4.5 Bioretention

4.5.1 Overview

Description

As a stormwater filter and infiltration practice, bioretention temporarily stores, treats and infiltrates runoff. Depending on native soil infiltration rate and physical constraints, the system may be designed without an underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for filtration only, which can also be referred to as a biofilter. The primary component of a bioretention practice is the filter bed which is a mixture of sand, fines and organic material. Other important elements of bioretention include a mulch ground cover and plants adapted to the conditions of a stormwater practice. Pretreatment, such as a settling forebay, vegetated filter strip, or stone diaphragm, often precedes the bioretention to remove particles that would otherwise clog the filter bed. Bioretention is designed to capture small storm events or the water quality storage requirement. An overflow or bypass is necessary to pass large storm event flows.

Bioretention can be adapted to fit into many different development contexts and provides a convenient area for snow storage and treatment. In a low density development, it might have a soft edge and gentle slopes, while a high density application might have a hard edge with vertical sides. A number of common forms of bioretention design are illustrated in Figure 4.5.1.

Common Concerns

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

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

highways), nor from pollution hot spots (*e.g.*, source areas where land uses or activities have the potential to generate highly contaminated runoff such as vehicle fuelling, servicing or demolition areas, outdoor storage or handling areas for hazardous materials and some heavy industry sites);
- prioritize infiltration of runoff from source areas that are comparatively less contaminated such as roofs, low traffic roads and parking areas; and,
- apply sedimentation pretreatment practices (*e.g.*, oil and grit separators) before infiltration of road or parking area runoff.

- *Risk of Soil Contamination:* Available evidence from monitoring studies indicates that small distributed stormwater infiltration practices do not contaminate underlying soils, even after more than 10 years of operation (TRCA, 2008).

- *Performance in Winter Conditions and Spring Snowmelt*: Performance studies show that bioretention effectively captures and treats runoff during winter months with average daily temperatures in the -5 to 10 ºC range (Traver, 2005; UNHSC, 2005, Roseen *et al.*, 2009). Frost penetration of filter media varied from zero to 17 cm in studies at the University of New Hampshire (Roseen, 2007). Year round monitoring of a bioswale in the Greater Toronto Area showed the facility continued to function during winter, with temperatures in the filter bed remaining above zero at a depth of 50 cm below the surface (TRCA, 2008b). While bioretention frequently accepts runoff containing high chloride concentrations, the dissolved chloride will pass through to the groundwater without treatment. Cold climate adaptation for bioretention designs include extending the filter bed and underdrain pipe below the frost line, oversizing the underdrain to reduce the freezing potential, and selecting salt-tolerant vegetation. Some bioretention design variants, such as stormwater planters and curb extensions, are new to cold climates and have not been monitored in winter conditions. Stormwater planters that are wholly above ground should be given special consideration, as the underdrain and other conveyance structures will be more susceptible to freezing.

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

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

Figure 4.5.1 Forms of bioretention

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

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

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

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

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

(Source: City of Portland, BES)

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

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

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

Source: City of Portland, BES

- *On Private Property*: If bioretention practices are installed on private lots, property owners or managers will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and may be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices. Alternatively, bioretention areas could be located in an expanded road right-of-way or “stormwater easement” so that municipal staff can access the facility in the event it fails to function properly.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Typical Performance

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

Table 4.5.1 Ability of bioretention to meet SWM objectives

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

Water Balance

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

Table 4.5.2 Volumetric runoff reduction[1] achieved by bioretention

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

Notes:

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

Water Quality - Pollutant Removal Capacity

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

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

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

Notes:

