> Clean – Provide water quality treatment and infiltration** **> Store – Provide rate control/detention for safe conveyance** Determine expected site rainfall and stormwater capture targets for simplified sizing approach for GSI facility. Identity the current or potential (for new/retrofit developments) "effective" impervious area as the target runoff area for the GSI facility.
4. A. Site Analysis B. Design Considerations & Site Constraints C. Strategies for Dealing with Limited Space	Gather critical data for site: expected rainfall for site, infiltration potential and constraints (depth to ground water, site sloping, proximity to steep slopes, existing vegetation cover, soil mapping, infiltration tests, potential soil contaminants due to historical use of site). Determine the receiving waters and pollutants of concern for that aquatic ecosystem. Analyse the current and proposed land use(s) draining to the GSI facility should also be used to determine the stormwater pollutants of concern. Qualified Professional (i.e., experienced Professional Engineer, Professional Landscape Architect) is advised and may be required. Continued on next page

Design Stage	Objective
5. GSI for Contaminant Reduction & Treatment Trains	Examine performance of GSI facilities for site-specific-receiving water body contaminant reduction. Would the site benefit from stormwater treatment trains (i.e., sequence of multiple stormwater treatments)?
6. Detail Design of GSI	Design and size GSI facilities. Create technical details in plan, cross section and profile. Incorporate GSI facilities in construction and maintenance specs. The GSI design guidelines in this resource are not to be used as design standards – before starting please check with the respective local government for design specifications, regulations and jurisdictional authority. Check with respective local governments for rainfall capture targets specific to design standards that they may have that have been adjusted for predicted climate change.
7. Construction Staging of GSI	Schedule the installation of GSI facilities to optimize on synergies of project or other related or unrelated projects, avoid problems with severe rainfall events and other potential disturbances.
8. Field Review & Monitoring of GSI	Provide critical field inspections to ensure performance. Use post-construction monitoring and adaptive management to reduce costs.

3.0 Design Resources

3.1 Rainfall Amounts and Capture Targets

REFER TO: Appendix A, Table 1 Typical GSI Facility Design Guideline Rainfall Capture Targets to determine the rainfall required for sizing a given GSI facility. This table will be periodically updated to keep up with advances in research and practice.

In this resource, design guidelines for each GSI facility utilize a 'simplified sizing approach'[3] of the optimal rainfall or stormwater runoff capture volume is 72% of the 2-year, 24-hour event rainfall volume. For each GSI facility this is expressed in the sizing equation as millimeters of rainfall. The region can be divided up in to 5 climate zones throughout using rainfall data supplied from provincial rain gauges, or provided by the respective local government. Any updates provided by the local governments for rainfall capture targets will be updated periodically in Appendix A.

Consideration should be given to using climate adjusted rainfall capture targets for GSI. *Climate Projections for the Capital Region (April 2017)*[4]. This climate change report outlines that the Single-Day Maximum Precipitation will increase by 20% (2% to 37% range, 10% to 90% percentile values) for year 2050 and 35% (11% to 54% range) for year 2080.

3.1.1 Volume Reduction

The typical target for GSI is to capture and retain 72% of the 2-year, 24-hour event volume, which is roughly equivalent to the 6-month, 24-hour post development flow volume.

These rainfall capture targets are used to calculate the volume of rainfall that falls on the given impervious surface (thus generating stormwater runoff) to be captured, infiltrated, treated and/or detained by the GSI facility. Because rainfall patterns differ around the capital region, this rainfall capture target is area specific. Check with respective local governments for rainfall capture targets specific to design standards that they may have and ensure that they are based on the current climate projections.

3.1.2 Water Quality Treatment

Stormwater capture, volume reduction, water quality treatment, infiltration and rate control, go hand in hand. To protect the natural receiving environments (creeks, shorelines, and harbours) from the impacts of stormwater discharges. Regional climate projections predict that the region will be receiving less rain for longer periods in the summer and more rain during the winter. During the dry summers contaminants accumulate on the land and impervious surfaces, increasing the contaminant loading potential when heavy rains begin in the fall, known

[3] Modelling for the collection and treatment for 90% of the total rainfall from impervious areas can be determined using continuation simulation modelling. This modelling can take a significant amount of time and there is limited availability of long-term precipitation gauges. Modelling in Metro Vancouver has shown that 72% of the 2-year, 24-hour event is roughly equivalent to 90% of average annual rainfall. Therefore, using the R mm for the volume reduction and rate control are likely suitable for most sites.

[4] https://www.crd.bc.ca/about/data/climate-change

as "first flush". Maximizing infiltration will also aid in groundwater recharge and ensure interflow continues to provide adequate seasonal flow rates in creeks.

3.1.3 Rate Control

Local governments typically use Intensity-Duration-Frequency curves to represent the relationship between rainfall intensity, rainfall duration, and return period (or its inverse, probability of exceedance) of rainfall events. Developing a hyetograph for hydrologic modelling using the Soil Conservation Service Type 1A rainfall distribution is generally accepted in this region. Designers should check with the local jurisdiction for the hyetograph development and hydrologic modelling availability and requirements. In this resource, design guidelines for each GSI facility utilises a 'simplified sizing approach' of the optimal rainfall or stormwater runoff capture volume is 72% of the 2-year, 24-hour event rainfall volume.

3.2 Requirements for Site

Many municipalities have included requirements for stormwater management within their subdivision and development bylaws. Traditionally, these requirements have been focussed on conveyance and flood protection requirements, but many have now included GSI principles. Furthermore, many municipal official community planning documents include general provisions for stormwater management either at the municipal level or catchment-specific requirements. Some municipalities have developed watershed-specific plans which may identify specific stormwater targets based on the constraints and opportunities in that watershed. The developer, planner and designer should familiarize themselves with these requirements at the early stages of a project.

In the absence of specific site requirements, the generally accepted GSI guidelines are as follows:

Table 5 Generally Accepted GSI Drivers and Targets

Design Driver		Rainfall Capture Target*
Capture & Slow >	the flow of stormwater by re-directing it into naturalized facilities with safe dispersion.	• 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 GSI will be equal to the calculated release rate of an infiltration system.
Clean & Infiltrate >	stormwater runoff before it reaches natural receiving environments.	• Collect and treat the volume of the 24-hour precipitation event of the total rainfall from impervious areas suitable GSI.
Store & Convey >	stormwater to minimize peak flows in heavy rain events and for safe conveyance in the piped and natural storm drain system.	• Reduce post-development flows (volume, shape and peak instantaneous rate) to pre-development levels for the 6-month/24-hour, 2-year/24-hour, and 5-year/24-hour precipitation events.

*Note: Refer to the local jurisdiction requirements for management of flood events.

For sites that discharge directly to receiving bodies not impacted by runoff rates from a specific site (e.g., tidal waters, large lakes), consideration should be given to focus on water quality and not on volume control and runoff rates.

3.3 Selecting GSI Facility

REFER TO: Appendix A – Table 2 GSI Information Table to assist in the selection of the GSI based on stormwater management drivers, land use application, site constraints, peripheral benefits and cost criteria.

Selecting the optimal GSI facility or facilities for a retrofit or a new development is an art as well as a science. Different factors must be considered when selecting GSI facilities that are appropriate for the site conditions, project budget and GSI drivers for a particular site. A traditional Stormwater Rehabilitation Unit (SRU) may also be required by the local government in order to meet water quality guidelines, bylaw or planning policy. Where a SRU is required, GSI may still be part of a treatment train.

3.4 Various GSI Facility Common Design Guidelines

REFER TO: various appendices for common design guidelines for a variety of GSI facilities (i.e., Swale, Rain Garden, Cisterns & Detention Tanks)

3.5 Planting Templates and Plant Lists

REFER TO: Supplemental 1, Planting Templates & Plant Lists as a design companion resource for any vegetated GSI facility. Recommendations for planting templates and plant lists are presented. Plant selection principles of design include: plants and trees should fit into the existing natural and built environment; utilize native species indigenous to southern Vancouver Island; use of a columnar variety of tree is recommended for urban streetscapes as they require less maintenance costs and have less interaction with overhead transmission lines, neighbouring buildings and vehicle traffic; select plant species based upon an understanding of hardiness and habitat requirements; design planting plans with an appropriate mix of trees and shrubs as well as native perennials, wildflowers and aquatics.

3.6 Overcoming Challenges and Constraints

Each site will have its own unique site challenges and constraints. This section offers some design resources to assist planners and GSI designers with selecting a suitable GSI facility, sizing and overcoming site challenges and constraints.

3.6.1 Soil Infiltration

There are a wide variety of soil conditions across the capital region, and infiltration rates will vary considerably seasonally at the same site. Depending on soil conditions and other site constraints, various GSI designs for full or partial infiltration source controls are appropriate. Much of the populated area in the capital region has low infiltration rates due to clay soils. Resources such as Addressing Green Infrastructure Design Challenges in the

Pittsburgh Region – Clay Soils (EPA, Jan 2014) (https://www.epa.gov/sites/production/files/2015-10/documents/pittsburgh-united-clay-soils-508.pdf) may provide helpful insights.

Regional Infiltration Potential Resource

Site-specific soils and infiltration information should be obtained by a geotechnical engineer at the design phase if at all possible. However, for generalized information only, a recent report and set of regional infiltration potential maps can aid in understanding the native soil infiltration potential of a given watershed. This resource can be found at: https://www.crd.bc.ca/education/our-environment/watersheds/watershed-maps-flow-diagrams

On-site infiltration testing

Infiltration tests have their limitations, as they may be difficult to perform or interpreted due to historic site disturbance or alteration, existing impervious cover, seasonal variation in soil saturation, etc. For all GSI facilities that utilize infiltration, on-site infiltration testing is required at the elevation (depth) of the proposed infiltration facility. The BC Environment Percolation Test Requirements recommend using the double ring infiltrometer testing methodology. Infiltration rates should be reported in mm/hr. Ideally, the test would be performed in the wet season (or simulate the wet season conditions) and testing results would be available when the GSI facility is designed, but testing may not be performed until the site is under construction and the design has been finalized. In the absence of test results, literature values for saturated hydraulic conductivity are often used in conjunction with an appropriate "correction" or "safety" factor. 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 pre-treatment. Selection of a correction factor is based on the judgement of the Qualified Professional.

Strategies to Deal with Limited Infiltration Rates

All sites in the capital region can incorporate some form of GSI, 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 GSI facilities are advisable on the development site, professional geotechnical engineers, hydrogeologists, and designers should identify site or neighbourhood features that may act as constraints.

Table 6 provides general guidance on the match between source control type and infiltration rate. Use these as guidelines, not rules.

Table 6 Tentative Match: GIS Facility to Soil Infiltration

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
High infiltration rate >30 mm/hr	x	x		
Moderate infiltration rate 15-30 mm/hr	x	x	x	
Low infiltration rate 1-15 mm/hr		x	x	x
Very low infiltration rate <1 mm/hr			x	x

*Note: In some cases, bioretention facilities with subdrains have the potential to export Phosphorus and Nitrogen at a higher rate than contained in the stormwater they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions.

Infiltration Constraints

The Infiltration Constraints discussion below provides a partial list of site-specific considerations to be considered to help determine what GSI may or may not be suitable. The BC Ministry of Environment publication Underground Stormwater Infiltration Best Practices for Protection of Groundwater Resources in British Columbia (Nov. 2014) (http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/library/underground_stormwater_infiltration-2014.pdf), is an important guidance document to review for the protection of groundwater when considering GSI infiltration facilities.

Historical or Current Land Uses that are Pollutant Hot Spots: Infiltration should not be undertaken from historical or current land uses that present a high risk of groundwater pollution e.g., historical industrial sites, automobile service yards, wrecking yards, public works yard, sites storing industrial chemicals or wastes, unless appropriate pre-treatment is included.

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.

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 600 mm 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 pre-treatment 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 30 m (or greater in some areas) 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 – 3-5 m 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.

3.6.2 Strategies to Deal with Limited Space

A key advantage of integrating GSI into the overall design of a project is to avoid requirements for additional land. Strategies to minimize the requirement for extra land for GSI include:

- ✓ Use required landscape areas as GSI – 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 rather than raised landscaping.
- ✓ 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 subsurface soils 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. Good growing medium soils will be capable of storing water in up to 20% of their volume. 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. When the ratio of impervious area to pervious area remains small, this absorbent landscaping can absorb the runoff from disconnected areas and reduce the area of impervious surface that must be accommodated in separate source control facilities or that runs off to the storm drainage system.

- ✓ Install pervious paving. Pervious paving of several types is highly suitable for pedestrian areas, overflow parking, and main parking areas.
- ✓ Place infiltration trench or soak-a-way 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, due to the volume of space taken up by the rock.
- ✓ 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 cisterns and detention tanks.
- ✓ Install a green roof, either intensive or extensive, to provide rainfall capture above buildings and parkades.
- ✓ Consider rainwater, for flushing toilets, irrigation and/or laundry uses. This technique is with "purple pipe" building systems for non-potable water. NOTE: this is not discussed in this resource. For more information see the British Columbia Building and Plumbing Code.

3.6.3 GSI Facilities and Contaminant Removal

GSI facilities can significantly reduce stormwater contaminants through sedimentation, filtration, adsorption, vegetative uptake, and infiltration. However, nutrient removal efficiencies vary greatly due to the complex chemical processes involved. GSI facilities can be effective at capturing the "first flush" of runoff from impervious surfaces and this is where pollutant loadings are most concentrated. Proper operation and maintenance of the GSI facilities is crucial for long term contaminant removal performance. It is important to note that in some studies, phosphorus levels may increase in Vegetated and Grassy Swales.

When choosing a GSI facility to reduce a specific contaminant, volume reduction or detention/reduction volume, the following webpages are excellent resources. The basic contaminant reduction table in each appendix is for quick reference only. Here are more comprehensive resources:

1. The International Stormwater Best Management Practices (BMP) Data Base (www.bmpdatabase.org) has compiled research and monitoring programs of both GSI and proprietary devices performance for runoff reduction and suspended and dissolved contaminant removal for solids, bacteria, nutrients, and metals. This website features a database of over 600 studies, performance analysis results, tools for use in performance studies and summaries, monitoring guidance and other study-related publications looking at GSI and manufactured devices.

2. The Center for Watershed Protection has numerous resources, including the document: National Pollution Removal Performance Data Base (Version 3, September 2007). http://www.stormwaterok.net/CWP%20Documents/CWP-07%20Natl%20Pollutant%20Removal%20Perform%20Database.pdf

3. The Minnesota Stormwater Manual outlines typical stormwater contaminants, sources of stormwater contamination and mechanisms of contaminant removal. These can be found at: https://stormwater.pca.state.mn.us/index.php?title=Pollutant_fate_and_transport_in_stormwater_infiltration_systems

3.6.4 Stormwater Treatment Trains

The term 'Stormwater Treatment Train' represents a multi-level approach to managing the quantity and quality of stormwater runoff. Treatment trains utilize operational or behavioural source control BMP and grey or structural source control facilities such as oil grit separators, along with green infrastructure. On a watershed or catchment scale, the treatment train sequence often starts with pollution prevention and progresses through source control BMP, green infrastructure facilities, and may require end-of-pipe treatment such as hydrodynamic separators before the runoff water is discharged to receiving waters, when these approaches are linked it is known as a stormwater treatment train.

It can be effective to distribute GSI facilities on a site such that a single GSI facility treats a single impervious or portion of impervious area. This makes for a site design that is easy to map in a stormwater management plan for construction that shows how each area is treated by each facility. Designers are also encouraged to think about combinations of GSI facilities, if needed, to improve and maximize the benefits for the site. A 'Stormwater Treatment Chain' is a group of source controls that are arranged in series, flowing from 1 facility to another. It should be noted that the term is used generically to refer to a series of facilities, and water quality treatment may or may not be part of the function of the series.

3.6.6 Sanitary Sewers and GSI

REFER TO: Supplemental 2, Leaky Sanitary Sewers & Green Stormwater Infrastructure Management Considerations

Like all infrastructure, sanitary sewers deteriorate over time. This can result in leakiness, which municipalities refer to as "inflow and infiltration". Leaky sewers can unintentionally drain groundwater into the sewer system or leak sewage out to the environment. Installing green infrastructure in areas with leaky sewers may result in positive, negative, or neutral impacts. Therefore, it is important to understand the site-specific interactions between proposed green infrastructure and existing sewers, which may or may not be leaky. It is also important for municipalities and homeowners to inspect their sewer pipes and to maintain/repair them to address sewer leakiness as appropriate.

3.7 Detail Design of GSI Checklists

The following checklists provide items to include or consider for inclusion on detailed design drawings.

	Plan Checklist GSI Detailed Design
☐	Extent of effective 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
☐	Overflow location to drainage system
☐	Utility crossings and seepage cut-off details
☐	Spot elevations, slope arrows and/or contours to show grading design, including pipe inverts, catch basin elevations, breaks in grade
☐	Proposed weir locations limiting slope to no more than 2%
☐	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

	Cross Section Checklist GSI Detailed Design
☐	Depth to ground water
☐	Surface grades
☐	Paving or 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

	Profile Checklist for GSI Design
☐	Surface grades
☐	Extent of proposed growing medium installation
☐	Extent of proposed drain rock reservoir or drainage layer installation (top and level bottom)
☐	Undisturbed native soil 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

3.8 Construction Sequencing and Oversight

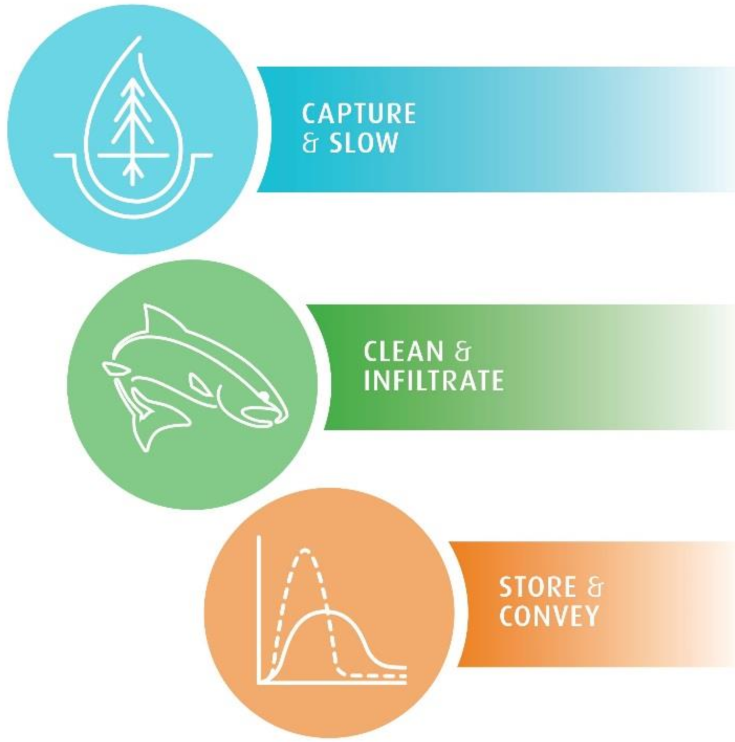
Appropriate oversite of construction sequencing, erosion and sediment control measures for more rain than expected can avoid additional stormwater pollution being generated from the work site.

A person trained and experienced in the construction, operation and maintenance of infiltration devices shall be responsible for construction of the device. The following apply:

- **Schedule** – Installation of GSI facilities should optimize on synergies of project or other related or unrelated projects, avoid problems with severe rainfall events and other potential disturbances.
- **Construction Site Stabilization** – Construction site runoff from disturbed areas shall not be allowed to enter the GSI facility. Runoff from pervious areas shall be diverted from the device until the pervious areas have undergone final stabilization.
- **Suitable Weather** – Construction shall be suspended during periods of rainfall or snowmelt. Construction shall remain suspended if ponded water is present or if residual soil moisture contributes significantly to the potential for soil smearing, clumping or other forms of compaction.
- **Compaction Avoidance** – Compaction and smearing of the soils beneath the floor and side slopes of the GSI facility, and compaction of the soils used for backfill in the soil planting bed, shall be minimized. During site development, the area dedicated to the GSI facility shall be cordoned off to prevent access by heavy equipment. Acceptable equipment for constructing the GSI facility includes excavation hoes, light equipment with turf type tires, marsh equipment or wide-track loaders.

3.9 Field Review and Monitoring of GSI

Post-construction monitoring and adaptive management is suggested to ensure performance of GSI facilities. Designers, land owners/managers and municipalities may find it beneficial to conduct both short and long term performance monitoring to ensure adequate maintenance requirements and future design considerations.



APPENDIX A - RAINFALL CAPTURE TARGETS & GSI SELECTION

Green Stormwater Infrastructure Design Guidelines for the Capital Region

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Rainfall Amounts and Capture Targets

Volume Reduction

These rainfall capture targets are used to calculate the volume of rainfall that falls on the impervious surface (thus generating stormwater runoff) to be captured, infiltrated, treated and/or detained.

The typical target is to capture and retain 72% of the 2-year, 24-hour event volume, which is roughly equivalent the 6-month, 24-hour post development flow volume, or 90% of annual rainfall.

Table 1 shows the rainfall capture targets assuming the typical design target of 72% of the 2-year, 24-hour event volume.

Table 1 Typical GSI Facility Design Guideline Rainfall Capture Targets

Rainfall Capture Depth "R"(mm) Targets for Design Guidelines – These "R" values to be used in the various sizing formulas for each GSI facility	
Climate Zone	**Rainfall Capture Target* (R mm)**
Core Area	32 mm – Gonzales rain gauge
Saanich Peninsula	39 mm – YYJ rain gauge
Westshore	47 mm – City of Langford IDF curve
Juan de Fuca EA	49 mm – Victoria Marine (Sooke) rain gauge* 65 mm – Jordan River rain gauge* 108 mm – Diversion reservoir rain gauge* 121 mm – Port Renfrew rain gauge*
Salt Spring Island & Southern Gulf Islands	32 mm – Saturna Island rain gauge*

Notes: *Rainfall capture targets are based on the current climate projections. Check with respective local governments for rainfall capture targets specific to design standards that they may have.

Consideration should be given to using climate adjusted rainfall capture targets for GSI. Climate Projections for the capital region (April 2017) can be found at: https://www.crd.bc.ca/about/data/climate-change

This climate change report outlines that the Single-Day Maximum Precipitation will increase by 20% (2% to 37% range, 10% to 90% percentile values) for year 2050 and 35% (11% to 54% range) for year 2080.

GSI Information Selection Table

Selecting the optimal GSI facility or facilities for a retrofit or a new development is an art as well as a science. Different factors must be considered when selecting GSI facilities that are appropriate for the site conditions, project budget and GSI drivers for a particular site. A traditional Stormwater Rehabilitation Unit (SRU) may also be required by the local government in order to meet water quality guidelines or municipal policies. Where a SRU is required, GSI may still be part of a treatment train. Table modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), technical aspects by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.

Table 2 GSI Information Selection Table

	Design Driver for GSI (Stormwater Benefits)			Land Use Applications					Suitability for Site Constraints					Peripheral Benefits						Cost Criteria	
Green Stormwater Infrastructure (GSI) Facility Type	**Capture & Slow** Volume Reduction into piped system with safe dispersion	**Clean & Infiltrate** Water Quality Treatment	**Store & Convey** Rate Control of Peak Flow / Detention with safe conveyance	Public Greenspace / Mixed Open Space[1]	Road Right of Ways[2]	Single family/Low density 30-50% building coverage	High Density/Commercial/ Institutional 50-90% building coverage	Parking Lots	Steep Slopes	High water tables	Soils with Low Infiltration Potential	Shallow / Exposed Bedrock	Hot Spots / Historical Use / Historical Fill	Mimic Natural Processes	Aesthetics / Greenspace	Biodiversity	Aquatic Habitat Protection	Raise awareness / Educational	Traffic Calming	Installation	Maintenance
Vegetated Facilities																					
Absorbent Landscapes	●	●	○	●	●	●	●	○	○	●	●	○	◐	●	●	●	◐	○	○	●	◐
Rain Gardens	●	●	◐	●	●	●	●	●	○	○	◐	○	◐	●	●	●	◐	●	○	◐	◐
Curb Extensions/Traffic Islands/Medians	●	●	◐	○	●	○	●	●	●	○	◐	○	◐	●	●	◐	◐	●	●	◐	◐
Vegetated or Grassy Swales	◐	◐	◐	●	●	●	●	●	●	◐	◐	○	◐	●	●	●	◐	●	○	●	◐
Infiltration Rain Planters	●	●	◐	◐	●	◐	●	○	●	○	○	○	◐	●	●	●	◐	●	○	○	◐
Flow-Through Rain Planters	●	●	◐	◐	●	◐	●	○	●	●	●	●	◐	◐	●	●	◐	●	○	○	◐
Structural Soil Cells with Trees	◐	●	○	○	●	○	●	●	◐	○	◐	○	◐	●	●	○	◐	○	◐	○	◐
Green Roofs (Extensive)	●	●	◐	○	○	○	●	○	●	●	●	●	●	●	●	●	◐	◐	○	○	○
Constructed Wetlands, Wet & Dry Ponds	●	◐	●	●	○	◐	○	◐	○	◐	●	○	◐	●	●	●	◐	●	○	○	◐
Non-Vegetated Facilities																					
Pervious Paving Systems	●	●	●	○	●	●	●	●	○	◐	◐	○	○	●	◐	○	◐	◐	○	○	●
Cistern & Detention Tanks	◐	○	●	○	○	◐	◐	○	●	●	●	◐	○	○	○	○	◐	◐	○	○	◐
Structural Soil Cell without Trees	◐	●	○	○	●	●	●	●	◐	○	◐	○	○	◐	○	○	◐	○	○	◐	○
Infiltration Trench & Soakaway Manholes	●	◐	●	●	○	●	●	○	◐	○	○	○	○	○	○	○	◐	○	○	●	●

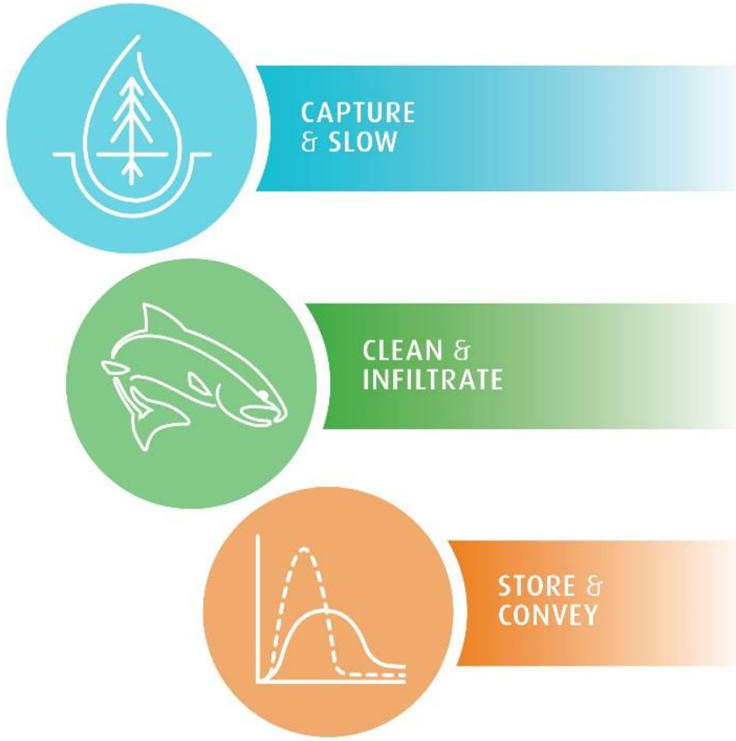
Effectiveness	
●	High
◐	Medium or Variable
○	Low

Application & Suitability	
●	Most Appropriate
◐	May be used if opportunities exist or requires under drain or further soil testing recommended
○	Not Applicable

Benefits	
●	High
◐	Medium or Variable
○	Low

Cost	
●	Low
◐	Med
○	High

[1] may include lands with building & parking lots
[2] dependent on road type



Appendix B - Absorbent Landscape

Green Stormwater Infrastructure Design Guidelines for the Capital Region

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Absorbent Landscape[1]

Description

Most landscapes – either natural or manmade – act like a sponge to soak up, store and slowly release rainfall. In most natural wooded areas 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. The trees, shrubs, grasses, surface organic matter, and soils all play a role in this absorbent landscape.

Stormwater Variables of Absorbent Landscape

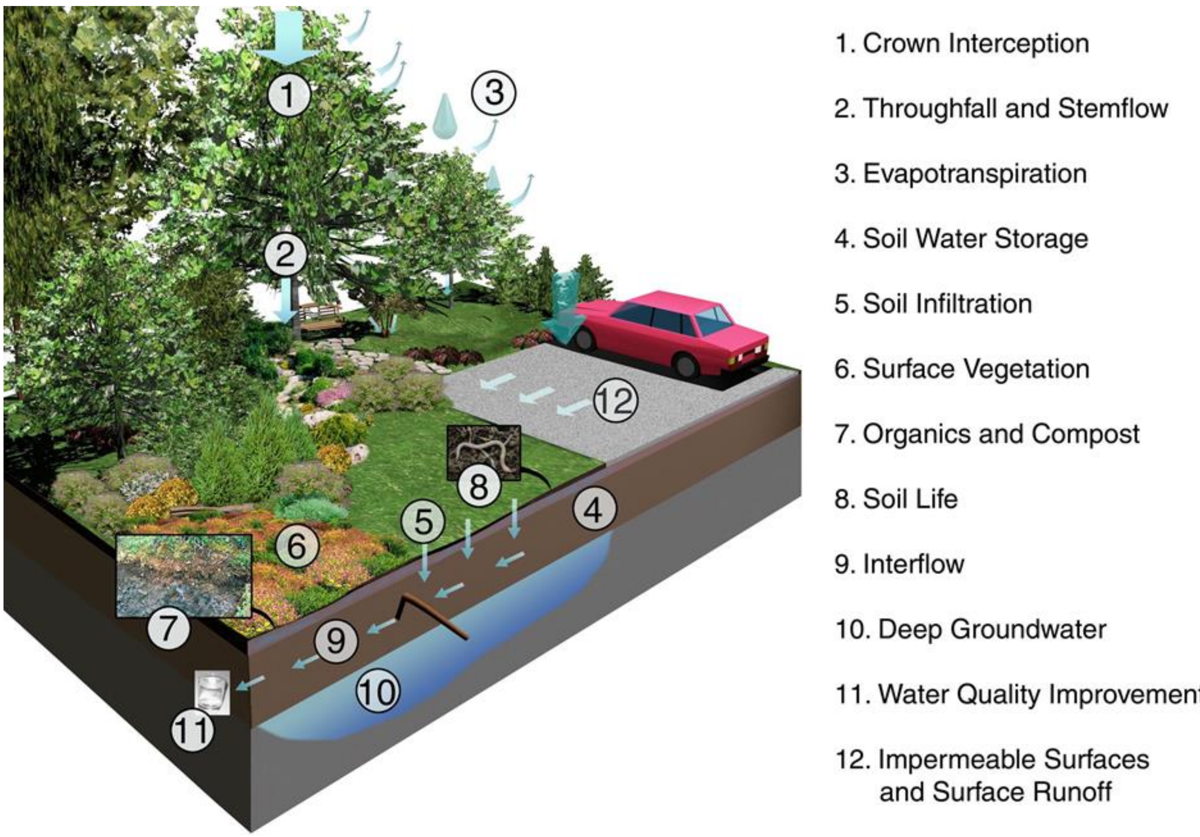

Figure 1 Shows a schematic representation of the 12 stormwater variables of absorbent landscape discussed below. Keeping these variables in balance is the key to successful stormwater source control using absorbent landscape.

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

Selection, Application and Limitations

- Top soil amendments have been found to have the greatest effect for managing stormwater during the heaviest rainfall events in the capital region.[2]
- Absorbent landscapes mimic the hydrologic function of undeveloped land on a development site. Its primary purpose is to absorb and infiltrate direct rainfall and has only limited capacity to accept and infiltrate runoff from impervious areas. Sites that drain large impervious areas into smaller areas risk overwhelming the absorbent capabilities of soil.
- Absorbent landscaping can accept runoff from disconnected roof leaders, sidewalks, and limited parking areas such as driveways. It may function best to achieve stormwater capture targets when combined with an overflow to an infiltration rock trench.
- Absorbent landscaping essentially consists of an absorbent layer of soil with vegetation. It differs from a rain garden in having:
  - no rock reservoir or subdrain
  - max. 2:1 ratio of impervious area to absorbent landscape
  - no ponding

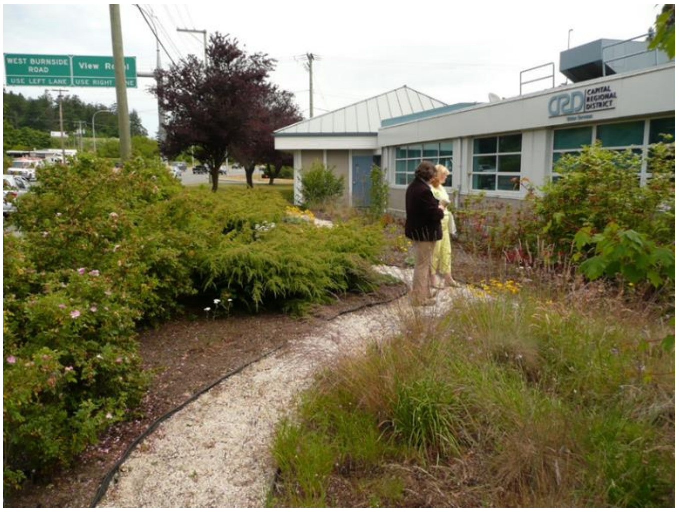

Figure 2 Absorbent landscaping at CRD office

- Where an impervious area is several times the area of an absorbent landscape, a rain garden should be considered instead.
- Absorbent landscapes need 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.
- To meet typical performance targets (e.g., infiltrating the first 25–60 mm 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.
- Trees in absorbent landscapes can greatly increase the absorption capacity of the area.
- A high level of scrutiny of any compost, growing media, amended soils or Bioretention Soil Mix brought to the site is highly recommended due to potential issues with invasive plant species.

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[2] Chris Jenson, A Hydrologic Assessment of using Low Impact Development to Mitigate the Impacts of Climate Change in Victoria, BC, Canada, 2005 https://pics.uvic.ca/sites/default/files/uploads/publications/Jensen_Thesis.pdf

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Maximize the area of absorbent landscape – either existing or constructed – on the site.

Figure 3 Pearkes Arena Absorbent Landscape, Photo Credit District of Saanich

5. 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.
6. Minimize impervious area through such techniques as multi-storey buildings, narrower roads, minimum parking, larger landscape areas, green roof, and pervious paving.
7. Disconnect impervious areas from the storm sewer system, having them drain to absorbent landscape with only an overflow to the storm drainage system.
8. Generally, an absorbent landscape is designed to infiltrate the rain that falls on it and may infiltrate runoff from limited upstream impervious area; no more than 2:1 ratio of impervious area to absorbent landscape should be utilized.
9. Design absorbent landscape areas as gently sloping (2%), with overflow only occurring in large rain events.
10. Inflows from impervious area to absorbent landscape should be distributed sheet flow from pavement over a flat-panel curb, or through frequent curb cuts. A drop of 50 mm from the pavement or flat curb edge to the top of the absorbent landscape surface is required to accommodate sediment accumulation.
11. Where inflow is from curb cuts or point discharge (as in a disconnected roof leader/downspout), a transition area at the inflow point(s) should incorporate erosion control and flow dispersion to distribute flow to the full absorbent landscape area. Clean crushed rock or rounded river rock may be used. NOTE: not all municipalities allow for disconnected roof leader/downspout – check with municipality.
12. 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.
13. 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.

14. 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.
15. Ensure adequate growing medium depth for both horticultural and stormwater needs – generally a minimum of 150 mm depth for lawn areas, and 450 mm depth for shrub/tree areas. In wetter areas of the capital region, near the mountains with till subsoil, a minimum growing medium depth of 300 mm for lawn areas is required to store 60 mm of rainfall.
16. Additional depth of weed-free growing media will be required where pervious areas are draining onto absorbent landscape.
17. 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 200 mm of growing medium. Ensure that all growing media is well aged and weed free.
18. 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 subsoil that is excessively compacted. Aerate compacted surface soil.
19. 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.
20. Provide vegetative cover (grass, groundcovers, shrubs, trees) or organic cover (mulch, straw, wood fiber) 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.
21. 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.
22. When planting trees, tree pit diameter should be at least 600 mm greater than the diameter of the root ball and the sides of the tree pit should be scarified. See Table 3 for soil volumes considerations for when planting trees.
23. Consider installing root barriers where potential for interference with infrastructure.
24. See Table 1 for setbacks for absorbent landscapes.

Sizing Absorbent Landscapes

Sizing for an absorbent landscape alone is fairly straightforward and a simplified sizing approach has been developed that does not require water balance modelling or continuous simulation.

1. In general, absorbent landscape area is sized to infiltrate the rain that falls directly on it, and may be designed to infiltrate runoff from a limited area of upstream impervious surface. The maximum ratio of impervious area to pervious area (I/P ratio) allowed will be 2:1. Pervious area refers to the absorbent landscape and the I/P ratio will be zero (0) where no impervious area is treated by the absorbent landscape.

2. Sizing presented here is for infiltration of rain water for "capture" and prevention of site runoff. Sizing and design according to this guide will generally provide water quality treatment for the volume of water infiltrated. If "water quality" criteria volumes are larger than "capture" volumes, additional sizing may be required and a professional engineer should be consulted.

3. The sizing process assumes that the area of absorbent landscape is constrained by the site and is used to determine the depth of soil required.

Table 1 Absorbent Landscape Setbacks

Setback From	Distance (m)
Down Slope of Building Foundation	1.5
Property Line	3
Drinking Water Well	30
Septic Field	3
Active or inactive landfill or contaminated site	30
Maximum slope	2%

Sizing for Depth Capture Criteria: R mm in 24 hrs

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area-specific rainfall capture targets – confirm with respective municipality.

1. Determine I/P ratio for the Absorbent Landscape:

$$\text{I/P ratio} = \frac{\text{Impervious Tributary Area}}{\text{Absorbent Landscape Area}}$$

2. Determine the soil depth required:

$$D_S = \frac{R \times (I/P + 1) - Ks \times 24}{0.2}$$

Where:
D_S = Depth (thickness) of amended soil (mm)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions.
I/P = Ratio of impervious tributary area to absorbent landscape area (unitless)

3. Check whether the calculated soil depth is within the standard depth range of 150 mm to 450 mm. If calculated depth exceeds 450 mm:

- The soil depth may be acceptable upon consultation (i.e., 500 mm soil may be acceptable if landscape designers concur);
- The I/P ratio may be reduced by routing runoff from a portion of the contributing impervious area to another facility and the soil depth recalculated; or
- Overflow from the absorbent landscape could be directed to a secondary GSI facility such as a rain garden or infiltration rock trench.

4. To determine the absorbent landscaping area:

$$Area = \frac{\text{Impervious } TributaryArea}{I/P}$$

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 requirements, and:

1. Growing media or Bioretention Soil Mix: As per Table 2, but with required minimum saturated hydraulic conductivity of 70 mm/hr. As with bioretention materials, compaction of soils and mulch should be avoided to allow water to infiltrate properly and the GSI facility to function for absorption. No manual compaction should be necessary. Allow for natural settlement up to 20%.
2. Seeding: to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (note – sodding will be required for erosion control in most instances).
3. Sodding: to Section 31 92 23 Sodding.
4. Plantings: see Supplemental 1: Plant Templates & Plant Lists.

Construction Practices shall meet Master Municipal Construction Document 2009 requirements, and:

1. Maintain grass areas to mowed height between 50 mm and 150 mm, Landscape Maintenance standards shall be to the Canada Landscape Standard, 1st Edition, Maintenance Level 4: Open Space / Play Area.

Bioretention Soil Medium

Composition of Bioretention Soil Medium (BSM) is an important factor in the performance of GSI facilities. Soil mixes for bioretention and vegetated infiltration facilities need to balance 3 primary design objectives for optimum performance:

- ✓ High enough infiltration rates to meet desired surface water drawdown and system dewatering.
- ✓ A growth media to support long term plant and soil health and water quality treatment capability.
- ✓ Infiltration rates that are not too high in order to optimize pollutant removal capability.

For the latest information on bioretention soil research see the Washington Stormwater Center's webpage on Bioretention http://www.wastormwatercenter.org/lid-bioretention/. Below are 2 local BSM suggested mixes.

Table 2 Absorbent Landscape Bioretention Soil Mix (BMS)[3]

	Absorbent landscape Lawn BMS	**Absorbent Landscape Vegetated BMS**
Minimum Total Depth	300 mm	450 mm
Minimum required saturated hydraulic conductivity	70 mm/hr.	
Component (Partial size classes)	Percentage by Dry Weight	
Gravel (greater than 2.5 mm)	0	0
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter. • Particle size in sand to be: a) 90-100% passing a 2.50 mm sieve, b) 0-65% passing a 0.500 mm sieve, c) 0-5% passing a 0.0500 mm sieve	65-80	50-70
Silt (greater than 0.002 mm and less than 0.05 mm)	5-10	5-10
Clay (less than 0.002 mm)	2-5	2-5
Organic Content (% dry weight) – ensure weed free • must be well aged organics weed-free, preferably manure-free and biosolid free.	5-20	15-20
Other Soil Considerations		
• **pH** of mixed materials between 6-8.5 • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017 B113 SAFE SOILS PROGRAM (page 111) http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf		

[3] Source: Absorbent Landscape, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Absorbent%20Landscape.pdf

Table 3 Soil Volumes per Tree[4]

	Minimum Volume of Bioretention Soil Mix	
Tree Size	**Single Tree**	**3 or More Trees**
Small	15 m^3	10 m^3
Medium	20 m^3	15 m^3
Large	30 m^3	20 m^3

[4] Minnesota Stormwater Manual, Examples of jurisdictions with minimum tree soil volume requirements, https://stormwater.pca.state.mn.us/index.php/Examples_of_jurisdictions_with_minimum_tree_soil_volume_requirements

Absorbent Landscape Design Example for Capture of R mm / 24-hour Criteria

Scenario Description

A landscaped area with absorbent topsoil is proposed to capture a portion of the runoff from a patio area.

The following parameters are known:

- Total patio area = 60 m^2
- Total landscaped area = 60 m^2
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm
- Native soil infiltration rate = 1.5 mm/hr

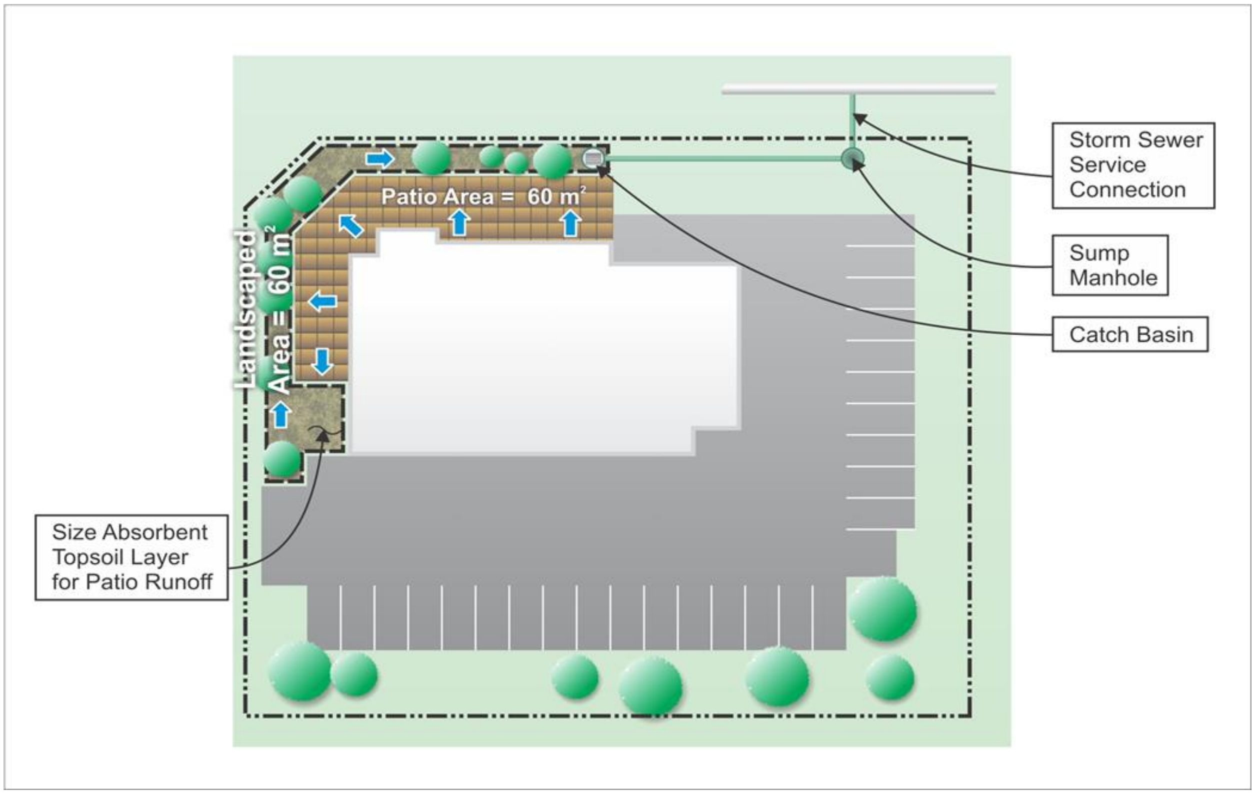


Figure 4 Example - Plan view of site with patio and landscape areas highlighted

Determine whether the landscaped area is large enough and the topsoil depth required.

Sizing

Determine the site I/P ratio:

$$I/P = \frac{60sq.m}{60sq.m} = 1.0$$

$$D_S = \frac{R \times (I/P + 1) - Ks \times 24}{0.2}$$

Where:
D_S = Depth (thickness) of amended soil (mm)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
I/P = Ratio of impervious tributary area to absorbent landscape area (unitless)

$$D_S = \frac{38mm \times 2 - (1.5mm/hr \times 24)}{0.2} = 200 \text{ mm}$$

Hydraulic Components

- Inlet: The impervious patio runoff sheet flows onto the landscaped area.
- Overflow: The landscaped area grading must allow overland flow to a catch basin for minor flows and overland flow to the municipal major system (typically roadway surface) for any water that overwhelms the catch basin capacity.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

Absorbent landscapes consist of an absorbent layer of soils, mulch, and vegetation which slow the flow of stormwater runoff. Its primary purpose is to absorb and infiltrate rainfall and imperious area runoff (roof leaders, sidewalks and driveways). Up to 20% additional runoff can be reduced using an absorbent landscape versus a traditional pervious surface. As runoff passes through the vegetation, pollutants are removed through the combined effects of filtration, infiltration and settling. Estimates of facility effectiveness of runoff reduction and pollutant removal efficiencies are shown in Table 4.

Table 4 Absorbent Landscape: Runoff Reduction and Contaminant Removal

GSI Driver	Approximate % Reduction or Removal*
Capture & Slow – Volume Runoff Reduction	High to moderate
Store & Convey – Rate Control Delay Peak	High to moderate
Clean & Infiltrate – Water Quality Treatment	High to moderate
Total Phosphorus	25-98
Total Nitrogen	15
Trace metals	80
Hydrocarbons	80

Note:*performance will vary based upon site characteristics (i.e., parcel size, percentage of watershed, native soil type and depth, depth of amend soil/BSM, type and vegetation cover).

Sources:

http://www.lid-stormwater.net/bio_benefits.htm
http://www.deq.virginia.gov/fileshare/wps/2013_DRAFT_BMP_Specs/
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/appendix-d-removal-rates.pdf
http://www.bmpdatabase.org/

Maintenance of Absorbent Landscapes

Maintenance of absorbent landscaping areas may include regular mowing, irrigation, and pruning. As well, re-grading may be necessary to reshape the absorbent landscaping area as sediments collect and form pools.

Further detailed maintenance tasks are listed in the procedures and checklists that follow.

Operation and Maintenance Procedures

The main tasks of maintenance and operations are to:

- ❑ Weed and replace dead plants once in the spring and once in the fall
- ❑ Inspect overflow monthly and keep free of debris
- ❑ Ensure stormwater is flowing to and through the absorbent landscaping areas
- ❑ Prevent or remove channelization, rilling, and erosion of the soils
- ❑ Maintain vegetation by removing weeds and replacing dead plants
- ❑ Remove accumulated sediment and debris
- ❑ Aerate soil profile by coring and de-thatching annually
- ❑ Test the infiltration capacity if there is a visible problem or once every 5 years
- ❑ Use watering bags for newly installed trees. Provide 90 litres of water once per week during normal conditions and 90 litres of water twice per week during drought conditions. Refer to municipal guidelines for more details.

The most intensive period of maintenance for absorbent landscaping areas is the first 2 years during plant establishment. During this period, regular watering, weed removal, and replanting may be required. As well, large loads of sediment could affect plant growth, particularly in areas with construction activity. After the vegetation is well established, the maintenance checklist should be used for 3 inspections per year; 1 in the spring, 1 in the mid-summer, and 1 in the fall.

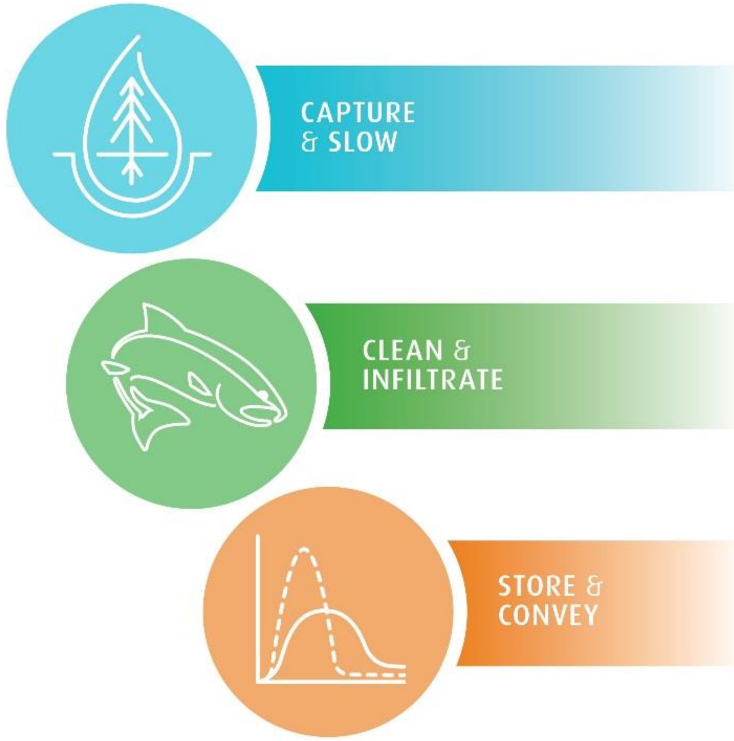
Debris, if not removed, can be unsightly and block inlets; therefore, debris should be removed between inspections whenever it is observed on site. Lastly, inspections are recommended following large storm events to ensure the overall performance of the absorbent landscaping areas as well as to check for scouring.

Operation and Maintenance Inspection Checklist

The impervious patio runoff sheet flows onto the landscaped area?

- ❑ Is sediment accumulating at inflow points?
- ❑ Is there erosion at the flow dispersion device or other structures?
- ❑ Has there been damage due to vehicle or pedestrian traffic?
- ❑ Is there evidence of dumping (e.g., building waste)?
- ❑ Is the vegetation in satisfactory condition (e.g., density, weeds)?
- ❑ Is replanting required?
- ❑ Is mowing required?

NOTE: No Design Figures included in this Appendix



APPENDIX C - VEGETATED & GRASSY INFILTRATION SWALE SYSTEMS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

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Vegetated & Grassy Infiltration Swale Systems[1]

Description

Swales are graded and engineered landscape features which generally have a linear open channel. Vegetated and grassy bioretention and infiltration swales are designed to collect, safely convey stormwater while reducing runoff (though infiltration), delaying peak flows and providing treatment. Swales can remove low concentrations and quantities of total suspended solids, heavy metals, petroleum hydrocarbons, and/or nutrients from stormwater.

Figure 1 Flat curbs with swale at South Valley Estates, District of Saanich

Simple grass channels or ditches have long been used for stormwater conveyance, particularly for roadway drainage. Vegetated and grassy swales incorporate design features such as modified geometry and check dams that improve the contaminant removal and runoff reduction functions of simple grass channel and roadside ditch designs.

Grassy swales promote the conveyance of stormwater at a slower, controlled rate and allow infiltration along its entire length. A vegetated swale has the same features as grassy swales, however, the presence of additional vegetation provides additional pollutant removal. Vegetated swales are essentially multiple rain gardens connected together with only the downstream rain garden having an overflow drain.

The surface component of an infiltration swale (also known as biofiltration swale, bioswale, dry swale with underdrain, swale/trench element) is a shallow channel, accepting flows from small areas of adjacent paved surfaces such as roads and parking. The swale is designed to hold the stormwater 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

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd. and/or as noted in figures.

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.

Where infiltration is not possible, consider a sunken or above ground Flow-Through Planter (see Appendix F) as an optimal alternative in an ultra-urban setting.

Selection, Application and Limitations

- Design may need to be adapted to address levels of phosphorus or nitrogen entering and leaving the facility.
- Swales can be used for contaminated stormwater runoff from roadways, driveways, parking lots, and highly impervious ultra-urban areas.
- An infiltration or bioswale is designed to provide conveyance, contaminant removal, as well as infiltrate the design volumetric capture target, and treat the design water quality volume.
- A rain garden and infiltration swale have similar design and functions; however, a swale provides conveyance of flows, but may provide less capture of peak flows than a rain garden (due to ponding).
- A grassy swale is generally less expensive to install than a vegetated swale (per unit area), but may require a larger area to meet the same capture targets.
- When lower capture targets are used such that a higher degree of surface conveyance is required, a grassy infiltration swale is advisable due to its lower susceptibility to erosion, compared to a mulched and planted swale or rain garden.
- Suitable for most development situations – residential areas, municipal office complexes, rooftop runoff, parking and roadway runoff, parks and greenspace, golf courses.
- With proper weir spacing, practical for profiles up to 10% slope.
- Maximum contributing area 2 ha.
- Standard minimum separation from base of drain rock reservoir to water table is 610 mm.

Figure 2 Grassy Swale, View Royal. Note: Flat over-flow drain may get blocked by debris, beehive style is recommended. Photo Credit: Town of View Royal

- ❑ Identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this GSI facility (infiltration swale system).

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. An infiltration swale should be designed with a trapezoidal cross-section. Swale bottom width: 600 mm minimum, 2,400 mm maximum (recommended), flat, in cross section.
5. The infiltration swale should be sized based on infiltration area, or base area of the swale, as the effective area for infiltration occurring in the swale.
6. Flow to the swale should ideally be distributed sheet flow. Provide non-erodible material for erosion and scour protection, sediment cleanout basins, and weir flow spreaders at point-source inlets.
7. Provide erosion control, vegetated or otherwise, along all sides of weirs and at drainage inlets.
8. Pavement edge at the swale may be wheel stop, flush curb, or reverse curb. Provide a 50 mm 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.

Figure 3 Vegetated Swale, Victoria Airport

9. Integrated mowing strip is desirable in lawn areas.
10. 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.

11. Footprint of Infiltration Swale = Base Area + Side Slope Area. Add additional area for side slopes according to the shape of the swale and the chosen side slopes; e.g., add [2 x slope x swale depth (m)] to each dimension of the base area to determine total footprint area.
12. Swale surface side slopes – 3 (horizontal):1 (vertical) maximum, 4:1 preferred for maintenance.
13. Design stormwater conveyance using Manning's formula, with attention to erosion of soils and vegetation and channel stability during maximum flows.
14. Longitudinal slope of the swale should be between 1%-2%.
15. For slopes of 2%-10%, the swale length may be broken up by terraces (steps) or weirs of up to 300 mm height to reduce the slope; 200 mm or less is preferred. Splash pads of cobble-sized rock (or similar) must be included below each step or weir to prevent erosion.
16. Where weirs are used to reduce the longitudinal slope, swale longitudinal slope should be 1%-2%, or dished, between weirs.
17. Weirs to have level top to spread flows and avoid channelization, keyed in 100 mm minimum.

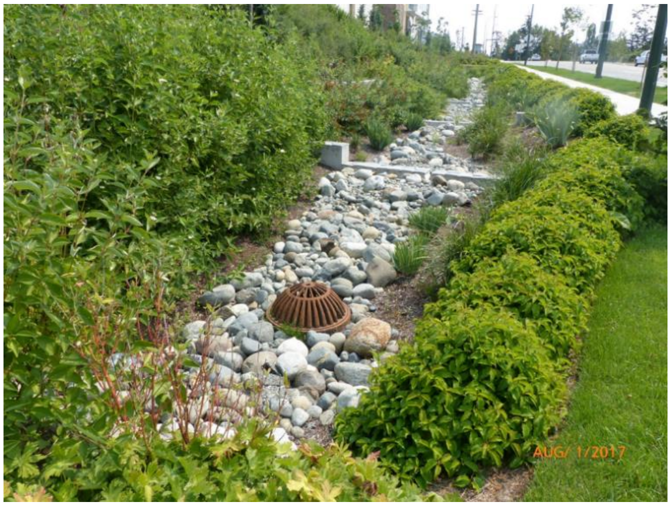


Figure 4 Swale, Watkiss Way, Eagle Creek, View Royal. Photo Credit: Town of View Royal

18. Maximum ponded level at weirs: 150 mm
19. Drawdown time for the maximum surface ponded volume – 48 hours maximum.
20. Minimum freeboard to adjacent paving: 100 mm or in accordance with swale conveyance design.
21. Treatment soil or Bioretention Soil Mix (BMS) depth: 450 mm minimum. Minimum can be decreased if design professional calculates adequate pollutant removal, or 100 mm minimum growing medium over 100 mm minimum washed sand. A standard value of 300 mm soil depth is common. BSM must be well aged organics, weed free, preferably manure free and biosolid free.
22. Drain rock reservoir bottom to be level.
23. Underground weirs of undisturbed native material or constructed trench dams to be provided to create underground pooling in the reservoir sufficient for infiltration performance.
24. A non-erodible outlet or spillway must be established to discharge overflow.
25. 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.
26. Refer to Figures 17-19 for curbing, inlet and flow dissipator detail options.
27. See Table 1 for setbacks for infiltration swales.

