Chapter 9

Redevelopment Projects

Chapter 9: Redevelopment Projects

This chapter outlines alternative approaches to stormwater management for redevelopment projects. The approaches set forth in this Chapter comply with the Department's technical standards. The document includes the following sections:

9.1 Introduction
9.2 Purpose
9.3 Scope and Applicability
9.4 How to Apply Alternative Stormwater Practices
9.5 Alternative Stormwater Management Practices Profile Sheets

Section 9.1 Introduction

Redevelopment of previously developed sites is encouraged from a watershed protection standpoint because it often provides an opportunity to conserve natural resources in less impacted areas by targeting development to areas with existing services and infrastructure. At the same time, redevelopment provides an opportunity to correct existing problems and reduce pollutant discharges from older developed areas that were constructed without effective stormwater pollution controls.

Redevelopment projects are typically located in older, more urban areas, and can range from large-scale redevelopment, where a new town center is created, to much smaller commercial or residential projects. The proposed density of such projects is typically high, resulting in space constraints to implement on-site stormwater controls. Added to this basic space constraint is the need to tie in to the existing drainage infrastructure, which may be at an elevation that does not provide enough head for certain stormwater management practices (SMPs). Other problems encountered in redevelopment include the presence of underground utilities, incompatible surrounding land uses, highly compacted soils that are not suitable for infiltration, and contaminated soils that require mitigation and can drive up project costs.

Because the technical standards contained elsewhere in this Manual were primarily intended for new development projects, compliance with the standards may present a challenge on some redevelopment projects. Therefore, this chapter sets forth alternatives for certain redevelopment projects. Implementation of these alternative controls can result in useful pollutant reductions, particularly when considering the cumulative effect of multiple projects.

For redevelopment projects located in critical environmental areas and other sensitive environmental or regulated areas, however, all attempts should be made to seek compliance with the technical standards set elsewhere in this manual.

Key Terminology:

Alternative Sizing Criteria - The sizing criteria that can be achieved in redevelopment projects through a variety of approaches as outlined in this chapter.

Alternative stormwater practices – Stormwater management practices that are outlined in this chapter for potential application in redevelopment scenarios and are designed and implemented in accordance with the recommendations in this chapter.

Disconnected impervious area - Impervious area that is not directly connected to a stream or drainage system, but which directs runoff towards pervious areas where it can infiltrate, be filtered, and slowed down.

Redevelopment - Reconstruction or modification to any existing, previously developed land such as residential, commercial, industrial, institutional or road/highway, which involves soil disturbance. Redevelopment is distinguished from development or new development in that new development refers to construction on land where there had not been previous construction. Redevelopment specifically applies to constructed areas with impervious surface.

Redevelopment Project – A project that undergoes redevelopment. The project area can be entirely under redevelopment or the project area can be a combination of redevelopment and new development.

Standard Practice – a stormwater management practice that appears on Table 5.1 of this Manual, sized in accordance with chapter 4, and designed in accordance with chapter 6 of this Manual.

Stormwater sizing criteria – Criteria comprised of the following four elements: water quality treatment, channel protection, overbank flooding, and control of extreme storms as defined in Chapter 4 of this Manual for standard practices and any other requirements for enhanced treatment.

Total impervious area – This is the total area within the drainage area comprised of all materials or structures on or above the ground surface that prevents water from infiltrating into the underlying soils. Impervious surfaces include, without limitation: paved and/or gravel road surfaces, parking lots, driveways, and sidewalks; compacted dirt surfaced roads; building structures; roof tops and miscellaneous impermeable structures such as patios, pools, and sheds.

Section 9.2 Purpose

The purpose of this chapter is to provide alternatives to the technical standards contained elsewhere in this Manual that would be acceptable for certain redevelopment projects. The primary focus of this chapter is to identify the alternative practices and their sizing criteria.

Redevelopment projects are generally expected to comply with technical standards contained elsewhere in this Manual. However, under circumstances where one of the redevelopment application criteria set forth in Section 9.3.1 are met and the design utilizes alternative sizing and selection of stormwater management controls defined in this chapter, the stormwater pollution prevention plan (SWPPP) will be considered to be in conformance with the State technical standards.

The SWPPP provides post construction runoff controls for the **disturbed area** including both **pervious and impervious areas**. As with design of any practice, sizing of structures should be based on all areas contributing to the stormwater management practice**.** Redevelopment, that reconstructs a portion of the site, may choose diversion or flow splitters to be able to size the control structures for the reconstructed area only.

Section 9.3 Scope and Applicability

The provision of stormwater management practices in redevelopment should follow an approach to balance between 1) maximizing improvements in site design that can reduce the impacts of stormwater runoff, and 2) providing a maximum level of on-site treatment that is feasible given the redevelopment project site constraints.

Under conditions where onsite treatment is not practicable, an appropriate off-site watershed improvement to off set the required level of control may be applied, in the presence of a regulated/permitted municipal stormwater management program. The off-site stormwater management approach is subject to applicable local agency approval for banking and trading of credits, may not be an acceptable option in all cases, and is not considered to be in full compliance with the standards defined in this Manual.