NT = not tested

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

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

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

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

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

Table 4.5.4 Factors that influence bioretention pollutant removal rates

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

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

Stream Channel Erosion Control

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

Other Benefits

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

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

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

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

4.5.2 Design Template

Applications

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

Figure 4.5.2 Example applications of bioretention

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

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

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

Rain Garden

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

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

Stormwater Planters

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

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

Extended Tree Pits

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

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

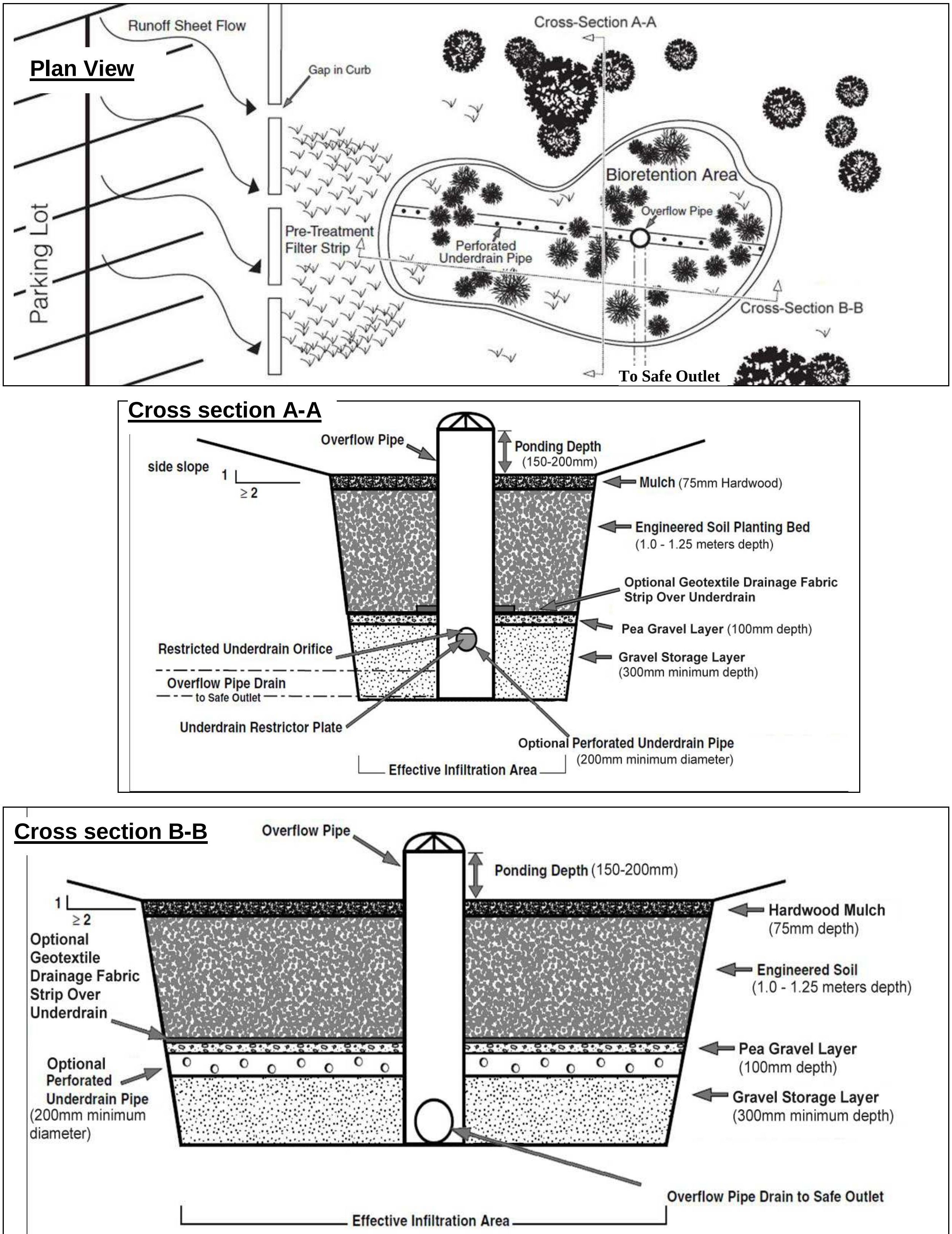
Stormwater Curb Extensions

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

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

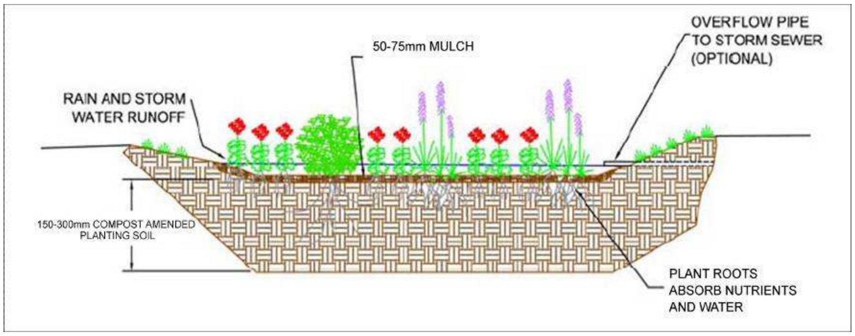
Typical Details

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



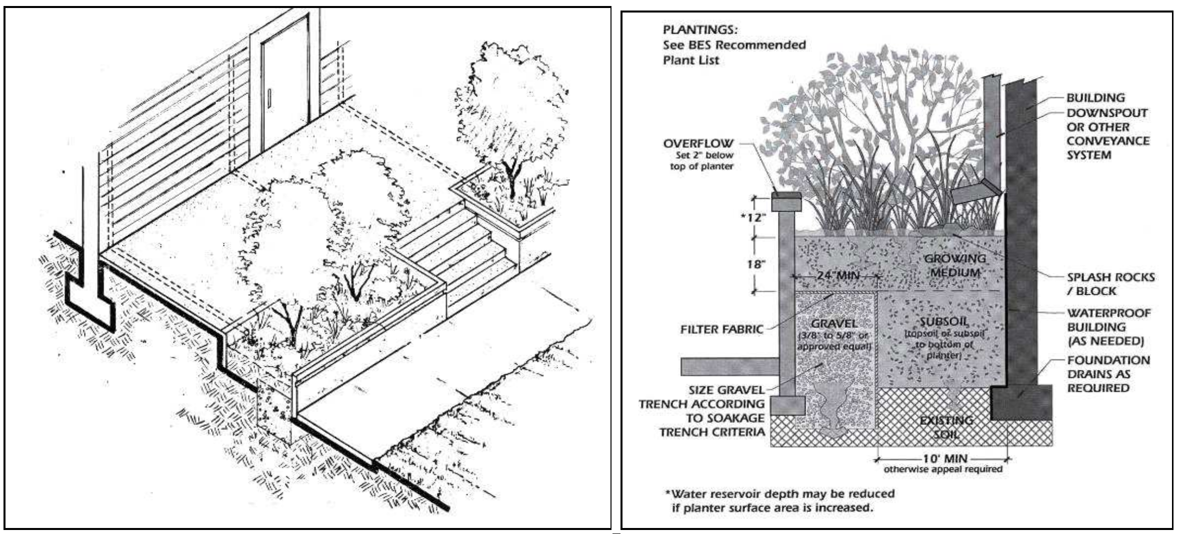
Source: adapted from Wisconsin Department of Natural Resources bioretention details