Table 1 Infiltration Swale Setbacks

Setback From	Distance (m)
Up-gradient of building foundations	3
Property Line	Site dependent
Drinking Water Well	30
Up-gradient of septic field	3
Seasonal High Water Table	1
Up-gradient of active or inactive landfill or contaminated site	30
Existing trees	Outside root protection zone

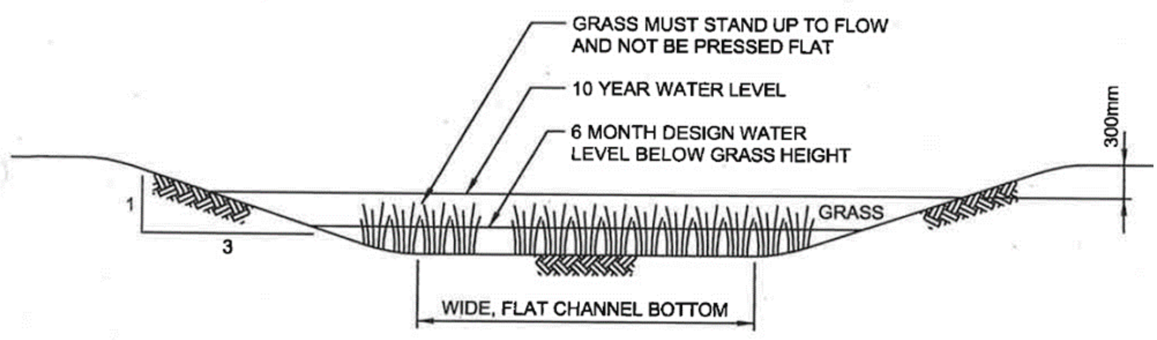


Figure 5 Grassy Infiltration Swale Section

Source: Saanich Engineering Specifications, 2003

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 (approximately rainfall intensity x (I/P ratio + 1); I/P ratio is defined below as part of Sizing).

Infiltration Swale Sizing

Infiltration swales may be sized using a simplified sizing approach that does not require water balance modelling or continuous simulation. The sizing approach presented below uses a depth capture criteria of X mm in 24 hours.

Figure 6 Swale Ditch, North Saanich

1. In general, the infiltration swale area is sized based on the upstream impervious area that it serves. This relationship can be defined by the ratio of impervious area to pervious area (e.g., I/P ratio). For the simplified sizing approaches here, this represents the ratio of upstream impervious area (also called catchment area) to the base area of the swale. I/P ratio to achieve the target capture criteria will be calculated by the 2 sizing methods below for various maximum allowable I/P ratio for given surface types is shown in Table 2. This maximum is based on ability of the vegetation to handle flows and pollutants and is not related to capture. Regardless of sizing calculation below, maximum I/P ratio for a given surface type should not be exceeded. The table shows maximum allowed I/P ratios, not recommended I/P ratios. I/P ratios must be calculated in order to achieve rainfall capture targets.
2. The simplified sizing process provides the base area of the swale which is the flat area at the bottom with uniform layers of topsoil and drain rock. Sizing by these methods does not account for any infiltration benefit provided by the sloped sides of the infiltration swale.
3. The base area of the infiltration swale will always be smaller than the total footprint of the facility, so the footprint must be calculated (see Design Guideline Item 8, above) in order to understand the actual site area required.

4. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. Sizing and design according to this guidance will generally provide water quality treatment for the volume of water infiltrated. If "water quality" criteria volumes are larger than "capture" volumes, additional sizing may be required and a professional engineer should be consulted.

5. Sizing the swale for conveyance is not covered here but should be done by standard methods. The simplified methods here may define the width of swale needed, but the depth and overall footprint should be based on the flow conveyance required.

Figure 7 Swale at Railyards, Victoria

Table 2 Swale Maximum I/P Ratios by Surface Type

Surface Type	Max. I/P Ratio
General/Industrial Storage/Loading Areas	20:1
Divided or Undivided Major Road (Expressway or Highway)	20:1
Collector Road	20:1
Parking >1 car/day/parking space	20:1
Local Road	30:1
Parking <1 car/day/parking space	40:1
Low traffic areas, no parking	50:1
Single Family Residential, Lot and Roof	50:1

Sizing for Depth Capture Criteria: R mm in 24 hrs

To determine R mm of rain in 24 hrs see Appendix A, Table 1 for area-specific typical GSI facility design guideline rainfall capture targets and confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; allowable depth range is 300 to 2,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

   Where:
   D_R = Depth (thickness) of rock reservoir (mm)
   Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
   T = allowable drain time (days)
   n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the base (bottom) area of the swale and rock reservoir required by finding the I/P ratio for the site:

$$I / P = \frac{24 \times Ks + D_R \times n + 0.2 \times D_S}{R} - 1$$

   Where:
   I/P = Ratio of impervious tributary area to swale base area (unitless)
   R = Rainfall capture depth (mm)
   Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr),
   D_R = Depth (thickness) of rock reservoir (mm)
   n = porosity of drain rock in reservoir (unitless, e.g., 0.35)
   D_S = Soil layer depth (thickness); standard value = 300 (mm)

3. Check that the I/P ratio calculated is less than the maximum allowed (Table 2). If it is not, use the maximum allowed I/P ratio. This may mean that the infiltration swale will exceed the % capture desired.

4. To find the swale base area:

$$BaseArea = \frac{\text{Impervious } TributaryArea}{I / P}$$

5. Calculate the footprint of the facility based on the base area and side slopes as described in Item 11 of Design Guidelines above.

6. If the site cannot accommodate the I/P ratio required to provide the target capture, a partial-infiltration swale with flow restrictor design may be used.

7. A 0.25 L/s/ha (or 0.09 mm/hr) unit discharge is the recommended flow restrictor at the downstream end of the swale underdrain.

8. Calculate the allowable discharge through the orifice:

$$Q = \frac{0.25 \times A_{SITE}}{1000}$$

Where:
Q = Allowable discharge through orifice (m^3/s)
0.25 = Recommended unit discharge (L/s/ha)
A_{SITE} = Total site area draining to the swale, including the swale area (ha)

Figure 8 Vegetated Swale, Tattersal Drive, Saanich

9. Solving the orifice equation for area of the orifice (AO):

$$A_O = \frac{Q}{K \times \sqrt{2gh}}$$

Where:
Q = Allowable discharge through orifice (m^3/s)
K = Orifice Coefficient (typical value 0.6)
g = gravitational constant (m/s^2)
h = head on the orifice when trench is 0.3 m full of water (typical value 0.3 m)
A_O = Area of the orifice opening (m^2) – generally assumed to be circular for calculation of orifice diameter.

10. The size of the swale is then determined by the available area on the site up to the maximum I/P ratio for the surface type as shown in Table 2.

$$I/P = \frac{\text{Impervious } TributaryArea}{BaseArea}$$

11. The depth of the rock reservoir above the orifice outlet is calculated as:

$$D_R = \frac{R \times (I/P+1) - 0.09mm/hr \times 24hrs \times (I/P+1) - 24 \times Ks - 0.2 \times D_S}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
R = Rainfall capture depth (mm)
I/P = Ratio of impervious tributary area to swale base area (unitless)
0.09 = Recommended unit discharge through orifice (mm/hr)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_S = Soil layer depth (thickness); standard value = 300 (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

Guideline Specifications

Materials shall meet Master Municipal Construction Document (MMCD) 2009 requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, 75 mm max, 38 mm min, 40% porosity or MMCD Section 31 05 17 Part 2.6 – Drain Rock, Coarse.
2. Pipe: PVC, DR 35, 150 mm min. dia. with cleanouts, certified to CSA B182.1 as per MMCD.
3. Geosynthetics: as per Section 31 32 19, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 31 05 17.
5. Growing Medium: Bioretention Soil Mix: As per Tables 3a and 3b, with required minimum saturated hydraulic conductivity of 70 mm/hr.

Figure 9 Vegetated Swale receiving runoff directly from road, Saanich

6. Seeding: to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (note – sodding will be required for erosion control in most instances).
7. Sodding: to Section 31 92 23 Sodding.
8. Planting: see Supplemental 1, Planting Templates & Plant Lists.

Construction Practices shall meet Master Municipal Construction Document 2009 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 300 mm of material over the final subgrade of the swale until after all sediment-producing construction in the drainage area has been completed.
2. Prevent natural or fill soils from intermixing with the Infiltration Drain Rock. All contaminated stone aggregate must be removed and replaced.
3. Infiltration Drain Rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.

Figure 10 Swale under construction at Oak Bay High School parking. Raised or beehive style grates are recommend.

4. Maintain grass areas to mowed height between 50 mm and 150 mm, but not below the design water level. Landscape Maintenance standards shall be to the Canada Landscape Standard, 1st Edition, Maintenance Level 4: Open Space / Play Area.

Bioretention Soil Medium

Composition of Bioretention Soil Medium (BSM) is an important factor in the performance of GSI facilities. Soil mixes for bioretention and vegetated infiltration facilities need to balance 3 primary design objectives for optimum performance:

- ✓ High enough infiltration rates to meet desired surface water drawdown and system dewatering.
- ✓ A growth media to support long term plant and soil health and water quality treatment capability.
- ✓ Infiltration rates that are not too high in order to optimize pollutant removal capability.

For the latest information on bioretention soil research see the Department of Ecology, State of Washington Stormwater Action Monitoring webpage on Effectiveness studies (https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Stormwater-monitoring/Stormwater-Action-Monitoring/SAM-effectiveness-studies).

Minimum infiltration rate (lab tested) of 70 mm/hr for BSM. Below are 2 local BSM suggested mixes.

Table 3.a Vegetated and Grassy Swale Bioretention Soil Mediums Mix 1[2]

Vegetated and Grassy Swale **Bioretention Soil Medium (BSM) Mix 1** Recommended depth: minimum of 450 mm Minimum required saturated hydraulic conductivity of 70 mm/hr.	
Component (partial size classes)	**Percentage by Weight**
Gravel (greater than 2.5 mm)	0
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter; and • Particle size in sand to be: a) 90-100% passing a 2.50 mm sieve, b) 0-65% passing a 0.500 mm sieve, c) 0-5% passing a 0.0500 mm sieve	70-80
Silt (greater than 0.002 mm and less than 0.05 mm)	5-15
Clay (less than 0.002 mm)	2-5
Organic Content (%dry weight) • must be well aged organics, weed free, preferably manure free and biosolid free.	10-15
Other Soil Considerations	
• **pH** of mixed materials between 6-8.5 • **Phosphorus (P) and Nitrogen (N) Management Recommendations:** In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the stormwater they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017 B113 SAFE SOILS PROGRAM (page 111) http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf	

[2] Modified from Vegetated Swale, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Vegetated%20Swale.pdf

Table 3.b Grassy and Vegetated Swale Bioretention Soil Mediums Mix 2[3]

<table>
<tr><td colspan="2">Grassy or Vegetated Swale
Bioretention Soil Medium (BSM) Mix 2*
Recommended depth: minimum of 450 mm
Minimum required saturated hydraulic conductivity of 70 mm/hr.</td></tr>
<tr><th>Component (partial size classes)</th><th>Percentage by Weight</th></tr>
<tr><td>Coarse Gravel (particles greater than 19 mm and less than 40 mm)</td><td>0 to 1</td></tr>
<tr><td>All Gravels (particles greater than 2 mm and less than 40 mm)</td><td>10 to 25</td></tr>
<tr><td colspan="2">Sand, Silt, Clay & Organic components measured from remaining non gravel portion of sample (% dry weight)</td></tr>
<tr><td>Sand (greater than 0.05 mm and less than 2.5 mm)
• Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter.
• Note: Growing medium/BSM to be manufactured with ‘2 mm minus’ sand to reduce gravel content in the soil. 2 mm minus sand is available from most local quarries upon request.</td><td>60-70</td></tr>
<tr><td>Combined Silt and Clays (less than 0.05 mm)</td><td>10-20</td></tr>
<tr><td>Organics (% dry weight)
• must be well aged organics, weed free, preferably manure free and biosolid free.</td><td>15-20</td></tr>
<tr><td colspan="2">**Other Soil Considerations**</td></tr>
<tr><td colspan="2">• **pH** of mixed materials between 6-8.5
• **Phosphorus (P) and Nitrogen (N) Management Recommendations:** In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the stormwater they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
• **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017, page 111 for B113 SAFE SOILS PROGRAM. http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf</td></tr>
</table>

[3] Modified from City of Victoria, Rainwater Management Standards – Professional Edition (June 2015) http://www.victoria.ca/assets/Departments/Engineering~Public~Works/Documents/SWVictoria_Professional_Rainwater_Mgmt_Stds_June2015.pdf

Infiltration Swale Design Example for Capture of R mm/24-hour Criteria

Scenario Description

An Infiltration Swale is proposed to capture a portion of the runoff from a paved parking area (see illustration below).

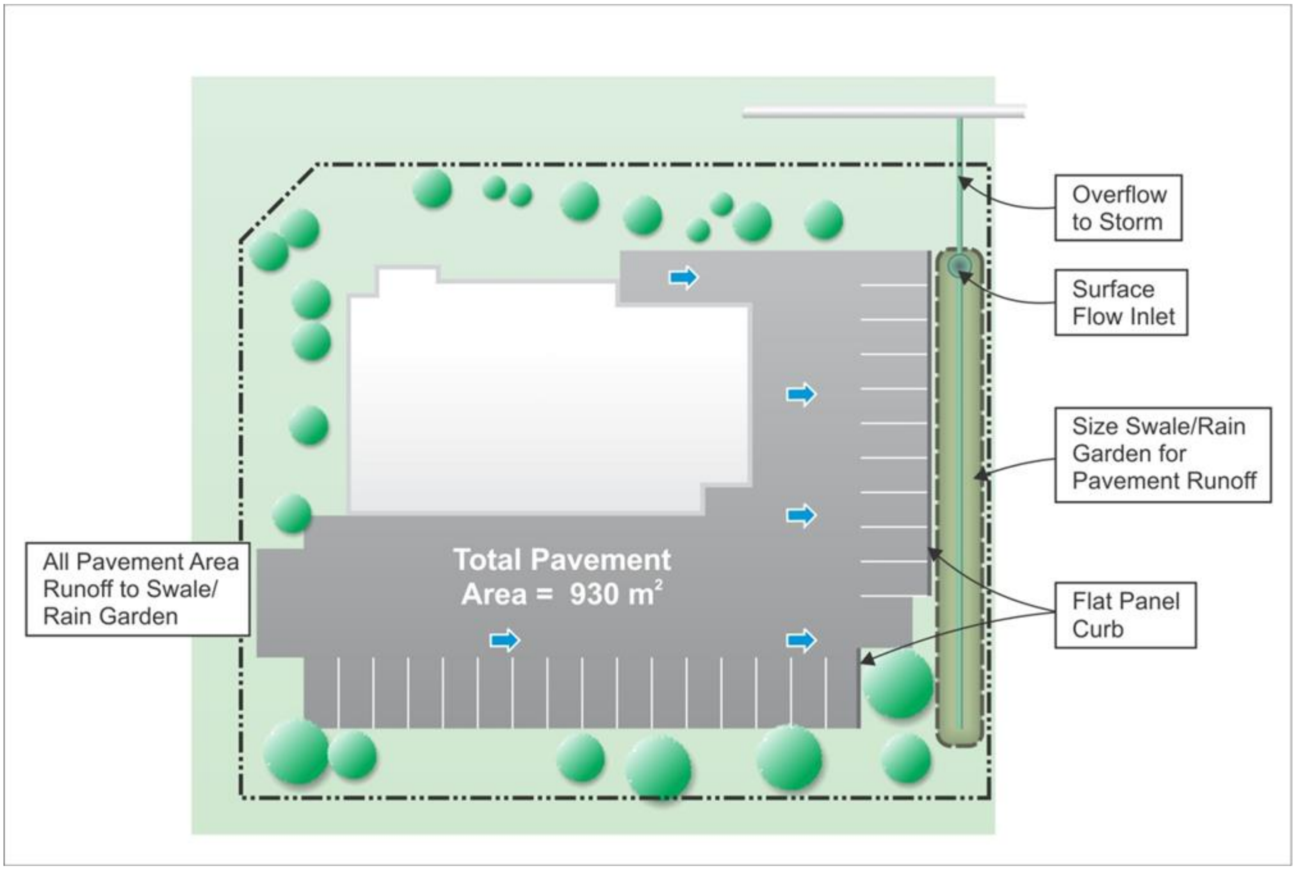


Figure 11 Example – Parking Area Draining To Infiltration Swale

The following parameters are known:

- Total pavement area = 930 m^2
- Available site area for swale = 90 m^2
- 2-year 24-hour rain depth = 92 mm
- Native soil infiltration rate = 1.5 mm/hr
- Parking use is more than 1 car per day
- Capture target is 72% of 2-year 24-hour rain = 66 mm

Determine the infiltration swale footprint area and rock trench depth. Also, estimate the annual percent capture of rainfall for the calculated infiltration swale size.

Sizing

Determine the maximum rock depth based on the 4-day maximum drain time:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{1.5mm/hr \times 4days \times 24hr/day}{0.35} = 411mm$$

Use 400 mm rock depth (see Table 2). Parking use of more than 1 car per day yields a maximum I/P ratio of 20.

Determine the base (bottom) area of swale and rock reservoir required by calculating the required I/P ratio:

$$I/P = \frac{24 \times Ks + D_R \times n + 0.2 \times D_S}{R} - 1$$

$$I/P = \frac{24 \times 1.5mm/hr + 400\,mm \times 0.35 + 0.2 \times 300\,mm}{66mm} - 1$$

$$I/P = 2.6$$

Check that the I/P ratio is less than the maximum (2.6 < 20, therefore, OK). However, with an I/P ratio of 2.6, the swale would need to be 358 m^2 in size and would not fit on the site. A partial-infiltration swale with flow restrictor is required to meet the capture target.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Vegetated swales act as both a stormwater conveyance and treatment system. Pollutant removal in swales is the result of filtration, infiltration, and microbial activity. The effectiveness of pollutant removal can vary greatly depending on swale geometry and soils. Swales often collect sediments and other gross particulate matter that may be exported during large rainfall events. This can result in an increase in effluent phosphorus concentrations. Long, shallow sloped, sandy soiled and densely grassed swales have the highest pollutant removal rates. Check dams can be added to slow conveyance and increase infiltration. The following table shows the effectiveness of vegetated swales for GSI drivers.

Table 4 Runoff Reduction and Contaminant Removal

Bioretention and Vegetated Infiltration GSI Facilities (rain gardens, swales, planters, curb extensions)	
GSI Driver	***Estimated Effectiveness or typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain
Store & Convey – Rate Control Delay Peak	Medium to high without under drain Medium with underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	35 to >90
Oil and Grease	>70 (higher with mulch)
Phosphorus	(-70) to >85
Nitrogen	20 to > 30
Total Suspended Solids (TSS)	60 to > 95
Bacteria (Fecal coliform bacteria or E. coli)	>70

Note: *Performance of individual facilities will vary depending on site-specific contexts and facility design. Negative numbers indicate contaminant loading from the given GSI facility producing a higher export of a given contaminant.

Sources:

http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.5-bioretention.pdf
http://roads.maryland.gov/OPR_Research/MD-05-SP208B4E-Grassed-Swale-Pollutant-Efficiency-Study-Report.pdf
http://www.lid-stormwater.net/bio_benefits.htm
http://www.deq.virginia.gov/fileshare/wps/2013_DRAFT_BMP_Specs/
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/appendix-d-removal-rates.pdf
http://www.bmpdatabase.org/

Maintenance of Infiltration Swales

The useful life of an infiltration swale system is directly proportional to its level of maintenance. With proper design and regular maintenance, infiltration swales can last indefinitely. The routine maintenance objectives are to maintain a dense healthy grass cover to ensure efficient hydraulics and pollutant removal. Routine maintenance includes spring clean-up, regular mowing, and pruning of trees and shrubs. The following is a table showing Operation, Maintenance, and Replacement Schedules for Infiltration Swales:

OPERATION ACTIVITY	SCHEDULE
Inspect for sedimentation, erosion, plant health, and mulch condition	Semi-annually (spring and fall) quarterly first 2 years
Irrigation	As needed
Street sweeping to reduce sedimentation	Semi-annually (spring and fall)
Soil infiltration testing	Bi-annually
MAINTENANCE ACTIVITY	**SCHEDULE**
Weed control	Bi-monthly
Mowing and clipping removal no shorter than maximum flow depth	Monthly (March-October)
Prune vegetation	As needed
Litter and debris removal	Bi-monthly
Tilling or deep raking	Bi-annually
Sand and sediment removal	Annually (spring)
Erosion repair	As needed
REPLACEMENT ACTIVITIES	**SCHEDULE**
Grass/plants	As needed(1-10 years)
Mulch	As needed(1-3 years)
Soils	As indicated by infiltration testing (2-20 years)
Gravel drainage layer	As indicated by infiltration testing (25-50 years)
Under drain	As indicated by flushing (25-50 years)

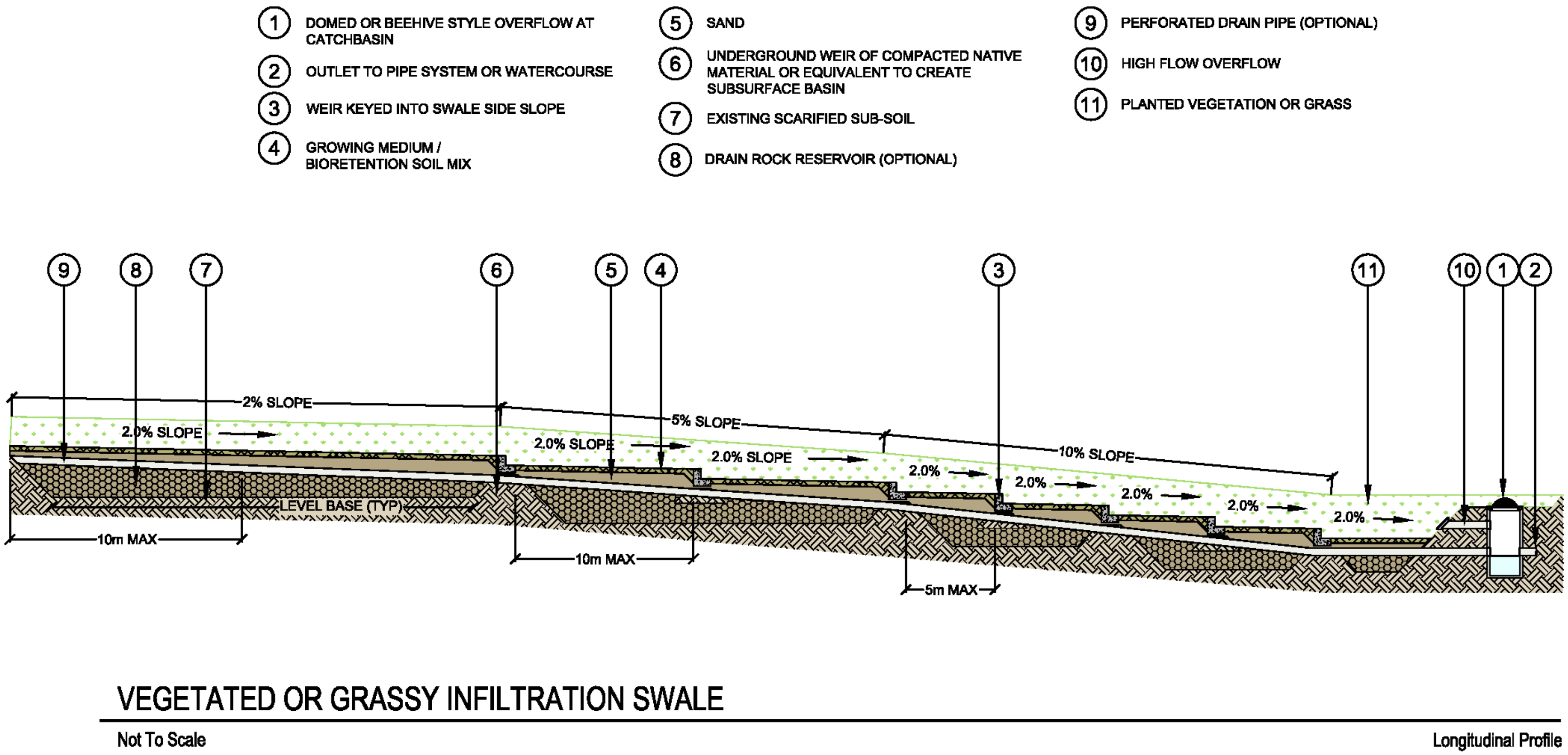


Figure 12 Vegetated or Grassy Infiltration Swale – No Flow Restrictor (Not to scale, Longitudinal Profile)

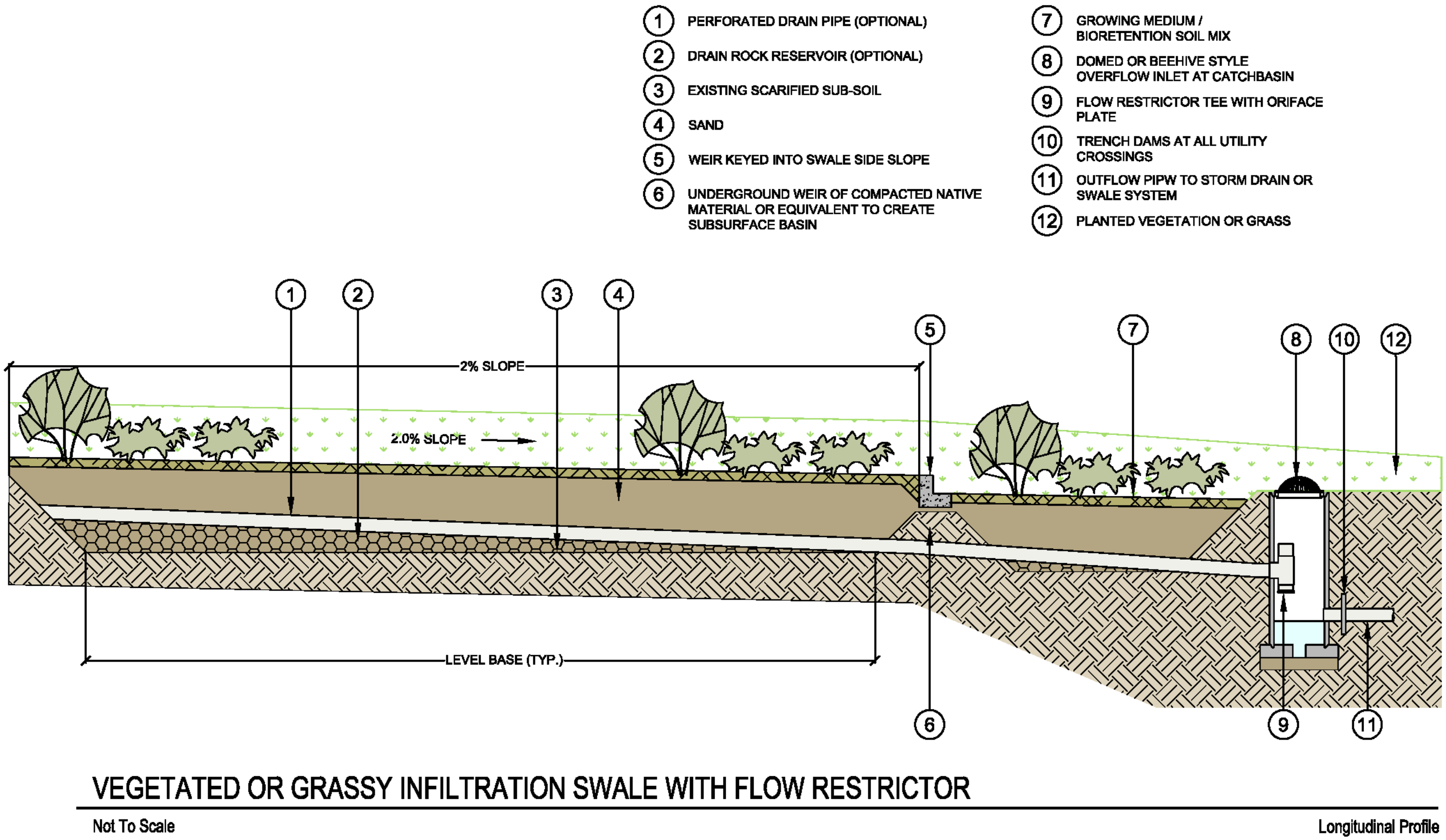


Figure 13 Vegetated or Grassy Infiltration Swale with Flow Restrictor (Not to scale, Longitudinal Profile)

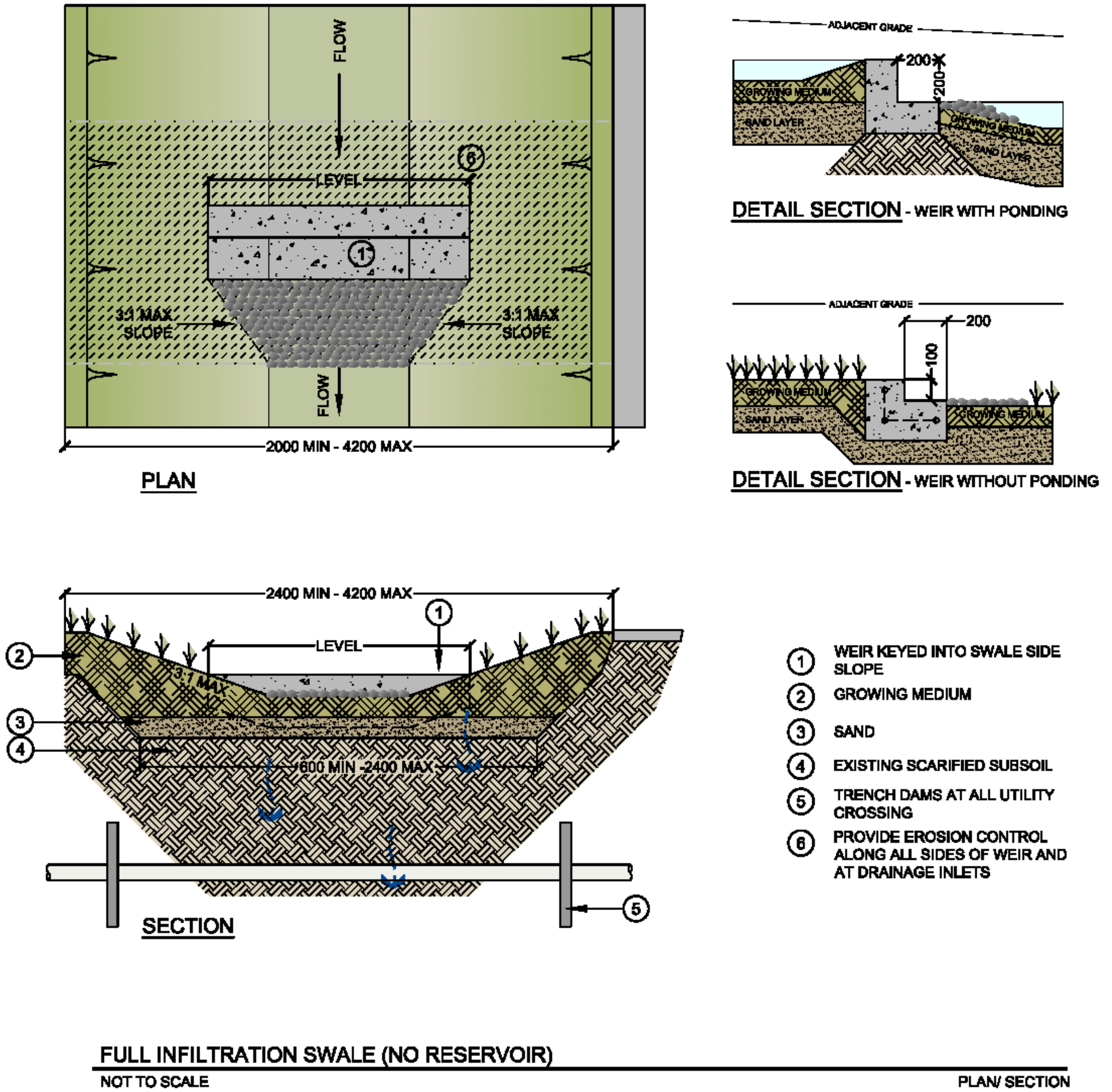


Figure 14 Full Infiltration Swale (No Reservoir) (Not to scale, Plan/Section)

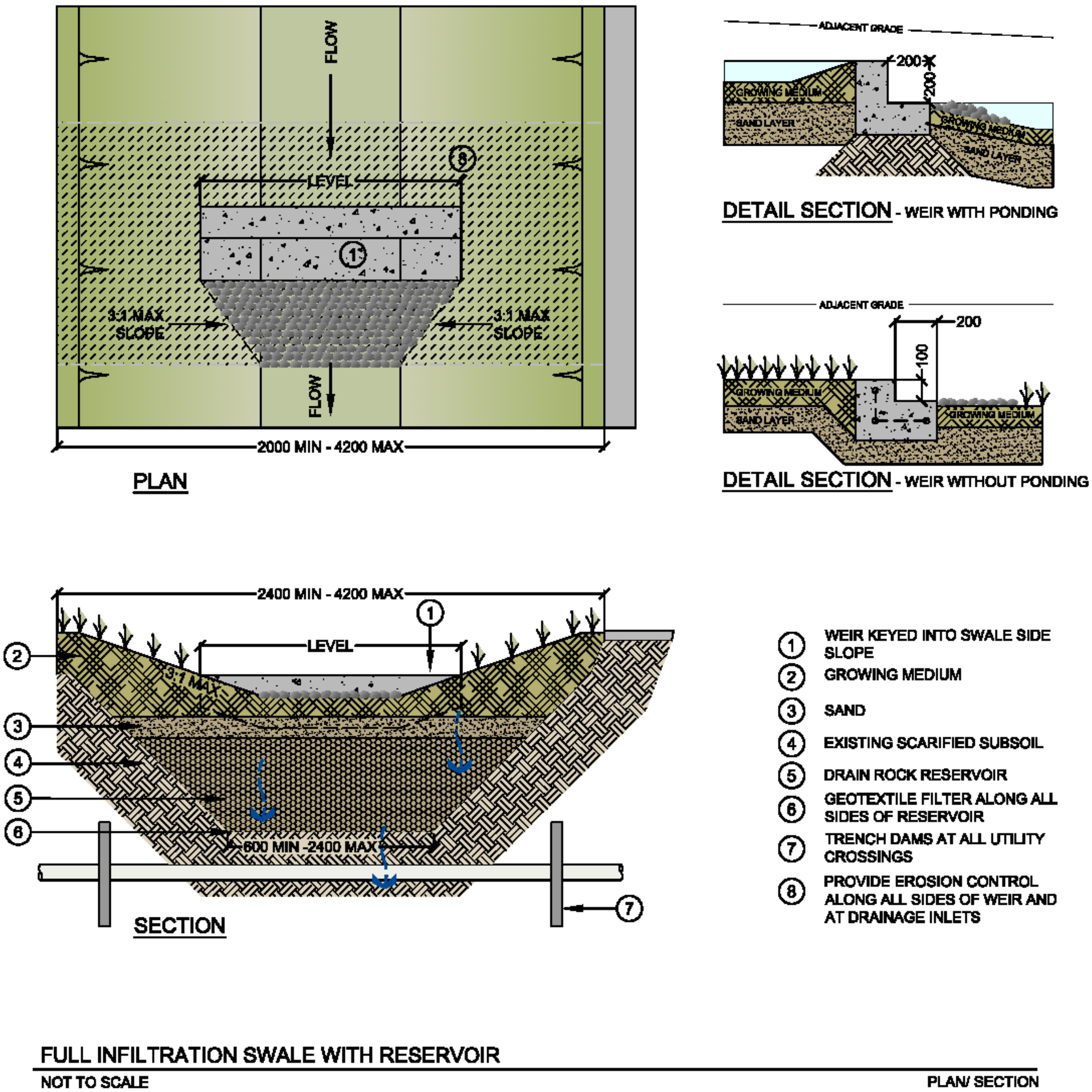


Figure 15 Full Infiltration Swale with Reservoir (Not to scale, Plan/Section)

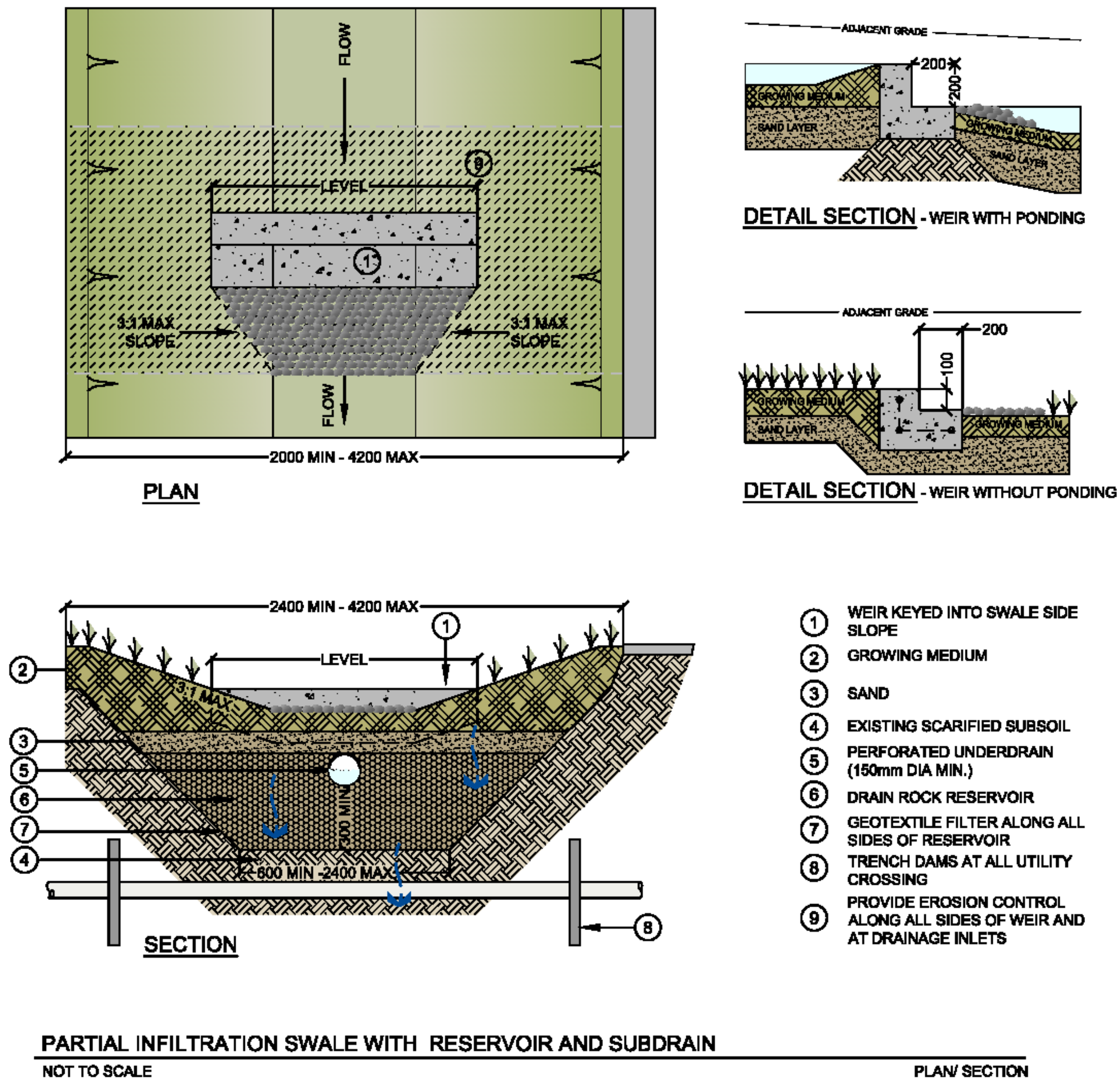
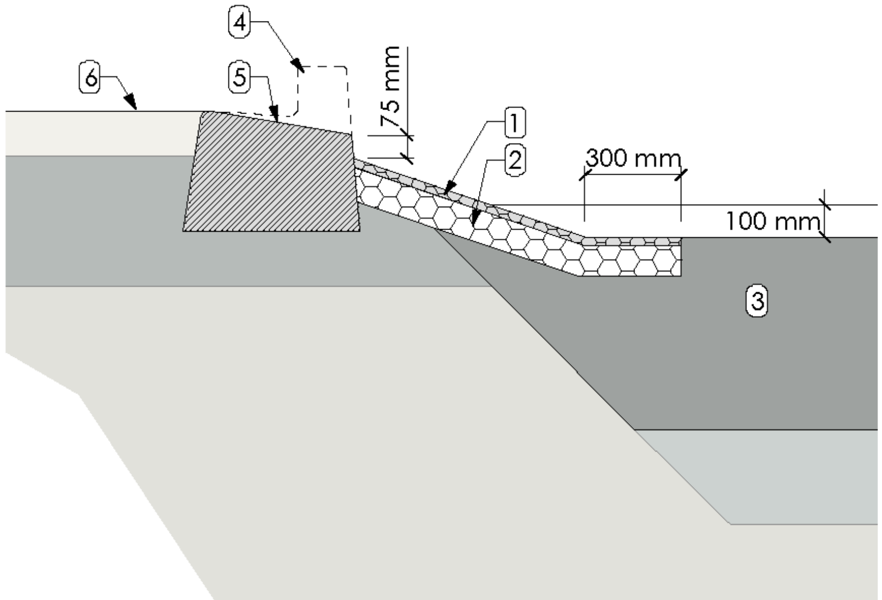


Figure 16 Partial Infiltration Swale with Reservoir and Subdrain (Not to scale, Plan/Section)



MATERIALS

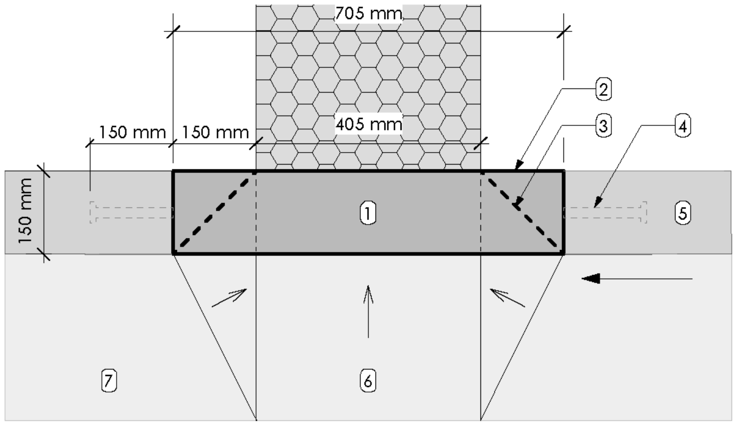
1. 25 mm - 25 mm dia drain rock
2. 100 mm - 50-75 mm dia drain rock
3. Growing medium
4. Curb (beyond).
5. Curb inlet, min 2%
6. Adjacent street surface

FLOW DISSIPATOR - PROFILE

NOT TO SCALE PROFILE

Figure 17 Flow Dissipator Options (Not to scale, Section)[4]

[4] Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



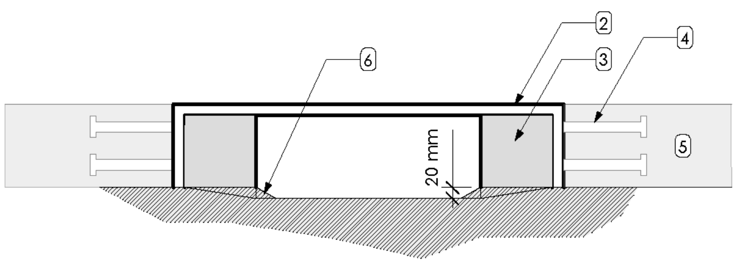
MATERIALS

1. Steel inlet structure
2. Steel rear wall
3. Steel baffle, angled 45 degrees towards rear wall.
4. Steel anchor, welded to inlet structure (2 each side)
5. Cast in place concrete curb
6. Hand trowel gutter to meet inlet base. Ensure positive drainage towards inlet.
7. Concrete gutter

STEEL CURB INLET

NOT TO SCALE

PLAN



STEEL CURB INLET

NOT TO SCALE

FRONT SECTION/ELEVATION DETAIL

Figure 18 Steel Curb Inlet Option[5]

[5] Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.

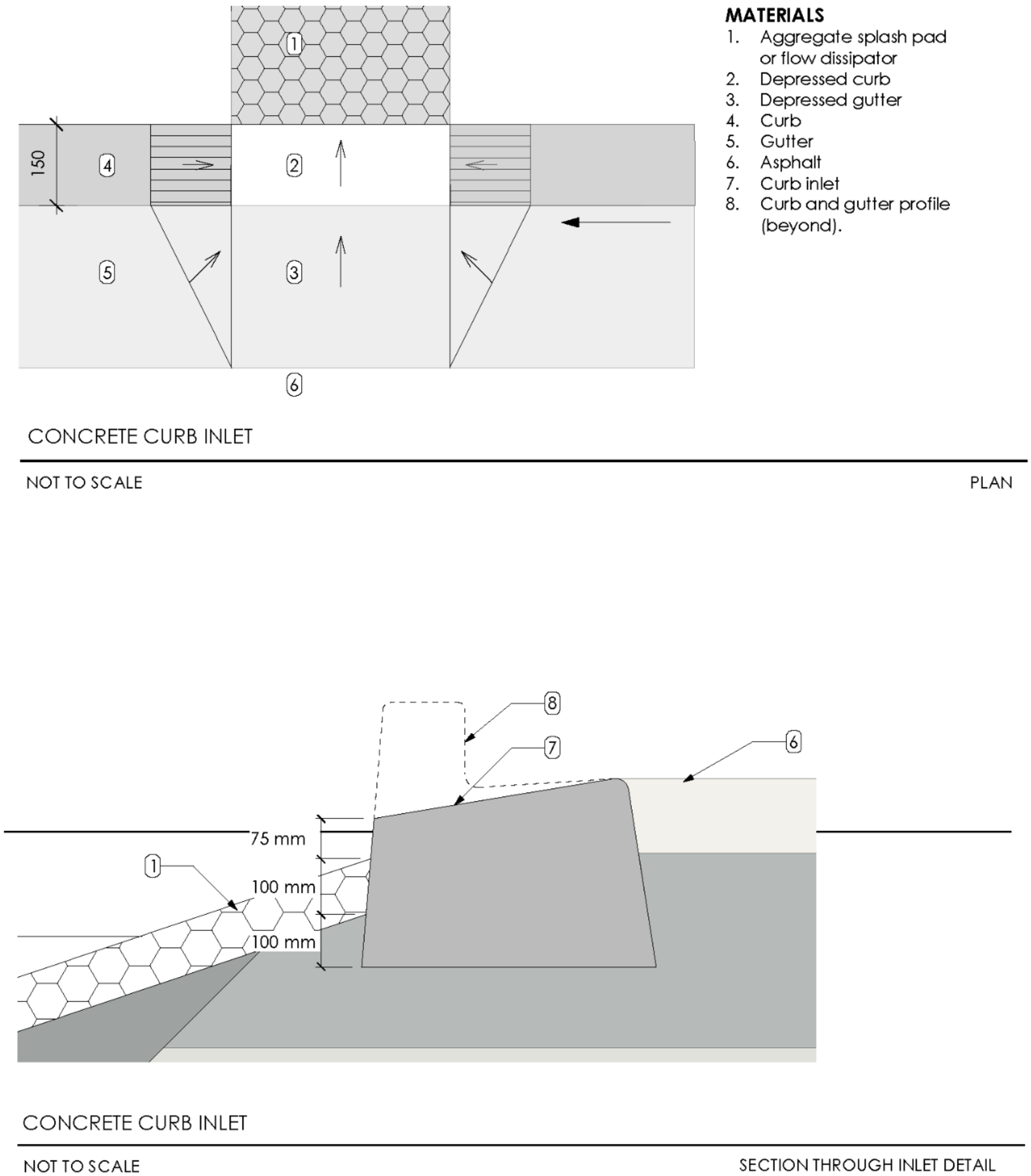
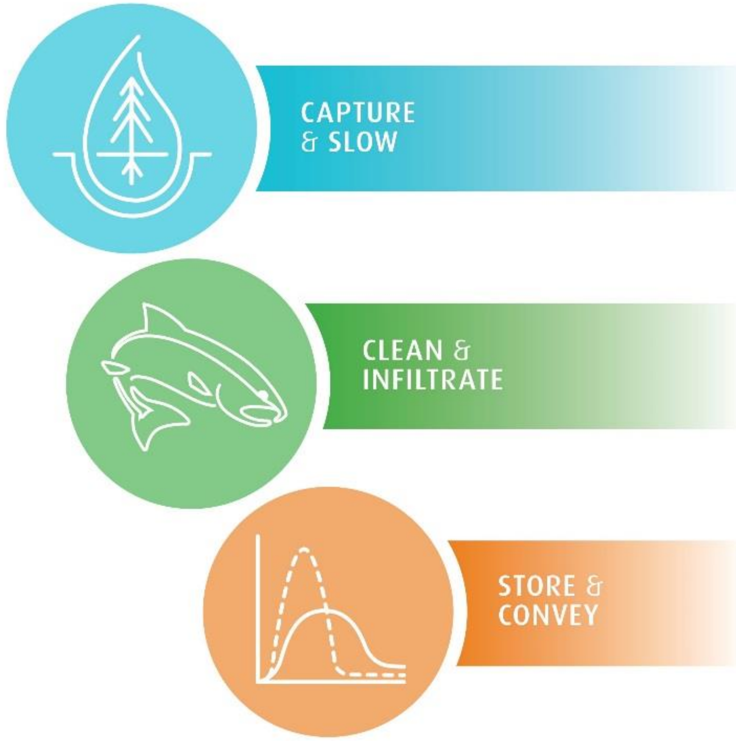


Figure 19 Concrete Curb Inlet Option[6]

[6] Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



Appendix D – Rain Garden

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Bioretention Rain Garden[1]

Description

The rain garden (bioretention basin or cell) is a form of bioretention that can be fully infiltrating or partial infiltrating (with underdrain). Typically, Bioretention Rain Gardens are designed as a concave landscaped area that collects, absorbs and filters stormwater runoff from roofs or paved surfaces. The stormwater is allowed to pond temporarily while infiltrating into soils below and include an adequate overflow connection to the storm drain network. Bioretention systems include the use of a specially formulated Bioretention Soil Mix (BSM) to treat the stormwater. Where infiltration is not advised or desired, flat bottomed above or below grade Flow-Through-Planters may be an option (see Appendix F Infiltration & Flow-Through Planters).

Figure 1 Rain garden on Camden Avenue, View Royal. Photo Credit: Town of View Royal

Bioretention is the process in which contaminants and sedimentation are removed from stormwater runoff. The surface planting of rain gardens is dominated by shrubs and groundcovers, with planting designs respecting the various soil moisture conditions in the garden. Plantings may also include trees, rushes, sedges and other grass-like plants, as well as sodded lawn areas for erosion control and multiple uses. Deciduous plants, especially trees, should be used carefully as the seasonal accumulation of leaves can be a concern for maintenance and may contribute to bind-off of the soil surface.

Figure 2 Rain garden on right-of-way, University of Victoria, Saanich

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd and/or as noted in figures.

Figure 3 Sunken planter style, flat bottom rain garden in commercial area parking lot, Saanich

Rain gardens generally have a drain rock reservoir and perforated drain system to collect excess water. 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.

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 (see Appendix C Grassy & Vegetated Swales). Other new designs of rain gardens include planter style flat bottomed raingardens (see Appendix F Infiltration & Flow-Through Planters or appendix E Infiltration Curb Extensions & Traffic Islands).

Selection, Application and Limitations

- Rain gardens are utilized for volume capture and stormwater treatment. Treatment is provided by the soil layer and volume capture by infiltration from the rock reservoir.
- Where the native soils have low infiltration rates, underdrain systems can be installed and the facility used to filter pollutants and detain flows that exceed infiltration capacity of the surrounding soil. However, designs utilizing underdrains provide less flow control benefits and may increase nutrient loading to nearby waterbodies.
- An impervious liner can be used to limit the risk of groundwater contamination in areas with high water tables, industrial areas or ultra-urban hotspots.
- A rain garden and infiltration swale have similar design and functions. A rain garden, or series of rain gardens, provides more capture of peak flows (due to ponding) and less conveyance of non-captured flows than a swale.
- If treatment is not required (e.g., for pre-treated or roof water only), an infiltration rock trench is more economical and space efficient, but does not provide the aesthetics and interactive value of the rain garden.
- A rain garden will provide increased volume capture over an infiltration trench due to the surface ponding and plant uptake of moisture.
- Smaller, distributed rain gardens are preferable to single large-scale facilities.
- Infiltration rain gardens may take a variety of shapes, from informal, organically shaped 'bowls' to formal, rectilinear planting areas and planters.

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives. Pre-treatment may be advised.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a qualified professional (i.e., professional engineer, landscape architect) for design is recommended.

Figure 4 Inlet type for rain garden with no dissipater

4. Site rain gardens similar to other infiltration facilities – minimum 30 m from wells, minimum 3 m downslope of building foundations, and only in areas where foundations have footing drains. See Table 1 for more details.
5. Inflows should be distributed sheet flow from pavement over a flat-panel curb, or through frequent curb cuts. A minimum drop of 50 mm from the pavement or flat curb edge to the top of the rain garden surface is required to accommodate sediment accumulation.
6. Where inflow is from curb cuts or point (pipe) discharge, a transition area at the inflow point(s) should incorporate erosion control and flow dispersion to distribute flow to the full rain garden area. Clean crushed rock or rounded river rock may be used. The slope of the transition area should be greater than 10% to move sediment through to the rain garden.
7. Flow may be pre-treated to remove sediment by travelling through a grassy swale prior to entering the rain garden (500 mm minimum, greater than 3,000 mm desirable swale length.)

Figure 5 Stormwater inlet to rain garden, Saanich

8. Experience has shown that grass is efficient at trapping sediment at a pavement edge and the sediment and grass matt will aggrade rapidly. In addition to the 50 mm drop (see Item 5, above) it is recommended that the transition slope or rain garden edge be covered with rock or sturdy mulch at the surface rather than grass.
9. Rain garden bottom or base area: flat cross section, with a longitudinal slope of 2% maximum (or 1% by US001, or dished by GE004).
10. Rain garden base area dimensions: bottom width 600 mm minimum, 3,000 mm is desirable.

Figure 6 Rain garden with beehive grate, Saanich

11. Provide a 50 mm–75 mm layer of non-floating organic aged mulch – well-aged compost, bark mulch or similar weed-free and manure-free material. The mulch is important for both erosion control and maintaining infiltration capacity.
12. Rain garden side slopes: 2 horizontal: 1 vertical maximum, 4:1 preferred for maintenance (i.e., mowing or other equipment access, if required). Provide organic mulch on side slopes similar to bottom.
13. Maximum ponded level: 150 mm to 300 mm. 200 mm maximum pond level is common and assumed for the simplified sizing approaches here.
14. For roadside applications, rock reservoir depth should generally not exceed the depth of the surrounding utilities.
15. Drawdown time for the maximum surface ponded volume: 48 hours preferred (72 hours max).
16. A non-erodible outlet or spillway must be established to discharge overflow to the storm sewer system. Use a beehive-type grate.
17. Rain garden depth includes ponding depth (depth to overflow level), an additional surcharge allowance (100 mm is common) to prevent overflow to the roadway or surrounding area, and sediment accumulation allowance (may be 3 mm/year or more depending on loading). Rain garden depth = ponding depth + surcharge allowance + sediment accumulation allowance.
18. Footprint of rain garden = base area + side slope area. Add additional area for side slopes according to the shape of the rain garden and the chosen side slopes; e.g., add [2 x slope x rain garden depth (m)] to each dimension of the base area to determine total footprint area. Flat bottom planter style rain gardens may also be considered.

19. Bioretention Soil Medium (BSM) (see details in Tables 3a and b) (i.e., treatment soil, growing media) depth: 450 mm minimum for most applications without an under-drain. BSM should have a minimum infiltration rate (lab tested) of 70 mm/hr, which is assumed in the sizing approaches in this document. BSM must be well-aged organics, weed free, preferably manure free and biosolid free.
20. Slope of the drain rock reservoir bottom shall be level to maximize infiltration area.
21. Avoid utility or other crossings of the rain garden. Where utility trenches must be constructed crossing below the garden, install low permeability trench dams to avoid infiltration water following the utility trench.
22. Drain rock reservoir and subdrain may be omitted 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 (approximately rainfall intensity x (I/P ratio + 1); I/P ratio is the ratio of impervious to pervious area and is defined below as part of sizing).
23. A perforated pipe subdrain is required to drain excess water from the soil and prevent root drowning of rain garden plantings. The subdrain should always be embedded in drain rock near the top of the rock reservoir to provide a storage volume below the subdrain unless a rain garden with flow restrictor option is used.
24. The subdrain should have flow and inlet capacity to carry the flow infiltrated through the soil layer. Consult pipe manufacturer for perforation inflow capacity. A maximum infiltration rate through the soil can be estimated by applying Darcy's equation:

    $$Q_{\max} = k \times L \times W_{base} \times \frac{h_{\max} + d}{d}$$

    where:
    k is the hydraulic conductivity of the growing medium (soil) (m/s), as measured during winter saturated soil conditions
    W_{base} is the average width of the ponded cross-section above the invert of the Rain Garden area (m)
    L is the length of the rain garden base area zone (m)
    $h_{\max}$ is the depth of the ponding above the growing medium (m)
    d is the thickness of the growing medium layer (m).
25. Refer to Figure 12 for curbing, inlet and flow dissipator detail options.
26. See Table 1 for setbacks for rain gardens.