Requirements for installation of post construction controls set forth in current stormwater regulations do apply to redevelopment projects. Redevelopment sites must first attempt to comply with all the post-construction management requirements outlined elsewhere in this Manual. When physical constraints in a redevelopment situation such as those described in Section 9.3.1 are present, alternatives presented in this chapter may be used. The SWPPP for a redevelopment project, with or without increased impervious area, must clearly state that the redevelopment conditions meet the application criteria in Section 9.3.1 in order to utilize alternative sizing and selection of stormwater management controls defined in this chapter.

The alternative methods described in this chapter are not applicable to areas of the site under new development (e.g. new impervious areas that are constructed over existing pervious areas) in projects that include both redevelopment and new development areas. For the new development areas associated with a redevelopment project, 100% of the stormwater quality and quantity controls contained in Chapters 4, 5 and 6 must be provided. The reconstructed impervious areas, must be subject to treatment equal to the existing treatment or treatment options defined in Section 9.3.2 of this chapter, whichever is more effective.

Section 9.3.1 Application Criteria

This Chapter applies when specific physical constraints are present at a site in reconstruction of an existing impervious area. Where site-specific circumstances do not allow proper sizing and installation of the management practices contained in Chapter 6, a SWPPP must identify the design difficulties that meet redevelopment application criteria and provide documented justification for the use of proposed alternative approaches presented in this chapter. To make such determination, the following criteria must be met:

(1) An already impervious area is reconstructed, and
(2) there is inadequate space for controlling stormwater runoff from the reconstructed area, or
(3) the physical constraints of the site do not allow meeting the required elements of the standard practices.

The physical constraints pertain to soils, water table, and head; details of the constraints are listed in Table 7.2, Physical Feasibility Matrix, of this Manual.

The application criteria are not solely based on the conditions within the disturbed area. In determining the feasibility of siting SMPs, the entire site within the property boundary must be considered.

Section 9.3.2 Sizing Criteria

A. Water Quantity controls can be sized using the following options:

I- If redevelopment results in no increase of impervious area or changes to hydrology that increases the discharge rate, the **ten-year and hundred-year criteria** do not apply. This is true because the calculated discharge of pre-development versus post-development flows results in zero net increase. This consideration does not mean that **existing quantity controls** may be neglected in planned designs. Existing quantity controls must be maintained in post development flow discharge control.

II- **Channel protection** for a redevelopment project is not required if there is no increase in impervious area or changes to hydrology that increase the discharge rate. This criterion, as defined in Chapter 4 of this Manual, is not based on a pre versus post development comparison. However, in a redevelopment project this requirement is relaxed. If the hydrology and hydraulic study shows that the post construction 1-year 24 hour discharge rate and velocity remains below the pre-construction discharge rate, 24 hour detention for the 1-year storm to meet the channel protection criteria will not be necessary.

III- If the redevelopment results in an **increase in the total impervious area** and subsequently increased discharge rate, apply **quantity controls** for the increased discharge. If the redevelopment results in modified hydrology or flow due to discharge to other sub-watersheds, slope change, direct channelization, curb-line modification, etc., apply **quantity controls** for the increased discharge.

B. Water Quality Treatment Objective can be achieved using the following options, which at minimum must be equal to the existing treatment system:

I- The plan proposes a reduction of impervious cover by a minimum of 25% of the existing total site impervious area. A reduction in site imperviousness will reduce the volume of stormwater runoff, thereby achieving, at least in part, stormwater criteria for both water quality and quantity. The final grading of the site should be planned to minimize runoff contribution from new pervious area onto the impervious cover. Some alternative practices are acceptable means of providing impervious cover reduction, as explained in the profile sheets.

II- The plan proposes that a minimum of 25 % of the water quality volume (WQv) from the **disturbed area** is captured and treated by the implementation of standard practices. For all sites that utilize structural stormwater management practices, these practices should be targeted to treat areas with the greatest pollutant generation potential (e.g. parking areas, service stations, etc.). If redevelopment results in the creation of additional impervious area, treatment would be required for 25% of the existing impervious area, plus 100% of the additional impervious area. As with design of any practice, sizing of structures should be based on all areas contributing to the stormwater management practice**.** Redevelopment, which reconstructs a portion of the site, may choose diversion or flow splitters to be able to size the control structures for the reconstructed area only.

III- The plan proposes the use of alternative practices to treat 75 % of the water quality volume from the disturbed area as well as any additional runoff from tributary areas that are not within the disturbed area. The use of alternative practices is discussed in Section 9.3.3 of this chapter. The alternative practices in Table 1 are effective when site impervious cover is broken up in diffuse treatment areas that can be managed by these practices. The sizing criteria presented in the profile sheets provide a means of quantifying this effect in terms of water quality volume or impervious cover reduction.