Figure 4.5.4 Rain garden cross section



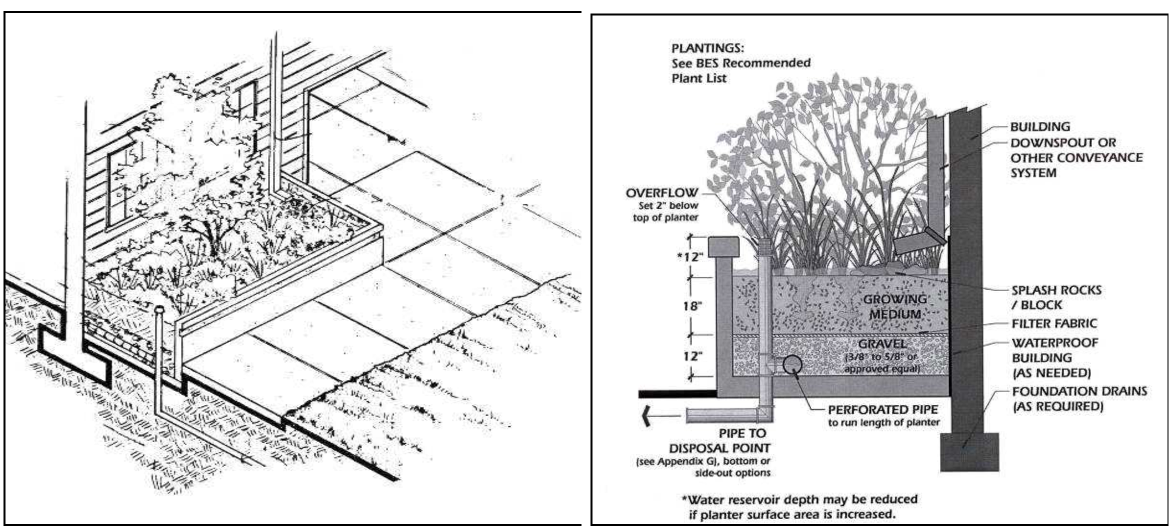
Source: MDE, 2000

Figure 4.5.5 Infiltrating stormwater planter box



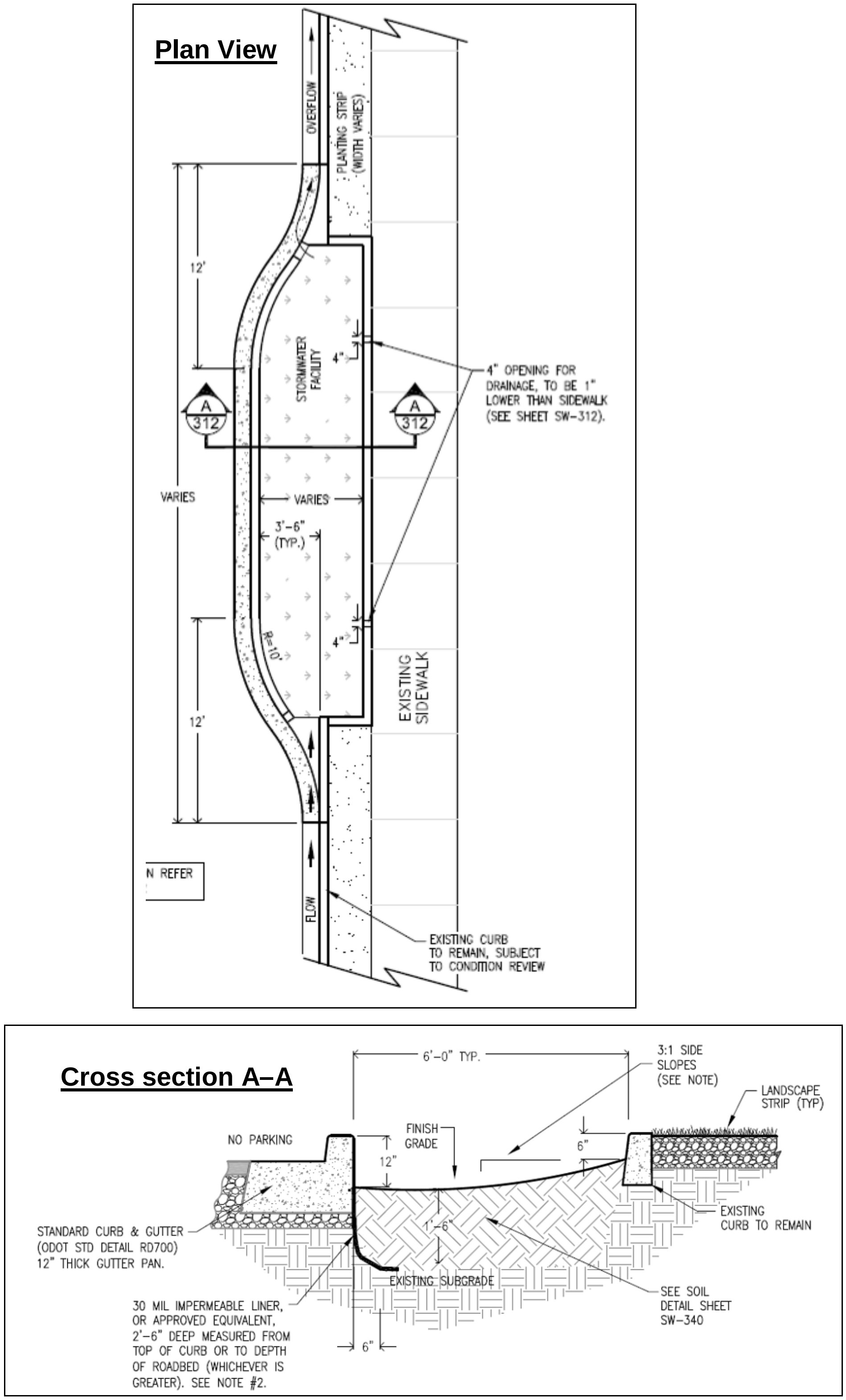
Source: City of Portland, 2004

Figure 4.5.6 Stormwater planter box biofilter (filtration only)