Table 1 Rain Garden/ Bioretention Basin/Cell Setbacks

Consideration for Setbacks From	*Distance (m)
Up-gradient of building foundations	3
Property Line	Site dependent
Drinking Water Well	30
Up-gradient of septic field	3
Seasonal High Water Table	1
Up-gradient Active of inactive landfill or contaminated site	30
Existing trees	Outside root protection zone
Up-gradient of steep (> 15%) slope	30

Note: *or as directed by a Qualified Professional

Rain Garden Sizing

In this guide, a simplified sizing approach has been developed that does not require water balance modelling or continuous simulation.

1. In general, the rain garden area is sized based on the upstream impervious area that it serves. This relationship can be defined by the ratio of impervious area to pervious area (e.g., I/P ratio). For the simplified sizing approaches here, this represents the ratio of upstream impervious area (also called catchment area) to base area of the rain garden. The I/P ratio to achieve the target capture criteria will be calculated by the sizing method below.
2. The maximum allowable I/P ratio for given surface types is shown in Table 2. This maximum is based on ability of the vegetation to handle flows and pollutants and is not related to capture. Regardless of sizing calculation below, maximum I/P ratio for a given surface type should not be exceeded.
3. The sizing process provides the base area of the rain garden, which is the flat area at the bottom with uniform layers of mulch, topsoil and drain rock. Sizing by these methods does not account for any infiltration benefit provided by the sloped sides of the rain garden.
4. The base area of the rain garden will always be smaller than the total footprint of the facility, so the footprint must be calculated (see Item 18 in previous section) in order to understand the actual site area required.
5. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. Sizing and design according to this guidance will generally provide water quality treatment for the volume of water infiltrated. If "water quality" criteria volumes are larger than "capture" volumes, additional sizing may be required and a professional engineer should be consulted.

Table 2 Rain Garden Maximum I/P Ratios by Surface Type

Surface Type	Max. I/P Ratio
General/Industrial Storage/Loading Areas	20:1
Divided or Undivided Major Road (Expressway or Highway)	20:1
Collector Road	20:1
Parking >1 car/day/parking space	20:1
Local Road	30:1
Parking <1 car/day/parking space	40:1
Low traffic areas, no parking	50:1
Single Family Residential, Lot and Roof	50:1

Sizing Method Using Depth Capture Criteria: R mm in 24 hours

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area-specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; allowable depth range is 300 to 2,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr)
T = allowable drain time (days)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the base (bottom) area of rain garden and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_P + D_R \times n + 0.2 \times D_S}{R} - 1$$

Where:
I/P = Ratio of impervious tributary area to rain garden base area (unitless)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_P = Depth of ponding (mm); 200 mm standard
D_R = Depth (thickness) of rock reservoir (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)
D_S = Soil layer depth (thickness); standard value = 450 (mm)

3. Check that the I/P ratio calculated is less than the maximum allowed (Table 2). If it is not, use the maximum allowed I/P ratio. This may mean that the rain garden will exceed the % capture desired.

4. To find the rain garden base area:

$$BaseArea = \frac{\text{Impervious } TributaryArea}{I / P}$$

5. Calculate the footprint of the facility based on the base area and side slopes as described in Item 18 in previous section.

6. If the site cannot accommodate the I/P ratio required to provide the target capture, a partial-infiltration rain garden with flow restrictor design may be used.

7. A 0.25 L/s/ha (or 0.09 mm/hr) unit discharge has been recommended by DFO for the flow restrictor at the downstream end of the subdrain.

8. Calculate the allowable discharge through the orifice:

$$Q = \frac{0.25 \times A_{SITE}}{1000}$$

Where:
Q = Allowable discharge through orifice (m^3/s)
0.25 = Recommended unit discharge (L/s/ha)
A_{SITE} = Total site area draining to the rain garden, including the rain garden area (ha)

9. This discharge is used to size the orifice on a flow restrictor at the downstream end of the rain garden subdrain.

10. Solving the orifice equation for area of the orifice (AO):

$$A_O = \frac{Q_{SITE}}{K \times \sqrt{2g\Delta h}}$$

Where:
Q_{SITE} = Theoretical discharge through infiltration from the impervious area (m^3/s)
K = Orifice Coefficient (typical value 0.6)
g = gravitational constant (m/s^2)
h = differential head equivalent to depth of the perforated drain pipe in the rock layer (typical value 0.3 m)
A_O = Area of the orifice opening (m^2) – generally assumed to be circular for calculation of orifice diameter.

The size of the rain garden is then determined by the available area on the site up to the maximum I/P ratio for the surface type as shown in Table 2.

11. For the flow restrictor option, the subdrain should be at bottom of the rock in the rock reservoir. The depth of the rock reservoir above the orifice outlet is calculated as:

$$D_R = \frac{R \times (I/P + 1) - 0.09mm/hr \times 24hrs \times (I/P + 1) - 24 \times Ks - 0.2 \times D_S}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
R = Rainfall capture depth (mm)
I/P = Ratio of impervious tributary area to rain garden base area (unitless)
0.09 = Recommended unit discharge through orifice (mm/hr)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_S = Soil layer depth (thickness); standard value = 300 (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, with a porosity of 35% to 40% such as 75 mm max., 38 mm min, or MMCD Section 31 05 17 Part 2.6 – Drain Rock, Coarse.
2. Pipe: PVC, DR 35, 150 mm min. dia., with cleanouts, certified to CSA B182.1 as per MMCD.
3. Geosynthetics: as per Section 31 32 19, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 31 05 17.
5. Growing Medium: Bioretention Soil Media (i.e., growing media): As per Tables 3a and 3b Bioretention Soil Medium but with required minimum saturated hydraulic conductivity of 70 mm/hr.
6. Seeding: conform to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding. (Note: seeding will be required for erosion control in most instances).
7. Sodding: conform to MMCD Section 31 92 23 Sodding. (Note: sodding will be required for erosion control in most instances).
8. Planting: see Supplemental 1, Planting Templates & Plant Lists.

Construction Practices shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Isolate the rain garden site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300 mm of material over the final subgrade of the rain garden until after all sediment-producing construction in the drainage area has been completed.
2. Prevent natural or fill soils from intermixing with the infiltration drain rock. All contaminated stone aggregate must be removed and replaced.

3. Infiltration drain rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
4. Maintain grass areas to mowed height between 50 mm and 150 mm, but not below the design water quality flow level. Landscape Maintenance standards shall be to the Canadian Landscape Standard, 1st Edition, Maintenance Level 4: Open Space / Play.

Bioretention Soil Medium

Composition of Bioretention Soil Medium (BSM) is an important factor in the performance of GSI facilities. Soil mixes for bioretention and vegetated infiltration facilities need to balance 3 primary design objectives for optimum performance:

- ✓ High enough infiltration rates to meet desired surface water drawdown and system dewatering.
- ✓ A growth media to support long term plant and soil health and water quality treatment capability.
- ✓ Infiltration rates that are not too high in order to optimize pollutant removal capability.

For the latest information on bioretention soil research see the Washington Stormwater Center's webpage on Bioretention http://www.wastormwatercenter.org/lid-bioretention/. Below are 2 local BSM suggested mixes.

Table 3.a Rain Garden Bioretention Soil Mediums Mix 1[2]

Rain Garden
Bioretention Soil Medium (BSM) Mix 1
Recommended depth: minimum of 450 mm
Minimum required saturated hydraulic conductivity of 70 mm/hr.

Component (partial size classes)	Percentage by Weight
Gravel (greater than 2.5 mm)	0
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter; and • Particle size in sand to be: a) 90-100% passing a 2.50 mm sieve, b) 0-65% passing a 0.500 mm sieve, c) 0-5% passing a 0.0500 mm sieve	70-80
Silt (greater than 0.002 mm and less than 0.05 mm)	5-15
Clay (less than 0.002 mm)	2-5
Organic Content (%dry weight) • must be well aged organics, weed free, preferably manure free and biosolid free.	10-15
Other Soil Considerations	
• **pH** of mixed materials between 6-8.5 • **Phosphorus (P) and Nitrogen (N) Management Recommendations:** In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017 B113 SAFE SOILS PROGRAM (page 111) http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf	

[2] Source: Rain Gardens, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Rain%20Garden.pdf

Table 3.b Rain Garden Bioretention Soil Mediums Mix 2[3]

Rain Garden **Bioretention Soil Medium (BSM) Mix 2*** Recommended depth: minimum of 450 mm **Minimum required saturated hydraulic conductivity of 70 mm/hr.**	
Component (partial size classes)	**Percentage by Weight**
Coarse Gravel (particles greater than 19 mm and less than 40 mm)	0 to 1
All Gravels (particles greater than 2 mm and less than 40 mm)	10 to 25
Sand, Silt, Clay & Organic components measured from remaining non gravel portion of sample (% dry weight)	
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter. • Note: Growing medium/BSM to be manufactured with '2 mm minus' sand to reduce gravel content in the soil. 2 mm minus sand is available from most local quarries upon request.	60-70
Combined Silt and Clays (less than 0.05 mm)	10-20
Organics (% dry weight) • must be well aged organics, weed free, preferably manure free and biosolid free.	15-20
Other Soil Considerations	
• **pH** of mixed materials between 6-8.5 • **Phosphorus (P) and Nitrogen (N) Management Recommendations**: In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017, page 111 for B113 SAFE SOILS PROGRAM. http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf	

[3] Source: City of Victoria, Rainwater Management Standards – Professional Edition (June 2015) http://www.victoria.ca/assets/Departments/Engineering~Public~Works/Documents/SWVictoria_Professional_Rainwater_Mgmt_Stds_June2015.pdf

Rain Garden Design Example for Capture of R mm/24-hour Criteria

Scenario Description

A Rain Garden is proposed to capture a portion of the runoff from a paved parking area (see illustration below).

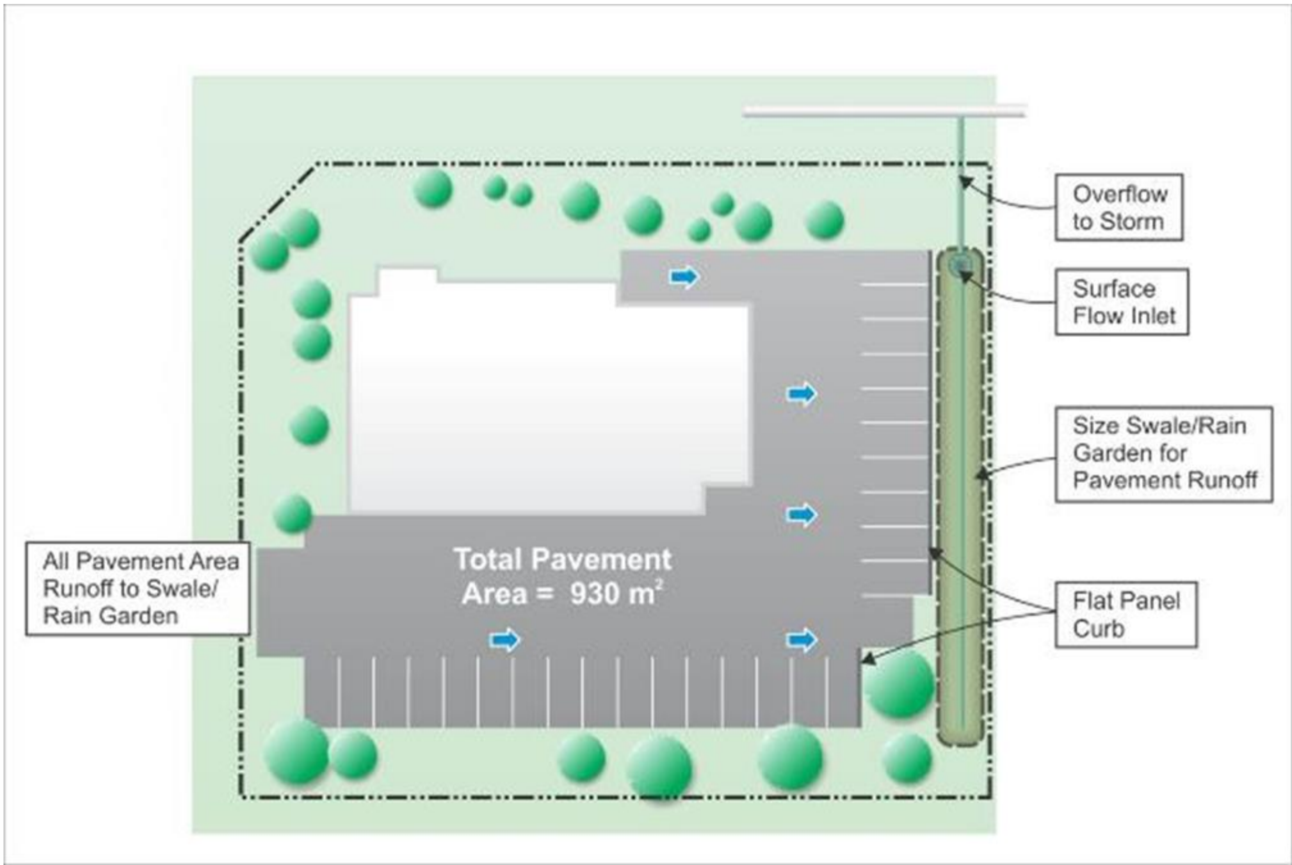


Figure 7 Example – Parking Area Draining to Rain Garden

The following parameters are known:

- Total pavement area = 930 m^2
- Annual rainfall = 1,200 mm
- 2-year 24-hour rain depth = 53 mm
- Native soil infiltration rate = 1.5 mm/hr
- Parking use is more than 1 car per day
- Capture target is 50% of 2-year 24-hour rain amount = 38 mm

Determine the rain garden footprint area and rock trench depth.

Sizing

Determine the maximum rock depth based on the 4-day maximum drain time:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{1.5mm/hr \times 4days \times 24hr/day}{0.35} = 411mm$$

Use 400 mm rock depth.

Determine the maximum I/P ratio (see Table 2). Parking use of more than 1 car per day yields a maximum I/P ratio of 20.

Determine the base (bottom) area of rain garden and rock reservoir required by calculating the required I/P ratio:

$$I/P = \frac{24 \times Ks + D_P + D_R \times n + 0.2 \times D_S}{R} - 1$$

$$I/P = \frac{24 \times 1.5mm/hr + 200mm + 400mm \times 0.35 + 0.2 \times 450mm}{38mm} - 1$$

$$I/P = 11.3$$

Check that the I/P ratio (Table 2) is less than the maximum (11.3 < 20, therefore OK).

Calculate the rain garden base area:

$$BaseArea = \frac{imperviousTributaryArea}{I/P} = \frac{930\,sq.m}{11.3} = 82\,sq.m$$

Example Hydraulic Components

- Inlet: Pavement runoff sheet flows over a panel curb into the rain garden.
- Overflow: A surface inlet in the rain garden decants water that cannot infiltrate into the soil once the ponding reaches a depth of 200 mm. The surface inlet is connected to the municipal storm sewer connection.
- Subdrain: A perforated pipe located along the top of the rock layer decants excess water into the municipal storm sewer connection when the rock layer is full of water.

Example Operation and Maintenance

- Correct erosion problems as necessary. Ensure distributed sheet flow into the rain garden.
- Mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.
- Remove leaves each fall, inspect overflow, hydraulic and structural facilities annually.
- Replace dead plants, as required.
- Surface inlet sump should be inspected annually and cleaned, as required. Sediment should be removed from the sump bottom and floatables removed from the water surface.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Bioretention areas function as soil and plant-based devices that can achieve both runoff reduction and pollutant removal. Runoff reduction is achieved through canopy interception, soil infiltration, and evapotranspiration. Pollutant removal is achieved through a variety of physical, biological, and chemical treatment processes. A number of pollutants including trace metals, suspended solids, nutrients, and oil and grease are removed from stormwater by filtering, adsorption, biological uptake, and denitrification within the bioretention cell's mulch and soil media. The pollutant removal efficiency can be increased or decreased based on the design components, underlying soil infiltration capabilities and what pollutants are being targeted for reduction. The following table shows the effectiveness of bioretention facilities for GSI drivers, including contaminant removal and stormwater runoff reduction.

Table 4 Runoff Reduction and Contaminant Removal

Bioretention and Vegetated Infiltration GSI Facilities (rain gardens, swales, planters, curb extensions)	
GSI Driver	***Estimated Effectiveness or typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain low with liner and underdrain
Store & Convey- Rate Control Delay Peak	Medium to high without under drain Medium with underdrain Low with liner and underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	35 to 90
Oil and Grease	>70% (higher with mulch)
Phosphorus	-70 to >85
Nitrogen	20 to >30
Total Suspended Solids (TSS)	60 to >95
Bacteria (Fecal coliform bacteria or E. coli)	>70

Note: * Performance of individual GSI facilities will vary depending on site-specific contexts and facility design. Negative numbers indicate contaminant loading from the given GSI facility producing a higher export of a given contaminant.

Sources:
http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.5-bioretention.pdf
http://www.lid-stormwater.net/bio_benefits.htm
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/appendix-d-removal-rates.pdf
http://www.bmpdatabase.org/
https://stormwater.pca.state.mn.us/index.php?title=Information_on_pollutant_removal_by_BMPs

Maintenance

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. The successful establishment of a bioretention area requires a first year inspection and maintenance operation that includes the following tasks:

- Initial inspections after storm events of over 13 mm of rainfall
- Spot reseeding of bare or eroding areas
- Spot fertilization requirements of initial plantings
- Watering once a week during first 2 months and as needed during first growing season
- Remove and replace dead plants to ensure that vegetation is properly established (up to 10% of plant stock may die off in the first year)

After the first year, it is highly recommended that an annual spring maintenance inspection and cleanup be conducted at all bioretention facilities which would include the following:

- Check % cover of mulch plus vegetative cover
- Check for sediment buildup at entrance points
- Check for winter killed vegetation and replace
- Note presence of accumulated sediment
- Check for any erosion
- Check for signs of excessive ponding
- Check for clogged soil media and crust formation

Maintenance of bioretention areas can be divided into routine and non-routine tasks.

Routine Maintenance

Most routine maintenance procedures are typical landscape care activities performed by landowners.

Routine Maintenance for Bioretention Facilities – Rain Gardens and Planters		
ACTIVITY	**OBJECTIVE**	**SCHEDULE**
Watering (by hand or irrigation system)	Maintain a minimum 80% survival rate of plants	Once established (2-3 years), watering may be required during prolonged dry periods or as indicated by plant health.
Debris and trash removal Cleaning entrance points and basin	Maintain proper flow from impervious areas, maintain aesthetics and prevent clogging	Twice annually (October & January)
Inspect for erosion control	Maintain flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred	Twice annually (October & January)
Pruning vegetation and remove dead plants	Maintain plant coverage and health, soil health, and infiltration capability – remove all clippings and dead plant material	Once or twice annually
Weeding (by hand)	Reduce plant competition and maintain aesthetics	Twice annually preceding weed seed disbursement
Mulching – Replace mulch annually or semi-annually with 50-75 mm mulch free of weeds	Replenish organic material, reduce erosion, and maintain soil moisture in bioretention facilities where heavy metal deposition is high (e.g., contributing areas that include gas stations, ports and roads with high traffic loads). In residential settings or other areas where metals or other pollutant loads are not anticipated to be high, replace or add mulch as needed (likely 3 to 5 years) to maintain a 50-75 mm depth.	Annually
Minor sediment removal (with shovel or rake)	Reduce clogging, maintain plant survival, maintain ponding depths	Annually

Non-routine Maintenance

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments or repairs may be needed.

Non-Routine Maintenance for Bioretention Facilities

ACTIVITY	OBJECTIVE	SCHEDULE
Spill clean-up – block under drain temporarily	Stop flow exiting	As needed
Major sediment removal (with shovel, vactor intake structures)	Reduce clogging, maintain plant survival, maintain ponding depths	By inspection and after a major storm event (10-year, 24-hour)
Clean under drains (jet clean or rotary cut roots)	Maintain drainage, ponding depths, and dewatering rates	Determined by inspection
Clean border of pavement and vegetation (trimmer, rake, or shovel)	Maintain proper sheet flow to bioretention area	By inspection
Replace vegetation (reseed/replant)	Maintain dense vegetation to prevent erosion and exclude weeds	By inspection
Replace soil (by hand or small excavator)	Maintain infiltration, soil fertility, and pollutant removal capability	By inspection (visual and infiltration testing)
Rebuild structures (walls, intakes, weirs, etc.)	Maintain proper drainage	By inspection
Re-grade side slopes (by hand or small excavator)	Prevent erosion	By inspection
Full soil removal and replacement	Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Regular replacement of mulch media in bioretention facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.	Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems, but this will vary according to pollutant load.

Adapted from: Western Washington manual
http://www.ecy.wa.gov/programs/wq/stormwater/manual/2014SWMMWWinteractive/Content/Topics/VolumeV2014/VolV%20Ch7%202014/VolV%20BMPt730%202014.htm

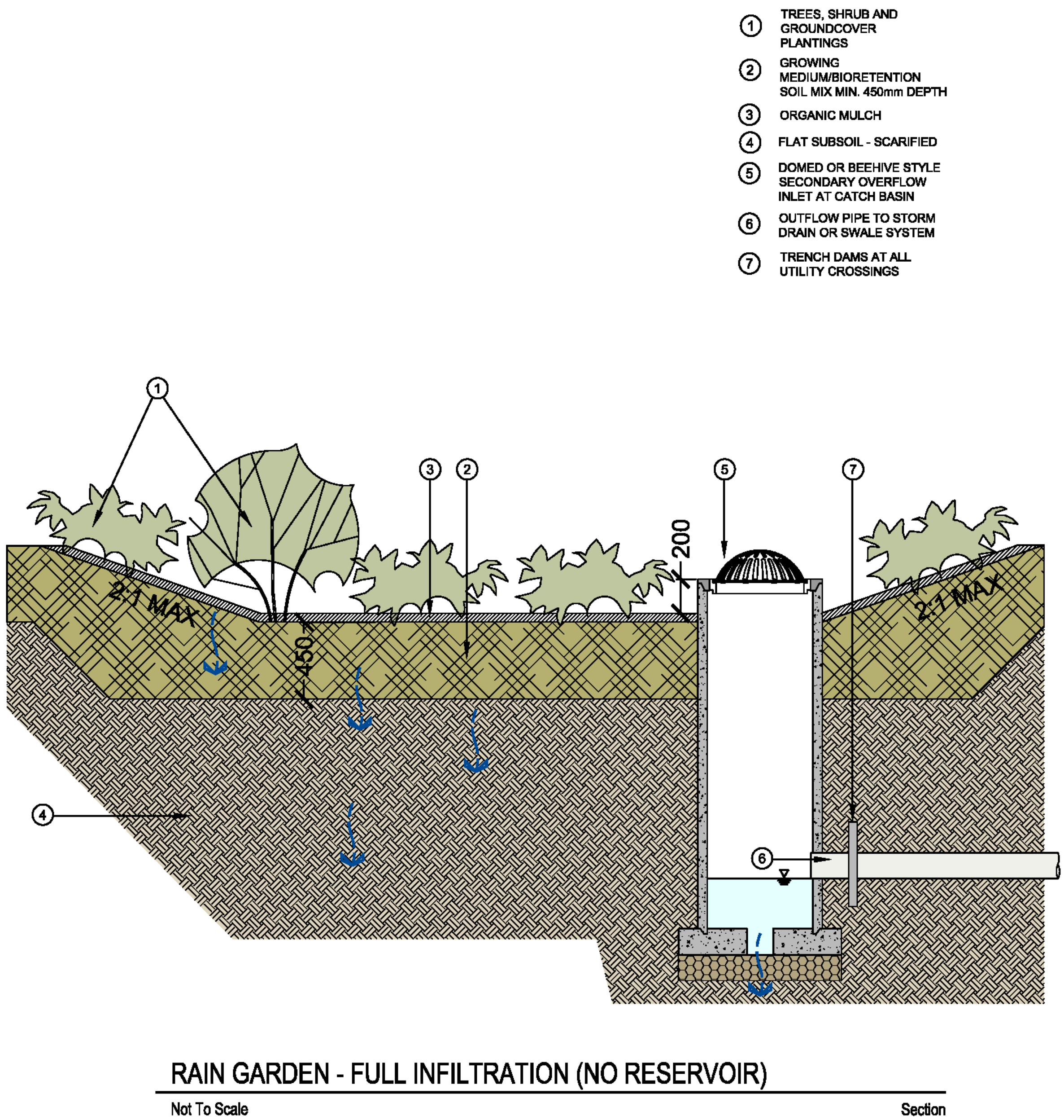


Figure 8 Rain Garden – Full Infiltration (No Reservoir) (Not to scale, Section)

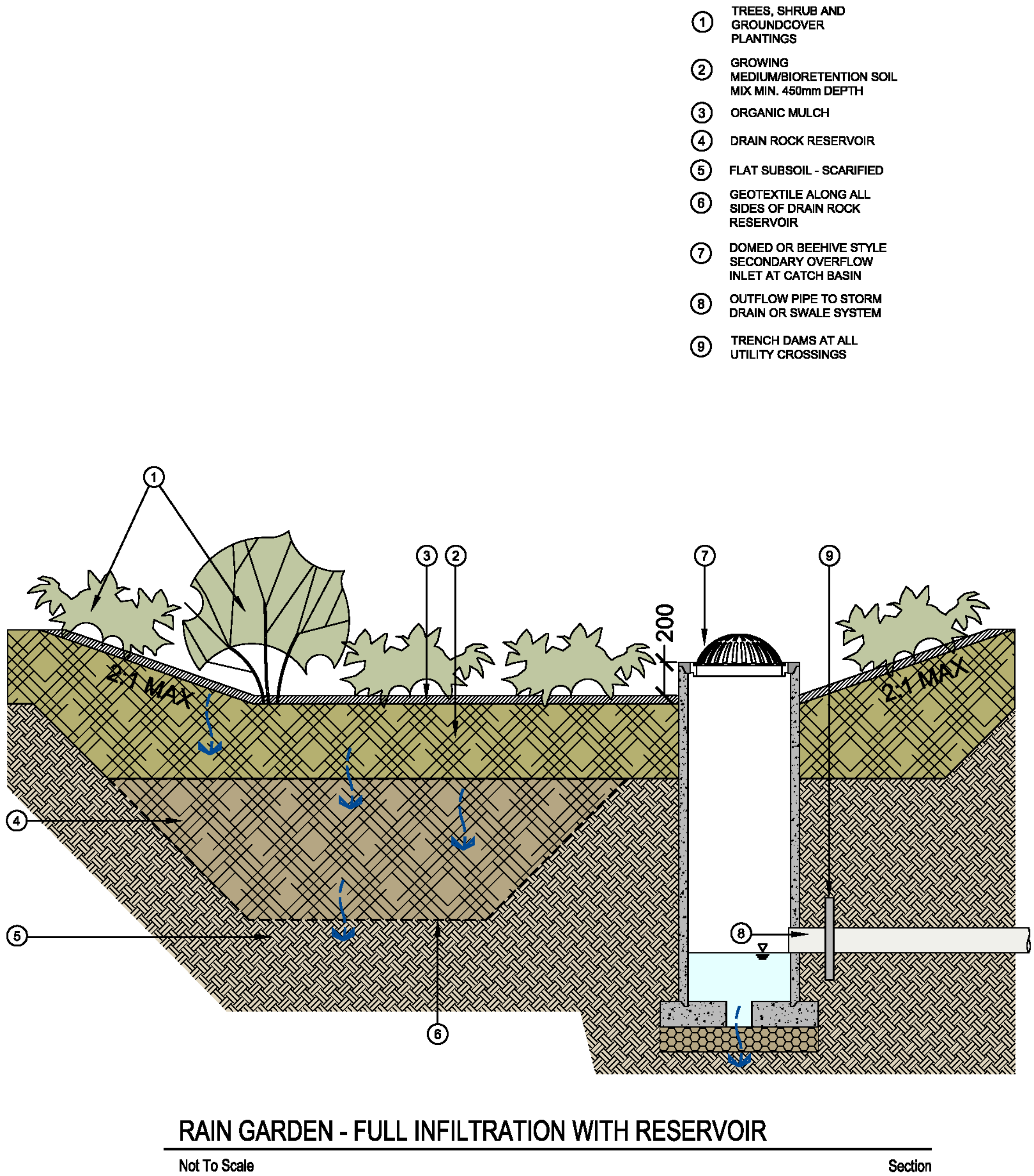


Figure 9 Rain Garden – Full Infiltration with Reservoir (Not to scale, Section)

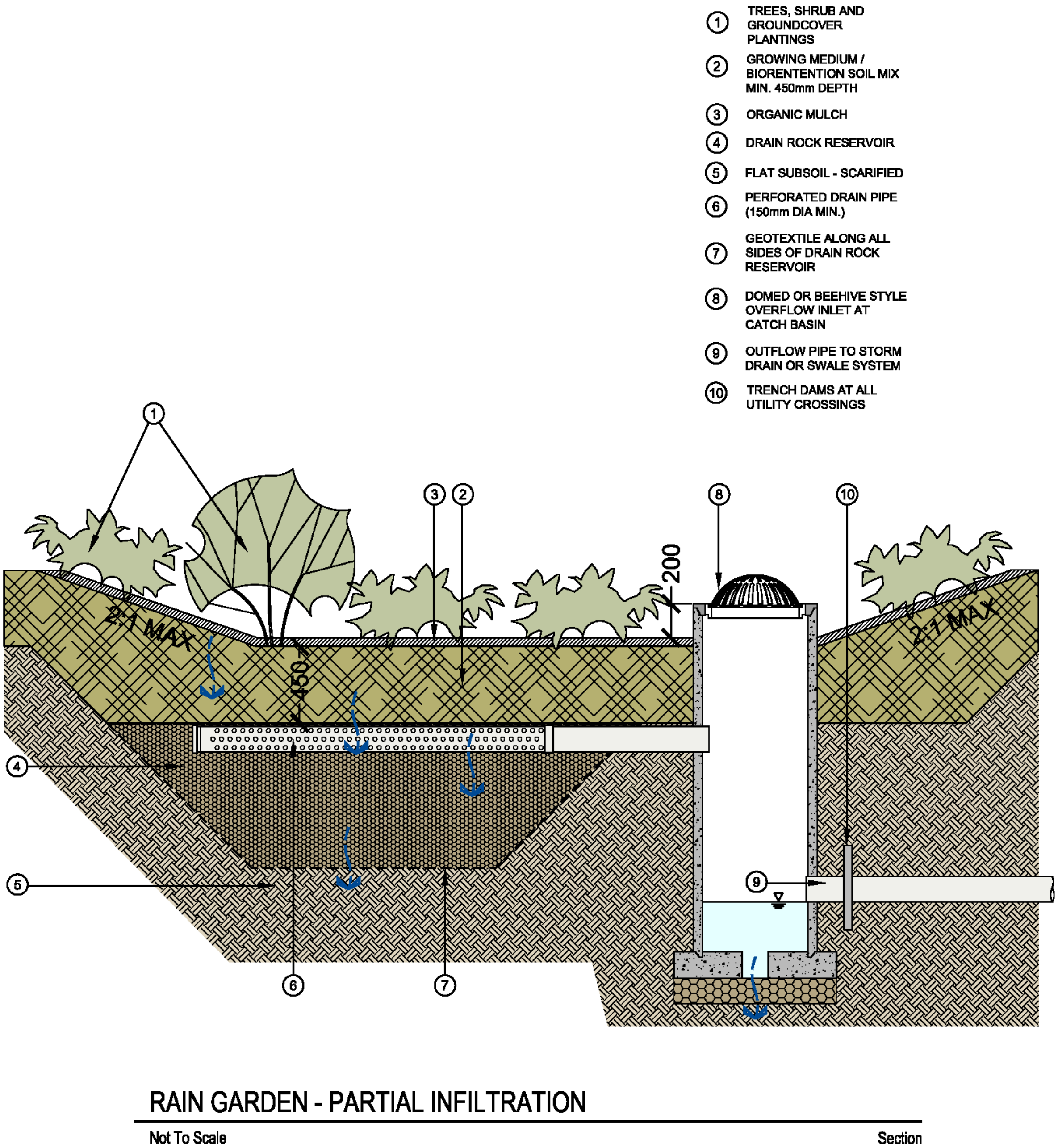


Figure 10 Rain Garden – Partial Infiltration (Not to scale, Section)

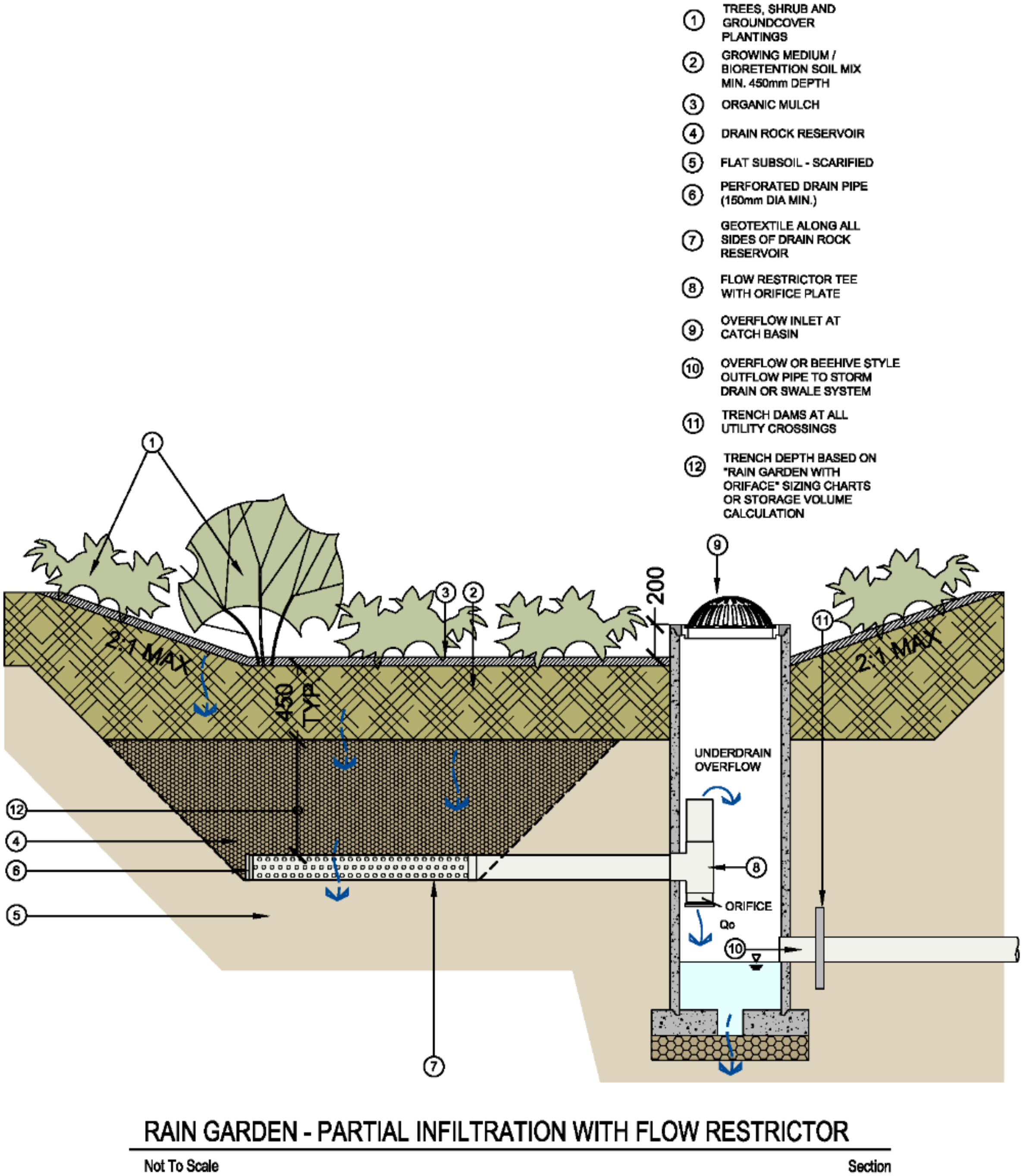


Figure 11 Rain Garden – Partial Infiltration with Flow Restrictor (Not to scale, Section)

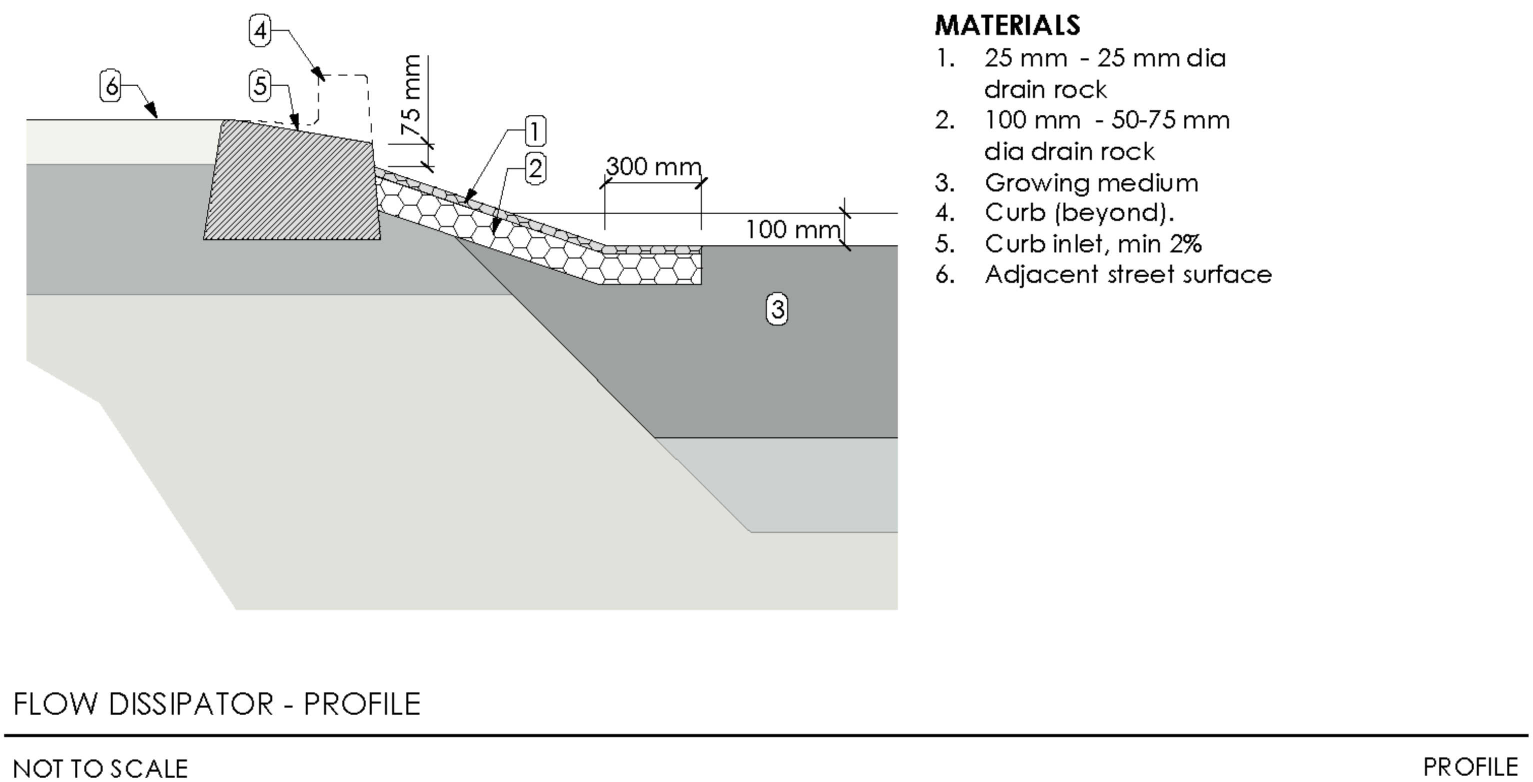
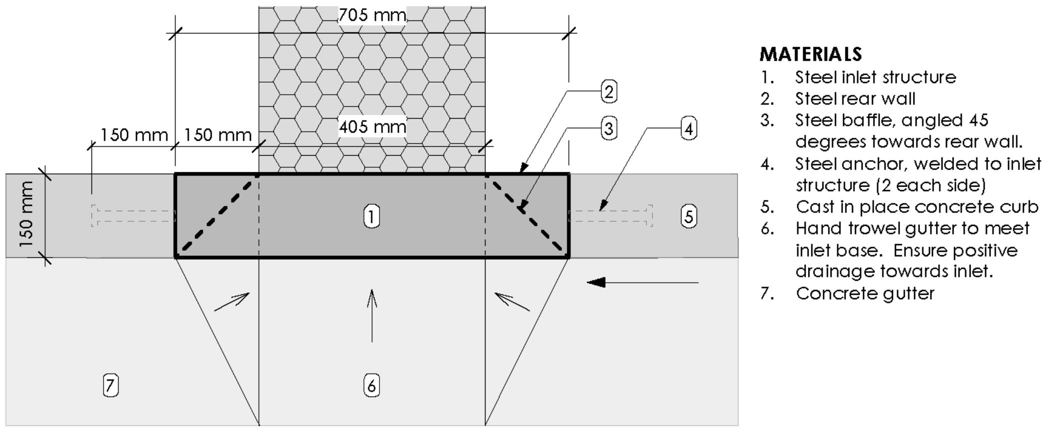


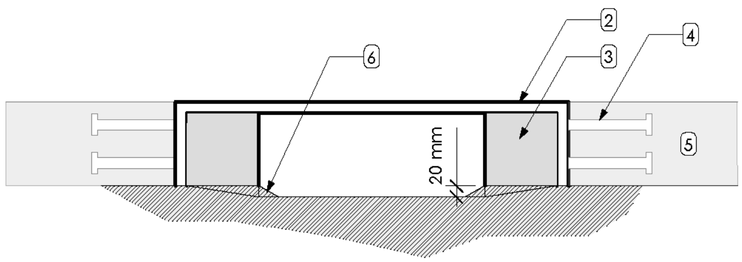
Figure 12 Flow Dissipator Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



STEEL CURB INLET

NOT TO SCALE PLAN

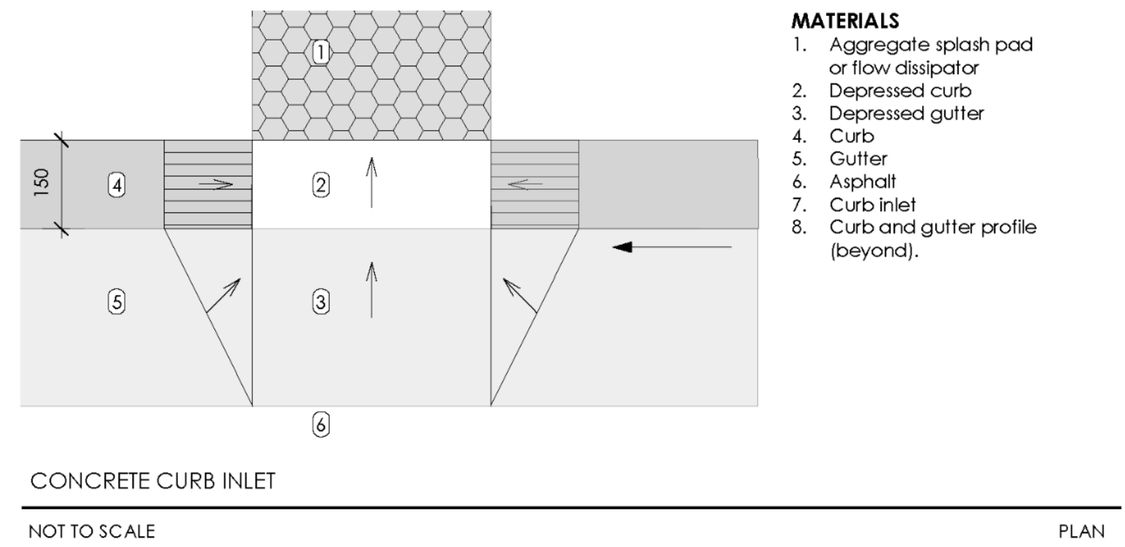


STEEL CURB INLET

NOT TO SCALE FRONT SECTION/ELEVATION DETAIL

Figure 13 Steel Curb Inlet Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



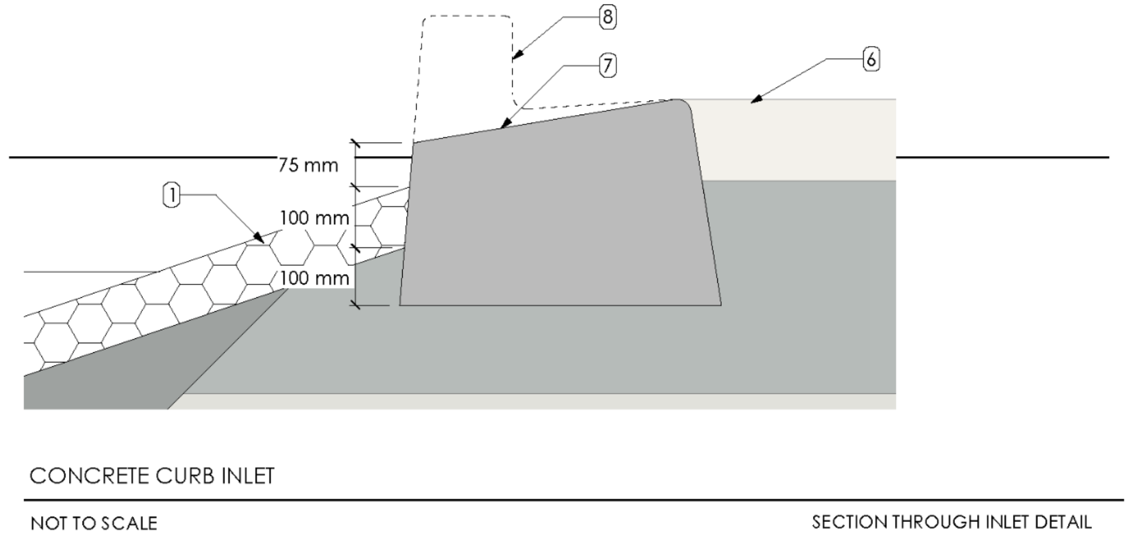
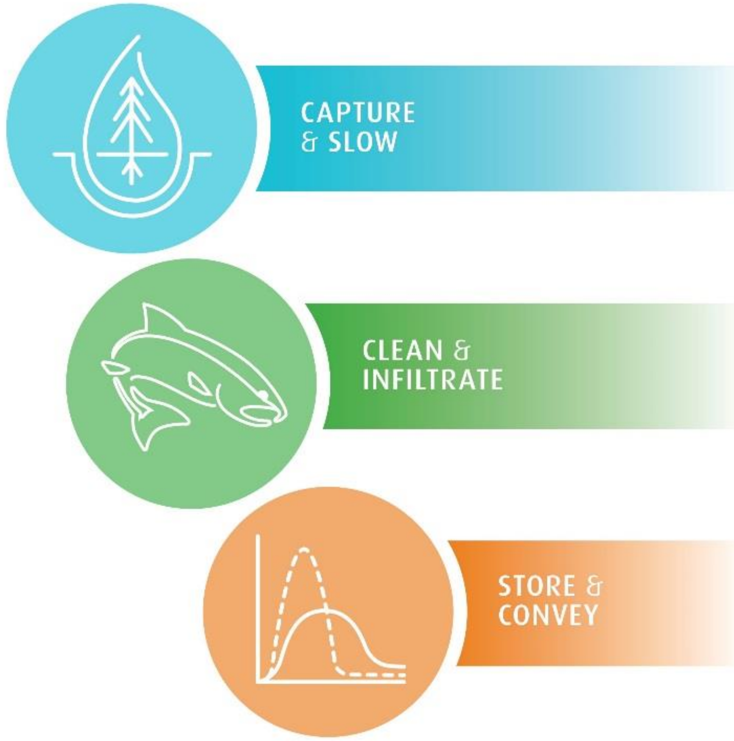


Figure 14 Concrete Curb Inlet Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



APPENDIX E - INFILTRATION CURB EXTENSIONS & TRAFFIC ISLANDS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Infiltration Curb Extensions & Traffic Islands[1]

Description


Figure 1 Infiltration curb extension on Shelbourne. Photo Credit: District of Saanich

Infiltration curb extensions (also called infiltration bulges) is a form of bioretention or infiltration facility located in rights-of-way between the sidewalk and the roadway. Vegetated curb extensions are commonly a concave landscape area where runoff from the street gutter is temporarily collected while it infiltrates into the soils below.

Infiltration curb extensions can either be positioned mid-block or at street corners.

The surface planting of infiltration curb extensions is dominated by groundcovers and fine close-growing grasses, with planting designs respecting the various soil moisture conditions in the extension. Plantings may also include rushes, sedges and other grass-like plants, as well as sodded lawn areas for erosion control and multiple uses.

Infiltration curb extensions have a drain rock reservoir and perforated drain system to collect excess water. 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 vegetated curb extensions between storms.

Infiltration curb extensions also provide aesthetic value and can improve the safety of all road users by reducing the width of the road.

Curb extensions visually and physically narrow the roadway which causes drivers to slow the speed of their vehicle. They also create safer and shorter crossings for pedestrians.

Infiltration traffic islands have many of the same features as curb extensions, however, they require the street to be constructed such that stormwater flows towards the center of the street. Due to this, their main application is during new street construction or a major street rehabilitation.

[1] Authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd and/or as noted in figure.

Selection, Application and Limitations

- Infiltration curb extensions are utilized for volume capture and stormwater treatment. Treatment is provided by the soil layer and volume capture by infiltration from the rock reservoir.
- If treatment is not required (e.g., for pre-treated or roof water only), an infiltration rock trench is more economical and space efficient, but does not provide the aesthetics and interactive value of the vegetated curb extension.
- Will provide increased volume capture over an infiltration trench due to the surface ponding and plant uptake or moisture.

Figure 2 Curb side infiltration, Saanich

- The availability of street space and presence of utilities will affect the placement and design.
- Infiltration curb extensions and traffic islands promote traffic calming and pedestrian safety.
- Trees may be included, columnar versions of tree species are recommended due to less maintenance for overhead wires and vehicle clearance.

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Site vegetated curb extensions similar to other infiltration facilities – minimum 30 m from wells, minimum 3 m downslope of building foundations, and only in areas where foundations have footing drains.
5. A minimum length of 4 m and width of 2 m should be achieved.

Figure 3 vegetated infiltration traffic island, Island Highway, View Royal. Photo Credit: Town of View Royal

6. A steel curb inlet is used to allow water to pass through the concrete curb but protect road users from entering the vegetated curb extension, however, require higher maintenance to prevent clogging. Newer topless designs that are less likely to clog with debris include concreate curb cuts with steel or concrete flow dissipator (see Figure 9).
7. When infiltration curb extensions are installed at corners with pedestrian curb ramps, stormwater should be collected within the facility.
8. When infiltration curb extensions are installed at mid-block locations, stormwater can either be collected within the facility or flow through the facility.
9. A minimum drop of 50 mm from the pavement or flat curb edge to the top of the vegetated curb extension surface is required to accommodate sediment accumulation.
10. Clean crushed rock or rounded river rock may be used at inflow point(s). The slope of the transition area should be greater than 10% to move sediment through to the curb extension.
11. Experience has shown that grass is efficient at trapping sediment at a pavement edge and the sediment and grass matt will aggrade rapidly. In addition to the 50 mm drop (see Item 9, above) it is recommended that the transition slope or vegetated curb extension edge be covered with rock or sturdy mulch at the surface rather than grass.


Figure 4 Steel curb inlet example


Figure 5 Curb example with steel flow dissipator

12. Provide a 50 mm–75 mm layer of non-floating organic mulch – well-aged compost, bark mulch or similar weed-free material. The mulch is important for both erosion control and maintaining infiltration capacity.
13. Rock reservoir depth should generally not exceed the depth of the surrounding utilities.
14. Drawdown time for the maximum surface ponded volume: 48 hours preferred (72 hours max.).
15. A non-erodible outlet or spillway must be established to discharge overflow to the storm sewer system. This often takes the form of a grated inlet raised above the vegetation to create the ponding depth.

16. Bioretention Soil Media (BSM) (i.e., treatment soil, growing medium) depth: 450 mm minimum for most applications. Treatment soil should have a minimum infiltration rate (lab tested) of 70 mm/hr, which is assumed in the sizing approaches in this document.

17. Slope of the drain rock reservoir bottom shall be level to maximize infiltration area.

18. Avoid utility or other crossings of the vegetated curb extension. Where utility trenches must be constructed crossing below the vegetated curb extension, install low permeability trench dams to avoid infiltration water following the utility trench.

Figure 6 Curb cut example - Concrete curb let down with rocks

19. Drain rock reservoir and subdrain may be omitted 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.

20. A perforated pipe subdrain is required to drain excess water from the soil and prevent root drowning of vegetated curb extension plantings in poorly draining soils. The subdrain should always be embedded in drain rock near the top of the rock reservoir to provide a storage volume below the subdrain unless a vegetated curb extension with flow restrictor option is used.

21. The subdrain should have flow and inlet capacity to carry the flow infiltrated through the soil layer. Consult pipe manufacturer for perforation inflow capacity. A maximum infiltration rate through the soil can be estimated by applying Darcy's equation:

$$Q_{\max} = k \times L \times W_{base} \times \frac{h_{\max} + d}{d}$$

where:

k is the hydraulic conductivity of the growing medium (soil) (m/s), as measured in winter saturated soil conditions

W_{base} is the average width of the base area zone (m)

L is the length of the base area zone (m)

$h_{\max}$ is the depth of the ponding above the growing medium (m)

d is the thickness of the growing medium layer (m).

22. See Table 1 vegetated curb extension setbacks.

23. Refer to Figure 9 for detailed design for curbing, inlet and flow dissipator options.

Table 1 Vegetated Curb Extension Setbacks

Setback From	Distance (m)
Down Slope of Building Foundations	3-5
Property Line	3
Drinking Water Well	30
Septic Field	3
Seasonal High Water Table	1
Active or inactive landfill or contaminated site	30
Existing trees	Outside root protection zone

Infiltration Vegetated Curb Extensions Sizing

1. In general, the size of vegetated curb extensions should balance the need for stormwater management with other roadway needs.
2. Where on-street parking is present, the width is typically the width of the parking lane (roughly 2.5 m).
3. The area is sized based on the upstream impervious area that it serves. This relationship can be defined by the ratio of impervious area to pervious area (e.g., I/P ratio). For the simplified sizing approaches here, this represents the ratio of upstream impervious area (also called catchment area) to base area of the vegetated curb extension. The I/P ratio to achieve the target capture criteria will be calculated by the sizing method below.
4. The maximum allowable I/P ratio for given surface types is shown in Table 2. This maximum is based on ability of the vegetation to handle flows and pollutants and is not related to capture. Regardless of sizing calculation below, maximum I/P ratio for a given surface type should not be exceeded.
5. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. Sizing and design according to this guidance will generally provide water quality treatment for the volume of water infiltrated. If "water quality" criteria volumes are larger than "capture" volumes, additional sizing may be required and a professional engineer should be consulted.

Table 2 Vegetated Curb Extension Maximum I/P Ratios by Surface Type

Surface Type	Max. I/P Ratio
Divided or Undivided Major Road (Expressway or Highway)	20:1
Collector Road	20:1
Parking >1 car/day/parking space	20:1
Local Road	30:1
Low traffic areas, no parking	50:1

Sizing Method Using Depth Capture Criteria: R mm in 24 hours

See Appendix A, Table 1 to determine R mm of rain in 24 hrs area-specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; allowable depth range is 300 to 2,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr)
T = allowable drain time (days)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the area of the vegetated curb extension and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_P + D_R \times n + 0.2 \times D_S}{R} - 1$$

Where:
I/P = Ratio of impervious tributary area to vegetated curb extension base area (unitless)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_P = Depth of ponding (mm); 200 mm standard
D_R = Depth (thickness) of rock reservoir (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)
D_S = Soil layer depth (thickness); standard value = 450 (mm)

3. Check that the I/P ratio calculated is less than the maximum allowed (Table 2). If it is not, use the maximum allowed I/P ratio. This may mean that the vegetated curb extension will exceed the % capture desired.a

4. To find the vegetated curb extension base area:

$$BaseArea = \frac{\text{Impervious } TributaryArea}{I/P}$$

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, with a porosity of 35% to 40 % such as 75 mm max, 38 mm min., or MMCD Section 31 05 17 Part 2.6 – Drain Rock, Coarse.
2. Pipe: PVC, DR 35, 150 mm min. dia., with cleanouts, certified to CSA B182.1, as per MMCD.
3. Geosynthetics: as per Section 31 32 19, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand as per Section 31 05 17.
5. Growing Medium: Bioretention Soil Media (i.e., growing media): As per Tables 3a and 3b Bioretention Soil Medium, but with required minimum saturated hydraulic conductivity of 70 mm/hr.
6. Seeding: conform to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (Note: seeding may not be required for erosion control in most instances).
7. Sodding: conform to MMCD Section 31 92 23 Sodding (Note: seeding may not be required for erosion control in most instances).
8. Planting: see Supplemental 1 Planting Templates & Plant Lists.

Construction Practices shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Isolate the vegetated curb extension site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300 mm of material over the final subgrade of the vegetated curb extension until after all sediment-producing construction in the drainage area has been completed.
2. Prevent natural or fill soils from intermixing with the Infiltration Drain Rock. All contaminated stone aggregate must be removed and replaced.
3. Infiltration Drain Rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
4. Plant and maintain planted areas to conform with municipal standards for visibility and access in the Right-of-Way and Landscape Maintenance standards shall be to the Canada Landscape Standard, 1st Edition, Maintenance Level.

Bioretention Soil Medium

Composition of Bioretention Soil Medium (BSM) is an important factor in the performance of GSI facilities. Soil mixes for bioretention and vegetated infiltration facilities need to balance 3 primary design objectives for optimum performance:

- ✓ High enough infiltration rates to meet desired surface water drawdown and system dewatering.
- ✓ A growth media to support long term plant and soil health and water quality treatment capability.
- ✓ Infiltration rates that are not too high in order to optimize pollutant removal capability.

For the latest information on bioretention soil research see the Washington Stormwater Center's webpage on Bioretention http://www.wastormwatercenter.org/lid-bioretention/

Below are 2 local BSM suggested mixes. Minimum infiltration rate (lab tested) of 70 mm/hr for BMS.

Table 3.a Infiltration Curb Extension Bioretention Soil Mediums Mix 1[2]

<table>
<tr><td colspan="2">Infiltration Curb Extension
Bioretention Soil Medium (BSM) Mix 1
Recommended depth: minimum of 450 mm
Minimum required saturated hydraulic conductivity of 70 mm/hr.</td></tr>
<tr><th>Component (partial size classes)</th><th>Percentage by Weight</th></tr>
<tr><td>Gravel (greater than 2.5 mm)</td><td>0</td></tr>
<tr><td>Sand (greater than 0.05 mm and less than 2.5 mm)
• Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter; and
• Particle size in sand to be:
a) 90-100% passing a 2.50 mm sieve,
b) 0-65% passing a 0.500 mm sieve,
c) 0-5% passing a 0.0500 mm sieve</td><td>70-80</td></tr>
<tr><td>Silt (greater than 0.002 mm and less than 0.05 mm)</td><td>5-15</td></tr>
<tr><td>Clay (less than 0.002 mm)</td><td>2-5</td></tr>
<tr><td>Organic Content (%dry weight)
• must be well aged organics, weed free, preferably manure free and biosolid free.</td><td>10-15</td></tr>
<tr><td colspan="2">Other Soil Considerations</td></tr>
<tr><td colspan="2">• pH of mixed materials between 6-8.5
• Phosphorus (P) and Nitrogen (N) Management Recommendations: In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions.
http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
• Safe Soils: The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017
B113 SAFE SOILS PROGRAM (page 111)
http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf</td></tr>
</table>

[2] Source: Rain Gardens, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Rain%20Garden.pdf

Table 3.b Vegetated Curb Extension Bioretention Soil Mediums Mix 2[3]

<table>
<tr><td colspan="2" align="center">Infiltration Curb Extension
Bioretention Soil Medium (BSM) Mix 2*
Recommended depth: minimum of 450 mm
Minimum required saturated hydraulic conductivity of 70 mm/hr.</td></tr>
<tr><th>Component (partial size classes)</th><th>Percentage by Weight</th></tr>
<tr><td>Coarse Gravel (particles greater than 19 mm and less than 40 mm)</td><td>0 to 1</td></tr>
<tr><td>All Gravels (particles greater than 2 mm and less than 40 mm)</td><td>10 to 25</td></tr>
<tr><td colspan="2">Sand, Silt, Clay & Organic components measured from remaining non gravel portion of sample (% dry weight)</td></tr>
<tr><td>Sand (greater than 0.05 mm and less than 2.5 mm)
• Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter.
• Note: Growing medium/BSM to be manufactured with ‘2 mm minus’ sand to reduce gravel content in the soil. 2 mm minus sand is available from most local quarries upon request.</td><td>60-70</td></tr>
<tr><td>Combined Silt and Clays (less than 0.05 mm)</td><td>10-20</td></tr>
<tr><td>Organics (% dry weight)
• must be well aged organics, weed-free, preferably manure-free and biosolid free.</td><td>15-20</td></tr>
<tr><th colspan="2" align="left">Other Soil Considerations</th></tr>
<tr><td colspan="2">• pH of mixed materials between 6-8.5
• Phosphorus (P) and Nitrogen (N) Management Recommendations: In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
• Safe Soils: The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017, page 111
for B113 SAFE SOILS PROGRAM.
http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf</td></tr>
</table>

[3] Source: City of Victoria, Rainwater Management Standards – Professional Edition (June 2015) http://www.victoria.ca/assets/Departments/Engineering~Public~Works/Documents/SWVictoria_Professional_Rainwater_Mgmt_Stds_June2015.pdf

Vegetated Curb Extension Design Example for Capture of R mm/24-hour Criteria

Scenario Description

A vegetated curb extension is proposed to capture a portion of the runoff from a paved local road (see Figure 7).

The following parameters are known:

- Local road, Total pavement area = 225 m^2
- 2-year 24-hour rain depth = 53 mm
- Native soil infiltration rate = 1.5 mm/hr
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine the curb extension footprint area and rock trench depth.

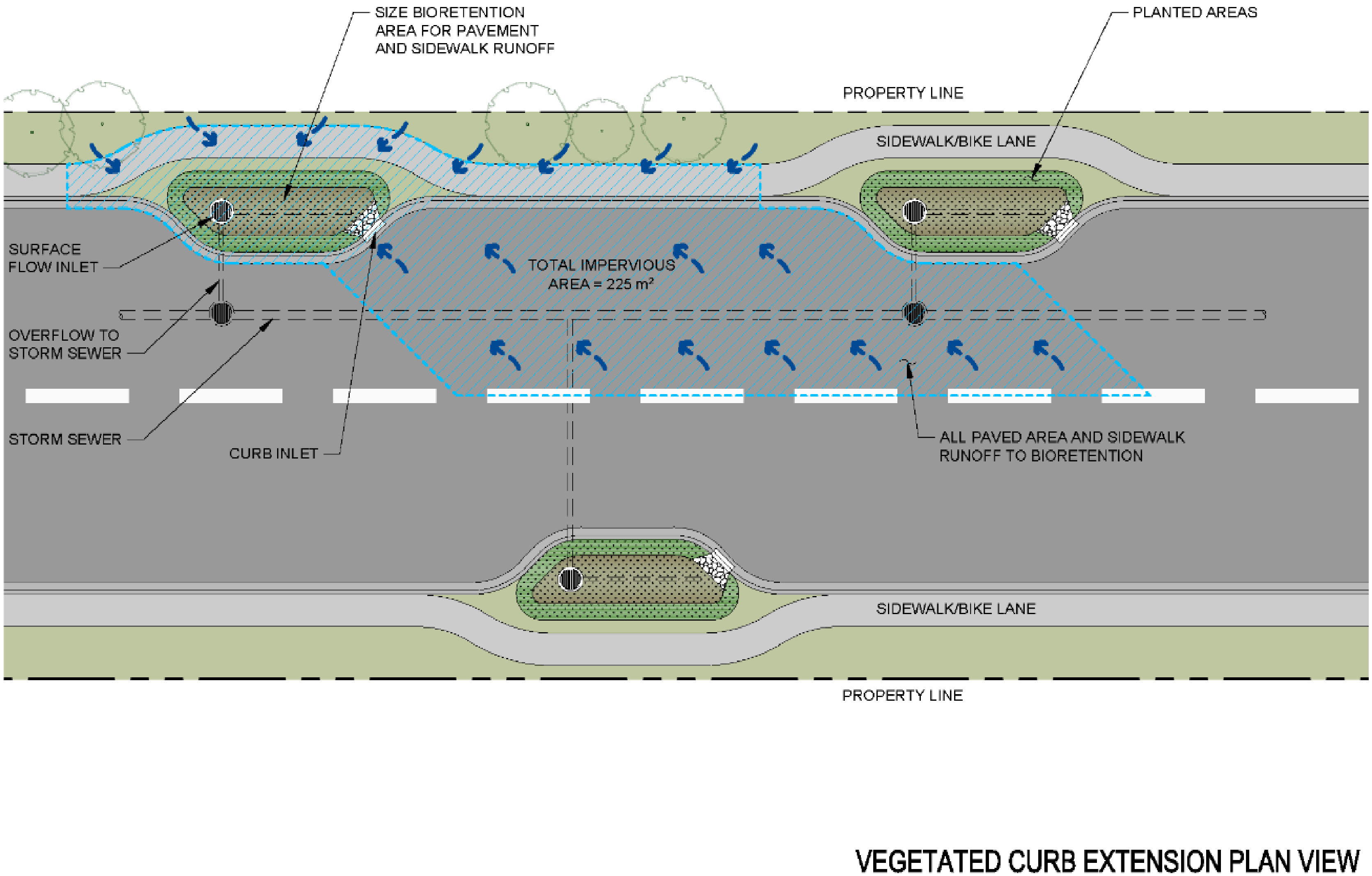


Figure 7 Example - Local Residential Street Retrofitted with a Mid-Block Vegetated Curb Extension

Sizing

Determine the maximum rock depth based on the 4-day maximum drain time:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{1.5mm/hr \times 4days \times 24hr/day}{0.35} = 411mm$$

Use 400 mm rock depth.

Determine the maximum I/P ratio (see Table 2). Local road use yields a maximum I/P ratio of 30.

Determine the area of the vegetated curb extension and rock reservoir required by calculating the required I/P ratio:

$$I/P = \frac{24 \times Ks + D_P + D_R \times n + 0.2 \times D_S}{R} - 1$$

$$I/P = \frac{24 \times 1.5mm/hr + 200mm + 400mm \times 0.35 + 0.2 \times 450mm}{38mm} - 1$$

$$I/P = 11.3$$

Check that the I/P ratio is less than the maximum (11.3 < 30, therefore OK).

Calculate the vegetated curb extension base area:

$$BaseArea = \frac{imperviousTributaryArea}{I/P} = \frac{225sq.m}{11.3} = 20sq.m$$

Example Hydraulic Components

- Inlet: Pavement runoff sheet flows over a panel curb into the vegetated curb extension.
- Overflow: A perforated pipe located along the top of the rock layer decants excess water into the municipal storm sewer connection when the rock layer is full of water.

Example Operation and Maintenance

- Correct erosion problems as necessary. Ensure distributed sheet flow into the vegetated curb extensions.
- Mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.
- Remove leaves each fall, inspect overflow, hydraulic and structural facilities annually.
- Replace dead plants, as required.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Bioretention areas function as soil and plant-based devices that can achieve both runoff reduction and pollutant removal. Runoff reduction is achieved through canopy interception, soil infiltration, and evapotranspiration. Pollutant removal is achieved through a variety of physical, biological, and chemical treatment processes. A number of pollutants including trace metals, suspended solids, nutrients, and oil and grease are removed from stormwater by filtering, adsorption, biological uptake, and denitrification within the bioretention cell's mulch and soil media. The pollutant removal efficiency can be increased or decreased based on the design components, underlying soil infiltration capabilities and what pollutants are being targeted for reduction. The following table shows the effectiveness of bioretention facilities for GSI drivers, including pollutant removal and stormwater runoff reduction.

Table 4 Runoff Reduction and Contaminant Removal

Bioretention and Vegetated Infiltration GSI Facilities (rain gardens, swales, planters, curb extensions)	
GSI Driver	***Estimated Effectiveness or Typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain low with liner and underdrain
Store & Convey – Rate Control Delay Peak	Medium to high without under drain Medium with underdrain Low with liner and underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	35-90
Oil and Grease	>70% (higher with mulch)
Phosphorus	(+70) – 85
Nitrogen	20 – 30+
Total Suspended Solids (TSS)	60 – 95+
Bacteria (Fecal coliform bacteria or E. coli)	>70%

Note: *Performance of individual GSI facilities will vary depending on site-specific contexts and facility design.

Sources:

http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.5-bioretention.pdf
http://www.lid-stormwater.net/bio_benefits.htm
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/appendix-d-removal-rates.pdf
http://www.bmpdatabase.org/
https://stormwater.pca.state.mn.us/index.php?title=Information_on_pollutant_removal_by_BMPs

Maintenance

Infiltration areas require annual plant, soil, and mulch layer maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. The successful establishment of an infiltration area requires a first year inspection and maintenance operation that includes the following tasks:

- Initial inspections after storm events of over 13 mm of rainfall
- Spot reseeding of bare or eroding areas
- Spot fertilization requirements of initial plantings
- Watering once a week during first 2 months and as needed during first growing season
- Remove and replace dead plants to ensure that vegetation is properly established (up to 10% of plant stock may die off in the first year)

After the first year, it is highly recommended that an annual spring maintenance inspection and cleanup be conducted at all infiltration facilities which would include the following:

- Check % cover of mulch plus vegetative cover
- Check for sediment buildup at entrance points
- Check for winter killed vegetation and replace
- Note presence of accumulated sediment
- Check for any erosion
- Check for signs of excessive ponding
- Check for clogged soil media and crust formation

Maintenance of infiltration areas can be divided into routine and non-routine tasks.

Routine Maintenance

Most of the routine maintenance procedures are typical landscape care activities.

ACTIVITY	OBJECTIVE	SCHEDULE
Watering (by hand or irrigation system)	Maintain a minimum 80% survival rate of plants	Once established, water thoroughly every 2 weeks or as indicated by plant health
Cleaning entrance points	Maintain proper flow from impervious areas	Twice annually (October & January)
Pruning vegetation	Maintain plant coverage and health, soil health, and infiltration capability	Once or twice annually
Weeding (by hand)	Reduce plant competition and maintain aesthetics	Twice annually preceding weed seed disbursement
Mulching (replace or add mulch to a depth of 23 inches)	Replenish organic material, reduce erosion, and maintain soil moisture	Annually
Trash removal	Maintain aesthetics and prevent clogging	Twice annually
Minor sediment removal (with shovel or rake)	Reduce clogging, maintain plant survival, maintain ponding depths	Annually

Non-routine Maintenance

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments or repairs may be needed.

ACTIVITY	OBJECTIVE	SCHEDULE
Major sediment removal (with shovel, vactor intake structures)	Reduce clogging, maintain plant survival, maintain ponding depths	Determined by inspection
Clean under drains (jet clean or rotary cut roots)	Maintain drainage, ponding depths, and dewatering rates	Determined by inspection
Clean border of pavement and vegetation (trimmer, rake, or shovel)	Maintain proper sheet flow to bioretention area	By inspection
Replace vegetation (reseed or replant)	Maintain dense vegetation to prevent erosion and exclude weeds	By inspection
Replace soil (by hand or small excavator)	Maintain infiltration, soil fertility, and pollutant removal capability	By inspection (visual and infiltration testing)
Rebuild structures (walls, intakes, weirs, etc.)	Maintain proper drainage	By inspection
Re-grade side slopes (by hand or small excavator)	Prevent erosion	By inspection

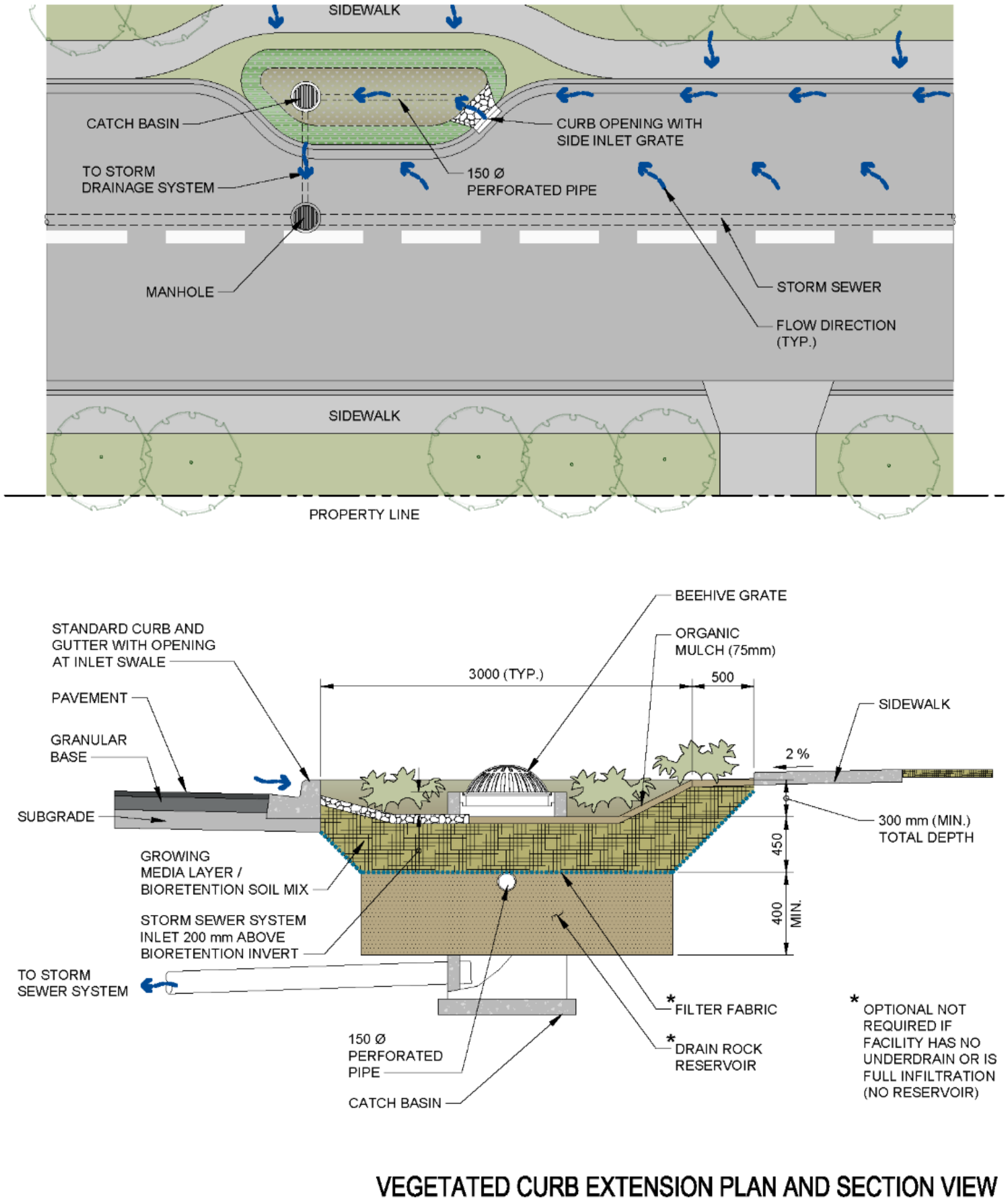


Figure 8 Vegetated Curb Extension Plan and Section View

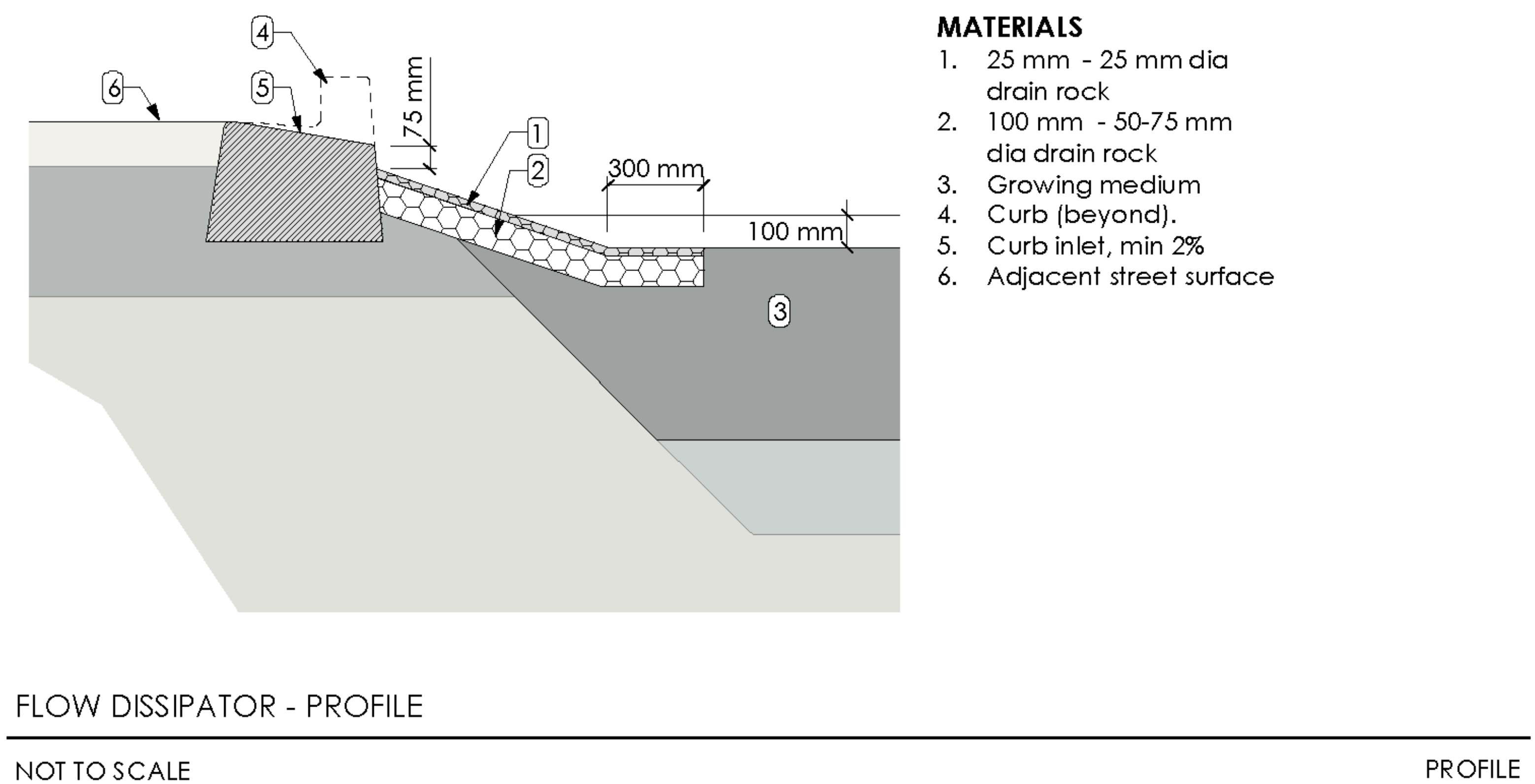
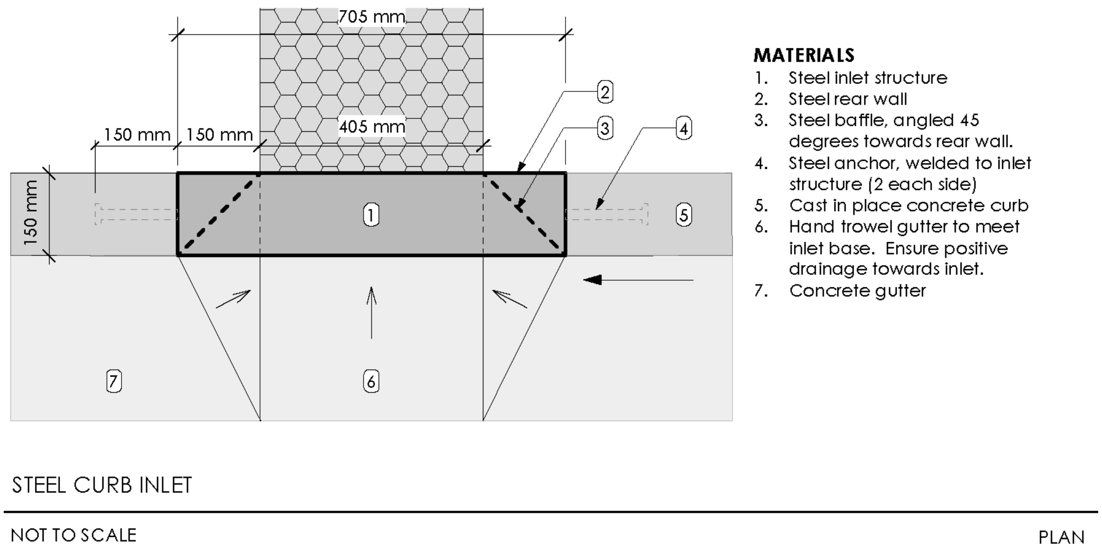


Figure 9 Flow Dissipator Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



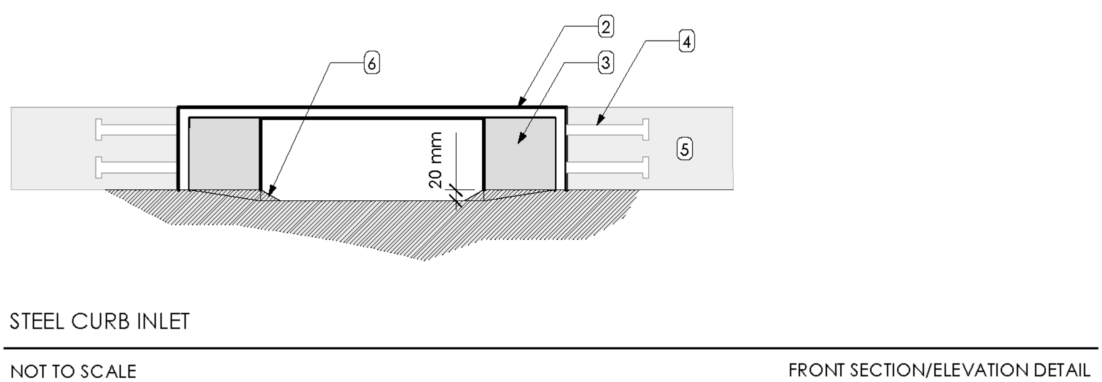
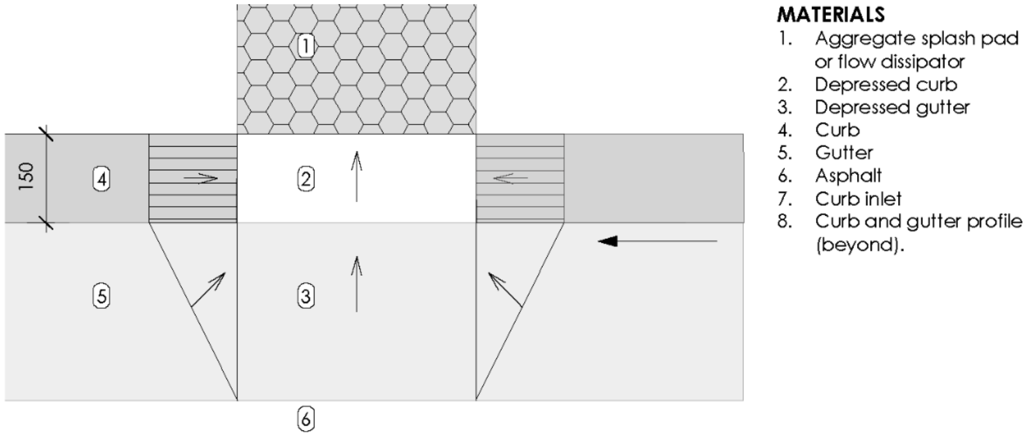


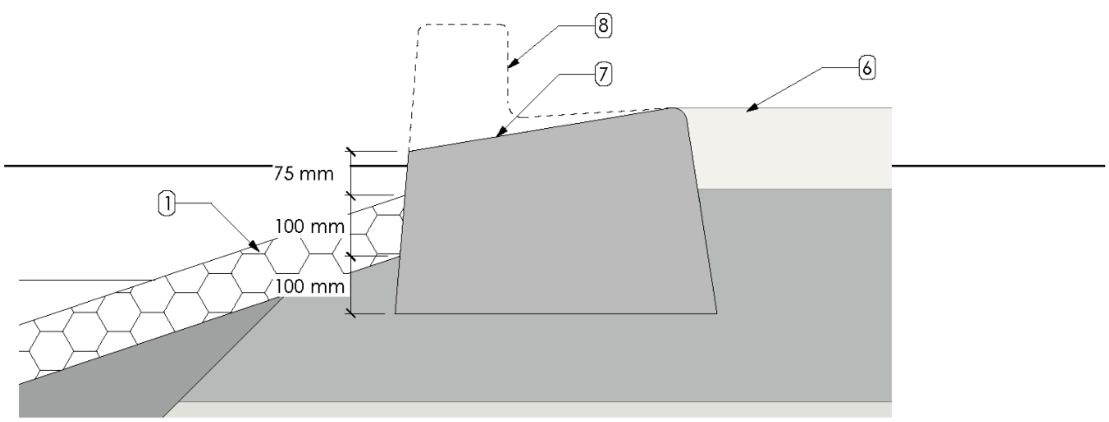
Figure 10 Steel Curb Inlet Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



CONCRETE CURB INLET

NOT TO SCALE PLAN

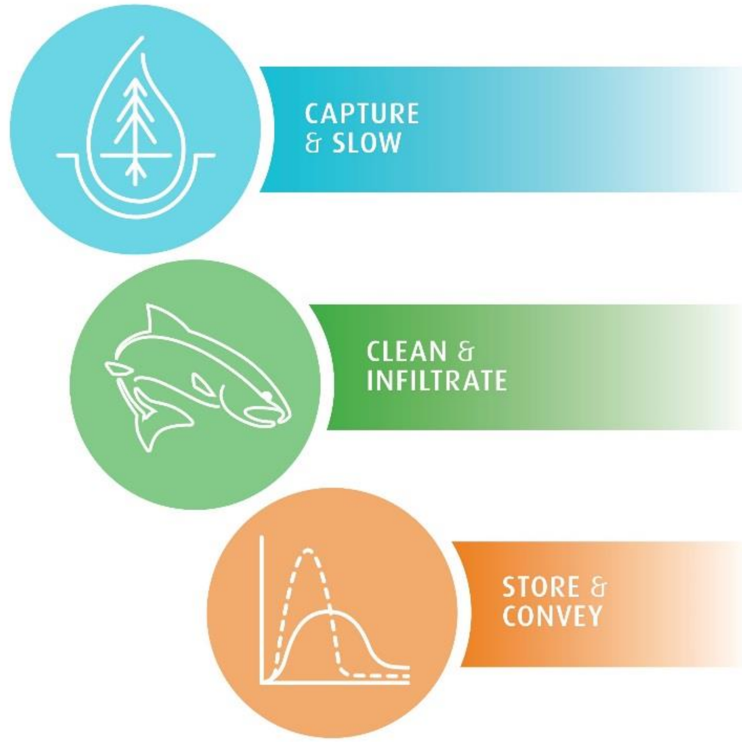


CONCRETE CURB INLET

NOT TO SCALE SECTION THROUGH INLET DETAIL

Figure 11 Concrete Curb Inlet Option

Modified from: District of Saanich Stormwater Management Guidebook (2011, Unpublished Draft), written by Kerr Wood Leidal Associates Ltd. and Murdoch de Greeff Inc.



APPENDIX F - INFILTRATION & FLOW-THROUGH PLANTERS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Infiltration and Flow-Through Planters[1]

Description

These planter guidelines focus on diversion of stormwater from roofs for areas less than 1,000 m² and maybe designed to be raised or subgrade (sunken). If considering planters for stormwater management from impervious surfaces, such as parking lots or roadways, please refer to design guidelines for Rain Gardens, Infiltration Curb Extensions or Vegetated or Grassy Swales in this resource. When these GSI facilities are in a dense urban environments they may look like planters (vertical cement sides and flat bottom planted areas), however, require design appropriate to capture, treat and often convey stormwater.

Figure 1 Planter irrigated by roof water collected in underground detention tanks.

The **flow-through rain planter** is a contained stormwater storage and treatment unit with primary functions of reducing stormwater pollution loads and flow rates. It is essentially a contained rain garden. The flow-through planter has structural walls and a sealed bottom such that water cannot infiltrate into the ground. Stormwater runoff typically enters the unit from a downspout or scupper from a nearby roof drain. Pollutants and nutrients are removed from the runoff using 3 mechanisms including biological decomposition, plant assimilation (in the form of nutrients) and adsorption of heavy metals to soil organics. Flow control is achieved by storing runoff in the reservoir above the soil. Flow-through planter requires a high capacity overflow.

Figure 2 Flat drains such as in the infiltration planter can easily get clogged with leaves

The **infiltration rain planter** is similar to a flow-through rain planter, but with an open bottom. This GSI facility can, therefore, function to reduce stormwater pollution loads and flow rates, but also volume since water can infiltrate into the ground. Stormwater runoff typically enters the unit from a downspout or scupper from a nearby

[1] Authored by: Opus International Consultants (Canada) Limited Source: Stormwater Management Manual, City of Eugene, Oregon, 2014 https://www.eugene-or.gov/DocumentCenter/View/15783 Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

roof drain. Flow control is achieved by storing runoff in the reservoir above the soil and volume control is achieved by infiltration of water into the ground. The infiltration planter requires a high capacity overflow.

Selection, Application and Limitations

- The **flow-through rain planter** option is most applicable on highly constrained sites with little available landscape area at grade.
- Flow-through planters should be used where there is seasonally high groundwater (<1 m from the bottom of the planters), where bedrock is less than 600 mm below the bottom of the planter, in areas of new fill, within 30 m of a groundwater well, or within 3 m of a building wall/footing.
- The use of a waterproof lining enables these units to be installed adjacent to building foundations, over slab construction, adjacent to property lines (if less than 750 mm in height), on bedrock controlled sites, or sites with poorly draining soils and sites with steep slopes.
- Flow-through rain planters can fit into most landscape designs and are suitable for highly urbanized areas and can replace traditional concrete planters.
- The **infiltration rain planter** option is most applicable on sites with steeper slopes or urban sites with more land available for construction on grade.
- The use of a waterproof lining between the building and main infiltration zone of the planter enables these units to be installed adjacent to building foundations.
- Due to the complexity of the design and construction techniques, infiltration and flow-through rain planters are suitable for commercial, institutional and high density multi-family buildings, however, they are not suitable for single-family applications.

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Planter walls should be constructed of stone, brick, concrete, wood or other durable material (do not use chemically treated wood).
5. Slope to be 0.5% or less.
6. Provide 50 mm notch in wall for overflow.
7. Allow for 50 mm minimum free board.
8. Provide 100 mm from top of Bioretention Soil Mix (BSM) or growing medium to overflow.
9. Provide overflow bypass drain with beehive grate.

10. Provide 400 mm bioretention growing medium over 400 mm mixture over 50% sand/50% bioretention growing medium.
11. Provide flow dissipator, either washed pea gravel, river rock or splash pad at inlet.
12. Line box with 30-mil PVC liner (flow-through planter only).
13. Minimum width is 900 mm, measured within the walls.
14. Walls must be less than 750 mm high.
15. A facility with more plants will provide more treatment capacity.
16. There are no setbacks for lined flow-through planters.
17. Infiltration planters must be 1.5 m from property lines.
18. Infiltration planter setbacks are similar to other infiltration facilities – minimum 30 m from wells, minimum 3 m downslope of building foundations, and only in areas where foundations have footing drains.
19. The use of a waterproof lining between the building and main infiltration zone of the planter (see detail) enables infiltration planters units to be installed adjacent to building foundations.
20. Drawdown time for the maximum surface ponded volume: 24-36 hours and to bypass during larger storm events (72 hours max.).
21. A non-erodible outlet or spillway must be established to discharge overflow to the storm sewer system. This often takes the form of a grated inlet raised above the rain garden invert to create the ponding depth.
22. Avoid utility or other crossings below an infiltration planter. Where utility trenches must be constructed crossing below the planter, install low permeability trench dams to avoid infiltration water following the utility trench.
23. See Table 1 for setbacks for planters.

Table 1 Planter Setbacks

Setback From	Distance (m)	
	Infiltration	**Lined Flow Through**
Down Slope of Building Foundations	3 to 5	0
Property Line	1.5	0
Drinking Water Well	30	30
Septic Field	3	3

Sizing Planters

Sizing for both flow-through and infiltration planters is straightforward and a simplified sizing approach can be used.

1. In general, stormwater planters are sized to infiltrate or filter runoff from a limited area of upstream impervious surface, typically from a roof drain discharging through a downspout or scupper into the planter.
2. In general, the planter area is sized based on the upstream impervious area that it serves. This relationship can be defined by the ratio of impervious area to pervious area (e.g., I/P ratio). For the simplified sizing approach, this represents the ratio of upstream impervious area to the base area of the planter.
3. An infiltration planter cannot be used where the infiltration rate of the underlying soil is less than 12.5 mm/hr. Where infiltration rates are less than 12.5 mm/hr, a flow-through or partial infiltration planter must be used.
4. The simplified approach should only be used to size stormwater planters where the upstream impervious area is less than 1,000 m^2.
5. For the simplified sizing approach, the minimum size factor is 0.07 for infiltration planters and 0.03 for flow-through planters, where an impervious area of 100 m^2 would require 7 m^2 planter area for an infiltration planter and 3 m^2 planter area for a flow-through planter to manage the runoff.[2]
6. For sites with an infiltration rate of greater than 50 mm/hr, the size of the infiltration planters may be decreased, but must be sized by a professional engineer.
7. An engineered approach may be used with a measured infiltration rate to size stormwater facilities with respect to native infiltration rates and other unique site conditions of the project.
8. Sizing presented here is for filtering or infiltration of rain water for "capture" and prevention of site runoff. Sizing and design according to this guide will generally provide water quality treatment for the volume of water infiltrated. If "water quality" criteria volumes are larger than "capture volumes", additional sizing may be required and a professional engineer should be consulted.

[2]Stormwater Management Manual, City of Eugene, Oregon, 2014
https://www.eugene-or.gov/DocumentCenter/View/15783

Sizing for Depth Capture Criteria: R mm in 24 hrs

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine I/P ratio for the infiltration planter:

$$\text{I/P ratio} = \frac{\text{Impervious Tributary Area}}{\text{Planter Area}}$$

2. Determine the soil depth required:

$$D_S = \frac{R \times (I/P + 1) - Ks \times 24}{0.2}$$

   Where:

   D_S = Depth (thickness) of amended soil (mm)

   R = Rainfall capture depth (mm)

   Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions.

   I/P = Ratio of impervious tributary area to planter area (unitless)

3. Check whether the calculated soil depth is within the standard depth of 400 mm. If calculated depth exceeds 400 mm:
   - The soil depth may be acceptable upon consultation (i.e., 500 mm soil may be acceptable if landscape designers concur);
   - The I/P ratio may be reduced by routing runoff from a portion of the contributing impervious area to another GSI facility and the soil depth recalculated; or
   - The planter could be designed as a partial infiltration or lined flow-through planter, with an overflow to an approved discharge location.
4. To determine the infiltration planter area:

   Area = size factor x Impervious *Tributary Area*

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Pipe: PVC, DR 35, 100 mm min. dia. with cleanouts certified to CSA B182.1 as per MMCD.
2. Sand: Pit Run Sand as per Section 31 05 17.
3. Growing Medium: Bioretention Soil Medium (i.e., growing media): As per Tables 2.a and 2.b Bioretention Soil Medium, but with required minimum saturated hydraulic conductivity of 70 mm/hr.

4. Seeding: conform to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (Note: seeding will be required for erosion control in most instances).
5. Sodding: conform to MMCD Section 31 92 23 Sodding. (Note: sodding will be required for erosion control in most instances).
6. Planting: see Supplemental 1, Planting Templates & Plant Lists.

Construction Practices shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Isolate the infiltration or flow-through planter site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300 mm of material over the final subgrade of the vegetated curb extension until after all sediment-producing construction in the drainage area has been completed.
2. Prevent natural or fill soils from intermixing with the infiltration drain rock. All contaminated stone aggregate must be removed and replaced.
3. Infiltration drain rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
4. Plant and maintain planted areas to conform with municipal standards for visibility and access in the Right-of-Way and Landscape Maintenance standards shall be to the Canada Landscape Standard, 1st Edition, Maintenance Level.

Bioretention Soil Medium

Composition of Bioretention Soil Medium (BSM) is an important factor in the performance of GSI facilities. Soil mixes for bioretention and vegetated infiltration facilities need to balance 3 primary design objectives for optimum performance:

- ✓ High enough infiltration rates to meet desired surface water drawdown and system dewatering.
- ✓ A growth media to support long term plant and soil health and water quality treatment capability.
- ✓ Infiltration rates that are not too high in order to optimize pollutant removal capability.

For the latest information on bioretention soil research see the Washington Stormwater Center's webpage on Bioretention http://www.wastormwatercenter.org/lid-bioretention/.

Below are 2 local BSM suggested mixes. For infiltration rates see information in "Sizing Planters".

Table 2.a Planter Bioretention Soil Mediums Mix 1[3]

Infiltration and Flow-Through Planters **Bioretention Soil Medium (BSM) Mix 1** See 'Design Guidelines' and 'Sizing Planters' for recommended BSM depth and minimum required saturated hydraulic conductivity of mm/hr.	
Component (partial size classes)	**Percentage by Weight**
Gravel (greater than 2.5 mm)	0
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter; and • Particle size in sand to be: a) 90-100% passing a 2.50 mm sieve, b) 0-65% passing a 0.500 mm sieve, c) 0-5% passing a 0.0500 mm sieve	70-80
Silt (greater than 0.002 mm and less than 0.05 mm)	5-15
Clay (less than 0.002 mm)	2-5
Organic Content (%dry weight) • must be well aged organics, weed free, preferably manure free and biosolid free.	10-15
Other Soil Considerations	
• **pH** of mixed materials between 6-8.5 • **Phosphorus (P) and Nitrogen (N) Management Recommendations**: In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017 B113 SAFE SOILS PROGRAM (page 111) http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf	

3 Source: Rain Gardens, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Rain%20Garden.pdf

Table 2.b Planter Bioretention Soil Mediums Mix 2[4]

Infiltration and Flow-Through Planters **Bioretention Soil Medium (BSM) Mix 2*** See 'Design Guidelines' and 'Sizing Planters' for recommended BSM depth and minimum required saturated hydraulic conductivity of mm/hr.	
Component (partial size classes)	**Percentage by Weight**
Coarse Gravel (particles greater than 19 mm and less than 40 mm)	0 to 1
All Gravels (particles greater than 2 mm and less than 40 mm)	10 to 25
Sand, Silt, Clay & Organic components measured from remaining non gravel portion of sample (% dry weight)	
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter. • Note: Growing medium/BSM to be manufactured with '2 mm minus' sand to reduce gravel content in the soil. 2 mm minus sand is available from most local quarries upon request.	60-70
Combined Silt and Clays (less than 0.05 mm)	10-20
Organics (% dry weight) • must be well aged organics, weed-free, preferably manure-free and biosolid free.	15-20
Other Soil Considerations	
• **pH** of mixed materials between 6-8.5 • **Phosphorus (P) and Nitrogen (N) Management Recommendations**: In some cases, bioretention facilities have the potential to export P and N at a higher rate than contained in the storm water they are receiving. See Low Impact Development Technical Guidance Manual for Puget Sound 2012 (chapter 6.1.2 Bioretention Design) for nutrient management suggestions. http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017, page 111 for B113 SAFE SOILS PROGRAM. http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf	

[4] Source: City of Victoria, Rainwater Management Standards – Professional Edition (June 2015) http://www.victoria.ca/assets/Departments/Engineering~Public~Works/Documents/SWVictoria_Professional_Rainwater_Mgmt_Stds_June2015.pdf

Infiltration Planter Design Example for Capture of R mm/24-hour Criteria

Scenario Description

A planter is proposed to capture a portion of the runoff from a building roof (see illustration below).

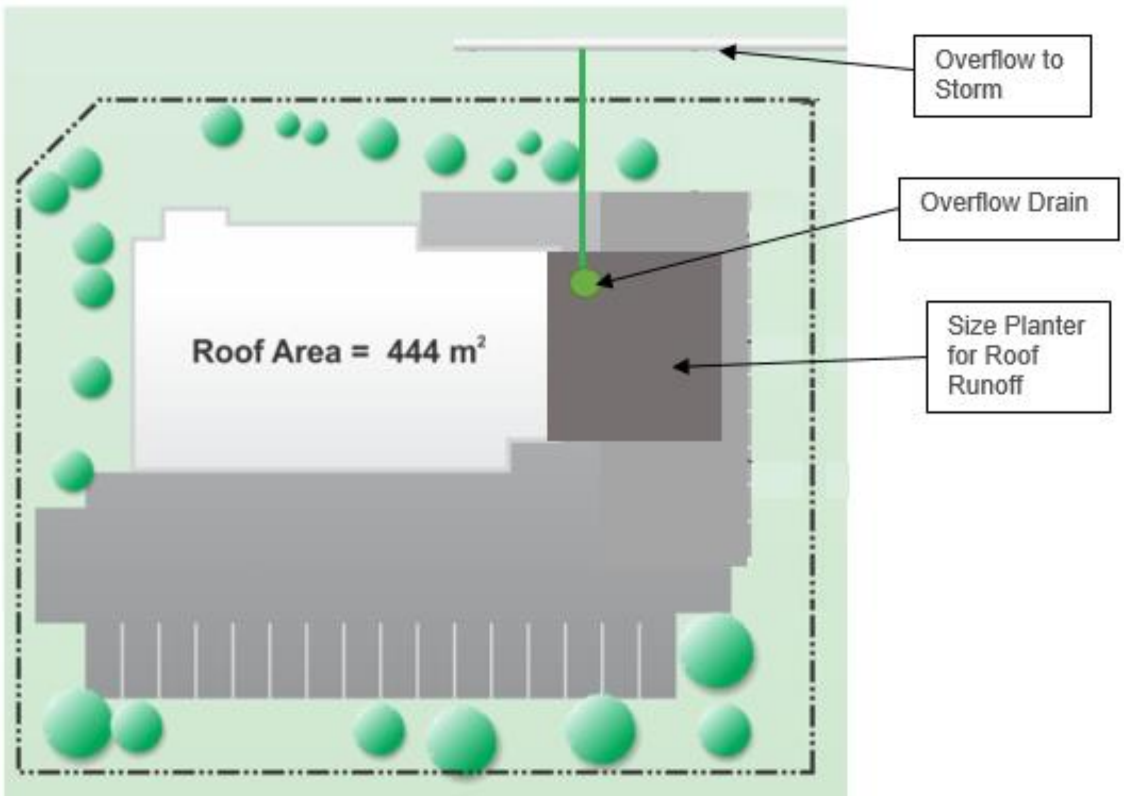


Figure 3 Example – Roof Area Draining to Planter

The following parameters are known:

- Roof area = 444 m^2
- Total Planter Area = 104 m^2
- 2-year 24-hour rain depth = 53 mm
- Native soil infiltration rate = 5 mm/hr
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine whether the plater area is large enough and the growing medium depth required.

Sizing

Determine the site I/P ratio:

$$I/P = \frac{444\,sq.m}{104\,sq.m} = 4.3$$

$$D_S = \frac{R \times (I/P + 1) - Ks \times 24}{0.2}$$

Where:

D_S = Depth (thickness) of amended soil (mm)

R = Rainfall capture depth (mm)

Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions

I/P = Ratio of impervious tributary area to absorbent landscape area (unitless)

$$D_S = \frac{38mm \times 5.3 - (5mm/hr \times 24)}{0.2}$$ = 407 mm

Hydraulic Components

- Inlet: Roof runoff is piped onto a flow dissipator or splash pad in the planter.
- Overflow: Surface overflow notch in top of planter wall or overflow stand pipe connects to the municipal major system.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Bioretention areas function as soil and plant-based devices that can achieve both runoff reduction and pollutant removal. Runoff reduction is achieved through canopy interception, soil infiltration, and evapotranspiration. Pollutant removal is achieved through a variety of physical, biological, and chemical treatment processes. A number of pollutants including trace metals, suspended solids, nutrients, and oil and grease are removed from stormwater by filtering, adsorption, biological uptake, and denitrification within the bioretention cell's mulch and soil media. The pollutant removal efficiency can be increased or decreased based on the design components, underlying soil infiltration capabilities and what pollutants are being targeted for reduction. The following table shows the effectiveness of bioretention facilities for GSI drivers, including pollutant removal and stormwater runoff reduction.

Table 3 Runoff Reduction and Contaminant Removal

Bioretention and Vegetated Infiltration GSI Facilities (rain gardens, swales, planters, curb extensions)	
GSI Driver	***Estimated Effectiveness or typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain low with liner and underdrain
Store & Convey – Rate Control Delay Peak	Medium to high without under drain Medium with underdrain Low with liner and underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	35-90
Oil and Grease	>70% (higher with mulch)
Phosphorus	(+70) – 85
*Nitrogen	20 – 30+
Total Suspended Solids (TSS)	60 – 95+
Bacteria (Fecal coliform bacteria or E. coli)	>70%

Note: *Performance of individual GSI facilities will vary depending on site specific contexts and facility design.

Sources:

http://extension.oregonstate.edu/stormwater/sites/default/files/Planters_0.pdf
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.5-bioretention.pdf
*http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
http://www.lid-stormwater.net/bio_benefits.htm
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/appendix-d-removal-rates.pdf
http://www.bmpdatabase.org/
https://stormwater.pca.state.mn.us/index.php?title=Information_on_pollutant_removal_by_BMPs

Maintenance

Bioretention and infiltration areas require annual plant, soil, and mulch layer maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. The successful establishment of a bioretention and infiltration area requires a first year inspection and maintenance operation that includes the following tasks:

- Initial inspections after storm events of over 13 mm of rainfall
- Spot reseeding of bare or eroding areas
- Spot fertilization requirements of initial plantings
- Watering once a week during first 2 months and as needed during first growing season
- Remove and replace dead plants to ensure that vegetation is properly established (up to 10% of plant stock may die off in the first year)

After the first year, it is highly recommended that an annual spring maintenance inspection and cleanup be conducted at all bioretention and infiltration facilities which would include the following:

- Check % vegetative cover
- Check for sediment buildup at entrance points
- Check for winter killed vegetation and replace
- Note presence of accumulated sediment
- Check for any erosion
- Check for signs of excessive ponding
- Check for clogged soil media and crust formation
- Remove leaves each fall

Routine Maintenance

Most of the routine maintenance procedures are typical landscape care activities.

ACTIVITY	OBJECTIVE	SCHEDULE
Watering (by hand or irrigation system)	Maintain a minimum 80% survival rate of plants	Once established, water thoroughly every 2 weeks or as indicated by plant health.
Cleaning entrance points	Maintain proper flow from impervious areas	Twice annually (October & January)
Pruning vegetation	Maintain plant coverage and health, soil health, and infiltration capability	Once or twice annually
Weeding (by hand)	Reduce plant competition and maintain aesthetics	Twice annually preceding weed seed disbursement
Trash removal	Maintain aesthetics and prevent clogging	Twice annually
Minor sediment removal (with shovel or rake)	Reduce clogging, maintain plant survival, maintain ponding depths	Annually

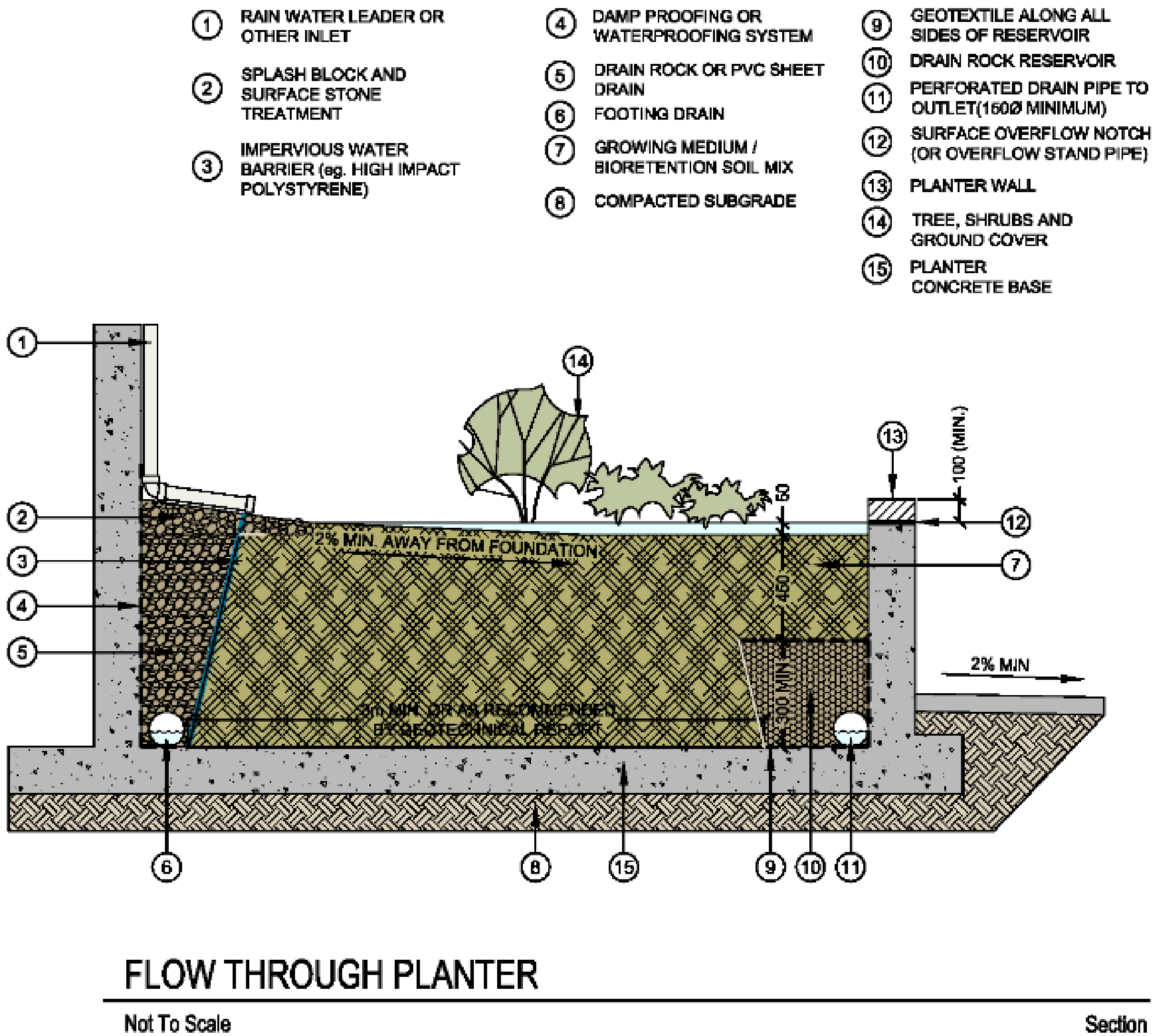


Figure 4 Flow-Through Planter

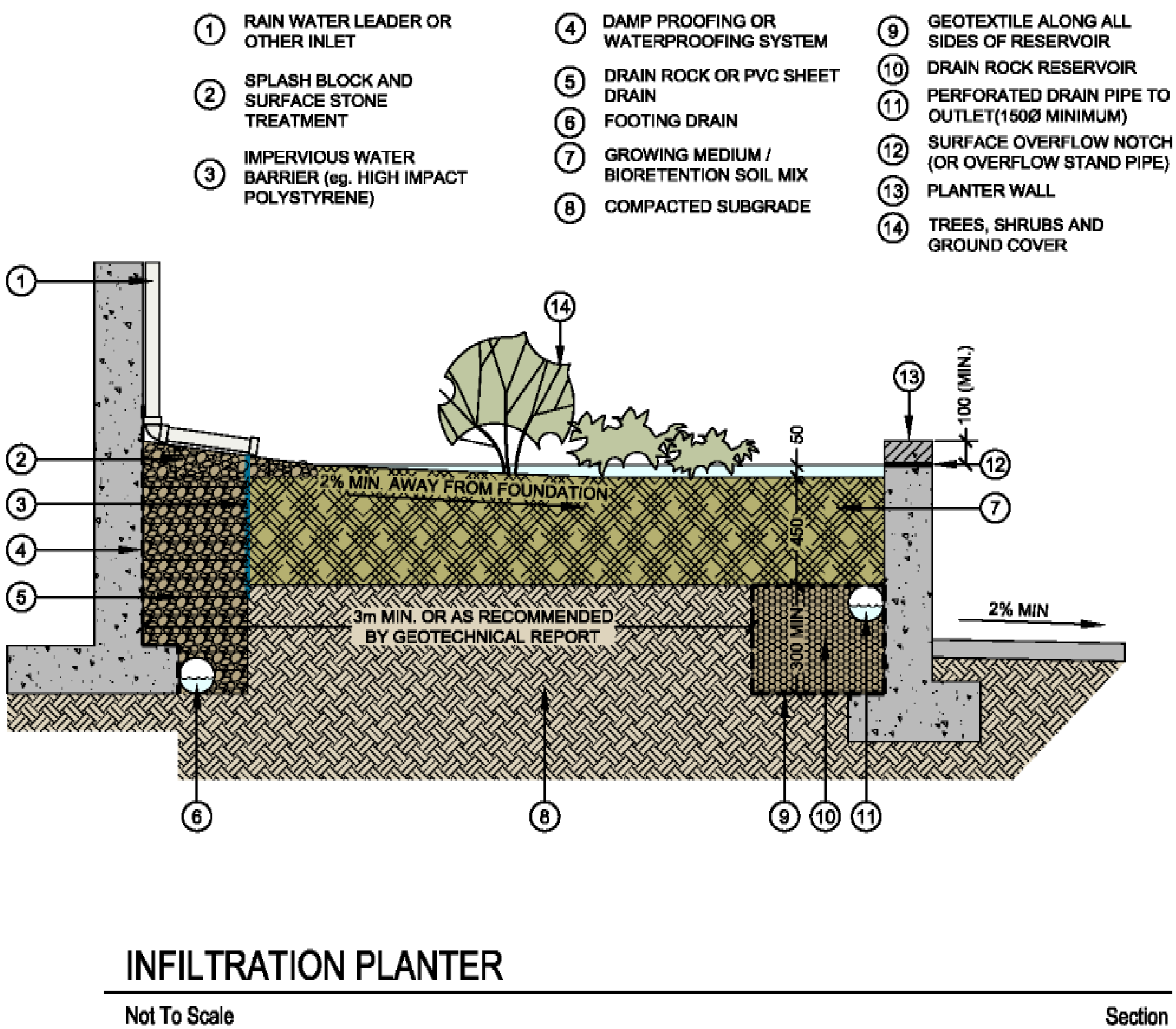
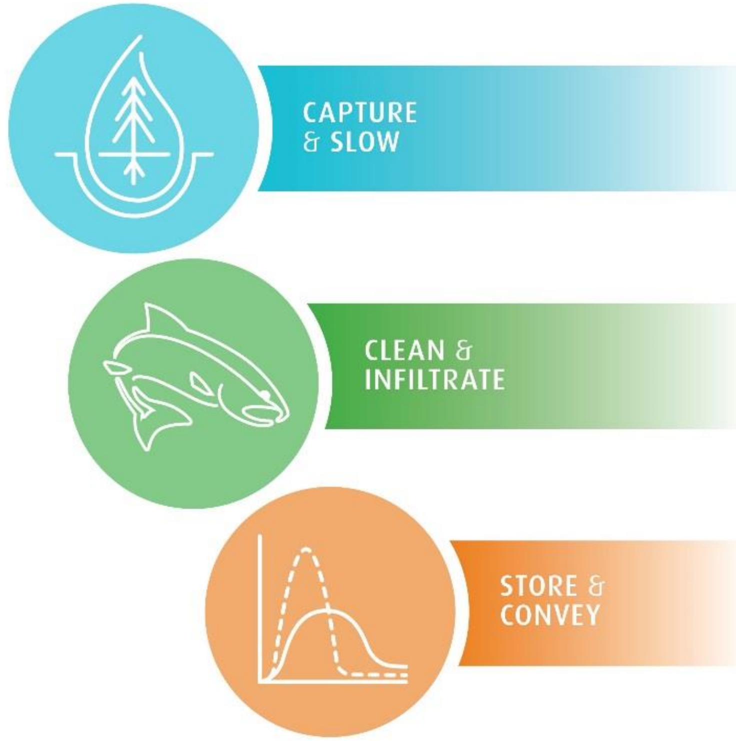


Figure 5 Infiltration Planter



APPENDIX G - STRUCTURAL SOIL: CELLS WITH & WITHOUT TREES

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Structural Soil Cells[1]

Description

Structural soil cells are a system for carrying structural loads while also providing a void below the street surface or the amenity zone in the street right-of-way, which is typically filled with a growing medium for trees or a growing medium strictly for bioretention. Structural soil cells transfer the vertical loads from the street or sidewalk to below the structural soil cells without compacting the growing medium through the placement of underground structural supports.