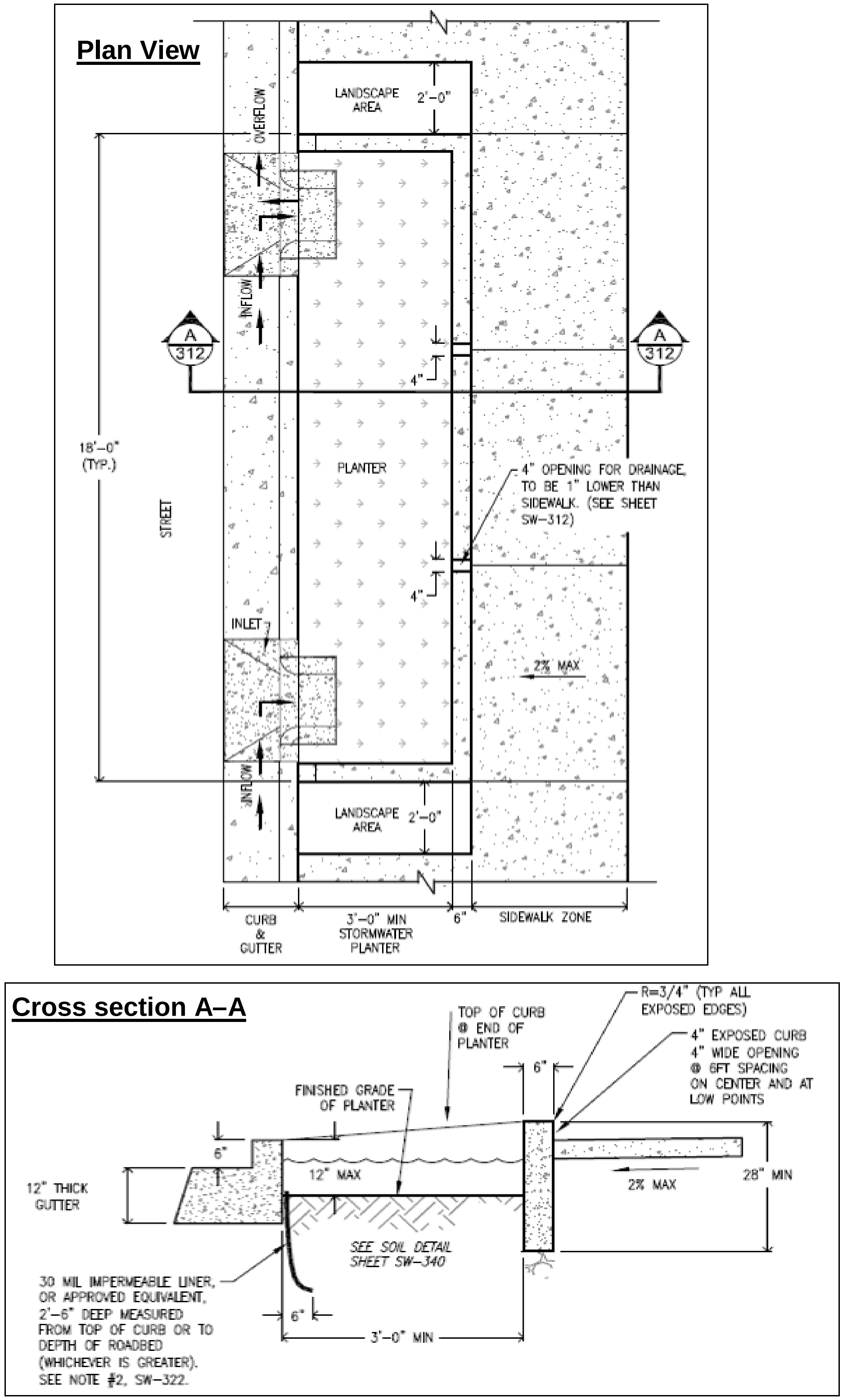
Source: City of Portland, 2004

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



Source: City of Portland, 2004

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



Source: City of Portland, 2004

Design Guidance

Geometry and Site Layout

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

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

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

- The geometric design of bioretention will be dictated by other elements of the landscape such as buildings, sidewalks, utility corridors, retaining walls, etc. Bioretention can be configured to fit into many locations and shapes. However, cells that are narrow or have narrow sections may concentrate flow as it spreads throughout the cell and result in erosion.

- The filter bed surface should be level to encourage stormwater to spread out evenly over the surface. Ponding in one location of the bioretention will result in increased sedimentation and clogging at the ponding location and uneven watering of the vegetation.

Pretreatment

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

- *Two-cell design (channel flow):* Forebay ponding volume should account for 25% of the water quality storage requirement and be designed with a 2:1 length to width ratio. This pre-treatment device is the most effective and can be designed for easy sediment-removal.

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

- *Gravel diaphragm (sheet flow):* A small trench filled with pea gravel, which is perpendicular to the flow path between the edge of the pavement and the bioretention practice will promote settling out of sediment. It also acts as a level spreader, maintaining sheet flow into the facility. If the contributing drainage area is steep, then larger stone should be used in the diaphragm. A drop of 50-150 mm into the gravel diaphragm can be used to dissipate energy and promote settling.

- *Rip rap and/or dense vegetation (channel flow):* These energy dissipation techniques are acceptable pretreatment on small bioretention cells with a drainage area of less than 100 square metres.

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

Conveyance and Overflow

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

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