Figure 1 Right-of-way before GSI retro fit. Photo Credit: Credit Valley Conservation

Structural soil cells can support a variety of surface materials including asphalt, concrete, and unit pavers. Structural soil cells can be placed under sidewalks and roadways.

Without structural soil cells, the growing medium would compress under the weight of the surface material and the street users. Structural soil cells provide the opportunity to have larger, healthy trees in locations which have insufficient space to separate planting areas from pedestrian/vehicle traffic. Where the structural soil cell features a single tree, the facility is referred to a tree pit, and for multiple trees, a tree trench.

Figure 2 Same site under construction. Existing catch basin was retrofitted to direct stormwater into GSI facility with a distribution pipe (seen here) with soil cells and bioretention media. Photo Credit: Credit Valley Conservation

Structural soil cells require significant design input from a professional and can also be quite costly to install. Only some utilities may be able to be placed in the root zone; coordination with utility organizations is encouraged.

[1] Authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

Structural soil cells act as a bioretention facility by being able to store stormwater underground in the growing medium, and if trees are present, they will use the water and remove pollutants. If the growing medium is a bioretention soil mix, about 20% of its volume can be used for stormwater storage (1,000 m^3 of soil could store 200 m^3 of stormwater)[2].

Stormwater can be directed to structural soil cells via pervious pavers, curb cuts, and catch basins, among other means.

Figure 3 Same site under complete installation of soil cells and tree trench. Photo Credit: Credit Valley Conservation

Selection, Application and Limitations

- Structural soil cells are used to provide an un-compacted growing medium for trees where they are not fully separated from pedestrian/vehicle traffic.
- Multiple trees planted in the amenity zone between the street and sidewalk is a type of structural soil referred to as a tree trench.
- As structural soil cells are quite costly they are typically only used in heavily urbanized environments where there is limited space to separate trees from pedestrian/vehicle traffic.
- Structural soil cells (with or without trees) act as an underground bioretention facility by being able to store large amounts of stormwater.
- Only limited utilities can be installed in the growing medium. Approval from utility providers is required.

[2]Suspended Pavements, Alberta Low Impact Development Partnership, https://alidp.org/what-is-lid/article/suspended-pavements 2013

Design Guidelines

Structural Soil Cells

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are required for design.
4. The design must be completed by a qualified professional. A structural engineer must design the structural supports for the soil cells.
5. A variety of structural soil cells are produced by different private companies. The producer design specifications should be used when completing the design.
6. The structural soil cells should be designed to a load capacity of AASHTO-H20[3].
7. Each stack of structural soil cells should be structurally independent of adjacent stacks.
8. Use either 1, 2, or 3 layers of structural soil cells.
9. Each cell should enable the movement of roots and water.[4]
10. An inspection riser should be installed in the concrete/pavement/paver surface.

Table 1 Non-Proprietary Structural Soil Cell Growing Medium

Component	Percentage by Volume
Base Soil	40-45
Coarse Sand	45-50
Organic Compost	8-10

Also see the Bioretention Soil Medium (BSM) mixes suggested in Appendices B-F.

Venders of various proprietary structural soil cell systems will recommend their proprietary growing medium.

Tree Trenches

1. A tree trench can treat runoff from the adjacent street and sidewalk.
2. A tree trench must be placed such that an upstream area drains to it.
3. Stormwater passes through a gravel filter for pre-treatment, then is conveyed through an underdrain to 1 or more trees, and exits through a water level control structure.

[3] Southeast False Creek Private Lands: Public Realm Enrichment Guide, City of Vancouver, 2009
[4] Suspended Pavements, Alberta Low Impact Development Partnership, https://alidp.org/what-is-lid/article/suspended-pavements 2013

4. Discharge from the underdrain is typically to a nearby inlet or manhole.
5. Trees are typically located 1.2 m to 2.0 m from the back of curb.
6. Final tree planting area minimum width of 0.5 m.
7. Preferred treatment around the tree is a 100 mm curb.
8. If tree grates are preferred, a minimum separation between the grate and tree trunk of 100 mm should be provided.
9. The growing medium should match the values presented in Table 1. Adjust the ratios to achieve water infiltration between 20 mm and 50 mm per hour[5]. See more information about growing media in Bioretention Soil Medium (BSM) mixes suggested in Appendices B-F.
10. Placement of permeable pavers above the tree trench is recommended.
11. Structural soil cells should be designed to provide a minimum of 30 m^3 of soil per tree[6]. Where multiple trees are sharing the same soil, the minimum amount of soil may be reduced. Trees in trenches typically require a rooting volume of 21 m^3 to 28 m^3.
12. A maximum of 3 trees is recommended per group of structural soil cells, but tree trenches can be placed back to back for any desired length.
13. For recommended tree species see Supplemental 1, Plant Templates & Plant Lists for planting considerations.
14. See Table 2 for structural soil cell setbacks.
15. Refer to qualified professional for guidance on curb inlet options.

Table 2 Structural Soil Cell Setbacks

Setback From	Distance (m)
Foundation	1.5
Property Line	3
Drinking Water Well	30
Septic Field	3
Seasonal High Water Table	1

[5] Southeast False Creek Private Lands: Public Realm Enrichment Guide, City of Vancouver, 2009
[6] Southeast False Creek Private Lands: Public Realm Enrichment Guide, City of Vancouver, 2009

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Infiltration Drain Rock: clean round stone or crushed rock, with a porosity of 35% to 40% such as 75 mm max, 38 mm min or MMCD Section 31 05 17 Part 2.6 – Drain Rock, Coarse.
2. Pipe: PVC, DR 35, 150 mm min. dia., with cleanouts, certified to CSA B182.1, as per MMCD.
3. Geosynthetics: as per Section 31 32 19, select for filter criteria or from approved local government product lists.
4. Sand: Pit Run Sand, as per Section 31 05 17.
5. Seeding: conform to Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (Note: sodding will be required for erosion control in most instances).
6. Sodding: conform to MMCD Section 31 92 23 Sodding.

Construction Practices shall meet Master Municipal Construction Document 2009 (MMCD) requirements, and:

1. Follow the manufacturer's recommendations during construction.
2. The growing medium should be protected from rain before and during construction.
3. Do not install structural soil cells when materials are wet, muddy or frozen.
4. The location of the structural soil cells should be recorded at the time of construction and incorporated into the record drawings.

Design Examples

The design of structural soil cell systems should be completed by a professional, meeting the recommendations listed in the design guidelines noted above. The design of a structural soil cell system is unique for each context, however, manufacturers typically provide design details for using their products.

The following design example shows how structural soil cells can be applied.

Case Study: Road Right-of-Way Retrofit, Soil Cells with Tree Trench, Central Parkway, Mississauga, Ontario.

Can be found at: http://www.creditvalleyca.ca/wp-content/uploads/2016/06/CaseStudy_CPW_Final.pdf

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

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Bioretention areas function as soil and plant-based devices that can achieve both runoff reduction and pollutant removal. Runoff reduction is achieved through canopy interception, soil infiltration, and evapotranspiration. Pollutant removal is achieved through a variety of physical, biological, and chemical treatment processes. A number of pollutants including trace metals, suspended solids, and nutrients are removed from stormwater by filtering, adsorption, biological uptake, and denitrification within the bioretention cell's mulch and soil media. The pollutant removal efficiency can be increased or decreased based on the design components and what pollutants are being targeted for reduction. The following table shows the effectiveness of the structural soil cell with trees for effectiveness of GSI drivers. Run-off reduction would primarily be based on the size of any trees placed in the structural soil cell system. The tested systems removed slightly more pollutants than typical at-grade bioretention facilities.

Table 3 GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

Bioretention and Vegetated Infiltration GSI Facilities Structural Soil Cells	
GSI Driver	***Estimated Effectiveness or Typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	40-80%
Store & Convey – Rate Control Delay Peak	High
Clean & infiltrate – Water Quality Treatment	
Copper	85-86%
Lead	90-94%
Zinc	76-83%
Total Phosphorus	72-74%
Total Nitrogen	66-82%
Total Suspended Solids	86-92%

**Source: Page, J.L, Winston, R.J., Hunt, W, F., Soils beneath suspended pavements: An opportunity for stormwater control and treatment (2015), Ecological Engineering, Vol. 82, Sept. 2015. Pg. 40-48.*

Maintenance

Structural soil cells do not require regular maintenance. However, additional care is needed when maintenance activities are required in close proximity to the structural soil cells.

Utility Access

The following steps should be taken when access to utilities either within or below the structural soil cell voids is required:

- Surface concrete or pavement is removed via sawcut where there is unit paving, the pavers are removed.
- The geotextile fabric is peeled back.
- The structural soil cells are removed by hand and set aside.
- An excavator may be used for the remaining excavation once the structural soil cells are removed.

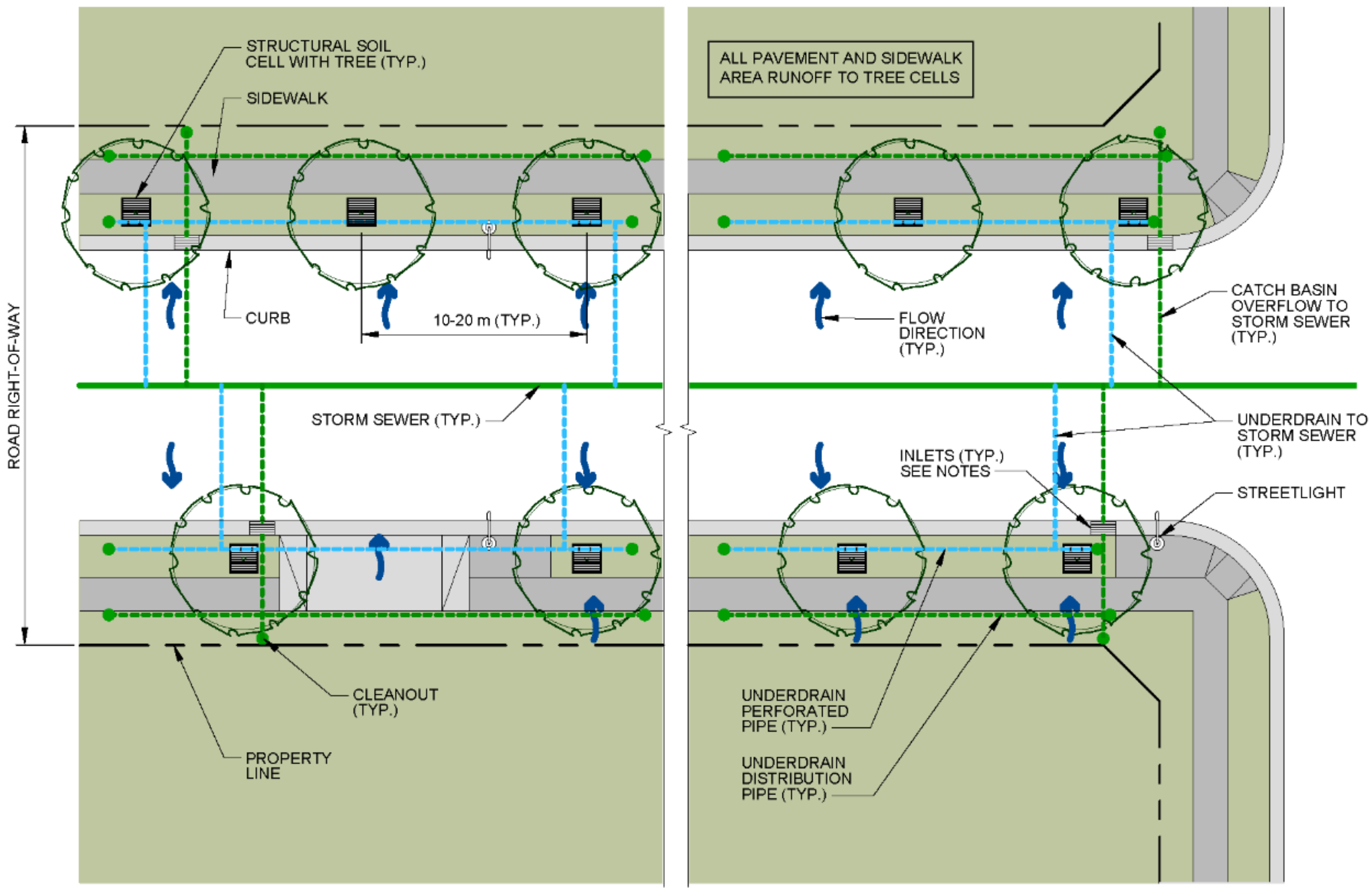
Repair

Repairs should be undertaken as per manufacture's specifications. The steps to undertake repairs should generally follow the steps for initial construction. Any damaged structural soil cells should be replaced prior to the repair being completed.

Tree Replacement

The following steps should be taken when a tree utilizing the structural soil cells need to be replaced:

- Remove any structure(s) at the tree opening such as tree grates.
- Remove any excess mulch and soil above the tree root using hand tools making sure the structural soil cells are not damaged.
- Consult and arborist to remove the tree.
- If using construction equipment to remove the tree, ensure that it meets the structural soil cell loading limits.
- Plant the new tree as per the structural soil cell manufacturer's specifications and with the consultation of an arborist. Replace any damaged structural soil cells



NOTES:
1. INLET OPTIONS INCLUDE:

A) PERMEABLE PAVEMENT (TYPICALLY IN PARKING LANE)
B) CURB CUTS (LOCATED AT EACH TREE CELL)
C) CATCH BASINS (ONE CATCH BASIN MAY FEED MULTIPLE TREE CELLS)

STRUCTURAL SOIL CELL WITH TREE - PLAN VIEW

Figure 4 Structural Soil Cell with Tree – Plan View

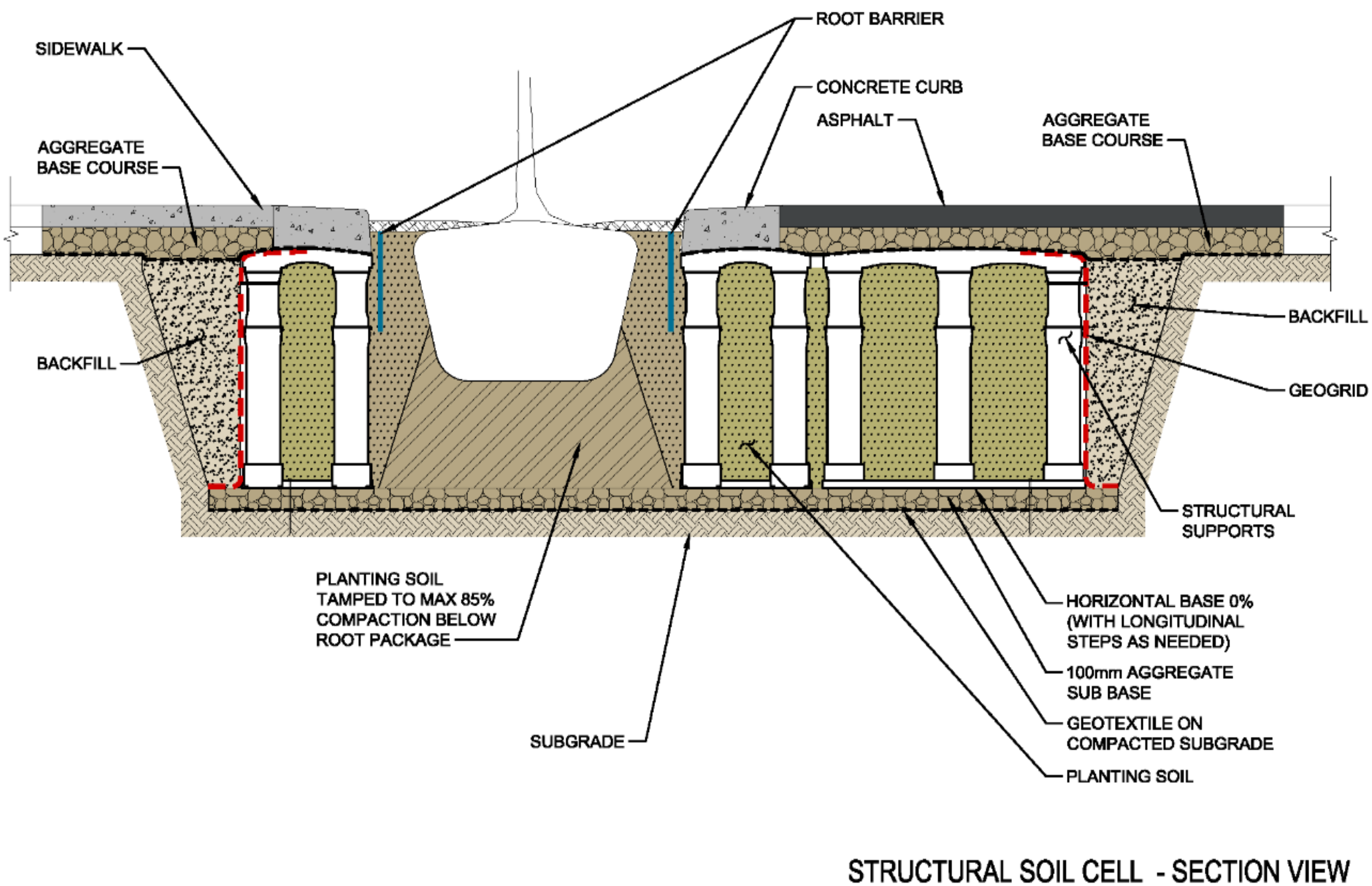


Figure 5 Structural Soil Cell – Section View

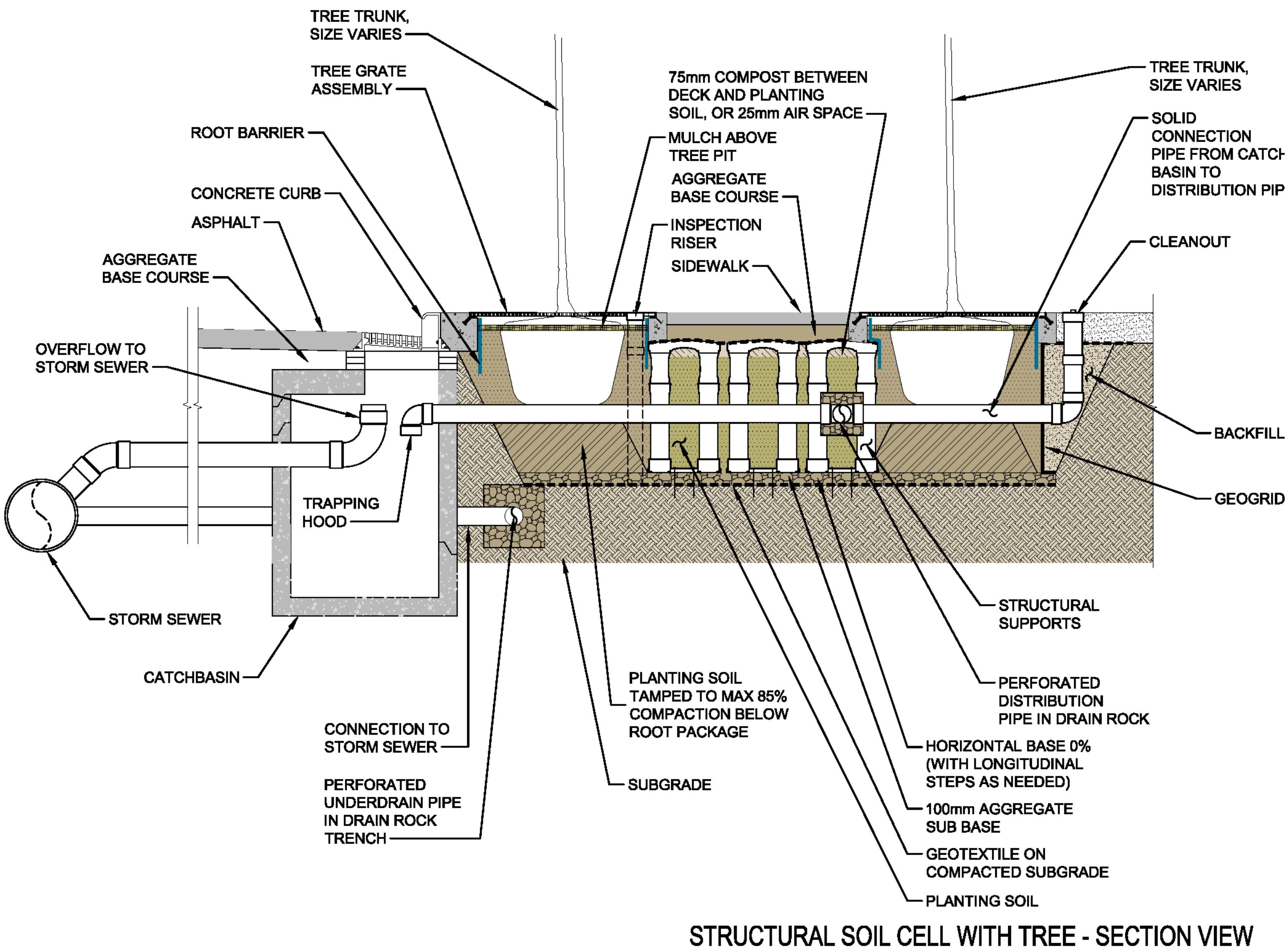
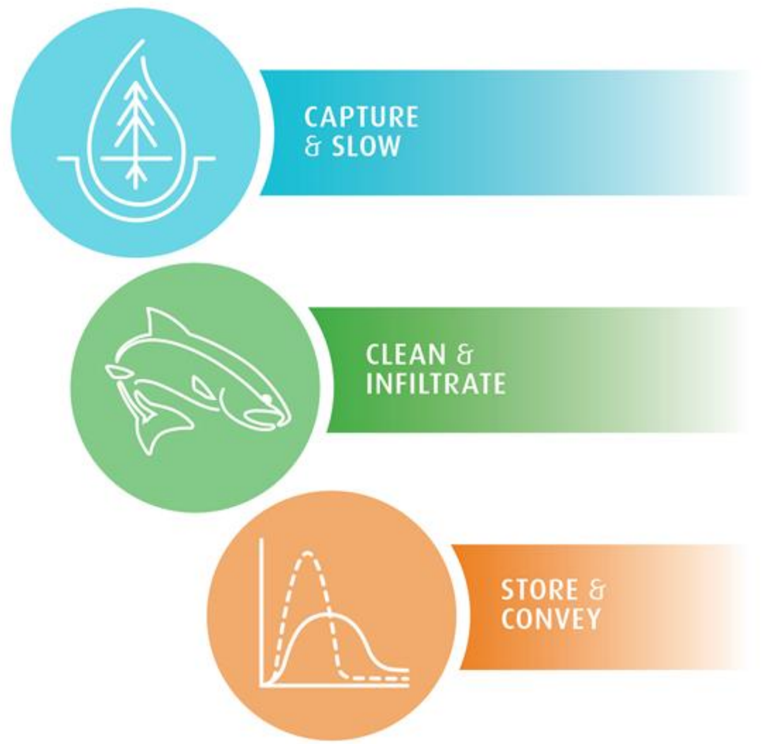


Figure 6 Structural Soil Cell with Tree – Section View



APPENDIX H – EXTENSIVE GREEN ROOFS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Green Roof Systems[1]

Description

A green roof is a conventional roof with a waterproof membrane and layers of drainage and growing medium that support living vegetation.

Green roofs with a relatively shallow growing medium thickness (less than 300 mm) are generally called 'extensive green roofs'. They may be designed for stormwater management, 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.

Figure 1 Extensive green roof, CRD Headquarters, Fisgard St., Victoria

'Intensive green roofs' are usually designed with public access and use in mind, and have deeper growing medium depths (greater than 300 mm) to support larger plants and trees. Intensive green roofs also have stormwater benefits, but are heavier and more expensive to develop and maintain.

This section is focused on the stormwater aspects of extensive green roofs.

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 specialized design, roofs of up to 20° slope. Roofs may be inverted or traditional flat roofing systems, but shingle and tile roofs are not suitable for greening.

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

- Green roofs provide multiple benefits, including:
  - Reduction in stormwater peak flows; smaller winter event peak flows were attenuated 30% in monitoring of the Vancouver Public Library roof.
  - Reduction in rainfall volume leaving the roof due to evaporation and evapo-transpiration. A typical extensive green roof of about 75 mm in growing medium can be designed to reduce annual runoff by more than 50%.
  - The seasonal rainfall patterns on the west coast mean that green roofs have less effect in the wet winter season, retaining 13-18% of rainfall, versus 86-94% in the summer in Metro Vancouver. However, no single GSI facility alone is effective to manage the entire range of rainfall events, rather a combination of GSI facilities are normally implemented to manage the stormwater.
  - The purpose of the green roof is to capture frequent rain with low intensity only. Once the soil is saturated, the runoff will flow through the outlets to the stormwater system.
  - 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.
  - Air filtration, removing fine particulates from the air.
  - Reduction in heat gain and the need for air conditioning in the summer – peak sensible cooling needs can be reduced by about 25%.
  - Reduced heat loss in the winter; heat loss in Toronto was reduced 10-30%. Research at BCIT found heat transfer through the roof was reduced 80% in summer and 40% in winter.

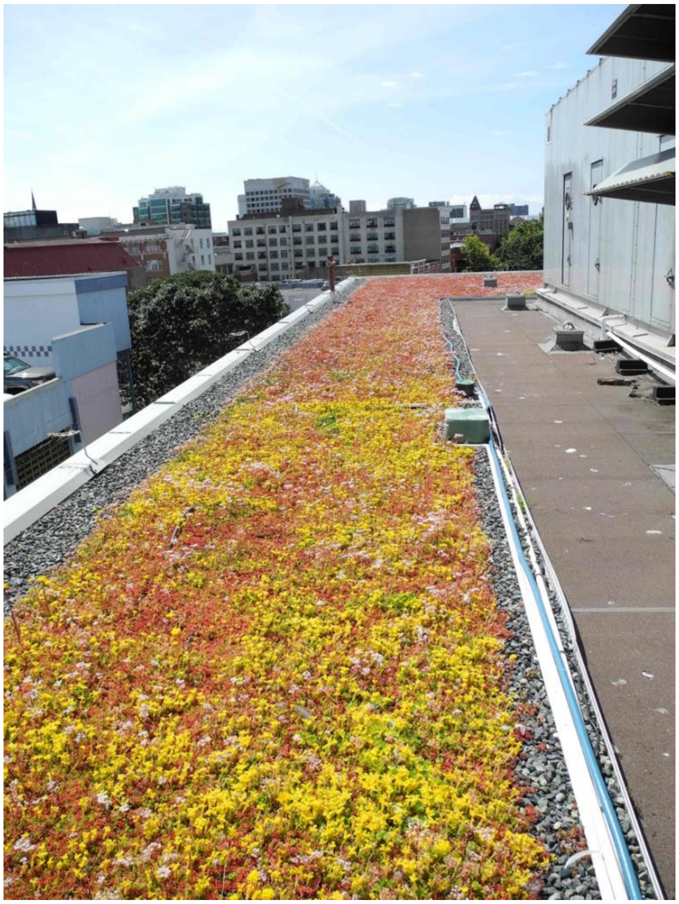


Figure 2 Extensive green roof, CRD Headquarters, Fisgard St., Victoria

Figure 3 Intensive green roof, CRD Headquarters, Fisgard St., Victoria

- There is no set equation to calculate this heat loss reduction with a green roof. Potential reductions are determined based on performance monitoring on some projects.
- 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.
- Sound insulation – tests at BCIT found that typical extensive green roof can reduce sound by 2 to 13 dB.
- 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.

Figure 4 Extensive green roof under construction, CRD Headquarters, Fisgard St., Victoria

Limitations

- Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing medium has created solutions where saturated growing medium can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction.
- National standard for green roofs are covered under the Canadian Landscape Standard.
- Green roofs, as extensions of the roofing system, must comply with the BC Building Code.

Professional Consultants

- Selection of professional consultants depends on the function of the green roof, the size of the project, the location of the project, and the green roof experience of the primary consultant and/or project instigator. A structural engineer may be required to determine the existing, or required, loading capacity of the roof. An architect may be required to co-ordinate the project as well as the design and detailing of the building and roof, including material specifications. A landscape architect may be required for the layout of the planting areas and the selection of the plants. A mechanical engineer may be required to calculate the heating and cooling implications of the green roof, and to discuss integration with existing and proposed rooftop mechanical equipment and drainage needs.

Extensive Green Roof Types

Extensive green roofs can be 1 of following designs:

- Multiple layer construction – consists of either: i) a 3-layer system including separate drainage course, filter layer and growing medium or; ii) a 2-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 – consists of a growing medium which includes the filter and drainage functions.

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. 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.
4. Provide construction and maintenance access to extensive green roofs. Access through a 'man door' is preferable to access through a small roof hatch. Provide areas of storage for maintenance equipment. Review the Workers' Compensation Board of British Columbia Standards' requirements for safety of maintenance workers. Provide a hose bib for manual watering during establishment if no automatic irrigation system is planned.
5. Roofs with less than 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° angle surfaces require special precautions against sliding and shearing. 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. With inverted roofs, the green roof components must allow moisture to move upwards from the insulation and to eventually evaporate.
6. 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.
7. 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. 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.

8. There are several choices of waterproof membranes. Thermoplastic membranes, such as polyvinyl chloride or thermal polyolefin using hot air fusion methods are commonly used for green roof applications. Elastomeric membranes like 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 2 layers and are commonly available. Liquid-applied membranes are generally applied in 2 liquid layers with reinforcement in between. The quality is variable. A factor in choosing a waterproofing system is resistance to root penetration (for more information see below).
9. Provide protection against root penetration of the waterproof membrane by either adding a root barrier or using a membrane that is itself resistant to root penetration (more cost efficient). Resistance to root penetration is not being tested in Canada at time of writing[2]. 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.
10. Chemically incompatible materials such as bitumen and polyvinyl chloride require a separation layer.
11. 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.
12. 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.
13. 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.
14. 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. Recommended between 6% and 8% organic matter. When properly sized, 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.
15. In calculating structural loads, always design for the saturated weight of each material.
16. 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.

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

17. 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 non-invasive mosses, sedums, sempervivums, alliums, other bulbs and herbs, and grasses (see Supplemental 1: Planting Templates & Plant Lists for suggestions).
18. 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.
19. Design planting to respect microclimate and sun/aspect conditions. Collaborate with mechanical engineers on placement of exhaust vents, and design plantings accordingly.
20. Avoid swaths of 1 species. The chances of creating a self-maintaining plant community are increased when a wide mix of species is used.

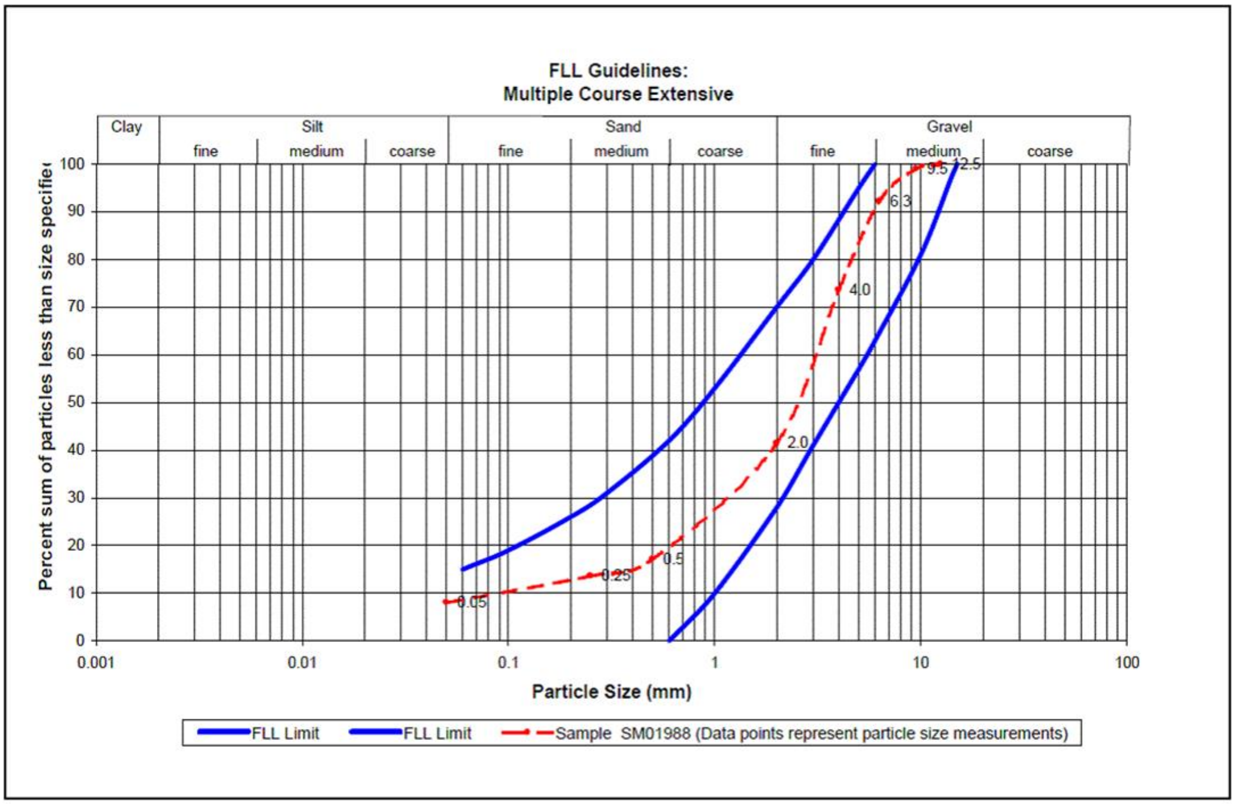


Figure 5 Particle (grain) size distribution range for substrates used in multiple layer extensive green roofs (FLL, 2008, Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites). Image Credit: Agricultural Analytical Services Laboratory, Pennsylvania State University

21. Planting methods include seeding, hydroseeding, spreading of sedum sprigs, planting of plugs or container plants, and installing pre-cultivated vegetation mats.
22. If automatic irrigation is required, low volume and rainwater reuse systems are preferred.

23. Provide intensive maintenance for the first 2 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. Once established, a typical extensive green should require only 1 or 2 annual visits for weeding of undesired plants, clearing of plant-free zones and inspecting of drains and the membrane. Installers should have experience with green roof systems. It may be preferable to have 1 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.
24. Although green roof membranes will last longer than others, leaks can still occur at flashings or through faulty workmanship. Some companies are recommending an electronic leak detection system to pinpoint the exact location of water leaks, for easier repair.
25. 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?
26. Several local companies provide 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.

Guideline Specifications

- ASTM E2777 – 14 Standard Guide for Vegetative (Green) Roof Systems.
- ASTM E2400 / E2400M – 06(2015)e1 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems.
- BC Standard for Extensive Green Roofs 'Growing Medium Type 1P: Extensive Green Roof-Inaccessible', or growing medium as approved by green roof system manufacturer.
- Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing medium has created solutions where saturated growing medium can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction.
- National standard for green roofs are covered under the Canadian Landscape Standard.
- Green roofs, as extensions of the roofing system, must comply with the BC Building Code.

Sizing Green Roofs

Sizing for a green roof alone is fairly straightforward and simplified sizing approaches have been developed that do not require water balance modelling or continuous simulation.

1. In general, a green roof is sized to capture a portion of the rain that falls on it through retention of water in the soil and on the vegetation, and evaporation and evapotranspiration.
2. Sizing presented here is for evaporation/evapotranspiration of rainwater for "capture" and prevention of site runoff.
3. Sizing process here assumes that the entire roof area will be covered by a green roof and sizing determines the depth of soil required.

Sizing for Depth Capture Criteria: R mm in 24 hrs

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area-specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine the soil depth required:

   $$D_S = \frac{R}{0.2}$$

   Where:
   DS = Depth (thickness) of Green Roof soil (mm)
   R = Rainfall capture depth (mm)
   0.2 = Water holding capacity of the soil calculated as field capacity minus wilting point (unitless)

2. Check whether the calculated soil depth is within the standard depth range of 150 to 600 mm. If the calculated depth exceeds 600 mm, the overflow from the green roof could be directed to an infiltration rock trench or other facility and the combined facilities should be evaluated using water balance calculations.

Green Roof Design Example for Capture of R mm/24-hour Criteria

Scenario Description

A green roof is proposed to capture a portion of the runoff from a building roof (see illustration below).

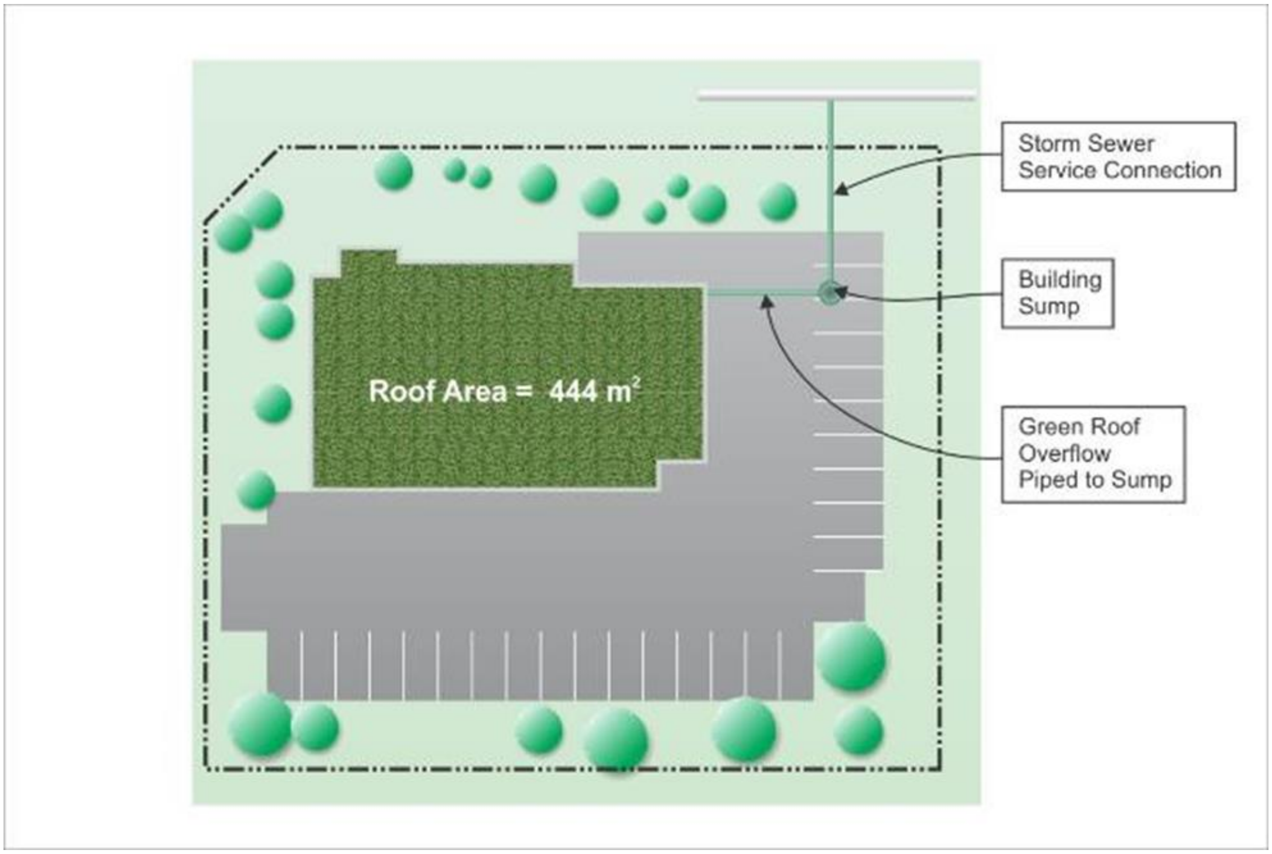


Figure 6 Example – Roof area covered with green roof

The following parameters are known:

- Roof area = 444 m^2
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine the required green roof topsoil thickness.

Sizing

Determine the soil depth required:

$D_S = \frac{R}{0.2} = \frac{38mm}{0.2}$ =190 mm of topsoil depth is required to meet the rainfall capture target.

Note: the above calculation assumes a "typical" green roof construction; there is significant room for improvement in performance with modifications to the underdrain or drainage layer to improve capture.

Hydraulic Components

- **Underdrain**: To prevent the green roof topsoil from becoming saturated and negatively impacting the plant roots, an underdrain layer is standard practice for green roofs. The underdrain layer also reduces the likelihood of roof membrane leakage by relieving water pressure on the membrane.
- **Overflow**: During extreme rainfall, the topsoil infiltration capacity may be overwhelmed resulting in ponding of water on the soil surface and runoff. This excess water is collected by an overflow designed to limit the water level on the roof.
- **Discharge**: The green roof topsoil underdrain and the overflow are connected to roof water leaders or downspouts to convey excess water to the municipal storm sewer.

GSI Driver Effectiveness – Runoff Reduction and Pollutant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Green roofs are designed so that water drains vertically through the media and then horizontally along a waterproof layer towards the outlet. The CRD has monitored the performance of the green roof on their downtown offices with the following results:

- 36% retention of annual rainfall
- 24-minute average delay of peak runoff during wet season and 2-hour average delay during dry season
- 90% reduction in peak runoff flow

Some pollutant removal occurs by the filtering of the stormwater in the growing medium. Green roofs are also efficient of reducing stormwater runoff. Estimates of GSI driver effectiveness are shown in Table 1.

Table 1 Runoff Reduction and Pollution Removal Summary Table

Green Roof GSI Facilities	
GSI Driver	***Estimated Effectiveness or typical % Removal**
Capture & Slow – Volume Runoff Reduction	40-60
Store & Convey – Rate Control Delay Peak	90
Clean & Infiltrate – Water Quality Treatment	Highly variable with design. Below are typical results. Research has observed good retention and at times production and export of nutrients.
Total Suspended Solids (TSS)	60 to >95
Phosphorus	Most green roofs see an increased export of nutrients

Note: * Performance of individual facilities will vary depending on site-specific contexts and facility design.

Sources:
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.2-green-roofs.pdf

Maintenance

Proper maintenance and operation of the green roof are essential to ensure the performance and benefits continue over the life of the installation. Each green roof installation will have specific design, operation, and maintenance guidelines provided by the manufacturer and installer.

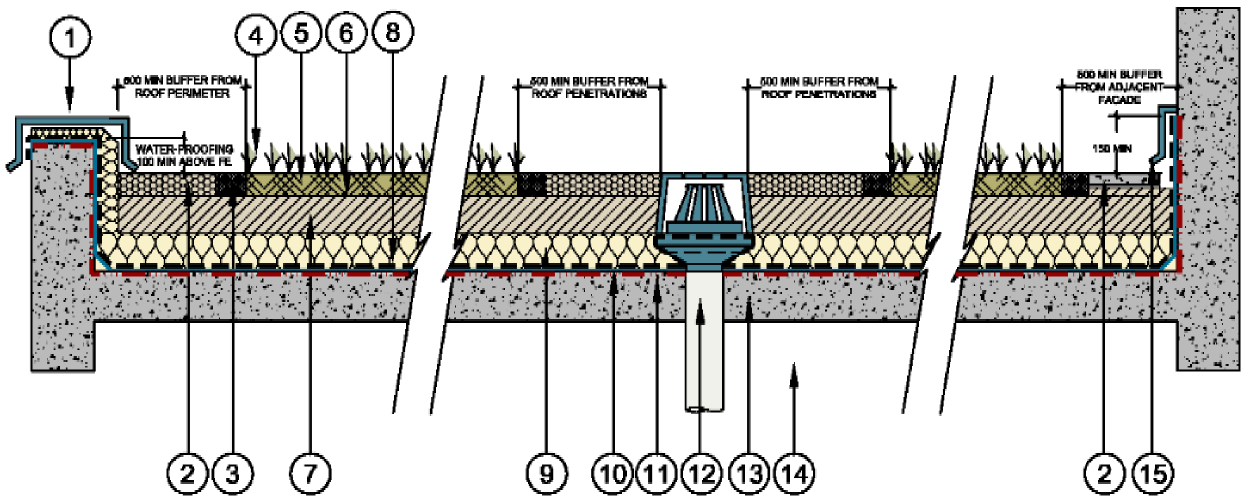
Routine Maintenance

The following maintenance guidelines are for extensive roof systems and provide a general set of standards for long-term roof garden performance:

- All green roof components (structural, waterproofing, drainage layers, soil substrate, vegetation, and drains) should be inspected biannually for proper operation throughout the life of the facility.
- Drain inlets should be inspected to ensure unrestricted rainwater flow from the drainage layer to the roof drain system.
- An operation and maintenance plan and inspection schedule should be provided to the property owner.
- Written guidance or training for operation and maintenance should be provided to the property owner.
- A maintenance log should be kept by the property owner.

ACTIVITY	OBJECTIVE	SCHEDULE
Clear inlet pipes	Maintain free drainage	Twice annually
Inspect drain pipe for cracks, settling and alignment	Maintain free drainage	Twice annually
Inspect fire ventilation points	Fire and safety	Twice annually
Remove invasive and nuisance plants	Promote selected plant growth and maintain aesthetics	Twice annually (schedule inspections prior to seed dispersal)
Remove and replace dead material	Maintain aesthetics and reduce weed growth	Annually
Irrigation	Maintain healthy vegetation	Consult manufacturer’s guidelines
Check for ponding water	Ensure proper infiltration and drainage	Monthly

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



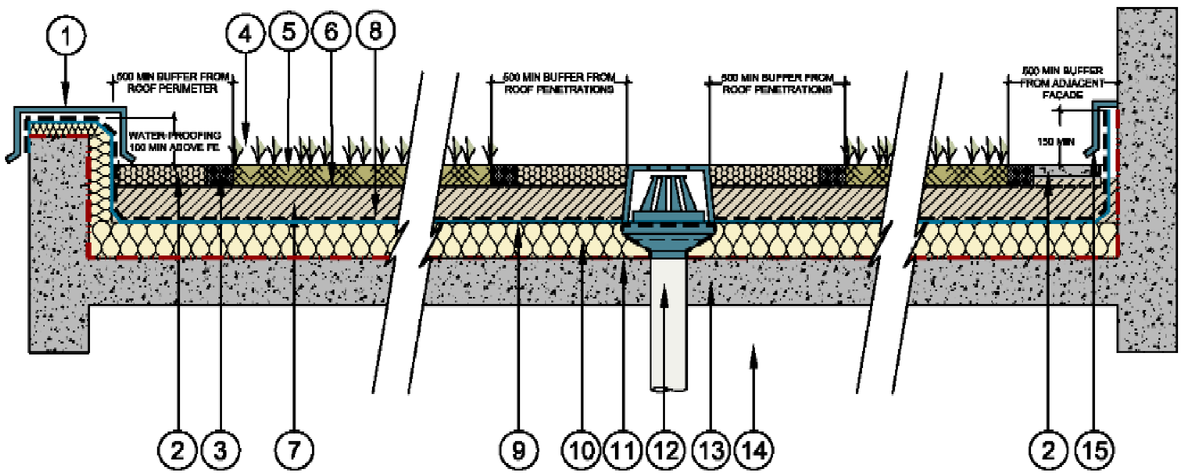
NOTE: UNLESS THE WATERPROOF MEMBRANE IS RESISTANT TO ROOT PENETRATION, A ROOT BARRIER IS REQUIRED BETWEEN THE PROTECTION LAYER AND WATERPROOF MEMBRANE. A SEPARATION LAYER MAY BE REQUIRED BETWEEN CHEMICALLY INCOMPATIBLE MATERIALS.

MULTIPLE LAYERS EXTENSIVE GREEN ROOF

NOT TO SCALE — SECTION

Figure 7 Multiple Layers 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.

MULTIPLE LAYERS EXTENSIVE "INVERTED" GREEN ROOF

NOT TO SCALE SECTION

Figure 8 Multiple Layer Extensive Green “Inverted” Roof (Not to scale, Section)

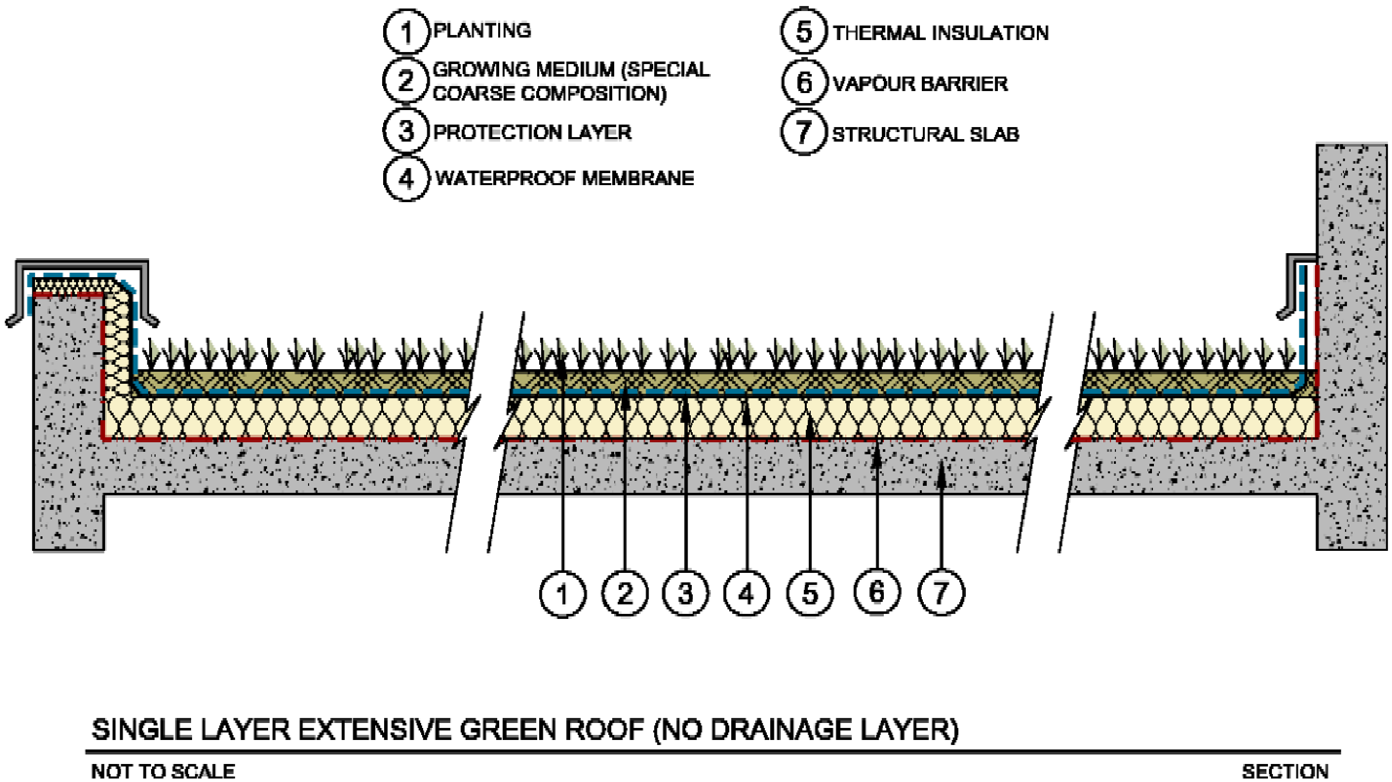
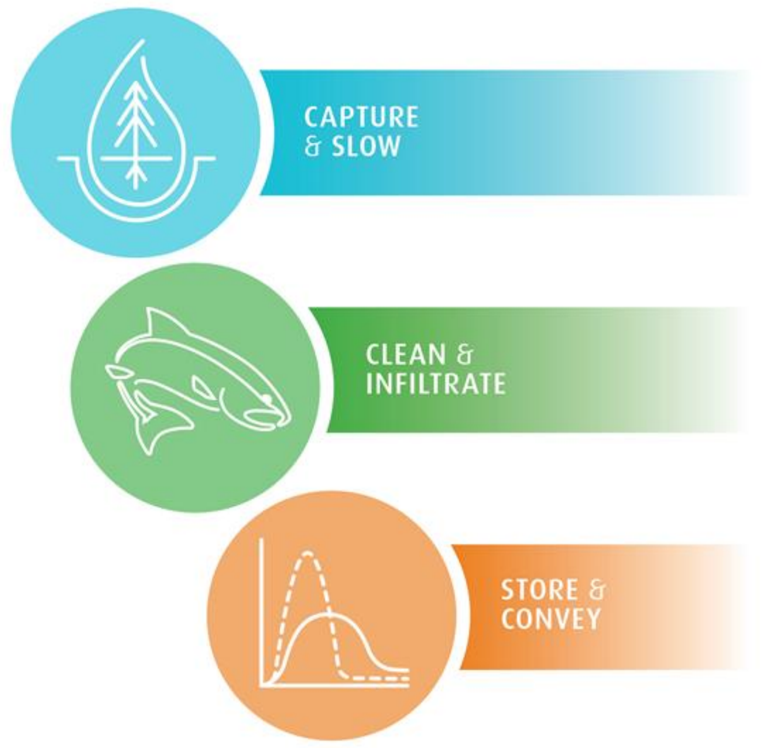


Figure 9 Single Layer Extensive Green Roof (No Drainage Layer) (Not to scale, Section)



APPENDIX I – CONSTRUCTED WETLANDS, WET PONDS & DRY PONDS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Constructed Wetlands, Wet Ponds & Dry Ponds[1]

Description

Constructed wetlands and detention ponds are open areas of shallow water designed so the water level can rise to provide temporary storage for excess water during rainfall events. The water level rises temporarily when it rains. Equally as important, they provide valuable environmental benefits by helping to remove pollution from surface water runoff. Ponds are similar to wetlands but have a greater focus on storing excess water whereas wetlands have a greater focus on treatment of pollution.

Figure 1 Constructed wetland at Peers Creek. Photo Credit: District of Saanich

Constructed wetlands are man-made, engineered wetland areas created through excavation and/or berming. They typically differ from natural or restored wetlands in that they are located in areas where no wetland existed before. Wetlands collect, detain and treat stormwater runoff during storm events and release it into the receiving environment. Properly constructed wetland systems provide a high level of contaminant removal through sedimentation and biological uptake. Wetlands can also provide benefits for flood protection, stream erosion, habitat creation and protection.

Figure 2 Dry pond University of Victoria

Constructed wetlands consist of a series of shallow ponds connected by an engineered marsh system designed to treat contaminated stormwater through the biological processes associated with emergent aquatic plants and via sedimentation. They are similar in nature and application to wet ponds, except that wetlands are normally relatively shallow

[1] Authored by: Opus International Consultants (Canada) Limited
Original design guidelines source: Stormwater Best Management Practices Guide Volume 1, Part 1-3, Greater Vancouver Sewerage and Drainage District (1999)
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol1a.pdf#search=%22BMP%22
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol1b.pdf#search=%22BMP%22
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol2c.pdf#search=%22BMP%22
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd.

and typically include emergent vegetation and marshy areas - suitable for controlling runoff flow rates and for removing particulate and dissolved contaminants. Some infiltration may also occur. Constructed wetlands can have the added benefit of creating habitat for aquatic and terrestrial wildlife.

Figure 4 Stormwater management wetland with invasive species “Parrot’s Feather” (*Myriophyllum aquaticum*). Photo Credit: Town of View Royal

Detention ponds provide extended detention storage of runoff. Extended detention refers to the dry or active storage provided by these facilities. Extended detention ponds reduce the rate of stormwater discharge by storing the stormwater runoff temporarily and releasing it at a controlled rate. Water quality treatment is provided through enhanced settling and biological processes. As such, extended detention storage provides benefits related to water quality, erosion protection, and flooding potential. There are several types of detention ponds that function similarly but differ in design and operation. Dry ponds fill during storm events and slowly release runoff at a predetermined rate until empty. They may be incorporated into sports fields, parks, rooftops or parking lots. Wet ponds maintain a minimum level of water and store runoff above the minimum level, releasing it at a predetermined rate. Wet ponds require a large enough contributing area to maintain the wet pool and prevent it from becoming stagnant. They may accommodate special recreational or aesthetic uses centred around the permanent pool.

Figure 3 Stormwater management pond with invasive species “Parrot’s Feather” (*Myriophyllum aquaticum*). Photo Credit: Town of View Royal

Selection, Application and Limitations

- Constructed wetlands and ponds can be land intensive because they are shallow facilities. The land requirements limit their use in highly urbanized areas.
- Constructed wetlands and ponds can provide effective flood control, streambank erosion control, removal of particulate and soluble contaminants, and limited groundwater recharge (depends on soil conditions).
- Location should be chosen to ensure a large enough catchment for continual flow though the dry season (June-September) so as not to allow stagnation.

- Constructed wetlands and ponds should be designed to mimic natural systems (varying depths, islands, high marsh peninsulas).
- Dry ponds are designed to impound run-off in catchment during large storms and gradually release it. Dry ponds mainly provide runoff rate control as opposed to water quality control.
- Wet Ponds control peak flow, protect streambank erosion, enhance water quality, and enhance the community (recreation, aesthetic value).
- Dry ponds are not as aesthetically pleasing as wet ponds and constructed wetlands.
- Dry ponds' limited effectiveness in removing soluble contaminants is an important factor in considering their application.
- Dry ponds are more expensive than vegetated swales/grassed channels, but less expensive than wet ponds and engineered wetlands.
- Wet ponds may not be appropriate, or may require specialized design, where receiving water temperatures are a concern.
- Some safety concerns are associated with side slopes and water pooling.

Mosquito Control

Mosquitoes complete their development in standing aquatic environments in 8 to 10 days. Unlike other vegetated facilities that are designed to infiltrate the water in 3 days or less, detention facilities such as constructed wetlands and wet ponds are designed to always have surface water, thus require mosquito control measures.

Mosquito control is undertaken to protect public health and maintain expected quality of life. Best management practice for control of mosquito production within constructed wetlands and ponds can be accomplished by a combination of source reduction techniques, such as vegetation management, and utilizing design features such as deep water zones that reduce mosquito production, application of mosquito control agents (where permitted), along with public education.

General Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Analysis should be completed or reviewed by a professional engineer.
5. Detailed designed requirements should be evaluated for each individual application based on site-specific constraints and objectives.
6. Select plant species for survival rather than contaminant uptake. Use a professional to determine the correct plants for each of the zones (wet to dry).
7. Minimize flow velocities to minimize sediment re-entrainment and erosion.

8. Minimum 65% of the pond should be less than 450 mm deep allowing for vegetation growth and contaminant uptake. Depths should vary (25% >1.2 m deep, 65% <450 mm deep, 35% <150 mm deep).
9. Length to width ratio of 3:1 to 5:1.
10. Recommended side slopes 5:1 (H:V) or flatter.
11. Permanently wetted area should hold capture target.
12. See Supplemental 1, Planting Templates & Plant Lists for planting considerations.
13. Volumetric water quality criteria for data collected in Ontario are presented in Table 1. The values are based on a 24-hour drawdown time and will vary based on climate.

Table 1 Water Quality Storage Requirements based on Receiving Waters[2]

Protection Level	Type	Storage Volume (m^3/ha) for Impervious Level			
		35%	55%	70%	85%
Enhanced 80% long-term suspended solids removal	Wet Pond	140	190	225	250
	Wetland	80	105	120	140
Normal 70% long-term suspended solids removal	Wet Pond	90	110	130	150
	Wetland	60	70	80	90
Basic 60% long-term suspended solids removal	Wet Pond	60	75	85	95
	Dry Pond	90	150	200	240
	Wetland	60	60	60	60

Vegetation and Landscaping Guidelines

1. Consider using landscape architect to integrate facility into the community.
2. Use vegetated buffers to discourage small children from approaching pool and post warning signs.

Wet Pond Sizing

1. Wet ponds are designed to meet specific water quality and/or discharge rate objectives.
2. Wet ponds designed to control peak discharge rates only do not normally provide optimum water quality enhancement. Flood control or peak flow control wet ponds are typically designed to control the large infrequent event storms.
3. The permanent pool is designed for water quality only – design additional live storage above permanent pool for streambank erosion protection and/or flood control.

[2] Environmental design criteria (Chapter 3), Ontario Stormwater Management Planning and Design Manual (2003) https://www.ontario.ca/document/stormwater-management-planning-and-design-manual/environmental-design-criteria

4. The Washington State Department of Ecology recommends the runoff from the 24-hour, 6 month event as the water quality volume.[3]

5. One design approach is to size the permanent pool volume to hold the runoff from the design water quality storm.

6. Sedimentation forebay with a volume equal to 10% of the total design volume is recommended for extended detention basins. Pre-treatment is achieved in the sediment forebay.

7. Typically, sediment may have to be removed from the forebay once every 10 years or after 50% of total forebay capacity has been lost.

8. Alternatively, size the storage pool volume based on the "volume ratio" as follows:

   Volume Ratio = V_B/V_R, where:
   V_B = permanent pool volume
   V_R = volume of runoff from the long-term average storm
   King County recommends $V_B/V_R = 3$ for 80% removal of suspended solids and $V_B/V_R = 4.5$ for 50% removal of total phosphorus.[4]

   Note that in the Seattle area where the long-term average storm is about 12 mm, ponds sized for the 6-month, 24-hour (30 mm) storm have a V_B/V_R of about 2.5.

9. Dispersion length = $\frac{8Q}{dV_f}$

   Where:
   Q = inflow (m^3/s)
   d = depth (m)
   V_f = velocity (m/s)

10. Forebay Length = $(\frac{rQ_p}{V_s})^{1/2}$

    Where:
    r = length-to-width ratio of forebay
    Q_p = peak flow rate from pond during quality design storm (m^3/s)
    V_s = settling velocity (m/s)

11. Average pond depth 1 m to 2 m, maximum pond depth 2.5 m to prevent anaerobic conditions.

12. Minimum 300 mm freeboard.

13. Include 2 or more distinct cells and baffles if necessary to minimize short-circuiting.

14. Minimum length to width ratio 3:1, preferably up to 5:1.

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[3] Stormwater Management Manual for Western Washington, 2012 https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals

[4] Surface Water Design Manual, King County, Washington https://www.kingcounty.gov/services/environment/water-and-land/stormwater/documents/surface-water-design-manual.aspx

15. Maximum side slope 3:1.
16. Benches: 150 mm to 300 mm drop.
17. Maintenance access maximum grade 8% to 10%.

Dry Pond Sizing

1. Size storage and outlet structure according to design objectives for flood control, streambank erosion control, or contaminant removal.
2. Typical detention times for the design runoff event as follows:
   a. Conventional dry pond for flood control – 1 to 2 hours.
   b. Extended dry pond for streambank protection – 24 hours.
   c. Extended dry pond basin for contaminant removal – 24 to 72 hours.
3. Allow an additional 20% storage volume to allow for sediment accumulation.
4. For contaminant removal, provide an outlet to empty less than 50% of the design volume during the first 33% of the emptying period.
5. Minimum length to width ratio of 4:1 to 5:1.
6. Two-stage basin recommended for extended detention – design volume of lower stage (micropool) should be 15% to 25% of total design volume with depth 1.1 m to 2.7 m, upper stage 0.6 m to 1.8 m deep with bottom sloping 2% toward low flow (pilot) channel – lower stage reduces standing water and sediment deposition in the rest of the basin and helps to prevent re-suspension of settled sediments and clogging of the low flow orifice.
7. Maximum basin side slopes 3:1 (preferably 4:1) for slope stability, ease of maintenance and safety.
8. Maintenance access maximum grade 8% to 10%.
9. Minimum 600 mm freeboard.
10. Inlet minimum diameter: 450 mm.

Constructed Wetland Sizing

Wetland design should be specific to the particular location. Most of the design elements discussed in the wet ponds section are applicable to constructed wetlands. The exceptions to the wet ponds guidelines are related to the depth and distribution of aquatic vegetation.

1. Wetlands should comprise of a mixture of water depths. Water levels greater than 1 m should be limited to a maximum of 20% of the wetland surface area. A minimum of 30% should be 0.5 m – 1.0 m deep and a minimum of 50% should be 0.0 m – 0.5 m deep.
2. Where wetlands are designed for flow attenuation, the temporary storage above the permanent water level should not exceed 1.5 m.

3. Peak outflow during quality design storm controlled by weir:

   $Q_p = C \times b \times H^{1.5}$

   Where:
   Q_p=flow (m^3/s)
   C = weir coefficient
   b = crest length (m)
   H = maximum height above crest (m)

4. Dispersion length = $\frac{8Q}{dV_f}$

   Where:
   Q = inflow (m^3/s)
   d = depth (m)
   V_f = velocity (m/s)

5. Forebay Length = $(\frac{rQ_p}{V_s})^{1/2}$

   Where:
   r = length-to-width ratio of forebay
   Q_p = peak flow rate from pond during quality design storm (m^3/s)
   V_s = settling velocity (m/s)

6. The flow path to width ratio should be greater than 3:1 (CIRIA, 2007). A length to width ratio of 5:1 is preferred, with a minimum ratio of 2:1 to enhance water quality benefits. The longer length allows more travel time and opportunity for infiltration, biofiltration and sedimentation.[5]

7. Maximum side slope 3:1.

8. Benches: 150 mm to 300 mm drop.

9. Maintenance access maximum grade 8% to 10%.

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements.

Construction Practices shall meet MMCD requirements, **and**:

1. The bottom and the side slopes of the pond, including any benches, should be carefully constructed to ensure that they are structurally sound.

2. Backfilling against inlet and outlet structures needs to be controlled to minimize settlement and erosion.

3. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

[5] The Sustainable Drainage Systems (SuDS) manual, CIRIA, London 2007
https://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx

Constructed Wetland Design Example

Scenario Description

This example provides forebay and wetland size calculations for a 4-hour 25-mm rainfall event (Saskatoon, 2014).

The following parameters are known:

- Q = Peak Inflow = 0.690 m^3/s
- C = weir coefficient = 1.5 (broad crested weir)
- b = crest length = 0.12 m
- H = maximum height above crest = 0.20 m
- d = depth = 1.0 m
- V_f = velocity = 0.4 m/s
- r = length to width ratio of the forebay = 3:1
- V_s = settling velocity = 0.0003 m/s
- Catchment area = 7.7 ha
- Percent impervious = 85%

Forebay Sizing

Determine the peak outflow during the quality design storm controlled by the weir:

$$Q_p = C \times b \times H^{1.5}$$

$$Q_p = 1.5 \times 0.12\, m \times (0.20\, m)^{1.5}$$

$$Q_p = 0.016\, \frac{m^3}{s}$$

Next, find the minimum forebay dispersion length:

$$Forebay\ (dispersion) Length = \frac{8Q}{dV_f}$$

$$Forebay\ (dispersion) Length = \frac{8 \times 0.690 \frac{m^3}{s}}{1.0\, m \times 0.4 \frac{m}{s}}$$

$$Forebay\ (dispersion) Length = 13.8\, m$$

Chosen forebay dispersion length = 15.0 m
Design width = 5.0 m
Length-to-width ratio: 3:1

Wetland Sizing

Required storage volume (80% long-term S.S. removal) = 140 m^3/ha (Table 1)
Total volume required = 1,078 m^3
Extended detention (40 m^3/ha) = 308 m^3
Permanent pool = total volume – extended detention
Permanent pool = 770 m^3

Example Hydraulic Components

- **Inlet**: Existing ditch with riprap at entry.
- **Outflow**: Two weirs with a 100-mm diameter pipe each.

Example Operation and Maintenance

- Mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.
- Replace dead plants, as required.
- Remove accumulated sediment.

GSI Driver Effectiveness – Runoff Reduction and Pollutant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Ponds and constructed wetlands can achieve pollutant removal through a variety of physical, biological, and chemical treatment processes. Although conventional dry ponds do not significantly remove pollutants, extended dry ponds can remove pollutants at similar rates to those of wet ponds. The pollutant removal efficiency can be increased or decreased based on the design components and what pollutants are being targeted for reduction. The following table shows the typical effectiveness of wet ponds, extended dry ponds, and constructed wetlands for pollutant removal.

Table 2 Runoff Reduction and Contaminant Removal

Constructed Wetlands, Wet Ponds and Dry Ponds GSI Facilities			
GSI Driver	*Estimated Effectiveness or typical % Reduction and Removal		
	Wet Ponds[1]	Extended Dry Ponds[2]	Constructed Wetlands[3]
Slow – Volume Runoff Reduction	Depends on Size		
Store – Rate Control Delay Peak	Depends on Size		
Clean – Water Quality Treatment			
Copper	57%	-	40%
Lead	73%	75-90%	-
Zinc	51%	30-60%	44%
Nitrate	24%	-	67%
Total Phosphorus	47%	20-40%	49%
Total Nitrogen	30%	20-40%	30%
Total Suspended Solids	77%	50-70%	76%
Hydrocarbons	83%	50-70%	-
Bacteria	65%	50-90%	-

Note: * Performance of individual GSI facilities will vary depending on site-specific contexts and facility design.

Sources:

1: Schueler, 1997b. Bacterial Levels in Urban Stormwater. Watershed Protection Techniques 3(1)

2: Horner, R.R., J.J. Skupien, E.H. Livingston, and H.E. Shaver, 1994. Fundamentals of Urban Runoff Management: Technical and Institutional Issues. Terrene Institute, Washington, DC.

3: Pennsylvania Stormwater Manual, 2006 http://www.stormwaterpa.org/from-the-foreword.html

Maintenance

A maintenance plan is recommended for ponds and constructed wetlands which would include the scope, schedule, record keeping, and responsibilities related to the facility.

Inspection Checklist

Activity	Schedule	Facilities
Inspect function during wet weather	Periodically during the winter or other wet periods	Wet Ponds Dry Ponds
Inspect hydraulic and structural facilities	Annually	Wet Ponds Dry Ponds
Inspect at outset of rainy season and after each significant storm – remove floatables, correct erosion problems, unclog outlet structures	As required	Dry Ponds

Routine Maintenance

Most of the routine maintenance procedures are related to the removal of accumulated sediment.

ACTIVITY	SCHEDULE	Facilities
Mow side-slopes, embankments and spillways to prevent woody growth and weeds, manage remaining buffer as meadow or forest	Annually or as required	Wet Ponds Constructed Wetlands
Clean sediment forebay	Every 5-7 years or when 50% of capacity has been lost (CWP et al., 1997)	Wet Ponds Constructed Wetlands
Remove accumulated sediments from pond bottom	When 10% to 20% of pool volume is lost – typical volume loss to sedimentation 1% per year	Wet Ponds Constructed Wetlands
Remove floatables, correct erosion problems, unclog outlet structures	At the outset of the rainy season and after each significant rainstorm	Wet Ponds Dry Ponds
Remove sediments from lower stage	Every 5-15 years, as required	Dry Ponds

Non-routine Maintenance

The majority of the non-routine maintenance activities involve managing insects and vegetation.

ACTIVITY	SCHEDULE	Facilities
Control nuisance insects and weeds	As required	Wet Ponds Constructed Wetlands
Vegetation on the pond fringes may have to be harvested the clippings removed	As required	Wet Ponds Constructed Wetlands
Routine mowing – maintain irrigated grass to 50-100 mm tall and non-irrigated native grasses to 100-150 mm tall	Regularly, as required	Dry Ponds

Recommended Inspection and Maintenance Resources:

Inspection and Maintenance Guide for Stormwater Management of Ponds and Constructed Wetlands, 2016, Toronto and Region Conservation and CH2M Hill Canada Ltd.

http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2016/06/SWMFG2016_Guide_June2016.pdf

Stormwater Pond Maintenance and Anoxic Conditions Investigation FINAL REPORT, 2011, Lake Simcoe Region Conservation Authority.

http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2015/01/LSRCA-Stormwater-Maintenance-and-Anoxic-Conditions-2011.pdf

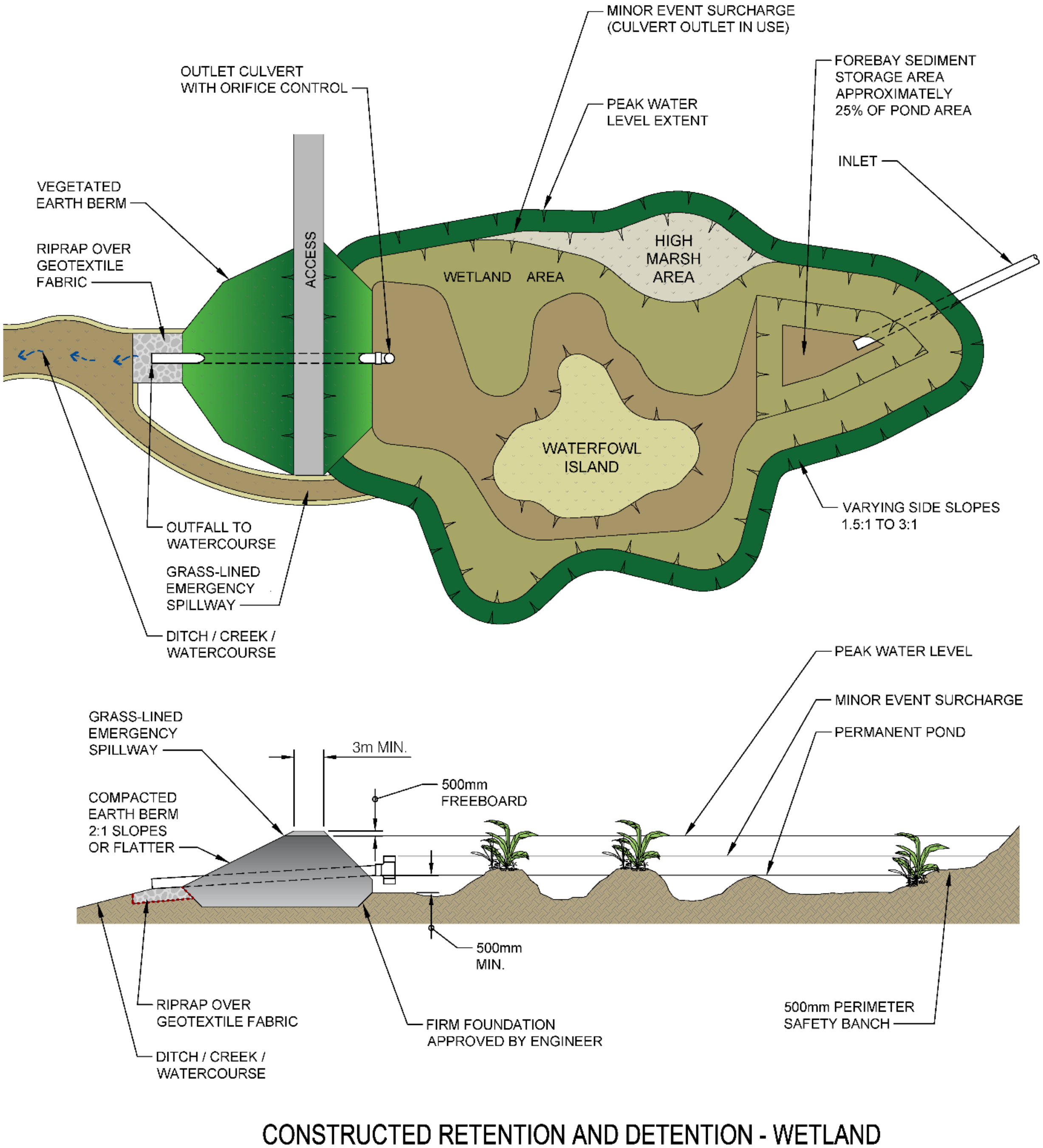


Figure 5 Constructed Retention and Detention – Wetland

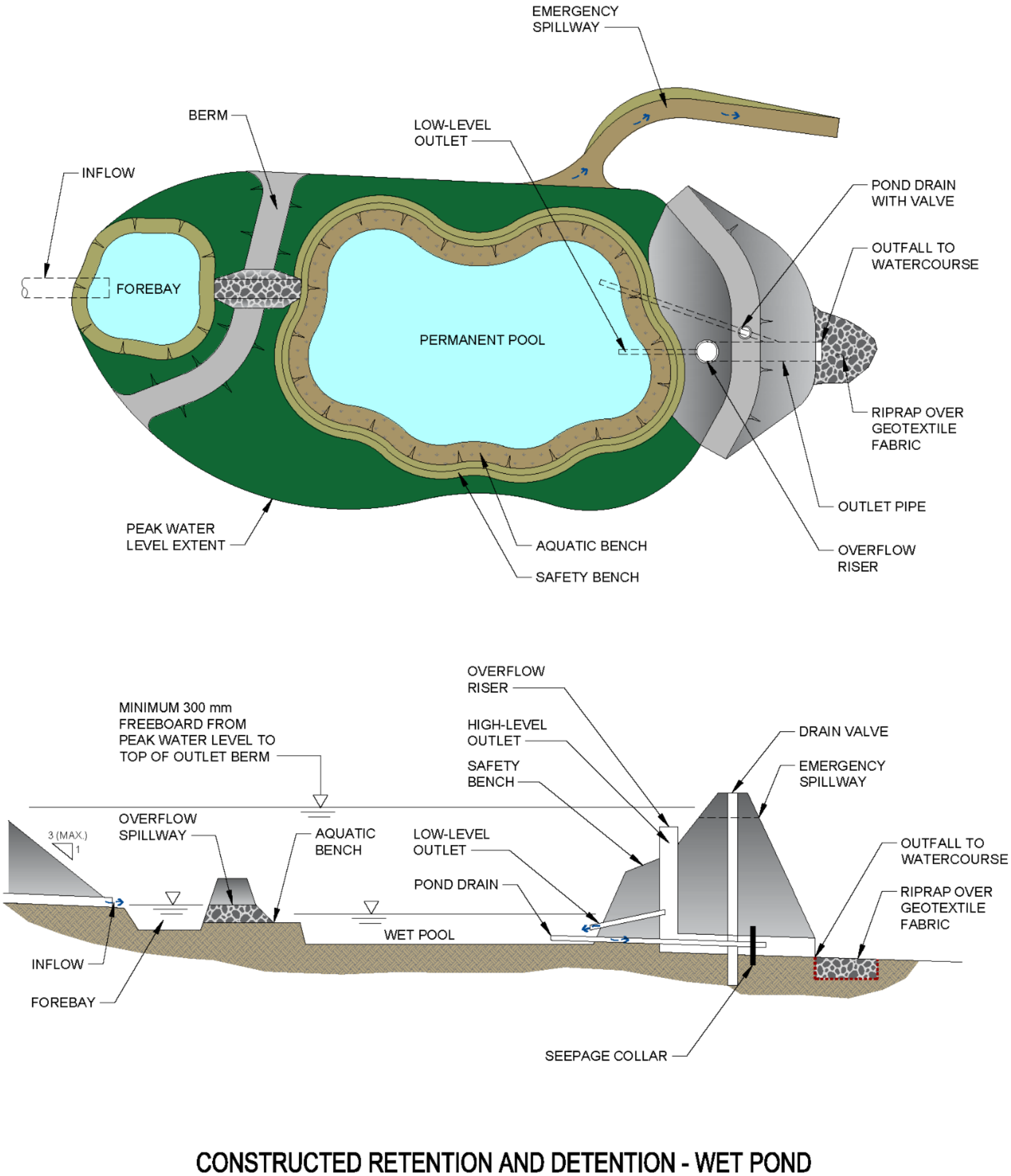


Figure 6 Constructed Retention and Detention – Wet Pond

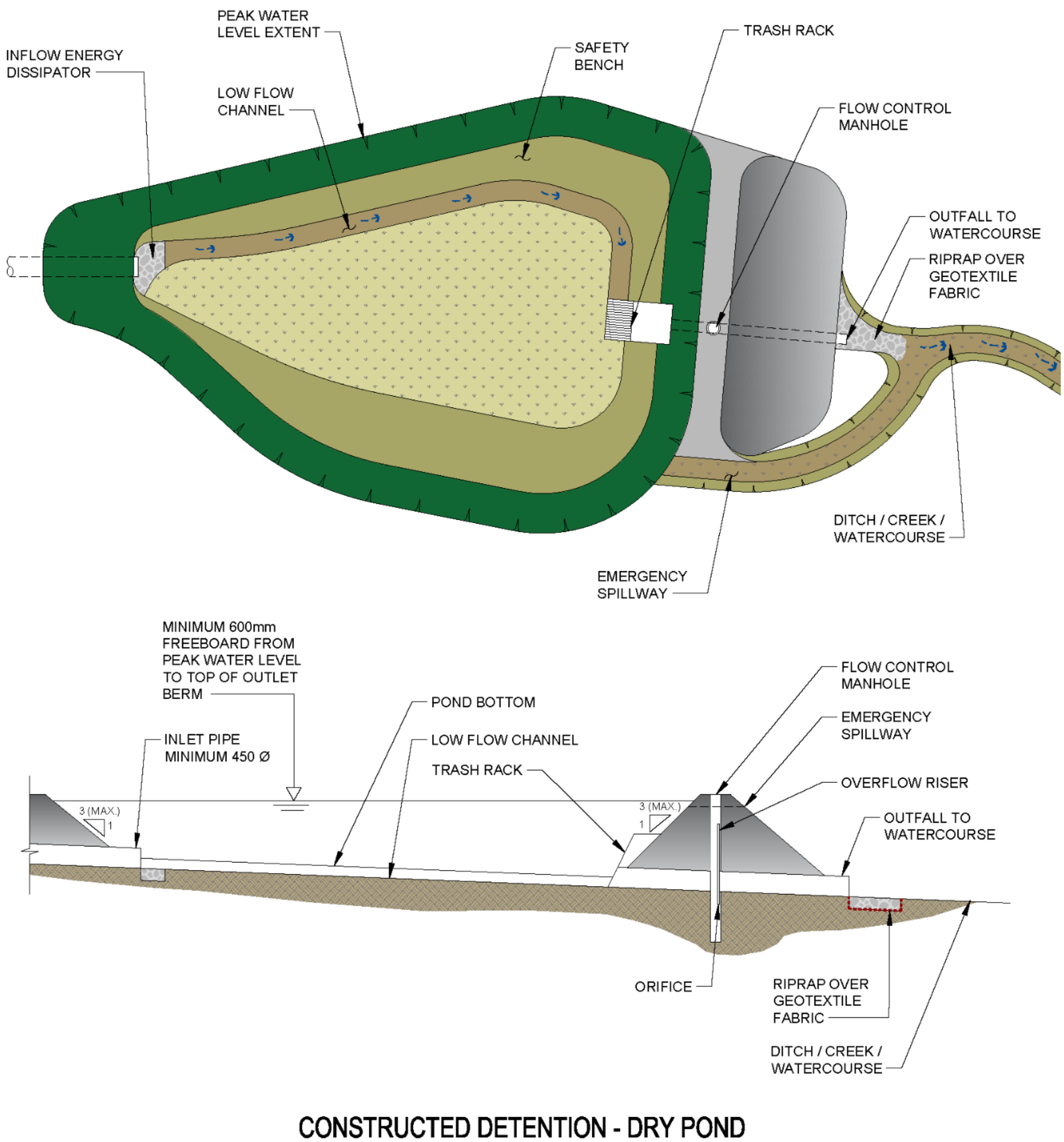
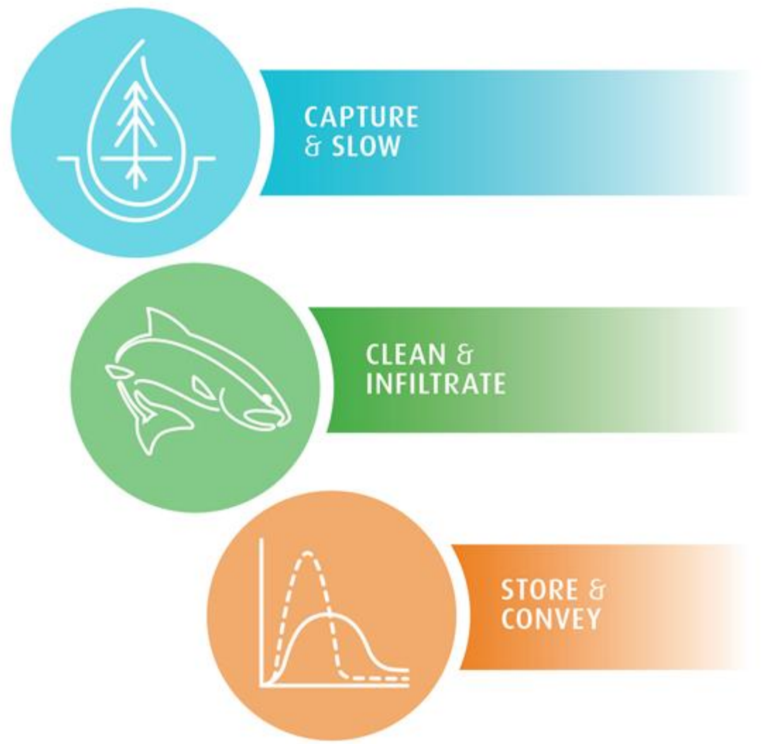


Figure 7 Constructed Detention – Dry Pond



Appendix J – Cisterns & Detention Tanks

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Cisterns & Detention Tanks[1]

Description

Figure 1 Cisterns capturing roof water for residential indoor and outdoor non-potable water use. Photo credit: Kim Stephens, Bowen Island, BC.

While other GSI facilities use bioretention and infiltration systems to reduce runoff volume, cisterns and detention tanks collect and store stormwater runoff during a storm event, then repurpose it or release it at controlled rates reducing peak discharge. With such systems in place, a drainage system can accommodate higher intensity rainfall events.

Detention tanks may be located above or below ground, but typically are underground concrete vaults or corrugated pipe tanks. Detention systems should be designed to reduce peak flows to pre-developed conditions to address a number of stormwater related issues including flooding, erosion and aquatic habitat protection. Detention requirements can be estimated by various methods including the SCS (U.S. Soil Conservation Service) Unit Hydrograph and Level Pool Routing and should be performed or reviewed by a professional engineer.

Cisterns use roof and hard surfaces runoff collection systems to store water in aboveground or underground storage tanks. With minimal pre-treatment, the captured rainwater can be used for outdoor non-potable water uses such as irrigation and pressure washing, or inside the building to flush toilets or urinals. These design guidelines are only for the harvesting and storage. These guidleines do not provide design standards for systems such as indoor non-potable use.

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

Selection and Application

- Cistern systems can be used to collect rainwater from most residential, commercial, industrial or institutional roofs.
- Detention tanks and cisterns are useful on infill and re-development sites that have little room for other GSI.
- Rainwater harvesting systems can be installed underground, indoors, on the ground next to a building or on the roof (for roof collection only).
- Rainwater that is captured and stored can be used to meet both outdoor and indoor non-potable water uses.
- Some indoor non-potable uses may be restricted and separate plumbing with purple pipes may be required.

Figure 2 Planter watered by roof water captured in underground detention tank, Salt Spring Island Library

- Outdoors, harvested rainwater can be used for residential lawn and garden watering, commercial and institutional landscaping irrigation, decorative fountains, or other non-potable uses such as vehicle washing, building washing and firefighting.
- Typically, indoor uses of harvested rainwater are for non-potable purposes only. Toilet flushing is the most common large-scale indoor use of harvested rainwater. Separate plumbing, pumps, pressure tanks, and backflow preventers are necessary for indoor use of harvested water. Back-up water supply system arrangements, which can be drawn upon when the cistern runs dry, are also necessary for indoor uses.
- Cisterns must be located where roof water can be directed to the tank. Only collect roof water for reuse. Do not reuse water from parking or pedestrian areas, surface water runoff, or bodies of standing water.
- Flat, stable surfaces must be provided to support the tank and designed for the weight of the tank when full of water. Underground tanks require flat, stable subgrade, but no constructed base other than crushed rock.
- A cistern is possible in areas where infiltration methods may not be feasible such as steep or hazardous slopes, bedrock, high water table, or contaminated soils.
- An elevated cistern requires design by a qualified professional.
- Cisterns must be connected to the municipal stormwater system for overflow or to a properly designed rainwater management method with an overflow connection to the stormwater system.
- A cistern should only be used where there is a use for the water, enabling the tank to be emptied. This may include irrigation of landscaping or re-use for toilet flushing where there is a consistent demand through the wet season of the year.
- If using the rainwater within a building, a professional is required to design and install the required “purple pipe” system.
- Cisterns and detention tanks must meet the setback requirements that apply to the main building within that particular zone.
- Collectively, the total surface area of the buildings, cistern or detention tank and other structures on a property must not exceed the maximum site coverage permitted in the zone.

- Cisterns/rain barrels (less than 1,200 litres) do not have setback requirements or site coverage limits.
- Roof material can impact the end use of the water collected in the rain barrel or cistern. Currently, no water quality standards for roofing types exist, and few roofing products carry water quality test information. Individual roof products vary. It is important to be mindful that any chemical treatment of a roof, such as moss inhibitors, could be harmful to plants.

Figure 3 Cistern collecting roof water with pump (covered to the left) pumping collected roof water to the garden. Photo Credit: Victoria Compost Education Centre

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. The size of the storage tank will depend on the catchment area, seasonal rainfall pattern, demand pattern, retention time and cost.
4. To provide storage to attenuate peak discharges, the design storm will need to be considered as well.
5. A pre-treatment sump may be required to remove sediment in the runoff.
6. Provide an overflow to allow larger storms to overflow the tank.
7. Tank should be designed to allow for access for maintenance or cleaning.
8. All underground tanks should have an air space equal to 20% of the maximum depth, connected to the atmosphere by a vent.
9. The maximum depth is a function of safety and convenience of users. A depth of over 2 m is not recommended.
10. Underground tanks must have a minimum of 0.5 m of cover and must be capable of handing the loads from the surface above.
11. Discharge either by gravity or through pumping, to ensure that detention volume is available for the next storm event.

Sizing Cisterns and Detention Tanks

Cisterns

1. Determine the available pervious area that will be used for irrigation (watered area).
2. Determine the impervious area that will be directed to the cistern.
3. Ratio of watered area to impervious area should not be smaller than 2:1.
4. Cisterns are typically designed to capture the runoff from the roof. Provide 0.025 m^3 of storage per 1 m^2 of impervious area being directed to the cistern.
5. The selection of the method of analysis depends on the size of the development and the intended application of the results.
6. Analysis should be done or reviewed by a professional engineer.
7. The potential amount of rainwater that can be collected in a cistern from a rooftop catchment can be estimated with the formula:

   Annual collectable rainfall (I) = Average annual rainfall (mm) x total catchment area (m^2) x filter efficiency

   Where:

   Average annual rainfall =

   Local meteorological data supplied by local Environmental Agency or Meteorological Office.

   Filter efficiency =

   The proportion of the collected water that is available for use, following filtering. Most manufacturers recommend that a factor of 0.9 be used.

   Drainage Coefficient =

   The proportion of the rainfall that runs off the catchment and reaches the collection tank. Light rainfall will only wet the roof then evaporate; heavy rainfall can overflow from the gutter and, therefore, be lost. The following figures are appropriate for different roof types:

Roof Type	Drainage Coefficient
Pitched roof, slate tiles	0.8
Flat roof	0.5
Flat roof, gravel	0.4
Extensive green roof*	0.3
Intensive green roof*	0.2

*Note: *The use of green roofs and rainwater harvesting together can be challenging. This is applies to both the hydraulic disadvantages as well as water quality issues of colour, sediment and bacteria.*

8. The volume estimated from the above formula can be compared with the demand to establish a potential for savings.
9. A common rule of thumb for household water use is to size the tank at 5% of the available rainwater supply, or the annual demand, using the lower of the two.

Detention Tanks

1. Detention requirements for stormwater management can be estimated by various methods including: the Rational Method, SCS (U.S. Soil Conservation Service) Unit Hydrograph and Level Pool routing as examples. Use of hydraulic model is recommended to estimate the detention storage requirement.
2. The selection of the method of analysis depends on the size of the development and the intended application of the results.
3. Analysis should be performed or reviewed by a professional engineer.
4. Stormwater detention tank systems can be configured as online or offline systems.
5. Stormwater in the detention tank may be discharged either by gravity or through pumping. In order to ensure that detention volume is available for the next storm event, it is recommended that discharge systems be designed to empty the tank within 4 hours after a storm event.
6. The maximum allowable peak discharge shall be computed at the downstream end of the internal drainage system of the development prior to its connection to the public drain.
7. Maximum allowable peak discharge for the proposed development should be calculated using the Rational Formula.

   $Qr = 1/360 \{CiA\}$
   Where
   Qr = Peak runoff at the point of design [m^3/s]
   C = Runoff coefficient
   i = Average rainfall intensity [mm/hr]
   A = Catchment area [ha]

8. The runoff coefficient (C) of a site depends on its land uses or surface characteristics. Pervious areas that allow water to infiltrate into the ground, such as grass or landscaped areas located on true ground, may assume a C value of 0.45 while impervious areas like roads, buildings and pavement may assume a C value of 1.
9. For a storm of return period of T years, the rainfall intensity (i) is the average rate of rainfall from a storm having a duration equal to the time of concentration (tc) of the catchment.
10. The average rainfall intensity (i) can be obtained from the Intensity Duration Frequency curves.
11. According to the Rational Method, the peak runoff (Qr) occurs when all parts of the catchment receiving a steady, uniform rainfall intensity are contributing to the outflow. This condition is met when the duration of rainfall equals the time of concentration (tc).

12. Based on the Rational Formula, the post-development peak runoff from a development site with no runoff controls should be calculated.
13. Hydrologic and hydraulic modelling method should be used for sizing online or offline detention systems, including detention systems for larger developments (greater than 10ha) or developments with more complex drainage systems. Developers may choose appropriate hydrological and hydraulic models such as U.S. EPA SWMM, or any other similar software to size or verify the adequacy of the proposed detention system.

Guideline Specifications

Materials and Construction Practices shall meet Master Municipal Construction Document (MMCD) 2009 requirements.

Recommended Resources

Regional Manuals:

- ✓ Rainwater Harvesting Best Practices Guidebook Developed For Homeowners of the Regional District of Nanaimo (British Columbia, Canada) Regional District of Nanaimo
  http://www.rdn.bc.ca/cms/wpattachments/wpID2430atID5059.pdf
- ✓ Rainwater Harvesting on the Gulf Islands – Guide for Regulating the Installation of Rainwater Harvesting Systems – Potable and Non-potable Uses (2006), Island Trust
  http://www.islandstrustfund.bc.ca/media/39066/guide_for_regulating_rainwater_harvesting_systems.pdf
- ✓ Rainwater Harvesting on the Gulf Islands - Frequently Asked Questions
  http://www.islandstrustfund.bc.ca/media/39063/rainwater_harvesting_faq.pdf
- ✓ Owner’s Manual Rainwater Harvesting and Water Supply System (2006), Island Trust
  http://www.islandstrustfund.bc.ca/media/39069/ranr_harvesting_system_manual.pdf

Websites:

- ✓ Canadian Association for Rainwater Management
  http://www.canarm.org/
- ✓ Rainwater Harvesting, Canadian Mortgage and Housing Corporation
  https://www.cmhc-schl.gc.ca/en/inpr/su/waho/waho_002.cfm

Cisterns and Detention Tanks Design Example for R mm/24-hour Criteria

Scenario Description – Commercial/Industrial Detention Tank

A detention tank is proposed to capture a portion of the runoff from a building roof (see illustration below).

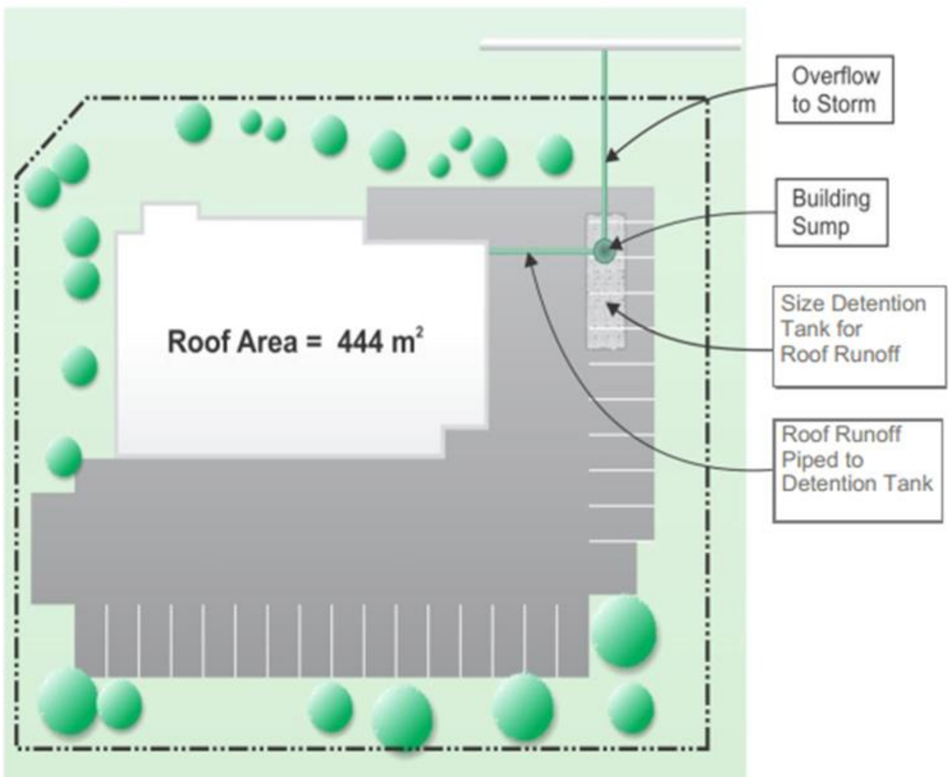


Figure 4 Example - Roof area draining to detention tank

The following parameters are known:

- Roof area = 444 m^2
- Annual rainfall = 1,300 mm
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine the cistern volume.

Scenario Description – Commercial, Industrial Detention Tank

The potential annual amount of rainwater that can be collected in a cistern or detention tank from a rooftop catchment can be estimated with the formula:

Annual collectable rainfall (I) = Average annual rainfall (mm) x total catchment area (m2) x filter efficiency

Where:

Average annual rainfall = local meteorological data supplied by local Environmental Agency or Meteorological Office.

Filter efficiency = The proportion of the collected water that is available for use, following filtering. Most manufactures recommend that a factor of 0.9 be used.

Drainage Coefficient = The proportion of the rainfall that runs off the catchment and reaches the collection tank. Light rainfall will only wet the roof then evaporate; heavy rainfall can overflow from cutter and therefore be lost. The following figures are appropriate for different roof types.

Roof Type	Drainage Coefficient
Pitched roof, slate tiles	0.8
Flat roof	0.5
Flat roof, gravel	0.4
Extensive green roof*	0.3
Intensive green roof*	0.2

*Note: *The use of green roofs and rainwater harvesting together can be challenging. This is dies to both the hydraulic disadvantages as well as water quality issues of colour, sediment and bacteria.*

Assuming a flat roof and filter efficiency of 0.9, Annual collectable rainfall = 1,300 mm x 444 m^2 x 0.5 x 0.9 = 260,000 L.

Scenario Description – Residential Cistern

An aboveground cistern is proposed to capture runoff from the roof of a single-family home for irrigation use.

- Roof area = 180 m^2
  Ratio of watered area to impervious area should not be smaller than 2:1 for irrigation use:
  watered area = 180 x 2 = 360 m^2
  Provide 0.025 m^3 of storage per 1 m^2 of impervious area being directed to the cistern:
  180 m^2 x 0.025 m^3/1 m^2 = 4.5 m^3

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Cisterns and detention tanks do not reduce runoff volumes, unless stored and used for irrigation, outdoor washing or indoor non-potable uses such as toilet flushing. These systems do not provide treatment of stormwater runoff, unless designed for sediment removal through settling. If the water is not re-purposed the water may be released into storm drain system during dry days, to reduce peak flows. The following table shows the effectiveness of cisterns and detention tanks facilities for GSI drivers, including pollutant removal and stormwater runoff reduction.

Table 1 Runoff Reduction and Pollution Removal Summary Table

Cisterns and Detention Tanks GSI Facilities	
GSI Driver	***Estimated Effectiveness or typical % Removal**
Capture & Slow – Volume Runoff Reduction	% re-purposed
Store & Convey – Rate Control Delay Peak	If sufficient storage is provided
Clean & Infiltrate – Water Quality Treatment	
Total Suspended Solids (TSS)	If filtered

Note: * Performance of individual GSI facilities will vary depending on site-specific contexts and facility design.

Maintenance

- Inspect tank annually and clean, as required.
- Sediment should be removed from the tank bottom and floatables removed from the water surface.
- Maintain any sumps or upstream pre-treatment regularly to ensure proper operation.

INSPECTION ACTIVITIES	SCHEDULE
Inspect for proper functioning	After every major storm for the first few months to confirm design drain times
Inspect for pollutant contamination, standing water, trash and debris, sediment accumulation	Semi-annual and after extreme events
Inspect pre-treatment devices and diversion structures for damage and sediment accumulation	Semi-annual and after extreme events
MAINTENANCE ACTIVITY	**SCHEDULE**
Cleaned plugged air vents	As needed
Remove sediment, debris, and oil/grease from pre-treatment devices when sediment depth exceeds 15% diameter of storage area	As needed
Repair joint between tank and inlet/outlet pipes	As needed
Repair/replace tank and pipes if tank/pipe is bent out of shape by more than 10% if its design shape	As needed

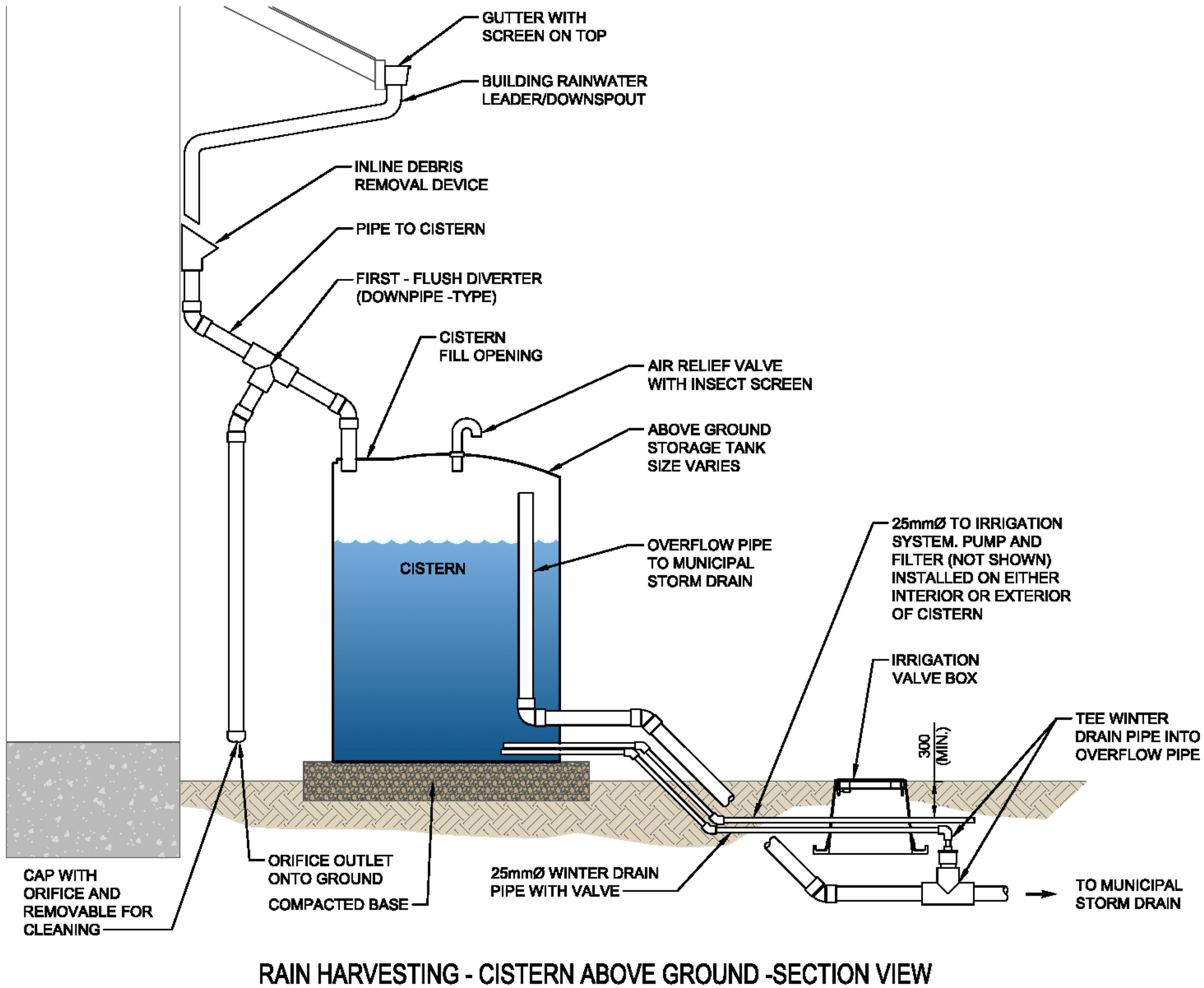


Figure 5 Rain Harvesting – Cistern Above Ground – Section View

Above depicts re-purpose of harvested roof water for irrigation purposes. This can be placed with a simple hose bib or a plumber may design a non-potable indoor (purple pipe) system requiring the BC Plumbing Code.

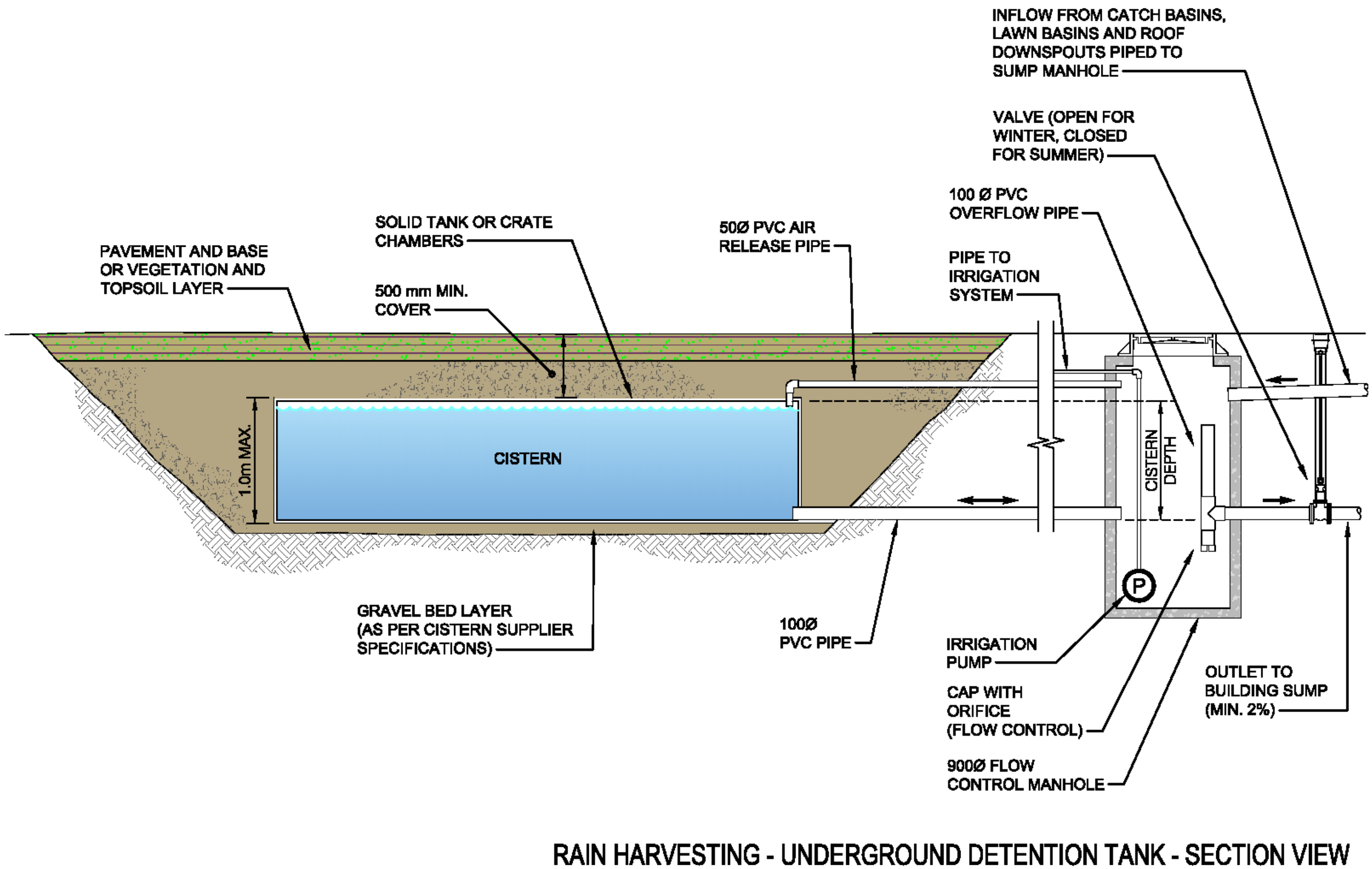
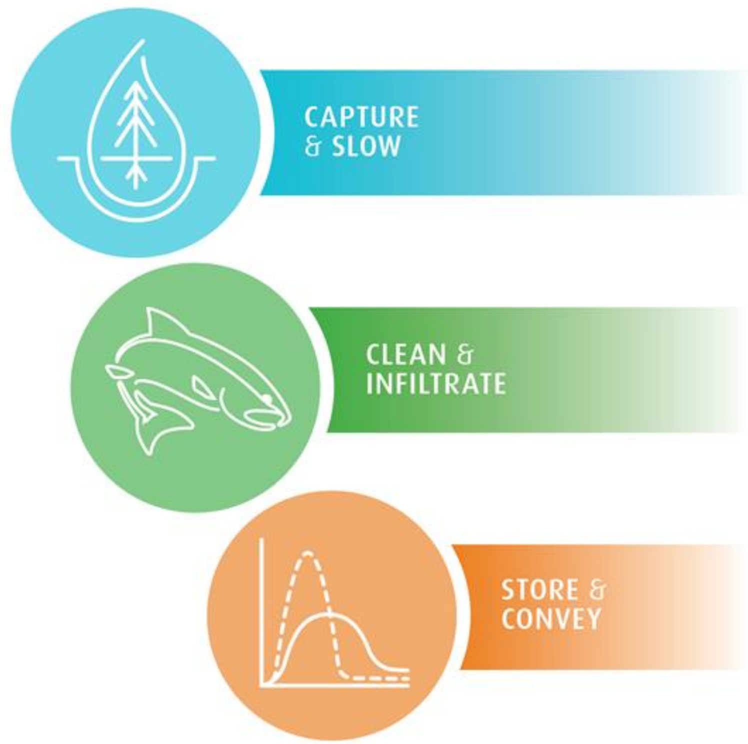


Figure 6 Rain Harvesting – Underground Detention Tank – Section View



APPENDIX K – PERVIOUS PAVING SYSTEMS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Pervious Paving Systems[1]

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 discharged via 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 permeable material – usually gravel or soil – and may have grass growing in the void spaces.
- Permeable unit pavers, made up of impervious concrete modular pavers with gapped joints that allow water to percolate between the pavers.

This section outlines permeable unit pavers and porous paving alternatives.

Figure 1 South Valley Estates, Saanich

Figure 2 Permeable paving system, Burnside Gorge Community Centre

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

Selection and Application

- Pervious paving does not have a soil layer that treats runoff and is subject to clogging from surface pollutants. Pervious paving should not be used to infiltrate runoff from moderate- to high-traffic roads and parking areas that receive more than 1 vehicle per day per space. For surfaces with higher potential contaminant runoff, absorbent landscaping, rain gardens (and other bioretention facilities) and infiltration swales should be considered.
- Pervious paving is suitable for low traffic areas – e.g., driveways, commuter parking areas, storage yards, bike paths, walkways, recreational vehicle pads, service roads, and fire lanes.