Figure 4.5.9 Examples of inline and offline bioretention

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

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

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

Figure 4.5.10 Examples of inlets to bioretention practices

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

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

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

Artistic Design Elements

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

Monitoring Wells

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

Gravel Storage Layer

- *Depth:* Should be a minimum of 300 mm deep and sized to provide the required storage volume. Granular material should be 50 mm diameter clear stone.

- *Pea gravel choking layer:* A 100 mm deep layer of pea gravel (3 to 10 mm diameter clear stone) should be placed on top of the coarse gravel storage layer as a choking layer separating it from the overlying filter media bed.

Filter Media

- *Composition*: The recommended bioretention filter media soil mixture is:

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

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

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

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

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

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

Underdrain

- Only needed where native soil infiltration rate is less than 15 mm/hr (hydraulic conductivity of less than $1x10^{-6}$ cm/s).
- Should consist of a perforated pipe embedded in the coarse gravel storage layer at least 100 mm above the bottom of the gravel storage layer.
- HDPE or equivalent material perforated pipes with smooth interior walls should be used. Pipes should be over-sized to accommodate freezing conditions. A minimum 200 mm diameter underdrain is recommended for this reason (MPCA, 2005). Underdrains should be capped on the upstream end(s).
- A strip of geotextile filter fabric placed between the filter media and pea gravel choking layer over the perforated pipe is optional to help prevent fine soil particles from entering the underdrain. Table 4.5.7 provides further detail regarding geotextile specifications.
- A vertical standpipe connected to the underdrain can be used as a cleanout and monitoring well.