Figure 3 Permeable paving at L'ecole Victor Brodeur, Esquimalt

- Pervious paving can receive runoff from other areas, if the tributary areas have low sediment loads or protection from sediment loads is provided. If the contributing impervious area is greater than 2x the area of pervious paving, alternative solutions such as bioretention facilities and infiltration swales or trench should be considered.
- Grid pavers with soil and grass should be restricted to areas with evening parking (i.e., residential) or periodic day parking to allow sunshine to reach the grass during the daylight hours.
- Suitable for reduction in peak flows and runoff volumes, contaminant removal, and groundwater recharge.
- May be used to retrofit existing developments and redeveloping areas as well as in new developments.
- A greater design and construction control effort is required when compared with impermeable pavements.
- Types of permeable interlocking concrete pavers that have wide joints (some manufacturers) should not be used for disabled persons parking stalls or pedestrian ramps at street crossings.

Design Guidelines for Permeable Interlocking Concrete Paving

Pervious pavement designs may be 1 of 3 types:

- Full Infiltration: where all inflow is intended to infiltrate into the underlying subsoil.
- Partial Infiltration: designed so that some water may infiltrate into the underlying soil while the remainder is drained by perforated pipes.
- Partial Infiltration with Flow Restrictor: designed with a perforated pipe and flow restrictor located at the bottom of the drain rock reservoir, allows the gradual decanting of water above the perforated pipe.

Design Guidelines for all 3 types include the following:

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. 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 occurring 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. This type of design is generally not needed if only upstream paved area is discharged to pervious paving at a ratio of 2:1 or less, but could be used if roof water is discharged to permeable paving at more than 2:1 I/P ratio.

Figure 4 Grass grid at Victoria Island Technology Park

5. Soil subgrade sampling and analysis should be provided by a professional engineer knowledgeable 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 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. Infiltration testing should be completed in the winter under saturated conditions.
6. Minimum recommended tested infiltration rate for a full infiltration pavement design is 13 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.
7. At least 30 m should be maintained between permeable pavements and water supply wells.
8. The pavement should be downslope from building foundations, and the foundations should have piped drainage at the footing.
9. To avoid surface plugging, it is critical to protect this GSI 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 GSI facility.

10. Where it is proposed to drain impermeable surfaces onto pervious pavement surfaces, it is recommended that a maximum ratio of 2:1 impermeable to permeable is used. This may vary by rainfall and soil characteristics as determined by modelling.
11. For draining roof water to pervious pavers, much higher ratios of upstream impervious surface to pervious pavers, such as 50:1, may be used. Sediment loading potential of the upstream surface will determine allowable ratio.
12. Permeable unit pavers should be selected and designed based on a manufacturer's tests that the installed unit paving system can maintain a minimum 28 mm/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 >280 mm/hr.
13. Permeable unit pavers are usually 80 mm depth. Provide edge restraint to contain the pavers, similar to standard unit paving. Edge restraints that use spikes are not recommended.
14. Permeable unit paving surface slope should be 1% minimum to avoid ponding on the surface, and related settlement of clay-sized particles.
15. 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. Vegetated joints are not suitable in heavily shaded areas such as under long-term parking.
16. 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, patching the cloth, and reusing the pavers.
17. Minimum depth from base of drain rock reservoir to water table or solid bedrock 600 mm.
18. Bottom of reservoir: flat in full infiltration designs, minimum 0.1% slope to drain in piped systems.
19. If the pavement is being designed for heavy loads, optional reinforcing grids (geogrid) may be included in the pavement subbase.
20. 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.
21. Design reservoir water levels and stormwater detention using a continuous modelling program. Base draw down time for the reservoir on the Green-Field runoff rate.
22. 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.
23. 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.
24. 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.

25. See Table 1 for setbacks for pervious paving. A liner may be required within 1.5 m of infrastructure.

Table 1 Pervious Paving Setbacks

Setback From	Distance (m)
Foundation	0
Property Line	0
Drinking Water Well	30
Septic Field	3
Active or inactive landfill or contaminated site	30
Minimum Slope	1%

Sizing Pervious Paving

In this guide, a simplified sizing approach has been developed that does not require water balance modelling or continuous simulation.

1. In general, pervious paving is sized to infiltrate the rain that falls directly on it and runoff from a limited area of upstream impervious surface. The maximum ratio of impervious paved area to pervious paving area (I/P ratio) allowed will be 2:1. Pervious area refers to the pervious paving area and the I/P ratio will be zero (0) where no impervious area is directed to the pervious paving.
2. This sizing approach does not apply to a partial infiltration reservoir and drain with flow restrictor under pervious paving.
3. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. Sizing and design according to this guidance will not provide adequate water quality treatment for runoff from high-vehicle-volume and other polluted surfaces. Sizing of treatment, when needed, must be performed separately.

Sizing for Depth Capture Criteria: R mm in 24 hrs

To determine R mm of rain in 24 hrs see Appendix A, Table 1 for area specific typical GSI facility design guideline rainfall capture targets and confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; allowable depth range is 300 to 1,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
T = allowable drain time (days)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the base (bottom) area of pervious paving and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_R \times n}{R} - 1$$

Where:
I/P = Ratio of impervious tributary area to pervious paving area (unitless)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_R = Depth (thickness) of rock reservoir (mm)

3. Check that the I/P ratio calculated is less than the maximum allowed (2:1). If it is not, the I/P ratio may be assumed to be a maximum of 2. Recalculate the minimum rock depth using the formula:

$$D_R = \frac{[(I/P + 1) \times R] - (24 \times Ks)}{n}$$

Where:
I/P = 2

4. To find the pervious paving area:

$$PerviousArea = \frac{\text{Impervious TributaryA rea}}{I/P}$$

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 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 an initial infiltration rate >280 mm/hr. and a maintained >28 mm/hr infiltration rate over the pavement life (usually 20 years).
2. Paver bedding course (50 mm thick) and joint filling material shall be open-graded crush 5 mm aggregate (or ASTM No.8 - no sand). A surface finish of 3 mm clean crush aggregate (or ASTM No 89) should be applied to the finish surface and brushed in.
3. Reservoir base course shall be clean crushed stone graded from 5 mm to 20 mm (approximately 100 mm deep or greater – varies with design). 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 10 mm to 63 mm, with void space ratio >35% (or ASTM No. 57 – approximately 250 mm deep or greater – varies with design).
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 31 32 19, select for filter criteria or from approved local government product lists.

Construction Practices shall meet Master Municipal Construction Document 2009 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 300 mm of material over the final subgrade of the pavement until after all sediment-producing construction in the drainage area has been completed.
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.
3. Scarify subgrade (native) soil prior to placement of filter cloth and aggregate to ensure the subsurface has not sealed due to equipment or raindrops.
4. 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.
5. Reservoir drain rock subbase and base courses shall be installed in 100 mm to 150 mm lifts and compacted with at least 4 passes with a minimum 9 T steel drum roller.
6. 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 manufacturer's specifications. Blocks should be vibrated with a vibrating plated compactor. Following a first pass, a light dressing of 3-mm single size clean stone should be applied to the surface and brushed in, approximately 2 kg/m^2. Blocks should again be vibrated and any debris brushed off.

7. 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.

Pervious Paving Design Example for Capture of R mm/24-hour Criteria

Scenario Description

Pervious paving is proposed to capture a portion of the runoff from a paved parking area (see illustration below).

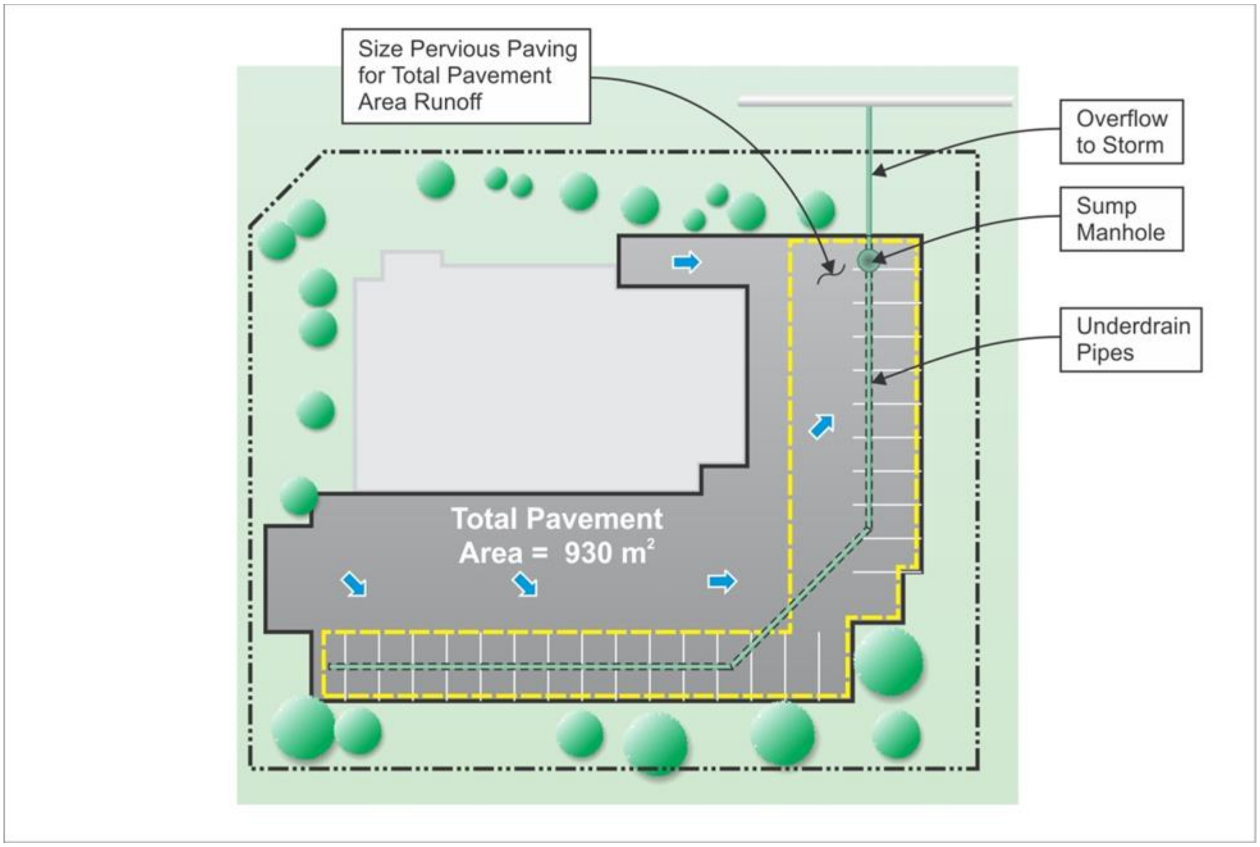


Figure 5 Example – Parking Area Draining to Pervious Paving

The following parameters are known:

- Total pavement area = 930 m^2
- Native soil infiltration rate = 2.0 mm/hr
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72 % of 2-year 24-hour rain amount = 38 mm

Determine the pervious paving area and rock reservoir depth.

Sizing

Determine the maximum rock depth based on the 4-day maximum drain time:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{2.0mm/hr \times 4days \times 24hr/day}{0.35} = 548\,mm$$

Use the following equation to determine the base (bottom) area of pervious paving and rock reservoir required by finding the I/P ratio for the site:

$$I/P = \frac{24 \times Ks + D_R \times n}{R} - 1$$

$$I/P = \frac{24hr \times 2mm/hr + 548\,mm \times 0.35}{38mm} - 1 = 5.3$$

Check that the I/P ratio calculated is less than the maximum allowed (2:1). If it is not, the I/P ratio may be assumed to be a maximum of 2. Recalculate the minimum rock depth using the formula:

$$D_R = \frac{[(I/P + 1) \times R] - (24 \times Ks)}{n}$$

$$D_R = \frac{[(2+1) \times 38mm] - (24hr \times 2mm/hr)}{0.35} = 189\,mm$$

Check that the rock trench depth is less than the maximum calculated above (189 mm <548 mm, therefore OK).

Calculate the pervious paving area:

$$PerviousArea = \frac{imperviousTributaryArea}{I/P}$$

$$PerviousArea = \frac{930\,sq.m. - PerviousArea}{2}$$

$$2 \times PerviousArea = 930sq.m. - PerviousArea$$

$$PerviousArea = \frac{930\,sq.m.}{3} = 310\,sq.m$$

Hydraulic Components

- **Inlet**: The impervious pavement runoff sheet flows onto the pervious paving.
- **Overflow**: The site grading and pavement grading must allow overland flow to the municipal major system (typically roadway surface) for any water that overwhelms the infiltration capacity of the pervious paving.
- **Underdrain**: A perforated pipe located along the top of the rock layer decants excess water into a sump manhole when the rock layer is full of water. The sump is connected to the municipal storm sewer connection.

Maintenance

- Vacuum sweep the pervious paving annually to remove built up fines on the surface. Some systems such as plastic grid panels cannot be swept.
- Underdrain sump should be inspected annually and cleaned, as required. Sediment should be removed from the sump bottom.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Pollutant removal in pervious pavement systems occurs by the filtering of stormwater that is infiltrated into the underlying fabric (if part of the design) or soil subgrade. As with all treatment GSI facilities that use infiltration to remove pollutants, one must ensure that there are sufficient organic content and adsorption capacity in the subgrade soils to remove contaminants and protect groundwater quality. Research indicates that pervious pavement systems are efficient at removing several of the common stormwater pollutants if they include a good subgrade soil for infiltration and filtering. Estimates of GSI driver effectiveness are shown below:

Table 2 Runoff Reduction and Contaminant Removal Summary Table

Pervious Paving Systems for GSI Facilities	
GSI Driver	***Estimated Effectiveness or Typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	85% without underdrain 45% with underdrain
Store & Convey – Rate Control Delay Peak	Medium to high without under drain Medium with underdrain
Clean & Infiltrate – Water Quality Treatment	Highly variable with design, BSM, native soil and depth, plant type. Below are typical results. Research has observed good retention and at times production and export. Export is more likely with an underdrain.
Heavy Metals (Copper, Lead, Zinc)	72-98
Oil and Grease / Hydrocarbons	80
Phosphorus	45-65
Nitrogen	50-60
Total Suspended Solids (TSS)	74-90
Bacteria (Fecal coliform bacteria or E. coli)	NA

**Sources:*
http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2013/02/4.7-Permeable-Pavement.pdf
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://www.bmpdatabase.org/

Maintenance

Maintenance is a crucial element to ensure the long term performance of pervious pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment that can reduce the pavement's flow capacity. Maintenance requirements for pervious paving will vary based on:

- Type of pervious paving system
- Ownership
- Type of use
- Level of traffic
- Contributing catchments

ACTIVITY	OBJECTIVE	SCHEDULE
Visually check observation ports	Ensure that the subgrade soils are not clogged and are draining properly	Twice annually
Inspect for ponding water	Ensure that the subgrade soils are not clogged and are draining properly	Following heavy rains (25 cm in 24 hours)
Manually sweep large debris and leaves	Ensure adequate flow capacity of pavers	Once annually in fall or as needed
Vacuum sweep with commercial sweeping machine (dependent on paving system)	Keep pavers clean and decrease sediment clogging	Twice annually
Manually remove weeds	Ensure perviousness of pavers	Annually or as needed
Refill gravels between pavers or open-celled systems	Maintain proper functioning of pervious paving	Annually minimum

Routine Maintenance

Most of the routine maintenance procedures are typical landscape care activities.

Non-routine Maintenance

The most common non-routine maintenance problem involves ponding water. If water remains on the surface for more than 72 hours after a storm, repairs may be needed.

ACTIVITY	OBJECTIVE	SCHEDULE
Reconstruction of part or all of the pervious surface	Restore desired infiltration rates	As needed (infrequent, 15-20 years)
Replace or clean sub-surface soils	Restore desired infiltration rates	As needed (infrequent, 15-20 years)
Replace damaged pavers	Maintain proper functioning of paving system	By inspection

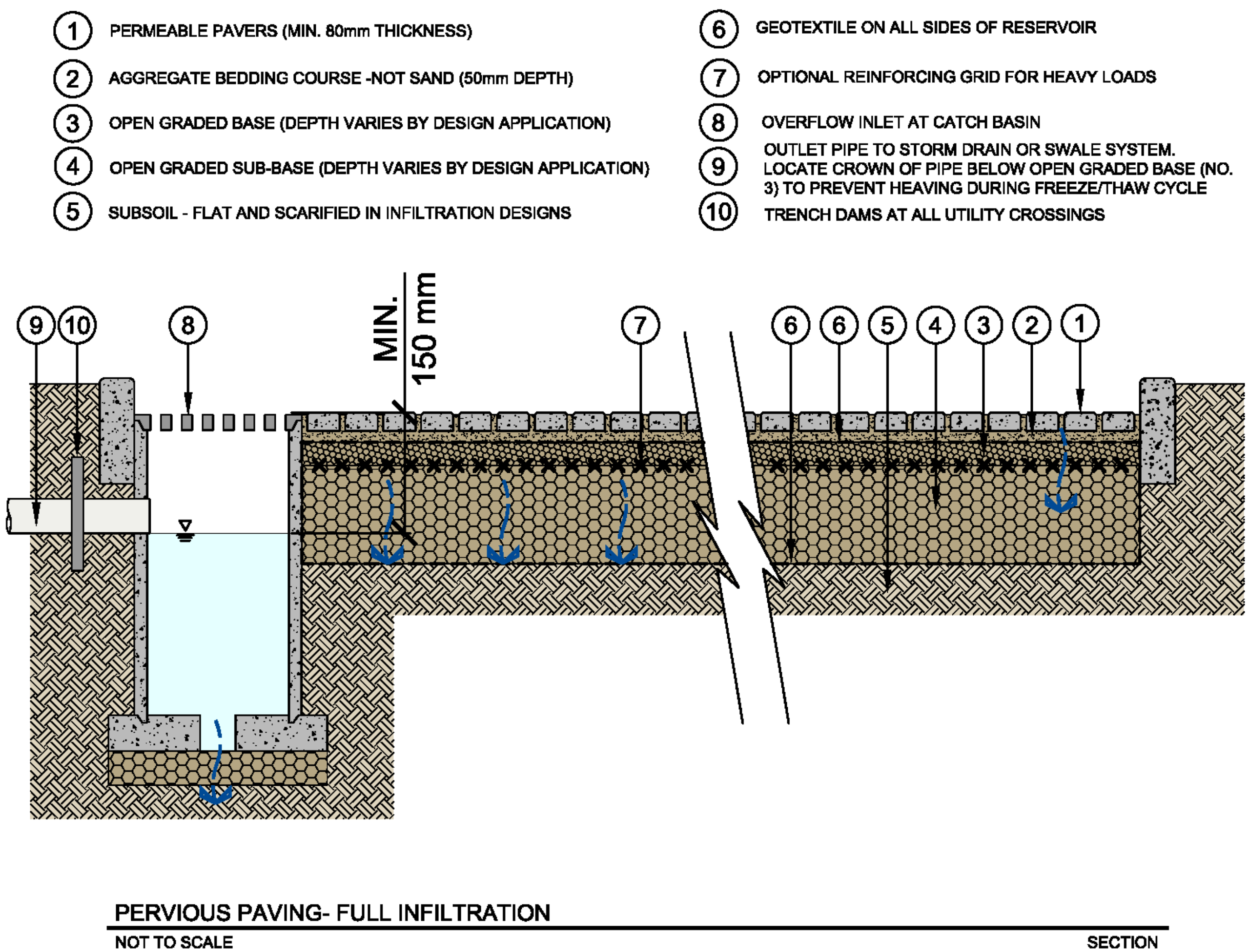


Figure 6 Pervious Paving – Full Infiltration (Not to scale, Section)

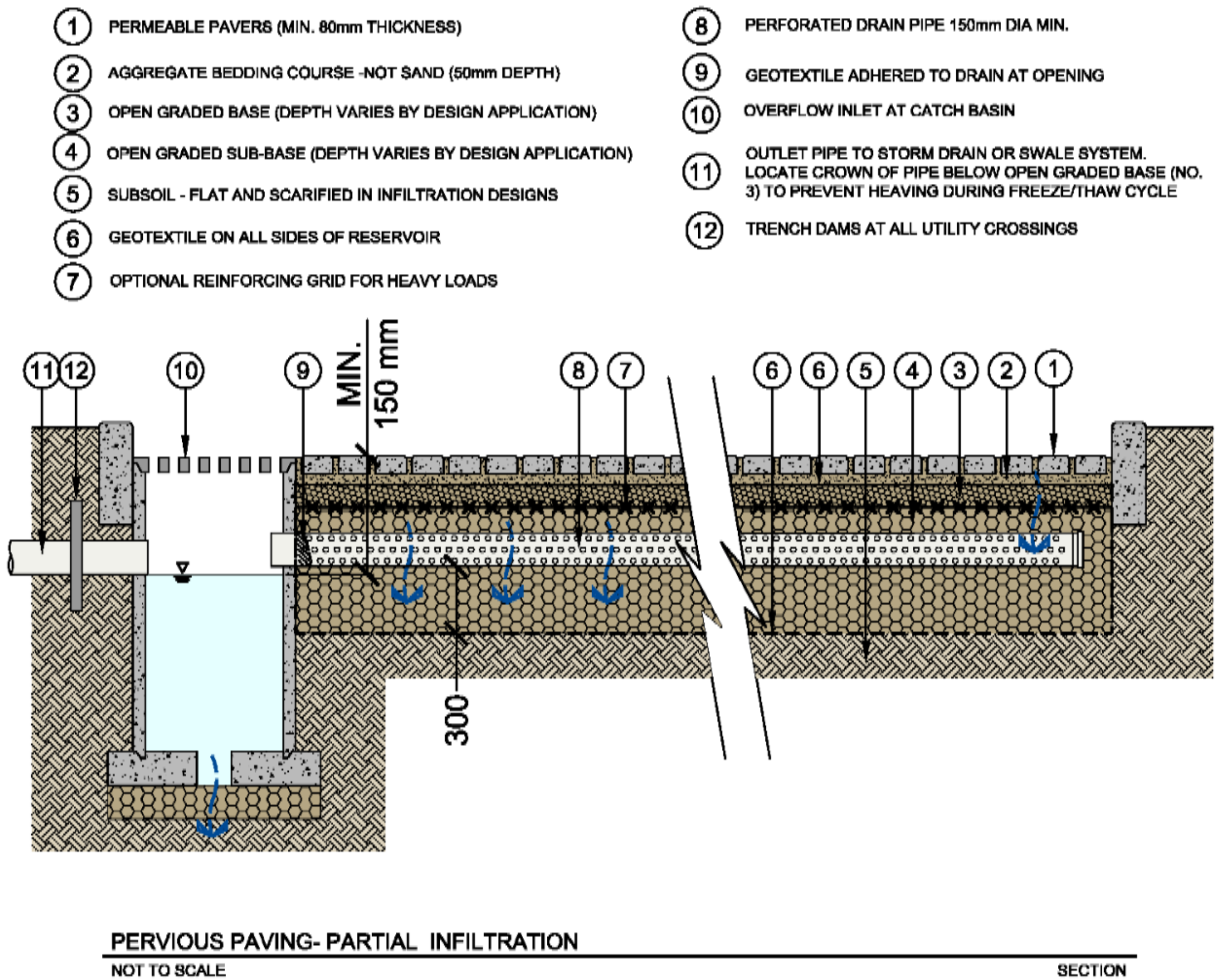
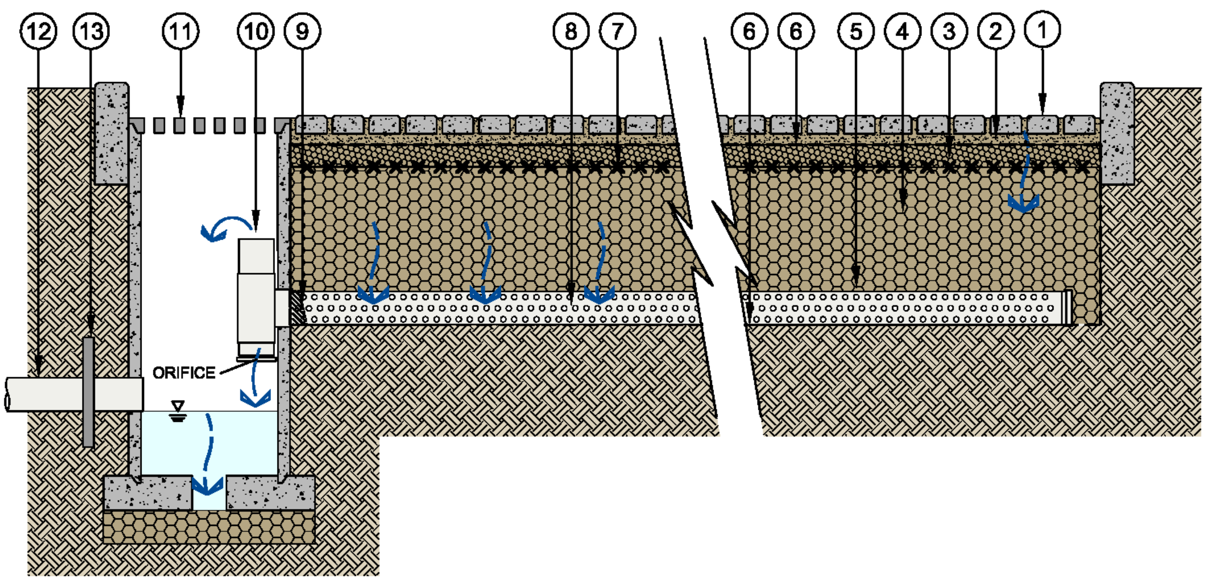


Figure 7 Pervious Paving – Partial Infiltration (Not to scale, Section)

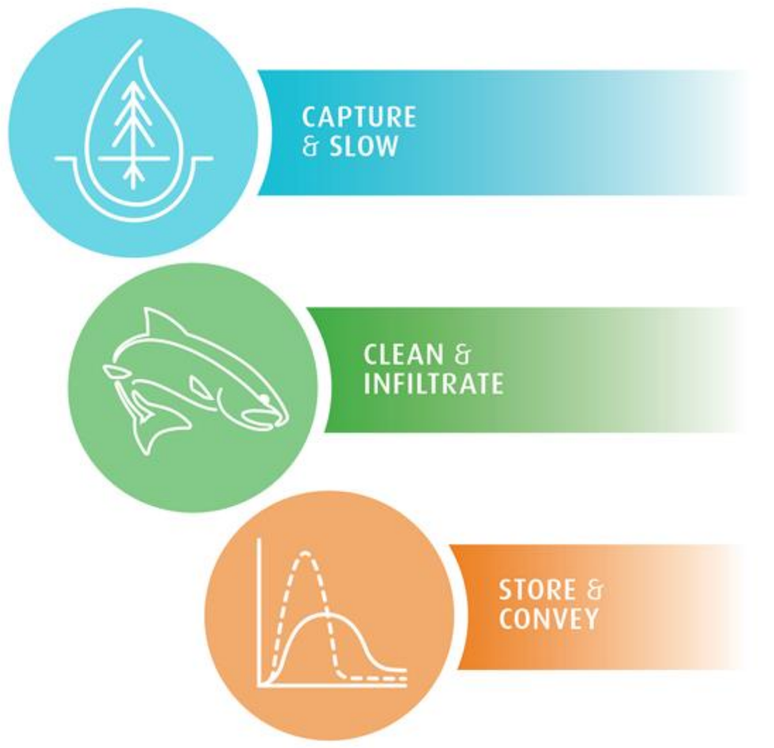
1. PERMEABLE PAVERS (MIN. 80mm THICKNESS)
2. AGGREGATE BEDDING COURSE -NOT SAND (50mm DEPTH)
3. OPEN GRADED BASE (DEPTH VARIES BY DESIGN APPLICATION)
4. OPEN GRADED SUB-BASE (DEPTH VARIES BY DESIGN APPLICATION)
5. SUBSOIL - FLAT AND SCARIFIED IN INFILTRATION DESIGNS
6. GEOTEXTILE ON ALL SIDES OF RESERVOIR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



PERVIOUS PAVING- PARTIAL INFILTRATION WITH FLOW RESTRICTOR

NOT TO SCALE SECTION

Figure 8 Pervious Paving – Partial Infiltration with Flow Restrictor (Not to Scale, Section)



APPENDIX L – INFILTRATION TRENCH & SOAKAWAY MANHOLE

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Infiltration Trench & Soakaway Manhole[1]

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. Other common terms used are rock trench or rock pit.

A soakaway manhole system includes an inlet pipe, a sedimentation manhole, and 1 or more soakaway manholes with connecting pipes.

Other common terms used are infiltration sump, dry well, or infiltration shaft.

Figure 1 Infiltration facility at University of Victoria

These GSI facilities allow the runoff to infiltrate into the native soil. They typically service individual lots and receive only roof and walk-way runoff. They are typically designed for a frequent, small storm such as a 1-yr event. These GSI facilities have limited capabilities for controlling the peak discharge from storms greater than the design storm. They are best used in conjunction with other GSI facilities to manage the peak discharges of runoff. Performance of these GSI facilities are based on the available soil infiltration capabilities at the site in question. These GSI facilities are suitable for small sites (area <2 acres).

Selection and 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 the structural design of the pavement is appropriate for this use.
- 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).
- In order to protect the groundwater they are not suited for parking and heavy traffic roadway runoff unless installed in conjunction with water quality pre-treatment designed to remove hydrocarbons and heavy metals.

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

- An infiltration trench does not itself provide treatment; for any situation where treatment is necessary, such as runoff from vehicle-accessible surfaces, an infiltration rain garden should be considered.
- Provision of underground overflow allows use of the technique in most soils, including clay with infiltration rates as low as 0.6 mm/hr.
- Due to the low infiltration rates and high rainfall common across the CRD, an infiltration trench will generally be more space-efficient for meeting volume capture targets for development. For small impervious areas, a soakaway manhole may be more appropriate.
- Soakaway manholes do not provide a large benefit, so are often used in conjunction with other GSI facilities.
- It is recommended to follow minimum setback requirements per the municipality/provincial guidelines to avoid slope failure issues, damage to the nearest structure and possibility of polluting the existing water wells, etc. If steep slopes or drinking water wells exist within 200 m 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 60 m from the tops of slopes more than 3 m high and steeper than 2h:1v. Setbacks to drinking water wells should at least equal the BC Ministry of Health minimum setback from well to septic field (30 m at time of writing).

Table 1 Infiltration Trench & Soakaway Manhole Setbacks

Consideration for Setbacks From	***Distance (m)**
Up-gradient of building foundations	Site dependent, 3 m minimum
Property Line	Site dependent, 1.2 m minimum
Drinking Water Well	Site dependent, 30 m minimum
Up-gradient of septic field	Site dependent
Seasonal High Water Table	Site dependent
Up-gradient Active of inactive landfill or contaminated site	Site dependent
Up-gradient of steep (>15%) slope	Site dependent, 200 m minimum

*or as directed by a Qualified Professional

Design Guidelines

Infiltration Trench System:

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. 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 occurring 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. This type of design is generally not needed if only upstream paved area is discharged to pervious paving at a ratio of 2:1 or less, but could be used if roof water is discharged to permeable paving at more than 2:1 I/P ratio.

5. Locate infiltration trench at least 3 m from any building, 1.2 m from property lines, and 6 m from adjacent infiltration facilities (or as recommended by local bylaws or a geotechnical engineer).
6. If any surface water is to enter the system, provide pre-treatment and upstream erosion control to avoid sedimentation in the infiltration trench. Provide non-erodible material and sediment cleanout basins at point-source inlets.
7. To avoid groundwater pollution, do not direct un-treated polluted runoff to infiltration trench or soakaway manhole:
   - Direct clean runoff (roof, non-vehicle paving) to infiltration trench or soakaway manhole.
   - For polluted runoff (roads, parking areas, other pollution sources), provide upstream source control (rain garden or infiltration swale) for pollutant reduction prior to release to infiltration trench or soakaway manhole.
8. Identify pollutant sources other than vehicles, particularly in industrial/commercial hotspots, that require pre-treatment or source control upstream of this GSI facility.
9. Sump: A 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. Weep holes may be included to dewater the sump, for mosquito management.
10. Perforated distribution pipe and bottom of drain rock to be installed level. If more than 1 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.
11. Separation from base of drain rock reservoir to water table should be a minimum of 600 mm.
12. Infiltration trench bottom width is not restricted to but is generally between 600 mm and 2,400 mm.
13. A minimum drainage time of 6 hrs should be provided to ensure satisfactory pollutant removal. The trench should drain prior to the next storm event. The drainage time will depend on the average time between storm events.
14. Install the infiltration trench in native ground, and avoid over-compaction of the trench sides and bottom, which reduces infiltration. Base of trench should be scarified to a minimum of 150 mm prior to installation of the rock reservoir material.
15. Observation well for each infiltration trench (optional, but recommended to allow monitoring of water depth in the reservoir): vertical standpipe, with perforated sides, and locking lid.

16. A bypass or overflow must be included in the facility design to accommodate flows in excess of the design infiltration volume.
17. 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.
18. A typical infiltration trench has a simple overflow to the storm system. In areas where native soil infiltration is poor, a partial-infiltration rock trench may be used to achieve increased capture of runoff. This design will separate the perforated inflow pipe and perforated outflow pipe such that a layer of storage is rock is provided between the inflow and outflow elevations. The outflow pipe will connect to a control structure in a catch basin that provides overflow while maintaining a slow decanting of the water in the rock trench between storms.

Soakaway Manhole System:

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. 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 600 mm above the seasonal high water table or bedrock, or as recommended by the engineer.
4. Provide a sedimentation manhole, and a maximum of 2 soakaway manholes in series, unless otherwise approved. Minimum distance between soakaway manholes shall be 8 m.
5. Provide an overflow from soakaway manhole to the storm drainage system or major storm flow path.
6. Size the soakaway manhole system by continuous flow modelling.

Infiltration Trench Sizing

Sizing methods are presented here for the infiltration trench, but not the soakaway manhole.

In this guide, a simplified sizing approach has been developed that does not require water balance modelling or continuous simulation.

1. For this approach, the infiltration trench is assumed to be a rectilinear underground facility defined by a base area which is the same as the footprint, and a depth of rock in the trench. Depth of cover over the rock trench is not considered or accounted for.
2. In general, the infiltration trench is sized based on the upstream impervious area that it serves. Similar to the rain garden, this relationship can be defined by the ratio of impervious area to pervious area (e.g., I/P ratio). For the simplified sizing approaches here, this represents the ratio of upstream impervious area (also called catchment area) to base area (bottom area) of the infiltration trench. I/P ratio to achieve the target capture criteria will be calculated by the 2 sizing methods below.

3. Sizing presented here is for infiltration of rainwater for "capture" and prevention of site runoff. No sizing and design is provided for any required pre-treatment facility.

Sizing for Depth Capture Criteria: R mm in 24 hrs

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area-specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine the maximum rock depth according to the drain time (4 days max.) and round down to the nearest 50 mm increment for constructability; standard depth range used in this sizing guidance is 300 mm to 2,000 mm:

$$D_R = \frac{Ks \times T \times 24}{n}$$

Where:
D_R = Depth (thickness) of rock in trench (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
T = allowable drain time (days)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

2. Use the following equation to determine the base (bottom) area of rock trench required by finding the I/P ratio for the site:

$$I / P = \frac{24 \times Ks + D_R \times n}{R} - 1$$

Where:
I/P = Ratio of impervious tributary area to rock trench base area (unitless)
R = Rainfall capture depth (mm)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_R = Depth (thickness) of rock reservoir (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

3. To find the rock trench base area:

$$BaseArea = \frac{\text{Impervious Tributary Area}}{I / P}$$

4. If the site cannot accommodate the I/P ratio required to provide the target capture, a partial-infiltration rock trench with flow restrictor design may be used.

5. A 0.25 L/s/ha (or 0.09 mm/hr) unit discharge may be recommended for the flow restrictor at the downstream end of the swale underdrain.

6. Calculate the allowable discharge through the orifice:

$$Q = \frac{0.25 \times A_{SITE}}{1000}$$

Where:
Q = Allowable discharge through orifice (m^3/s)
0.25 = Recommended unit discharge (L/s/ha)
A_{SITE} = Total site area draining to the swale, including the swale area (ha)

7. Solving the orifice equation for area of the orifice (A_0):

$$A_O = \frac{Q_O}{K \times \sqrt{2g\Delta h}}$$

Where:
Q_O = Theoretical discharge through infiltration from the impervious area that will be discharged via orifice (m^3/s)
K = Orifice Coefficient (typical value 0.6)
g = gravitational constant
h = differential head equivalent to depth of the perforated drain pipe in the rock trench (typical value 0.3 m)
A_O = Area of the orifice opening (m^2) – generally assumed to be circular for calculation of orifice diameter.

8. The size of the swale is then determined by the available area on the site.

$$I/P = \frac{\text{Impervious } TributaryArea}{BaseArea}$$

9. The depth of the rock reservoir above the orifice outlet is calculated as:

$$D_R = \frac{R \times (I/P+1) - 0.09mm/hr \times 24hrs \times (I/P+1) - 24 \times Ks - 0.2 \times D_S}{n}$$

Where:
D_R = Depth (thickness) of rock reservoir (mm)
R = Rainfall capture depth (mm)
I/P = Ratio of impervious tributary area to swale base area (unitless)
0.09 = Recommended unit discharge through orifice (mm/hr)
Ks = Saturated hydraulic conductivity of subsurface soil (mm/hr), as measured during winter saturated soil conditions
D_S = Soil layer depth (thickness); standard value = 300 (mm)
n = porosity of drain rock in reservoir (unitless, e.g., 0.35)

An orifice of no less than 10 mm is recommended to minimize clogging. A 10-mm orifice is the size required for a 0.46-ha tributary area. If the calculated orifice size is less than 10 mm, a regional capture facility servicing at least a 0.46-ha tributary area should be considered.

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements, **and**:

1. Infiltration Drain Rock: clean round stone or crushed rock, with a porosity of 35 to 40 % such as 75 mm max, 38 mm min, or MMCD Section 31 05 17 Part 2.6 – Drain Rock, Coarse.
2. Pipe: PVC, DR 35, 100 mm min. dia. with cleanouts certified to CSA B182.1, as per MMCD.
3. Geosynthetics: as per MMCD Section 31 32 19, select for filter criteria or from approved local government product lists.
4. Sand: Pit run sand, as per MMCD Section 31 05 17.
5. Growing Medium or Bioretention Soil Medium (see Table 2) over trench: As per MMCD Section 32 91 21 Topsoil and Finish Grading.
6. Seeding: conform to MMCD Section 32 92 20 Seeding or 32 92 19 Hydraulic Seeding (Note: sodding will be required for erosion control in most instances).
7. Sodding: to MMCD Section 31 92 23 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 1,200 mm of the cone (top section).

Construction Practices shall meet Master Municipal Construction Document 2009 (MMCD) 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 300 mm of material over the final subgrade until after all sediment-producing construction in the drainage area has been completed.
2. Prevent natural or fill soils from intermixing with the infiltration drain rock. All contaminated stone aggregate must be removed and replaced.
3. Infiltration drain rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
4. Provide a min. of 150 mm of 25 mm or 19 mm clean crushed rock under all pipes.

Table 2 Absorbent Landscape Bioretention Soil Mix (BMS)[2]

	Absorbent landscape Lawn BMS	**Absorbent Landscape Vegetated BMS**
Minimum Total Depth	300 mm	450 mm
Minimum required saturated hydraulic conductivity	70 mm/hr.	
Component (Partial size classes)	Percentage by Dry Weight	
Gravel (greater than 2.5 mm)	0	0
Sand (greater than 0.05 mm and less than 2.5 mm) • Sand to be hard, granular sharp sand well washed and free of impurities, chemicals or organic matter. • Particle size in sand to be: a) 90-100% passing a 2.50 mm sieve, b) 0-65% passing a 0.500 mm sieve, c) 0-5% passing a 0.0500 mm sieve	65-80	50-70
Silt (greater than 0.002 mm and less than 0.05 mm)	5-10	5-10
Clay (less than 0.002 mm)	2-5	2-5
Organic Content (% dry weight) – ensure weed free • must be well aged organics weed free, preferably manure free and biosolid free.	5-20	15-20
Other Soil Considerations		
• **pH** of mixed materials between 6-8.5 • **Safe Soils:** The spread and proliferation of invasive species through many regions of the province comes from the re-distribution of invasive species laden soils. In 2016, a Soils and Invasive Species Sub-Working Group was developed to explore province-wide solutions regarding the movement of soil and related materials that may contain invasive species. This Sub-Working Group involves provincial and local government representation. Learn more: Provincial Response to the Resolutions of the 2016 Union of British Columbia Municipalities Convention FEBRUARY 2017 B113 SAFE SOILS PROGRAM (page 111) http://www.ubcm.ca/assets/Resolutions~and~Policy/Resolutions/Provincial_Responses-2016_UBCM_Resolutions.pdf		

[2] Source: Absorbent Landscape, Stormwater Best Management Practices, District of Saanich
http://www.saanich.ca/assets/Community/Documents/Absorbent%20Landscape.pdf

Infiltration Trench Design Example for Capture of R mm/24-hr Criteria

Scenario Description

A partial infiltration trench is proposed to capture a portion of the runoff from a building roof (see illustration below).

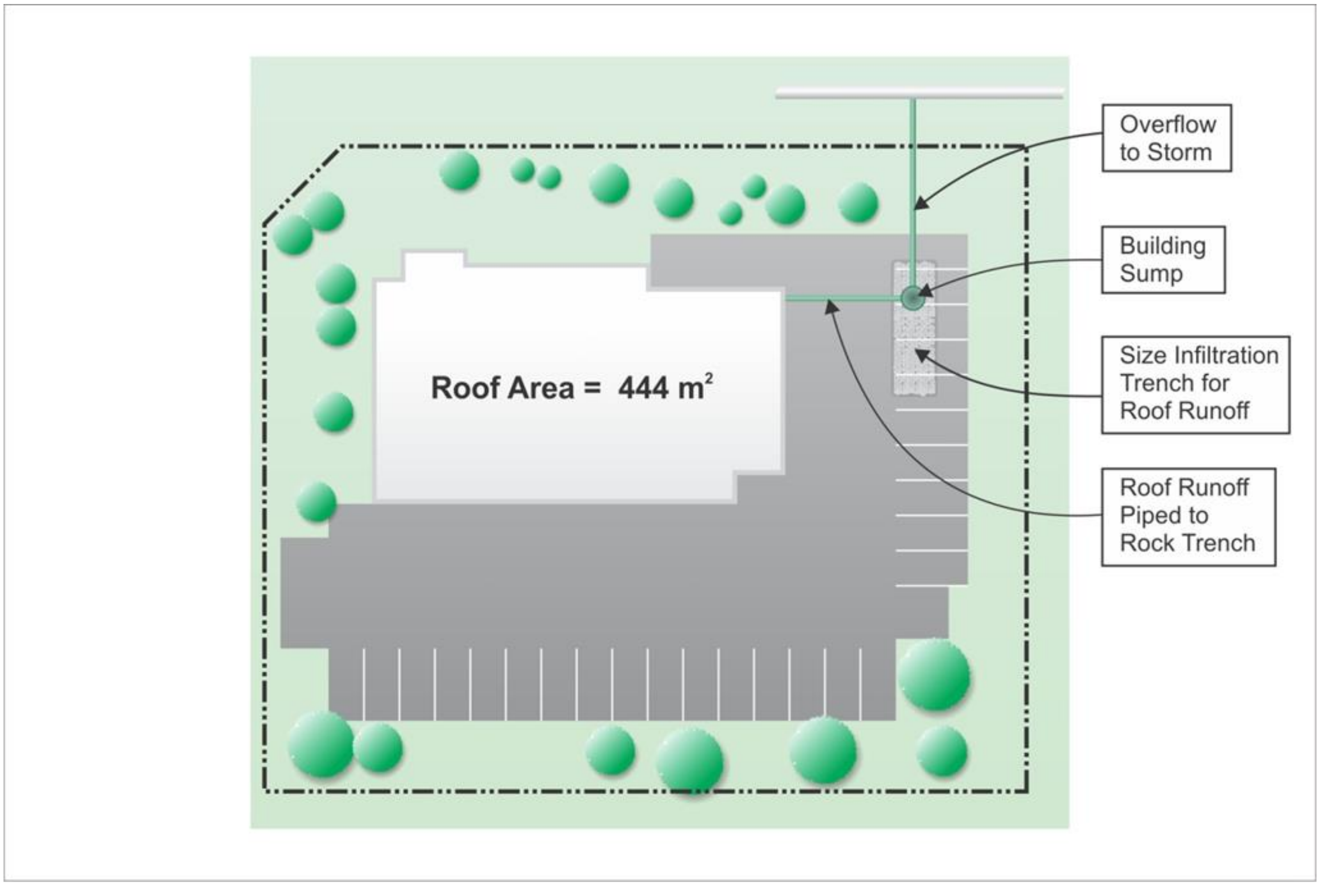


Figure 2 Example – Roof Area Draining to Infiltration Trench

The following parameters are known:

- Roof area = 444 m^2
- 2-year 24-hour rain depth = 53 mm
- Native soil infiltration rate = 5 mm/hr
- Drain time = 4 days
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine the infiltration trench footprint area, and rock depth and volume below the overflow level.

Sizing

The maximum rock depth for a 4-day drain time is computed using:

$$D_R = \frac{Ks \times T \times 24}{n} = \frac{5mm/hr \times 4days \times 24hr/day}{0.35} = 1{,}400 \text{ mm}$$

Therefore, a 1.4 m deep trench is required to meet the capture target.

The I/P ratio for the site is computed using:

$$I/P = \frac{24 \times Ks + D_R \times n}{R} - 1 =$$

$$\frac{(24hr/day \times 5mm/hr) + (1400\,mm \times 0.35)}{38mm} - 1 = 15$$

To find the rock trench base area:

$$BaseArea = \frac{\text{Impervious Tributary Area}}{I/P} =$$

$$\frac{444 \text{ m2}}{15} = 29.6 \text{ m}^2$$

The rock volume below the overflow elevation is 41 m^3 (29.6 m^2 x 1.4 m).

Hydraulic Components

- **Inlet**: Roof runoff is piped into the building sump. A perforated pipe or series of pipes convey the flow from the sump and distribute it throughout the infiltration trench.
- **Overflow**: The perforated pipes are located along the top of the infiltration trench rock layer. When the trench is full of water, the water level in the building sump reaches the invert of an overflow pipe which conveys excess water to the municipal storm sewer.

Operation and Maintenance Considerations

Infiltration trenches used for vehicle or pedestrian travelled areas require that a pre-treatment system be installed ahead of the infiltration trench to remove sediment and gross pollutants. This will maximize the longevity of the infiltration trench performance.

GSI Driver Effectiveness – Runoff Reduction and Contaminant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

An infiltration trench does not itself provide treatment of stormwater runoff, however, stormwater that is infiltrated and does not enter the storm drain system or receiving aquatic environments is removing all contaminants and provide a runoff volume reduction. Estimates of GSI facility effectiveness are shown in Table 3.

Table 3 Runoff Reduction and Contaminant Removal Summary Table

Infiltration Trench and Soakaway Manholes GSI Facilities	
GSI Driver	***Estimated Effectiveness or Typical % Reduction or Removal**
Capture & Slow – Volume Runoff Reduction	% infiltrated
Store & Convey – Rate Control Delay Peak	% infiltrated
Clean & Infiltrate – Water Quality Treatment	% infiltrated

Note: * Performance of individual GSI facilities will vary depending on site-specific contexts and facility design.

Maintenance

Effective long-term operation of an infiltration trench requires a consistent maintenance inspection schedule. The operation of the infiltration trench is dependent on the effectiveness of the pre-treatment, such as vegetated buffer strips and swales, at removing sediments. Therefore, most of the maintenance should be concentrated on these pre-treatment practices upstream of the trench. The following table lists inspection and maintenance activities for infiltration trenches.

INSPECTION ACTIVITIES	SCHEDULE
Inspect for proper functioning	After every major storm for the first few months to confirm design drain times
Inspect for pollutant contamination, standing water, trash and debris, sediment accumulation	Semi-annual and after extreme events
Inspect pre-treatment devices and diversion structures for damage and sediment accumulation	Semi-annual and after extreme events
MAINTENANCE ACTIVITY	**SCHEDULE**
Mow vegetated filter strips and remove clippings	As needed
Remove sediment, debris, and oil/grease from pre-treatment devices	As needed
Repair undercut and eroded areas and inflow and outflow structures	As needed
Remove trees and large vegetation form vicinity of the infiltration facility	Semi-annual
Replace drainrock/filter fabric	As needed when clogged

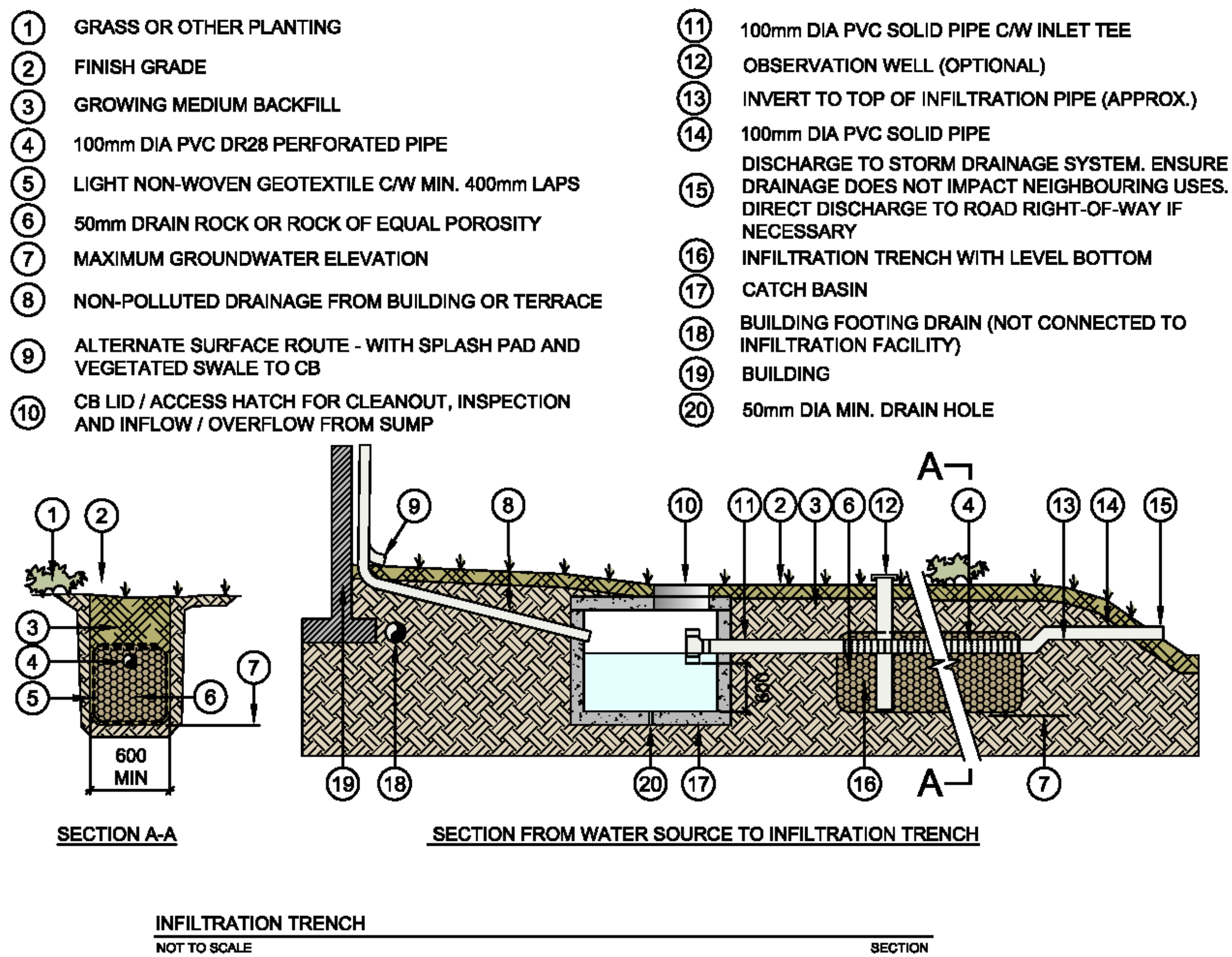


Figure 3 Infiltraiton Trench

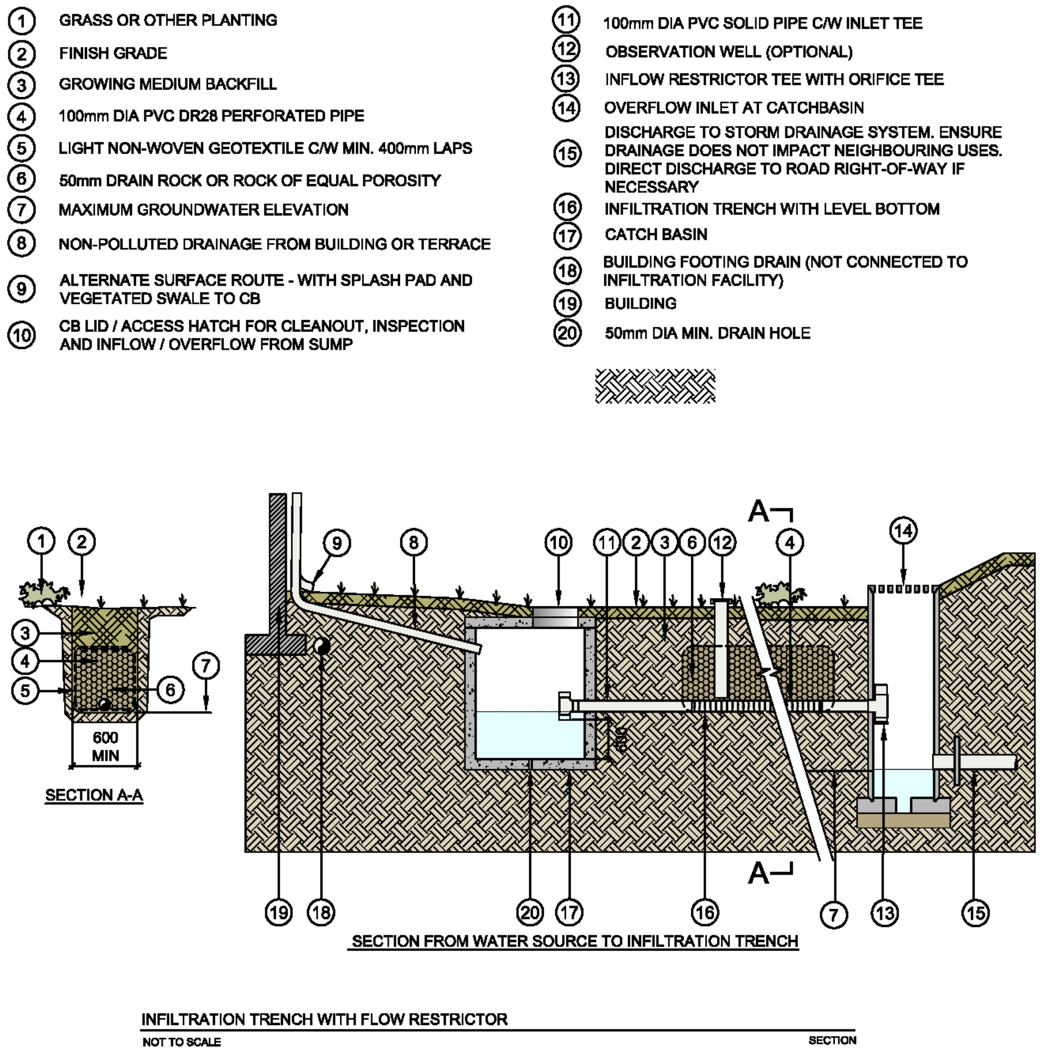


Figure 4 Infiltrtion Trench with Flow Restrictor

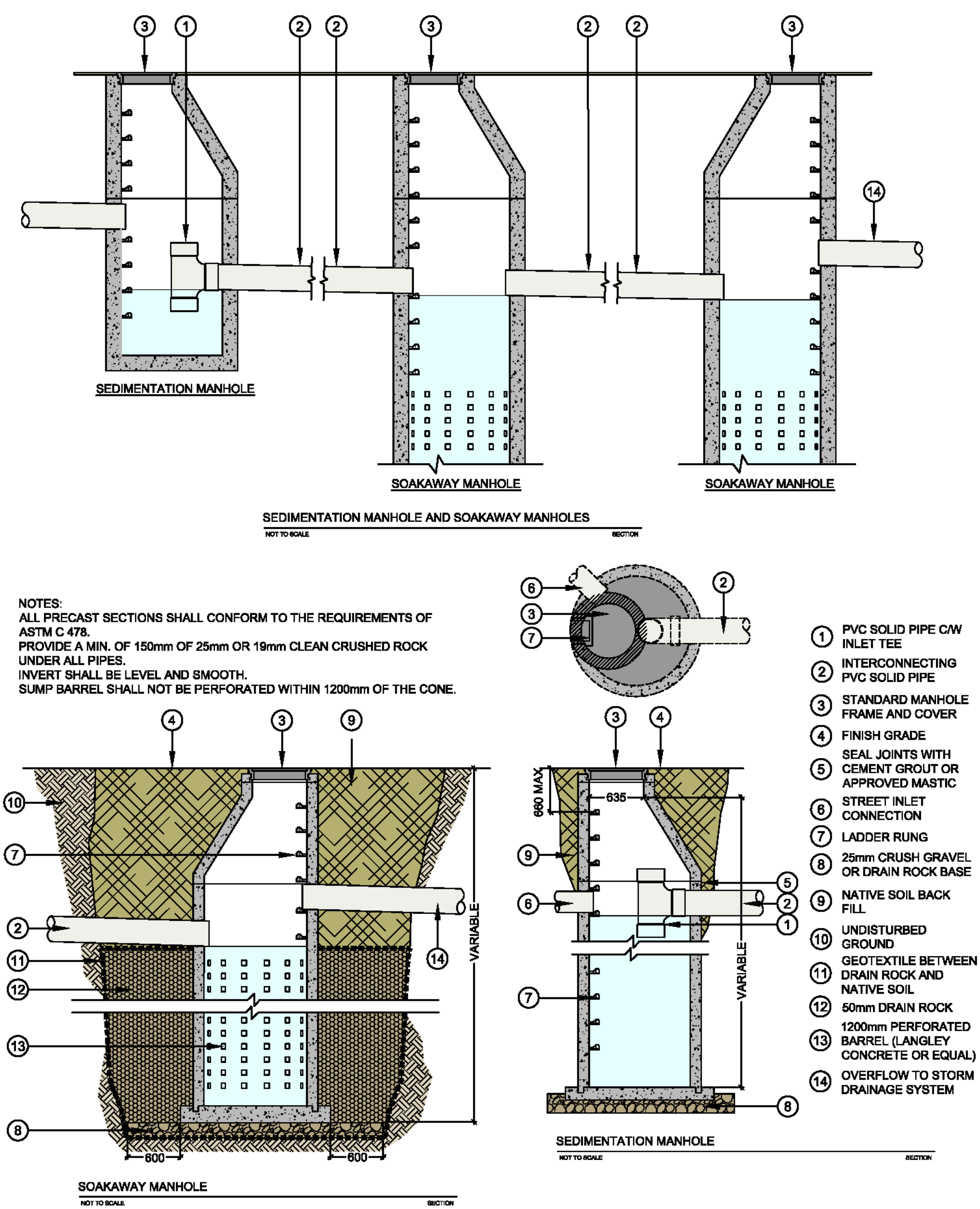
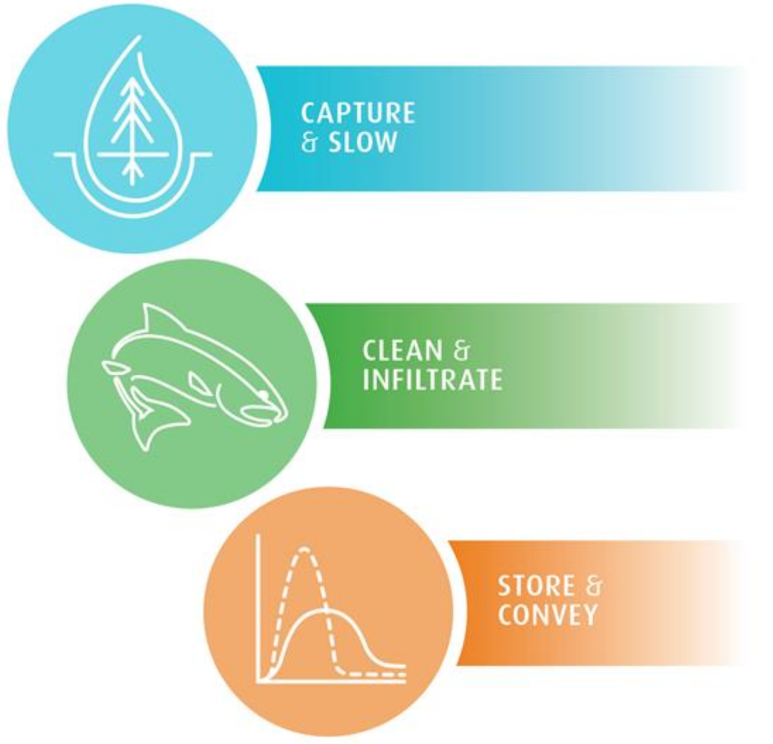


Figure 5 Sedimentation Manhole and Soakaway Manholes (Not to scale, Section)



SUPPLEMENTAL 1 – PLANTING TEMPLATES & PLANT LISTS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

SUPPLEMENTAL – PLANTING TEMPLATES & PLANT LISTS

This supplemental provides the following additional resources required for specific vegetated Green Stormwater Infrastructure (GSI) facilities of the design guidelines presented in this resource:

1. GSI planting templates
2. Candidate plants lists and planting details[1]

Note: Guidelines for Growing media or Bioretention Soil Medium (BSM) are contained in the respective appendix of each GSI facility type.