Landscaping

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

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

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

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

Other Details

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

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

Other Design Resources

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

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

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

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

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

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

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

BMP Sizing

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

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

Where:

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

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

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

Where:

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

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

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

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

$A_f = WQV / (d_c * V_r)$

Where:

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

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

Design Specifications

Table 4.5.5 Bioretention specifications

Material	Specification	Quantity
Filter Media Composition	Filter Soil Mixtures to contain: ▪ 85 to 88% sand ▪ 8 to 12% soil fines ▪ 3 to 5% organic matter in form of leaf compost Other Criteria: ▪ Phosphorus soil test (P-Index) value 10 to 30 ppm ▪ Cationic exchange capacity (CEC) greater than 10 meq/100 g ▪ pH between 5.5 to 7.5	Recommended depth is between 1.0 and 1.25 metres. Alternative depths may be appropriate in constrained applications. Volumetric computation based on surface area and depth used in design computations.
Mulch Layer	Shredded hardwood bark mulch	A 75 mm layer on the surface of the filter bed.
Geotextile	Material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. Primary considerations are: - Suitable apparent opening size (AOS) for non-woven fabrics, or percent open area (POA) for woven fabrics, to maintain water flow even with sediment and microbial film build-up; - Texture (*i.e.*, grain size distribution) of the overlying native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): <u>Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA)</u>	Strip over the perforated pipe underdrain (if present) between the filter media bed and gravel storage layer (stone reservoir)

Material	Specification	Quantity
	For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) Hydraulic Conductivity (k, in cm/sec) k (fabric) > k (soil) Permittivity (in sec^{-1}) Where, Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	
Gravel	Washed 50 mm diameter clear stone should be used to surround the underdrain and for the gravel storage layer Washed 3 to 10 mm diameter clear stone should be used for pea gravel choking layer.	Volume based on dimensions, assuming a void space ratio of 0.4.
Underdrain	Perforated HDPE or equivalent, minimum 100 mm diameter, 200 mm recommended.	▪ Perforated pipe for length of cell. ▪ Non-perforated pipe as needed to connect with storm drain system. ▪ One or more caps. ▪ T's for underdrain configuration.

Construction Considerations

Ideally, bioretention sites should remain outside the limit of disturbance until construction of the bioretention begins to prevent soil compaction by heavy equipment. Bioretention locations should not be used as the site of sediment basins during construction, as the concentration of fines will prevent post-construction infiltration. They should also not be used for storing materials. To prevent sediment from clogging the surface of a bioretention cell, stormwater should be diverted away from the bioretention site until the drainage area is fully stabilized. Due to the locations of many bioretention practices in the road right-of-way or tight urban spaces, considerations of traffic control and utility conflicts must be part of the plans and inspections.

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

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

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

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

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

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

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

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

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

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

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

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

Construction Inspection

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

Erosion and Sediment Control

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

Materials

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

Elevations

Elevations of the following items should be checked for accuracy:

- Depth of the gravel and invert of the underdrain
- Inverts for inflow and outflow points
- Filter depth after media is placed
- Ponding depth provided between the surface of the filter bed and the overflow structure
- Mulch depth

Landscaping and Stabilization

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

The following items should be checked after the first rainfall event, and adjustments should be made as necessary:

- Outfall protection/energy dissipation at concentrated inflow should be stable.
- Flow should not concentrate and should spread evenly over the filter bed.

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

4.5.3 Maintenance and Construction Costs

Inspection and Maintenance
Bioretention requires routine inspection and maintenance of the landscaping as well as periodic inspection for less frequent maintenance needs or remedial maintenance. Generally, routine maintenance will be the same as for any other landscaped area, weeding, pruning, and litter removal. Routine operation and maintenance tasks are key to public acceptance of highly visible bioretention units.

Periodic inspections after major storm events will determine whether corrective action is necessary to address gradual deterioration or abnormal conditions. For the first two years following construction the facility should be inspected at least quarterly and after every major storm event (> 25 mm). Subsequently, inspections should be conducted in the spring and fall of each year and after major storm events.

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

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

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

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

Table 4.5.6 Suggested routine inspection and maintenance activities for bioretention

Activity	Schedule
▪ Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years until vegetation is established;	As needed for first two years of operation.
▪ Remove trash and debris from pretreatment devices, the bioretention area surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the bioretention area surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the surface, regrading and revegetating may be required.	Annually or as needed

Annual Inspection and Maintenance

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

Table 4.5.7 Suggested inspection items and corrective actions for bioretention

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

Installation and Operation Costs

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

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

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