Generally, any good design is in line with the following principles:

1. Plants and trees should fit into the existing natural and built environment.
2. Utilize native species indigenous to southern Vancouver Island.
3. The use of a columnar variety of tree is recommended for urban streetscapes as they require less maintenance costs and have less interaction with neighbouring buildings, vehicle traffic and overhead wires.
4. Select plant species based upon an understanding of hardiness and habitat requirements, including soil type, soil chemistry, soil moisture, frequency of flooding and microclimatic conditions.
5. Design planting plans with an appropriate mix of trees and shrubs, as well as native perennials, wildflowers and aquatics.
6. Use GSI BSM or growing media as guidelines for proper soil composition to ensure good infiltration, removal of contaminants and support plant growth.

[1] Sources:
LID Manual for Puget Sound (2012) http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf
Washington (2014) https://fortress.wa.gov/ecy/publications/parts/1210030part6.pdf
Seattle Stormwater Manual (August 2017)
http://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/p3495552.pdf
2014 Stormwater Management Manual for Western Washington
https://static1.squarespace.com/static/528fd58de4b07735ce1807b2/t/55e4995ae4b0ae5c1abea514/1441044826151/Vol-V_GSI_OM_Manual+%26+Appendix_July+2015_for_web.pdf
Portland Stormwater Management Manual (2016)
https://www.portlandoregon.gov/bes/64040

Planting Templates

Absorbent Landscapes

As sites can vary greatly, a planting template is not provided for absorbent landscapes. Local resources such as The Garry Oak Gardener's Handbook, Habitat Ecosystem Recovery Team (2011)[2], provides a variety of landscaping plans appropriate for much of the Greater Victoria area. The below GSI Candidate Plant lists are generally appropriate for absorbent landscapes across the region. Other trees and plants will be appropriate on a biogeoclimatic zone or ecosystem site-specific basis.

Green Roofs

See below for Candidate Plant List - Green Roof, however, a planting template is not provided for Green Roofs, as they have more specific or complex patterns, it is advised to consult a professional.

Ponds and Constructed Wetlands

See below for Candidate Plant List – Ponds and Constructed Wetlands, however, planting template for ponds and constructed wetlands have more specific or complex patterns, thus planting templates are not provided for these facilities, however, suggested plantings is provided below, it is advised to consult a professional.

Rain gardens, swales and planters

Typically, these bioretention and infiltration GSI facilities' basins and swales can be divided into 1 to 3 planting zones. The 4th planting zone is applicable only in a Right-of-Way where sight clearance is required for safety and plants are required to remain under 60 cm to 1 m with minimal maintenance. Some plants are suitable in multiple zones, some are indicated in table below. Over time, well-established plants and trees will optimize the GSI facility runoff reduction and contaminant removal rates. Consult a qualified professional.

Zone 1: Bottom/lowest periodically ponded area of the bioretention and infiltration facilities. Plants should be tolerant of periodic or frequent standing or flowing stormwater inundation. Many plants in Zone 1 will also tolerate the seasonally dry periods of summer without irrigation. These plants will assist in water quality treatment.

Zone 2: Plants that are used for water quality in the lower sloped area of the bioretention and infiltration facilities. These soils are periodically moist or ponded/saturated during rains that are heavy or long in duration storms.

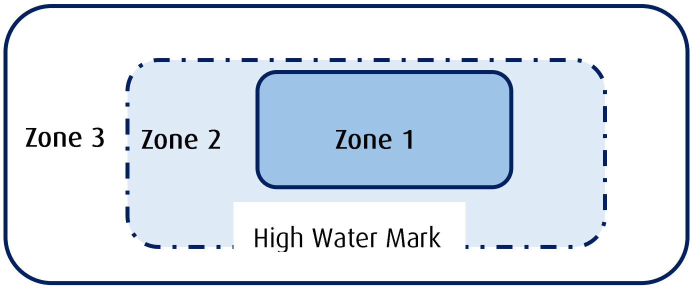
Zone 3: This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.

Note: Plantings that fall within the right-of-way areas that require sight clearance (i.e., street corners and driveway or parking lot ingress/exit). Recommended plantings are low growing, durable plants that mature height is under 60 cm to 1 m. Before planting, confirm maximum mature height and maintenance plan.

[2] http://www.goert.ca/gardeners_restoration/garryoak_gardener.php

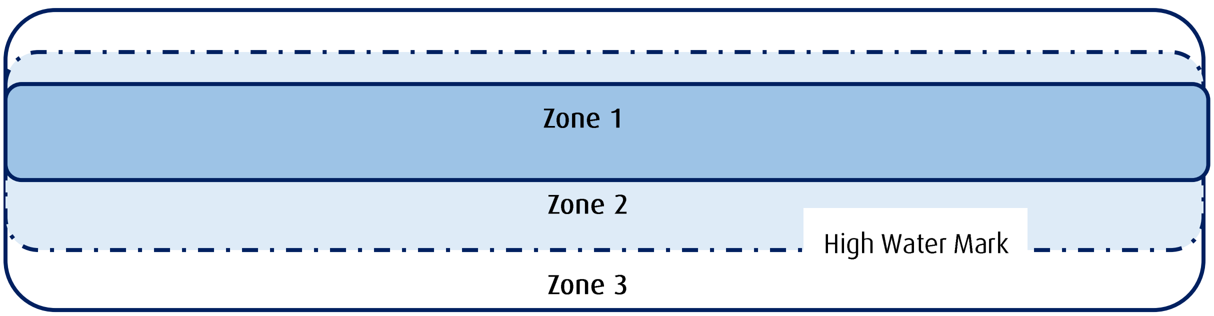
Planting Templates 1: Basins – Plan View Planting Zones for Bioretention and Infiltration Basins

i.e., rain gardens and curb bulges



Planting Templates 2: Swales – Plan View Planting Zones for Bioretention and Infiltration Swales

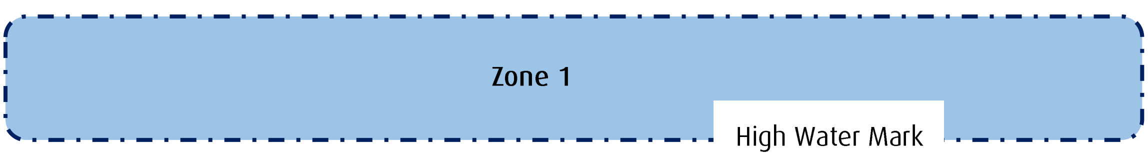
i.e., vegetated and grassy swales



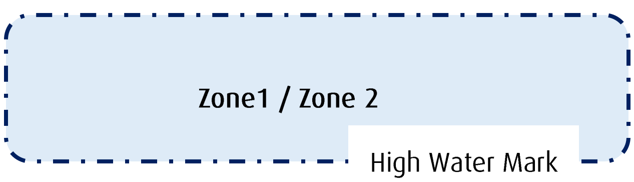
Planting Template 3: Planters – Plan View Planting Zone for Infiltration and Flow-Through Bioretention Planters

(A. typically below grade planter, and B. typically above grade planter)

A.



B.



Candidate Plant List and Details

Design plantings to respect the wet, moist or dry soil zones of the stormwater facilities. The plants listed in the following table are recommended for stormwater source control facilities[3]. Most plants listed are native.

Cautionary Notes:

- For information on invasive species see:
  Capital Regional Invasive Species Partnership (CRISP) http://crispinvasives.ca/
  Invasive Species Council of British Columbia (ISCBC) http://bcinvasives.ca/

Caution - Parrot's feather (*Myriophyllum aquaticum*) is an aquatic plant that is popular in recreational indoor fish tanks that can enter storm drainage system through incidental washing/rinsing/dumping into storm drain system. This plant has severely impacted several GSI facilities within the capital region and in the Lower Mainland. Routine maintenance of swales and constructed wetlands and ponds ought to include early detection and rapid response.

Learn more: http://bcinvasives.ca/invasive-species/identify/invasive-plants/parrots-feather

- Due to their invasive nature, the following sometimes commonly available species should not be utilized in GSI facilities or general landscaping:

Table 1 Commonly Available Plants That Should Not Be Utilized in GSI

Botanical Name	Common Name
Crataegus laevigata	English hawthorne
Hedera helix	all varieties English ivy
Buddleia	butterfly bush
Hypericum perforatum	St. John's-Wort
Iris pseudacorus	Yellow flag iris
Phalaris arundinacea	Reed canary grass
Polygonum cuspidatum	Japanese Knotweed
Daphne laureola	Spurge-laurel
Vinca minor	Periwinkle
Clematis vitalba	old man's beard
Ilex aquifolium	English holly
Prunus laurocerasus	English Laurel
Polygonum aubertii	silver lace vine

[3] Stormwater Source Control Design Guidelines, Metro Vancouver, 2012

Table 2 Zone 1 (Wet) Candidate Plant List for Vegetated GSI Facilities

The following table includes both native* and non-native plants commonly available and suitable for Bioretention and Infiltration GSI facilities suitable for planting in **Zone 1** in Rain Gardens, Swales and Planters.

Zone 1: Bottom - Wet Weather Inundation with Temporary Ponding
Bottom/lowest periodically ponded area of the bioretention and infiltration facilities. Plants should be tolerant of periodic or frequent standing or flowing stormwater inundation. Many plants in Zone 1 will also tolerate the seasonally dry periods of summer without irrigation. These plants will assist in water quality treatment.

Common Name	*Botanical Name*	Notes & Suitability	Also Zone
Emergents			
Slough sedge	*Carex obnupta**	Moist to seasonally saturated soils; shiny foliage; excellent soil binder; drought-tolerant; sun/partial shade; plant 15 cm apart or seed; spreads 30 cm to 1.5 m; good choices for swales with significant periods of flow, such as those downstream of a detention facility; plant 15 cm spread; height 60-122 cm+; can be sheared more frequently if overcrowding	2
Dense sedge	*Carex densa**	Wet soils; sun; plant as plugs; height 75 cm; urban frontage	2
Dewey's sedge	*Carex Deweyana**	Wet soils; sun/shade; limit to areas of approx. 90 x 90 cm, height 20-90 cm	2
Chamisso sedge	*Carex pachystachya**	Limit to areas of approx. 90 x 90 cm; plant as plugs; height 60-90 cm	2
Sawbeak or Beacked sedge	*Carex stipata**	Wet soils; excellent soil binder; partial shade; plant 15 cm spread; limit to areas of approx. 90 x 90 cm; height 60-90 cm; urban frontage	2
Tufted Hair Grass	*Deschampsia Caespitosa**	Limit to areas of approx. 90 x 90 cm; sun/shade; for neater appearance trim seed heads; height 60-100 cm	2
Common rush	Juncus effusus*	Wet soils; evergreen perennial; hardy and adaptable; drought-tolerant; small, non-showy flowers in summer; sun/partial shade	
Daggerleaf rush	*Juncus ensifolius**	Wet soils; shallow water; excellent soil binder	

Continued on next page

Zone 1: Bottom - Wet Weather Inundation with Temporary Ponding Bottom/lowest periodically ponded area of the bioretention and infiltration facilities. Plants should be tolerant of periodic or frequent standing or flowing stormwater inundation. Many plants in Zone 1 will also tolerate the seasonally dry periods of summer without irrigation. These plants will assist in water quality treatment.			
Common Name	***Botanical Name***	**Notes & Suitability**	**Also Zone**
Slender rush	*Juncus tenuis**	Moist soils; tufted perennial; sun; plant 15 cm spread or seed	
Watercress	*Rorippa nasturtium-aquaticum**	Spacing 30 cm; good choices for swales with significant periods of flow, such as those downstream of a detention facility; plant 30 cm spread	
Water parsley	*Oenanthe sarmentosa*	15 cm; good choices for swales with significant periods of flow, such as those downstream of a detention facility; plant 15 cm spread	
Hardstem bulrush	*Scirpus acutus**	Wet soils; favours prolonged inundation; excellent soil binder; sun; plant 15 cm spread	
Small-fruited bulrush	*Scirpus microcarpus**	Wet soils; tolerates prolonged inundation; good soil binder; drought tolerant; sun/shade; plant 30 cm spread	
Cattail (*Typha latifolia*) is <u>not appropriate</u> for most wet swales because of its very dense and clumping growth habit which prevents water from filtering through the clump.			
Shrubs			
Kelsey redstem dogwood	*Cornus sericea 'Kelseyii'**	Limit to areas of approx. 90 x 90 cm; sun/shade; stems fragile until established; dwarf version available; 60-75 cm; urban frontage zone	23
Black twinberry	*Lonicera involucrata**	Moist soils; prefers loamy soils; tolerant of shallow flooding; yellow, tubular flowers attract hummingbirds; partial shade/shade; spreads to 60 cm–2.40 m	
Pacific wax myrtle	*Myrica californica**	Evergreen shrub preferring moist soils; inconspicuous spring flowers; drought-tolerant; spreads to 9 m; sun/partial shade; if drought tolerance is not an issue try the smaller Washington native, *Myrica gale**	
Pacific ninebark	*Physocarpus capitatus**	Moist or dry soils; drought-tolerant; "snowball" shaped shrub; white flowers; seeds persist into winter; spreads to 4 m; sun/partial shade	
Clustered wild rose	*Rosa pisocarpa**	Moist soils, tolerates seasonal flooding but also tolerant of dry conditions; pink clustered flowers; fruits persist; sun/partial shade; spreads to 2.5 m	

Continued on next page

Zone 1: Bottom - Wet Weather Inundation with Temporary Ponding
Bottom/lowest periodically ponded area of the bioretention and infiltration facilities. Plants should be tolerant of periodic or frequent standing or flowing stormwater inundation. Many plants in Zone 1 will also tolerate the seasonally dry periods of summer without irrigation. These plants will assist in water quality treatment.

Common Name	*Botanical Name*	Notes & Suitability	Also Zone
Dwarf Artic willow	*Salix purpunea* 'Nana'	Grows well in poor soils; moderately drought-tolerant; small yellow flowers in the fall; sun/partial shade; spreads to 1.5 m	
Douglas spirea Steeplebush	*Spiraea douglasii**	Moist or dry, to seasonally inundated soils; spikes of small, pink flower clusters; sun/partial shade; spreads to 2 m	
Trees			
Red alder	*Alnus rubra**	Prefers moist, rich soils, highly adaptable, drought-tolerant; nitrogen fixer; rapid growing, relatively short lived (60-90 years); sun/partial shade; mature height = 9-35 m with canopy = 7 m	
Pacific willow	*Salix lucida**	Wet soils; tolerates seasonal flooding; should not be planted in areas near pavement or underground structures; sun; mature height = 12-18 m with canopy = 9 m	
Oregon ash	*Fraxinus latifolia**	Moist, saturated or ponded soils; flood tolerant; small green-white flowers; sun/partial shade; mature height = 12-24 m with canopy = 9 m	
Pacific crab apple	Malus fusca*	Tolerant of prolonged soil saturation; produces fruit (do not plant near public walkways); sun/partial shade; height to 12 m with canopy = 10 m	

Table 3 Zone 2 (Moist Sloped Sides) Candidate Plant List for Vegetated GSI Facilities

The following table includes both native* and non-native plants commonly available and suitable for Bioretention and Infiltration GSI facilities.

Zone 2: Sloped Sides – Wet Weather Inundation Plants that are used for water quality in the lower sloped area of the bioretention and infiltration facilities. These soils are periodically moist or ponded/saturated during rains that are heavy or long in duration storms			
Common Name	***Botanical Name***	**Notes**	**Also Zone**
Herbaceous			
Western columbine	*Aquilegia formosa**	Moist soils of varying quality; tolerant of seasonal flooding; red and yellow flowers attract hummingbirds and butterflies; sun/partial shade; spreads to 1 m, height 60-90 cm	3
Wild ginger	*Asarum caudatum**	Moist organic soils; heart-shaped leaves; reddish-brown flowers; partial shade/shade; spreads up to 25 cm	
Common California aster	*Aster chilensis**	Moist soils; white to purple flowers; sun; spreads to 1 m	
Douglas' aster	*Aster subspicatus**	Moist soils; blue to purple flowers; sun; spreads to 75 cm	
Common camas	*Camassia quamash**	Moist to dry soils; lots of watering needed to establish; loose clusters of deep blue flowers; sun/partial shade; spreads to 75 cm; height 60	
Giant camas	*Camassia leichtlinii*	Moist to dry soils; lots of watering to establish; large clusters of white, blue or greenish-yellow flowers; spreads to 1 m; height <60 cm	
Pacific coast iris	*Iris douglasiana**	Tolerates many soils; withstands summer drought and seasonal flooding; white, yellow, blue, reddish purple flowers; fast growing; velvety purple flowers; vigorous; sun/partial shade; spreads to 60 cm; height 60 cm; urban frontage	3
Gladwin iris	*Iris foetidissima*	Moist to dry, well-drained soils; pale lilac flower; also called Stinking Iris; sun/partial shade; spreads to 60 cm	
Slender rush	*Juncus tenuis**	Moist soils; yellow flowers; sun; spreads to 75 cm	
Siberian Iris	*Iris sibirca*	Moist soils; deep blue, purple to white flowers; sun; spreads to 75 cm	

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Zone 2: Sloped Sides – Wet Weather Inundation Plants that are used for water quality in the lower sloped area of the bioretention and infiltration facilities. These soils are periodically moist or ponded/saturated during rains that are heavy or long in duration storms			
Common Name	***Botanical Name***	**Notes**	**Also Zone**
Fringecup	*Tellima grandiflora**	Perennial preferring moist soils; yellowish-green to pink flowers; partial sun/shade; spreads 1 m	
Foamflower	*Tiarella trifoliata**	Moist soils; perennial with some drought tolerance after established; can form dense colonies; white flowers; partial sun/shade; spreads 60 cm	
Youth-on-age/ Piggyback plant	*Tolmiea menziesii**	Moist soils; brownish-purple flowers; also makes and effective ground cover; partial shade/shade; spreads 60 cm	
Violets	*Viola species**	Moist soils; yellow to blue flowers; partial shade/shade; spreads 15-30 cm	
		Deciduous Shrubs	
Vine maple	*Acer circinatum**	Dry to moist soils; tolerant of shade and clay soils; excellent soil binder; beautiful fall colour; filtered sun/shade; mature height 7 m	
Diane witchhazel	*Hamamelis Intermedia Diane*	Moist, fertile, acidic soil; showy fall colour – yellow to yellow-orange; long lasting, slightly fragrant, coppery-red flowers; not drought-tolerant; may require watering in dry season; sun/partial shade; mature height 6 m with 25 cm spread	
Indian plum	*Oemleria cerasiformis**	Moist to dry soils; prefers shade; tolerates fluctuating water table; sun/partial shade; mature height 4 m	
Mock-orange	*Philadelphus x lemoinei 'Belle Etoile'*	Prefers moist, well-drained soils, high in organic matter, but soil and pH adaptable; easily transplanted and established; fragrant, large white flowers, tinged red at the base; other cultivars available; sun/partial shade; 2 m	
Black swamp gooseberry	*Ribes lacustre**	Moist soils; deciduous shrub; reddish flowers in drooping clusters; dark purple berries; R. divaricatum* (Wild gooseberry) grows to 1.5 m and is also an option; attracts butterflies, but is very thorny; partial shade; mature height 1 m	
Nootka rose	*Rosa nutkana**	Moist to fairly dry soils; tolerates inundation and saturated soils; aggressive spreader; fruits persist; less thorny that R. rugose; sun/partial shade; mature height 3 m	

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Zone 2: Sloped Sides – Wet Weather Inundation
Plants that are used for water quality in the lower sloped area of the bioretention and infiltration facilities. These soils are periodically moist or ponded/saturated during rains that are heavy or long in duration storms

Common Name	*Botanical Name*	Notes	Also Zone
Rose (mixed varieties)	*Rosa rugosa*	Drought resistant; hardy, vigorous and aggressive; highly prickly; fragrant white to purple flowers; fruits persist; sun; mature height up to 2.5 m	
Thimbleberry	*Rubus parviflorus**	Moist to dry soils; white flowers; red berries; makes thickets and spreads easily; partial sun/shade; mature height 1.5-3 m	
Salmonberry	*Rubus spectabilis**	Prefers moist, wet soils; good soil binder; magenta flowers; yellow/orange fruit; early nectar source for hummingbirds; makes thickets; partial sun/shade; mature height 1.5-3 m	
Red elderberry	*Sambucus racemosa**	Moist to dry soils; small white flowers; bright red berries; vase shaped; pithy stems lead to "messy" form – prune for tidiness; partial sun/partial shade; mature height up to 6 m	
Snowberry	*Symphoricarpos albus**	Wet to dry soils, clay to sand; excellent soil binder; drought and urban air tolerant; provides good erosion control; spreads well in sun; white berries; flowers attract hummingbirds; sun/partial shade; mature height 0.5-2 m	
Red huckleberry	*Vaccinium parvifolium**	Slightly moist to dry soils; prefers loamy, acid soils or rotting wood; tolerant of dry, shaded conditions; red fruit; tricky to transplant; partial shade/shade; mature height 1-3 m	
Deciduous Trees			
Pacific sunset maple	*Acer truncatum*	Prefers moist, well-drained soils, but drought-tolerant; very cold hardy; deciduous tree with moderate growth rate; sun; mature height up to 7.5 m with 6 m canopy	
Western serviceberry	*Amelanchier alnifolia**	Moist to dry, well-drained soils; drought-tolerant; large white flowers; purple to black berries; deciduous; sun/partial shade; mature height 3-6 m with 7 m spread	
Beaked hazelnut	*Corylus cornuta**	Moist, well-drained soils; edible nuts; intolerant of saturated soils; catkins throughout winter add interest; deciduous; sun/partial shade; mature height 6-9 m with 7 m spread	

Continued on next page

Zone 2: Sloped Sides – Wet Weather Inundation
Plants that are used for water quality in the lower sloped area of the bioretention and infiltration facilities. These soils are periodically moist or ponded/saturated during rains that are heavy or long in duration storms

Common Name	*Botanical Name*	Notes	Also Zone
Black hawthorn	*Crataegus douglasii**	Moist to dry, well drained, gravelly soils; small white flowers, black berries; 1" spines; forms thickets; deciduous; sun/partial shade; mature height 2-9 m with up to 7 m canopy	
Raywood ash	*Fraxinus oxycarpa*	Drought-tolerant; grows in varying soil types; deciduous; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than do non-native ashes; inconspicuous flowers; sun; mature height 7-14 m with up to 7 m canopy	
Cascara sagrada	*Rhamnus purshiana**	Moist to fairly dry soils; small greenish-yellow flowers; deciduous; sensitive to air pollution; yellow fall colour; sun/partial shade; mature height 2-7 m; 7 m spread	
Sitka willow	*Salix sitchensis**	Moist soils; tolerates seasonal flooding; deciduous tree; do not plant near paved surfaces or underground structures; partial shade/shade; mature height 6-30 m + with up to 18 m canopy	

Table 4 Zone 3 (Upper Dry Flat Edge) Candidate Plant List for Vegetated GSI Facilities

The following table includes both native* and non-native plants commonly available and suitable for Bioretention and Infiltration GSI facilities.

Zone 3: Dry upper slope / top flat ground This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.		
Common Name	***Botanical Name***	**Notes**
Evergreen Groundcover		
Kinnikinnick	*Arctostaphylos vaursi**	Prefers sandy/rocky, well-drained soils; flowers pinkish-white; bright red berries; slow to establish; plant closely for good results; sun/partial shade; spreads up to 25 cm, height <60 cm; urban frontage
Wild/Coastal strawberry	*Fragaria chiloensis**	Sandy well drained soils; flowers white; small hairy strawberries; evergreen; aggressive spreader; sun/partial shade; spreads up to 25 cm
Sunrose	*Helianthemum nummularium*	Prefers moist, well-drained soils, but will tolerate various soils; low growing, woody perennial; many varieties are available with flowers in salmon, pink, red, yellow and golden colours; sun; spreads to 60 cm with 60 cm height
Lavender	*Lavandula angustifolia*	Adaptable to various soils; blue, lavender, pink to white flowers, semi-evergreen aromatic perennial; sun/partial shade; spreads to 50 cm
Creeping mahonia	*Mahonia repens*	Dry to moist soils; drought resistant; yellow flowers; blue berries; native of Eastern Washington; sun/partial shade; spreads up to 1 m
Davidson's penstemon	*Penstemon davidsonii**	Low growing evergreen perennial; prefers well-drained soils; drought tolerant; blue to purple flowers; sun; spreads up to 1 m
Perennials and Ornamental Grasses		
Western yarrow	*Achillea millefolium**	Dry to moist, well-drained soils; white to pink/reddish flowers; many other yarrows are also available; sun; spreads to 75 cm
Pearly verlasting	*Anaphalis margaritaceae*	Drought-tolerant perennial; spreads quickly; attracts butterflies; sun/partial shade; spreads to 45 cm
Native California brome	*Bromus carinatus**	Dry to moist soils; tolerates seasonal saturation; sun/partial shade; spreads up to 1.5 m

Continued on next page

Zone 3: Dry upper slope / top flat ground
This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.

Common Name	*Botanical Name*	Notes
Great Camus or Common Camus	*Camus leichtlinii** or *Camus quamash**	Plant for in groups for effect. Can be planted as a bulb; sun and shade; height 60–90 cm
Leather leaf edge	*Carex buchanaii*	Prefers moist, well-drained soils; copper-coloured foliage; perennial clumping grass; tolerant of a wide range of soils; inconspicuous flowers; sun/partial shade; spreads to 1 m
'Frosty curls' New Zealand hair sedge	*Carex comans*	Prefers moist soils; finely textured and light green; compact, clumping perennial grass; drought-tolerant when established; inconspicuous flowers; sun/partial shade; spreads up to 60 cm
Purple oneflower	*Echinacea purpurea*	Prefers well drained soils; hardy perennial; may need watering in dry months; sun; spreads up to 1.5 m
Blue wildrye	*Elymus glaucus**	Dry to moist soils; shade tolerant; rapid developing, but short lived (1-3 years); not good lawn grass; sun/partial shade; spreads to 1.5 m
Subalpine fleabane daisy	*Erigeron peregrinus*	Urban frontage; <60 cm
Pacific bleeding heart	*Dicentra formosa**	Moist, rich soils; heart-shaped flowers; sun/shade; spreads to 50 cm
Showy fleabane	*Erigeron speciosus**	Moist to dry soils; dark violet or lavender blooms; fibrous roots; sun/partial shade; spreads to 60 cm; under 60 cm; urban frontage
Idaho fescue	*Festuca idahoensis**	Bluish-green bunching perennial grass; drought-tolerant; sun/partial shade; spreads to 30 cm; height 90 cm
Wood strawberry	*Fragaria vesca**	Dry to moist soils; white flowers; partial shade; spreads to 30 cm
Salal	*Gaultheria shallon**	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit; spreads up to 2 m
Oregon wintergreen	*Gaultheria ovatifolia**	Sun to shade; <60 cm; If height is a problem, can be sheared with hedge trimmer
Large-leaved avens	*Geum macrophyllum**	Moist, well-drained soil; bright yellow flowers; other Geum cultivars available, some which may require supplemental watering; sun/partial shade; spreads to1 m

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Zone 3: Dry upper slope / top flat ground

This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.

Common Name	*Botanical Name*	Notes
Spotted eranium	*Geranium maculatum*	Moist, well-drained soils; low perennial; pale pink, blue to purple flowers; sun/shade; spreads to 4.5 cm
Curry Plant	*Helichrysum italicum*	Moist or dry soils; hardy evergreen perennial; a good companion to lavender; bright yellow flowers; fragrant; sun; spreads to 60 cm
Day lilies	*Hemerocallis fulva*	Tolerant of a variety of soil types; easy to grow and tolerant of neglect; hardy perennial; entire plant is edible; sun/partial shade; spread up to 1.2 m
'Palace purple' (alumroot)	*Heuchera micrantha*	Moist, well-drained soils; bronze to purple foliage in shade; small, yellowish-white flowers; perennial, evergreen; a number of other species and varieties are available (try *H. sanguinea* for bright red flowers); sun/partial shade; spreads to 60 cm
Lupine	*Lupinus bicolor** *Lupinus latifolius** *Lupinus polyphyllus**	Dry to moist, sandy to gravelly soils; perennial; sun; spreads up to 1 m
Tall Oregon grape	*Mahonia aquifolium**	Dry to moist soils; drought resistant; evergreen; blue-black fruit; bright yellow flowers; great low screening barrier; sun/partial shade; spreads to 3 m; '*Compacta*' form averages 60 cm tall
False lily-of-the-valley	*Maianthemum dilatatum**	Prefers moist soils; small, white flowers; light-green to red berries; partial shade/shade; spreads up to 30 cm
Fountain grass	*Pennisetum alopecuroides*	Moist, well-drained soils; tolerant of many soil types; clump forming grasses. A number of varieties are available in different heights and bloom times; sun/partial shade; spreads to 60 cm, in Zone 4 try *P. caudatum* (White-flowering fountain grass) and *P. alopecuroides* cultivars 'Hameln' and 'Little bunny' (Dwarf fountain grass).
Oriental fountain grass	*Pennisetum orientale*	Prefers moist, well-drained soils; somewhat drought-tolerant; small clumping, blooming grass, showy pink flowers; fountain grasses will benefit from annual shearing in late winter/early spring, but not required; sun/partial shade; spreads up to 1 m

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Zone 3: Dry upper slope / top flat ground This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.		
Common Name	***Botanical Name***	**Notes**
Bush penstemon	*Penstemon fruticosus*	Prefers well-drained soils; evergreen perennial; drought tolerant; violet-blue flowers 1" long attract hummingbirds; sun; spreads up to 25 cm
Swordfern	*Polystichum munitum**	Prefers moist, rich soil conditions, but drought-tolerant; large evergreen fern; partial shade/deep shade; spreads to 1.2 m
Black-eyed Susan	*Rudbeckia hirta*	Moist to dry soils; showy flowers, hardy and easy to grow; several other varieties are available; sun/partial shade; spreads to 1.4 cm
False Solomon's seal	*Smilacina racemosa**	Moist soils; creamy white flowers; red berries; partial sun/shade; spreads to 1 m
Canadian goldenrod	*Solidago canadensis**	Dry to moist soils; yellow flowers; sun/partial shade; spreads to 60 cm
Deciduous Shrubs		
Oceanspray	*Holodiscus discolor**	Dry to moist soils; drought tolerant; white to cream flowers; good soil binder; sun/partial shade; mature height 4.5 m
Mock-orange	*Philadelphus lewisii**	Adapts to rich moist soils or dry rocky soils; drought-tolerant; fragrant flowers; sun/partial shade; spreads 1.5-3 m
Mugho pine	*Pinus mugo pumilio*	Adapts to most soils; slow growing and very hardy; newer additions with trademark names such as 'Slo-Grow' or 'Lo-Mound' are also available; sun; mature height 1-1.5 m with 1.5–2 m spread
Shrubby cinquefoil	*Potentilla fruticosa*	Moist to dry soils; several cultivars available with varying foliage and flower hues; try 'Tangerine' or 'Moonlight'; sun; spreads 1 m
Graceful cinquefoil	*Potentilla gracilis**	Moist to dry soils; yellow flowers; sun; spreads 30-60 cm
Red-flowering currant	*Ribes sanguineum**	Prefers dry soils; drought-tolerant; white to deep-red flowers attract hummingbirds; dark-blue to black berries; thornless; sun/partial shade; 2.5-3.5 m
Baldhip rose	*Rosa gymnocarpa**	Dry or moist soils; drought tolerant; small pink to rose flowers; partial shade; up to 2 m spread
		Continued on next page

Zone 3: Dry upper slope / top flat ground
This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.

Common Name	*Botanical Name*	Notes
Evergreen Shrubs		
Glossy abelia	*Abelia x grandiflora*	Prefers moist, well-drained soils, but drought-tolerant; white or faintly pink flowers; partial sun/partial shade; mature height 2.5 m with 1.5 m spread
'Compacta'	*Arbutus unedo*	Prefers well drained soils; tolerant of poor soils; good in climate extremes; white to greenish-white flowers; striking red-orange fruit; sun/partial shade; up to 3 m spread
Orchid rockrose	*Cistus purpureus*	Moist to dry well-drained soils; drought resistant; fast growing; reddish purple flowers; sun; up to 1 m spread
White rockrose	*Cistus salviifolius*	Moist to dry well-drained soils preferred, but can tolerate poor soils; tolerant of windy conditions and drought; white flowers; sun; mature height 1 m with 1.8 m spread
Pink princess	*Escallonia x exoniensis 'fradesii'*	Tolerant of varying soils; drought tolerant when established; pink to rose coloured flowers; good hedge or border plant; attracts butterflies; sun/partial sun; 1–2 m spread
Salal	*Gaultheria shallon**	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit; partial shade; spread 1-2 m
Dull Oregon grape	*Mahonia nervosa**	Dry to moist soils; drought resistant; evergreen; yellow flowers; blue berries; partial shade/shade; spreads to 60 cm
Delavay Osmanthus	*Osmanthus delavayi*	Tolerant of a broad range of soils; attractive foliage and clusters of white fragrant flowers; slow growing; sun/partial shade; 1-2 m spread
Devil wood	*Osmanthus x burkwoodii*	Drought-tolerant once established; masses of small, white fragrant flowers; sun/partial shade; 1-2 m spread
'PJM' hybrids	*Rhododendron*	Moist to fairly dry soils; well drained organic soil; lavender to pink flowers; sun/partial shade; 1 m spread
Evergreen huckleberry	*Vaccinium ovatum**	Moist to slightly dry soils; small pinkish-white flowers; berries in August; sun/partial sun; 1-4.5 m spread

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Zone 3: Dry upper slope / top flat ground This area experiences dry to moist soils, commonly located on the upper side slopes or top even ground of the bioretention or infiltration facility. Plants should be drought tolerant and help stabilize the slope.		
Common Name	***Botanical Name***	**Notes**
Deciduous Trees		
Dogwood	*Cornus spp.*	Reliable flowering trees with attractive foliage and flowers; may need watering in dry season; try C. florida (Eastern dogwood), or C. nuttallii* (Pacific dogwood) or hybrid 'Eddie's White Wonder'. Also, C. kousa for small tree/shrub which is resistant to anthracnose; sun/partial shade; mature height 6-9 m with 9 m canopy
Bitter cherry	*Prunus emarginata**	Dry or moist soils; intolerant of full shade; purple to black cherries; bright fruits are attractive to birds; roots spread extensively; sun/partial shade; mature height 6-15 m with 6 m canopy
Douglas-fir	*Pseudotsuga menziesii**	Does best in deep, moist soils; evergreen conifer with medium to fast rate of growth; provides a nice canopy, but potential height will restrict placement
Garry oak (Oregon white oak)	*Quercus garryana**	Dry to moist, well-drained soils; slow growing; acorns; sun; mature height up to 22 m
Evergreen Trees		
Strawberry tree	*Arbutus unedo*	Tolerant of extremes; tolerant of urban/industrial pollution; white or greenish white flowers; sun/partial shade; mature height 2.5-10 m with 2.5-6 m canopy
Incense cedar	*Calocedrus decurrens**	Tolerant of poor soils; drought tolerant after established; fragrant evergreen with a narrow growth habit; slow growing; sun; mature height 2.5-10 m with 2.5-6 m spread
Hinoki false cypress	*Chamaecyparis obtusa*	Moist, loamy, well-drained soils; very slow growing; prefers sun, but tolerates shade; does not transplant well or do well in alkaline soils. Note there are many alternative varieties of false cypress of varying sizes and forms from which to choose; sun/partial shade; mature height 12-15 m with 4-9 m spread
Swiss mountain pine	*Pinus mugo*	Prefers moist well-drained soil; slow growing, broadly spreading, bushy tree; hardy evergreen; sun/partial shade; mature height 4-6 m with 7.5-9 m spread
Japanese black pine	*Pinus thunbergiana*	Dry to moist soils; hardy; fast growing; sun; mature height 30 m with 12 m spread

Grassy Swale Candidate Plant Lists

Below are planting list for consideration in grassy swales.

Table 5 Grassy Swale Mixes Good for Mowing

Grassy Swale Mixes (good for mowing)			
Grassy Swale Mix 1 (% by weight)		**Grassy Swale Mix 2** (% by weight)	
75-80%	tall or meadow fescue	60-70%	tall fescue
10-15%	seaside/colonial bentgrass	10-15%	seaside/colonial bentgrass
5-10%	Redtop	10-15%	meadow foxtail
		6-10%	alsike clover
		1-5%	marshfield big trefoil
		1-6%	Redtop

Table 6 Ground Covers and Grasses Suitable For Upper Side Slopes of Swales

Botanical Name	Common Name	Zone
Grasses (drought-tolerant, minimum mowing)		
Festuca spp. (e.g., Many Mustang, Silverado)	dwarf tall fescues	1,2
Festuca ovina duriuscula (e.g., Reliant, Aurora)	hard fescue	1,2
Festuca amethystine	tufted fescue	1,2
Buchloe dactyloides1	buffalo grass	1,2
Festuca rubra	red fescue	1,2
Festuca arundinacea	tall fescue grass	1,2
Helictotrichon sempervirens	blue oatgrass	1,2
Ground Covers (not for mowing)		
Arctostaphylos uva-ursi	kinnikinnick	2, 3, 4
Epimedium grandiflorum	Epimedium	2
Omphalodes verna	creeping forget-me-not	2
Euonymus lanceolata		2
Xanthorhiza simplissima	yellow-root	2
Genista		2
Trifolium repens	white lawn clover	2
Rubus calycinoides		2
Fragaria chiloensis	strawberry	2
Lupinus latifolius	broadleaf lupine	2

Table 7 Green Roof Candidate Plant List

Green Roofs require plant material adapted to hot/dry summers and wet winters. They must also be adapted to growing in very shallow soils. Plants suitable for growing in 100 mm deep extensive green roofs are sedums and stone crops. Plant composition for 150 mm deep extensive green roofs can include up to 50% grasses or perennials suitable for the site conditions with the remaining area being drought tolerant sedums.

Green Roof Plant Candidate List (native species*)

Botanic Name	Common Name	Evergreen (yes)	Potential Height (cm)	Full Sun	Partial Shade
Succulents					
Delosperma cooperi	Ice Plant	Y	10	X	X
Delosperma nubigenum	Ice Plant	Y	5	X	X
Opuntia spp.	Prickly-Pear Cactus		13	X	X
Sedum acre	Biting Stonecrop	Y	5	X	X
*Sedum divergens**	Pacific Stonecrop	Y	8	X	X
Sedum hispanicum	Spanish Stonecrop	Y	8	X	X
Sedum kamtschaticum	Kirin-so		15	X	X
*Sedum lanceolatum**	Lance-leaved Stonecrop		10	X	X
*Sedum oreganum**	Oregon Stonecrop	Y	10	X	X
Sedum oregonense	Creamy Stonecrop	Y	10	X	X
Sedum rupestre	Crooked Stonecrop	Y	15	X	X
Sedum sexangulare	Tasteless Stonecrop	Y	10	X	X
*Sedum spathulifolium**	Broad-leaved Stonecrop	Y	10	X	X
Sedum spurium	Two-row Stonecrop	Y	15	X	X
Sedum takesimense	Gold Carpet Stonecrop	Y	23	X	X
Sedum telephium	Autumn Joy		60	X	X
Sempervivum tectorum	Hens and Chicks	Y	15	X	X
CAUTIONARY NOTE: *Sedum album* (common name: White Stonecrop) is a succulent that has been commonly used for green roof installations, however, it has been found to have invasive qualities in the capital region with birds as the dispersion vector. Ensure that plantings or succulent mats do not include this succulent.					
Herbaceous Plants					
*Achillea millefolium**	Common Yarrow		90	X	X
*Allium acuminatum**	Hooker's Onion		15	X	X
*Allium cernuum**	Nodding Onion		30	X	X
Antennaria neglecta	Field Pussytoes		10	X	X
Arenaria montana	Sandwort		10	X	X
Aurinia saxatilis	Basket-of-Gold		15	X	X
*Campanula rotundifolia**	Common Harebell		20	X	X

Green Roof Plant Candidate List (native species*)					
Botanic Name	**Common Name**	**Evergreen (yes)**	**Potential Height (cm)**	**Full Sun**	**Partial Shade**
Dianthus spp.	Dianthus		30	X	X
Erigeron compositus	Fleabane		30	X	X
*Erigeron glaucus**	Beach Aster		15	X	X
*Festuca idahoensis**	Idaho Fescue	Y	30	X	X
*Fragaria chiloensis**	Coastal Strawberry	Y	15	X	X
*Fragaria virginiana**	Wild Strawberry	Y	15	X	X
Gaillardia aristata	Blanket Flower		50	X	X
Gazania linearis	Gazania		15	X	X
*Koeleria macrantha**	Junegrass		60	X	X
Lobularia maritima	Sweet Alyssum		30	X	X
*Phlox douglasii**	Tufted Phlox		10	X	X
*Polypodium glycyrrhiza**	Licorice Fern	Y	30	X	X
Polystichum munitum	Sword Fern	Y	60	X	X
Potentilla nepalensis	Nepal Cinquefoil		35	X	X
Potentilla neumanniana	Cinquefoil		35	X	
*Prunella vulgaris lanceolate**	Self-Heal		10	X	X
Silene acaulis	Moss Campion		8	X	X
Thymus serphyllum	Creeping Thyme		8	X	
Veronica liwanensis	Turkish speedwell		5	X	X
Accent Plants					
*Camassia quamash**	Common Camas		20	X	X
*Clarkia amoena**	Farewell-to-Spring		17	X	X
*Gilia capitate**	Globe Gilia		45	X	X
Linaria reticulata	Purplenet Toadflax		50	X	X
*Linum perenne**	Blue Flax		20	X	X
*Lupinus bicolor**	Two-Coloured Lupine		13	X	X
*Madia elegans**	Elegant Tarweed		45	X	X
*Nemophila menziesii**	Baby Blue Eyes		13	X	X
Phacelia campanularia	Desert Bluebells		25	X	X
*Plectritis congesta**	Sea Blush		13	X	X
*Triteleia ixoides**	Golden Star		25	X	X

Table 8 Emergent Wetland Plant Species Recommended for Wet Ponds and Wetlands Candidate Plant List for Vegetated GSI Facilities

Botanical Name (*native plant)	Common Name	Notes	Maximum Depth (cm)
Inundation to 30 cm			
*Agrostis exarata**	Spike bent grass		Up to 60
*Carex stipata**	Sawbeak sedge	Wet ground	
*Eleocharis palustris**	Spike rush	Margins of ponds, wet meadows	Up to 60
*Glyceria occidentalis**	Western mannagrass	Marshes, pond margins	Up to 60
*Juncus tenuis**	Slender rush	Wet soils, wetland margins	
*Oenanthe sarmentosa**	Water parsley	Shallow water along stream and pond margins; needs saturated soils all summer	
*Scirpus atrocinctus**	Woolgrass	Tolerates shallow water; tall clumps	
*Scirpus microcarpus**	Small-fruited bulrush	Wet ground to 45 cm depth	45 cm
*Sagittaria latifolia**	Arrowhead		
Inundation to 30 to 60 cm			
*Agrostis exarata**	Spike bent grass		
*Alisma plantago-aquatica**	Water plantain		
*Eleocharis palustris**	Spike rush	Margins of ponds, wet meadows	
*Glyceria occidentalis**	Western mannagrass	Marshes, pond margins	
*Juncus effuses ssp. pacificus**	Pacific Soft rush	Wet meadows, pastures, wetland margins	
*Scirpus microcarpus**	Small-fruited bulrush	Wet ground to 45 cm depth	45 cm
*Sparganium emersum**	Bur-reed	Shallow standing water, saturated soils	
Inundation to 30 to 90 cm			
*Carex obnupta**	Slough sedge	Wet ground or standing water	45 cm to 90 cm
*Beckmannia syzigachne**	Western sloughgrass	Wet prairie to pond margins	
*Scirpus validus**	Softstem bulrush		

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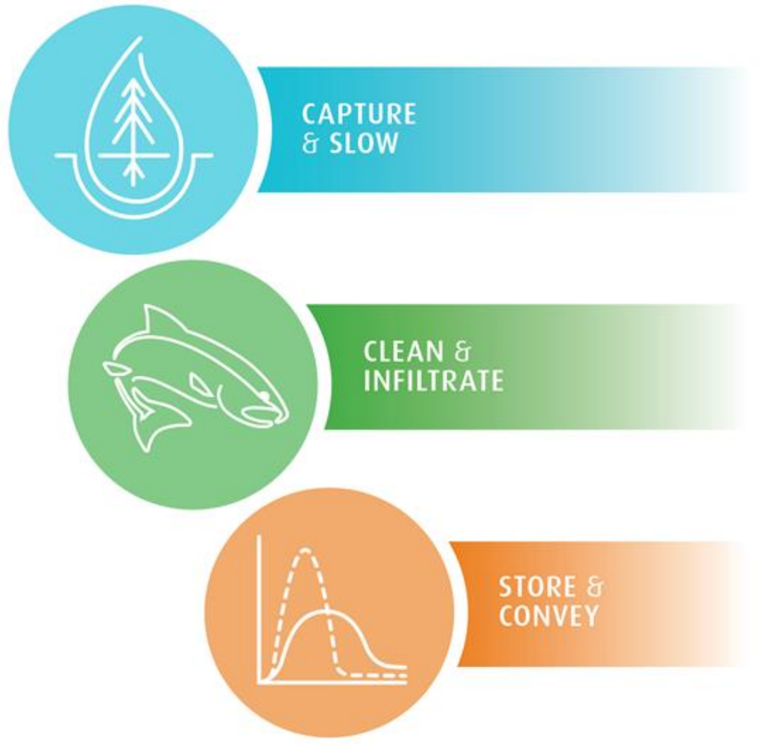
Botanical Name (*native plant)	Common Name	Notes	Maximum Depth (cm)
Inundation greater than 90 cm			
*Nuphar polysepalum**	Rocky Mountain pond-lily	Deep water	90 cm to 2.3 m
Caution - Parrot's feather (*Myriophyllum aquaticum*) is an aquatic plant that is popular in recreational indoor fish tanks that can enter storm drainage system through incidental washing/rinsing/dumping into storm drain system. This plant has severely impacted several GSI facilities within the capital region and in the Lower Mainland. Routine maintenance of swales and constructed wetlands and ponds ought to include early detection and rapid response. Learn more: http://bcinvasives.ca/invasive-species/identify/invasive-plants/parrots-feather			

Wet Pond Vegetation and Landscaping

- Plant native turf-forming grasses or irrigated turf on sloped area.
- Prohibit woody vegetation within 5 m of toe of embankment and within 7.5 m of spillway principal structure.

Dry Pond Vegetation and Landscaping

- Plant basin with native grasses or turf to enhance sediment entrapment and protect against erosion.
- Constructed Wetland Vegetation and Landscaping.
- Plant density of 4 to 8 plants per square metre.
- Planting should take place between April and mid-June so that plants have a full growing season to develop root reserves.
- Tall, emergent species should be planted on aquatic benches.
- Use native water plants, trees, shrubs or grass species.
- Remove grass clippings.



SUPPLEMENTAL 2 – LEAKY SANITARY SEWERS & GREEN STORMWATER INFRASTRUCTURE FOR STORMWATER MANAGEMENT PRACTICES

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Leaky Sewers & Green Stormwater Infrastructure Management Practices[1]

This section is divided into the following headings:

- Overview
- Interaction between leaky sewers and green infrastructure
- Research to date
- Who's responsible for leaky sewers
- How municipalities identify areas with leaky sewers
- Recommendations.

Overview

Sewer systems deteriorate over time resulting in sewer pipes that are leaky. Stormwater cross-connections (i.e., roof drains connected to the sanitary sewer system) are not permitted under the plumbing code and further contribute to sewer leakiness. A certain amount of sewer leakiness is unavoidable and is accounted for in typical sewer design. However, if leakage rates are high, the capacity of the sewer system can be overwhelmed, resulting in sewer overflows to the environment and basement flooding.

Leaky sewers may also interact with green infrastructure. The interactions may be positive, negative, or neutral. It's important to understand the site-specific interactions between green infrastructures and leaky sewers. It's also important for municipalities and homeowners to inspect their sewer pipes and to maintain/repair them to address sewer leakiness, as appropriate.

Interaction between Leaky Sewers and Green Stormwater Infrastructure

The interactions between leaky sewers and green infrastructure are site-specific and may include 1 or more of the following:

1. Leaky sewers can act as a "drainage field". By repairing them, more stormwater stays in the ground which supports the goals of green stormwater infrastructure.
2. Leaky sewers may leak sewage to the environment resulting in contamination, etc. This is against the principles of green infrastructure.
3. Actions that decrease the amount of water entering leaky sewers will decrease the likelihood of downstream sewer overflows, beach closures, etc. Conversely, actions that increase the amount of water entering leaky sewers may contribute to these negative outcomes.
4. Green infrastructure can reduce the potential for water entering leaky sewers by capturing and infiltrating stormwater into the ground. This reduces the potential for clean water to enter leaky sewers on site or downstream.

[1] Authored by: Opus International Consultants (Canada) Limited

5. Green infrastructure may be used as a tool for addressing improper stormwater cross-connections (i.e., stormwater pipes directly connected to the sewer). This is done by redirecting stormwater away from the sewer system to green infrastructure which infiltrates into the ground. This is especially valuable in areas with combined or semi-combined sewers. Examples of stormwater infrastructure that may be cross-connected include downspouts, foundation drains and sump pumps.
6. Green stormwater infrastructure facilities (such as those discussed in this document) are generally designed to increase stormwater infiltration into the ground instead of being directed into the stormwater drainage system. However, if there are leaky sanitary sewers located downslope of the green stormwater infrastructure, the water may drain into these sewers reducing the benefits of the green infrastructure.
7. Green infrastructure may raise the water table resulting in more water entering leaky sewers.

Research to Date

To date, minimal research has been carried out looking at the interactions between leaky sewers and green infrastructure.

One of the few organizations to carry out such research is the Milwaukee Metropolitan Sewerage District.[2] They commissioned 4 studies which evaluated the infiltration of porous pavements, rain gardens, and stormwater ponds into nearby sewers. Of note:

- The study authors recommended that smaller-scale green stormwater infrastructure facilities should be at least 3 m (10 feet) away horizontally from sewer pipes in order to reduce the chances of infiltration into the sewer pipes.
- No infiltration into sewer pipes was detected from large-scale stormwater ponds located 18 m (60 feet) from sewer the pipes. Tests were not completed on ponds located closer than 18 m.

It's preferable to build Green Stormwater Infrastructure (GSI) away from sewer pipes.

More research on the relationships between green infrastructure and leaky sewers would be greatly beneficial. Research linking the effects of green infrastructure to leaky sewers and the effects of soil types on this relationship would provide governments with increased knowledge on the use of their suite of stormwater management tools.

[2] Fresh Coast Green Solutions – Weaving Milwaukee's Green and Grey Infrastructure into a Sustainable Future, Milwaukee Metropolitan Sewerage District
https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf

Who's Responsible for Leaky Sewers

The local governments within the CRD are responsible for the municipal sewer mains and the portion of laterals located between the mains and the property line.

Property owners are responsible for sewer laterals located between their homes/buildings and the property line.

The exception to this is in Oak Bay where property owners are responsible for the full length of their sewer laterals between the home/building and the municipal sewer main.

How Municipalities Identify Areas with Leaky Sewers

The municipalities in the CRD routinely collect data on the condition of their sewer system. They understand that sewer systems deteriorate over time and require periodic inspection, maintenance, repair and eventual replacement. Leakiness is an indication of sewer health. To identify sources of leakiness, municipalities use the following methods:

Figure 1 Construction Specifier Magazine. Photo Credit: City of North Bay

1. **Flow monitoring** involves measuring sewer flows over time and analyzing the data along with rainfall data to quantify sewer leakiness.
2. **Closed circuit television inspections** use a video camera to record the condition of a sewer pipe. The video footage is reviewed to identify locations of sewer pipe defects and leakages.
3. **Dye testing** can be used to confirm connections within the sewer system. A non-toxic dye is added to a pipe and a downstream sewer manhole is monitored for the presence of the dye.
4. **Smoke testing** is used to identify stormwater cross-connections to the sanitary sewer system. Smoke is injected into a sanitary sewer manhole and the surrounding area is monitored to see where smoke comes to the surface. The smoke is non-toxic, stainless, odourless and vegetable based. Smoke testing is a key tool for identifying cross-connections from private properties.

Figure 2 Infiltration basin located away from sewer pipes. Photo Credit: Construction Specifier Magazine

Municipalities also encourage property owners to get camera inspections of their private property sewer laterals and maintain their pipes, when appropriate.

Recommendations

1. Site-specific interaction between leaky sewers and green infrastructure should be considered prior to undertaking work related to leaky sewers or green infrastructure.

2. When practical, smaller-scale green infrastructures should be located at least 3 m (10 feet) away horizontally from sewer pipes in order to reduce the chances groundwater draining into leaky sewer pipes.

   It's understood, however, that this recommendation may not be suitable in some situations. For example:

   - The use of permeable paving above a sewer lateral in an area with good drainage.
   - The use of green infrastructure in a narrow municipal "right-of-way" where conditions found to be acceptable.

   Site-specific expert judgement should be used to determine when the use of green infrastructure within 3 m of a sewer is considered practical.

3. Green infrastructure should receive strong consideration when addressing the issue of stormwater cross-connections (stormwater pipes directly connected to the sewer). This is especially important in areas with combined sewers or semi-combined sewers.

4. Fixing leaky sewers will improve the performance of GSI facilities.