IV- The plan proposes a combination of impervious cover (IC) reduction and standard or alternative practices that provide a weighted average of at least two of the above methods. The plan may provide a combination of the above options using the following calculation:

(25 - (% IC reduction + % WQv treatment by Standard practice)) * 3 = %WQv treatment by Alternative practice

For example, water quality volume for the alternative practice for the following scenarios can be computed as follows:

5% IC reduction, 20% Standard practice, 0% Alternative practice
5% IC reduction, 0% Standard practice, 60% Alternative practice
0% IC reduction, 10% Standard practice, 45% Alternative practice
5% IC reduction, 15% Standard practice, 15% Alternative practice

Section 9.3.3 Performance Criteria

The practices described in this chapter are to be used for redevelopment projects only. If a site meets the eligibility requirements for alternative practices referenced in this chapter, then the applicant may select from a list of practices outlined in this chapter and described in detail in the following profile sheets. These practices are collectively referred to as “alternative stormwater practices” and include the following:

Rain gardens
Cisterns
Green roofs
Stormwater planters
Permeable paving (including modular block)
Select proprietary products (hydrodynamic practices, etc.)

It should be noted that these practices differ (except porous pavement and proprietary products) from the non-standard or supplemental practices listed in Section 5.2 of the Manual. The non-standard practices in Section 5.2 are primarily meant for pretreatment or water quantity control purposes. By contrast, the alternative stormwater practices represent a group of practices that recently have been receiving a lot of attention in the field of stormwater management. By and large, these practices have associated research that indicates they have water quality benefits that begin to approach the water quality performance criteria identified in Chapter 5 of the Manual. However, research is limited to only a handful of studies, which lends enough uncertainty to not want to consider these practices as standard practices at this time.

Section 9.4 How to Apply Alternative Stormwater Practices

Meeting water quality control criteria in redevelopment scenarios is achieved by applying the sizing criteria in Section 9.3.2 to one of the alternative practices in Section 9.3.3.

For practices such as rain gardens, cisterns, some stormwater planters, and proprietary practices, where runoff from impervious areas are directed to the practice for treatment, a sizing approach based on impervious area treated is used. For example, a cistern that captures and manages runoff from a 1,000 square foot roof should be sized to be able to capture and temporarily hold the water quality volume (WQv) from that area to meet the total required water quality volume. Runoff that results from contributing areas must be addressed by additional measures if necessary.

In addition to meeting water quality performance goals, proprietary practices must be sized to capture and treat the WQv resulting from the contributing drainage area depending on whether it uses a volume-based or a rate-based sizing approach. For practices with a volume-based sizing approach, the practice must be sized to capture and treat 75 % of the WQv as defined in Chapter 4 of the Manual. For flow through practices, the practice must be sized to treat the peak rate of runoff as defined in Chapter 4 and Appendix B of this Manual. For off-line practices, the installation must include flow diversion that protects the practice from exceeding design criteria.

Section 9.5 Alternative Stormwater Management Practices Profile Sheets

Profile sheets follow that provide information on the practices listed in Section 9.3.3, including:

Practice Description
Recommended Application of the Practice
Benefits
Feasibility/Limitations of Practice
Sizing and Design Guidance
Environmental/Landscaping Considerations
Maintenance
Cost
References

Section 9.5.1 Alternative Stormwater Management Practices Rain Gardens

Description

The rain garden is a stormwater management practice to manage and treat small volumes of stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. They are most commonly used in residential land use settings. The method is a variation on bioretention and combines physical filtering and adsorption with bio-geochemical processes to remove pollutants. Rain gardens are typically smaller than bioretention and are generally designed as a more passive filter system without an underdrain connected to the stormdrain system, although a gravel filter bed is recommended. Rainwater is directed into the garden from residential roof drains, driveways and other hard surfaces. The runoff temporarily ponds in the garden and seeps into the soil over several days. The system consists of an inflow component, a shallow ponding area over a planted soil bed, a mulch layer, a gravel filter chamber, plant materials consisting of attractive shrubs, grasses and flowers, and an overflow mechanism to convey larger rain events to the storm drain system (see Figure 1) or receiving waters.

Recommended Application of the Practice

The rain garden is suitable for townhouse and single family residential applications where it is used to treat small storm runoff from residential rooftops, driveways, and sidewalks. Rain gardens can be utilized in residential redevelopment projects, including townhouse projects, and in some institutional settings such as schoolyard projects. Since rain gardens do not need to be tied directly into the stormdrain system, they can be used to treat areas that may be difficult to otherwise address due to inadequate head or other grading issues. Rain gardens are designed as an “exfilter,” allowing rainwater to slowly seep through the soil. They have a prepared soil mix and should be designed with a deeper gravel chamber to improve treatment volume, and to compensate for clays and fines washing into the area. They are typically 150 - 300 square feet for a residential area. Rain gardens can be integrated into a site with a high degree of flexibility and work well in combination with other structural management systems, including porous pavement, infiltration trenches, and swales.

http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_075.cfm

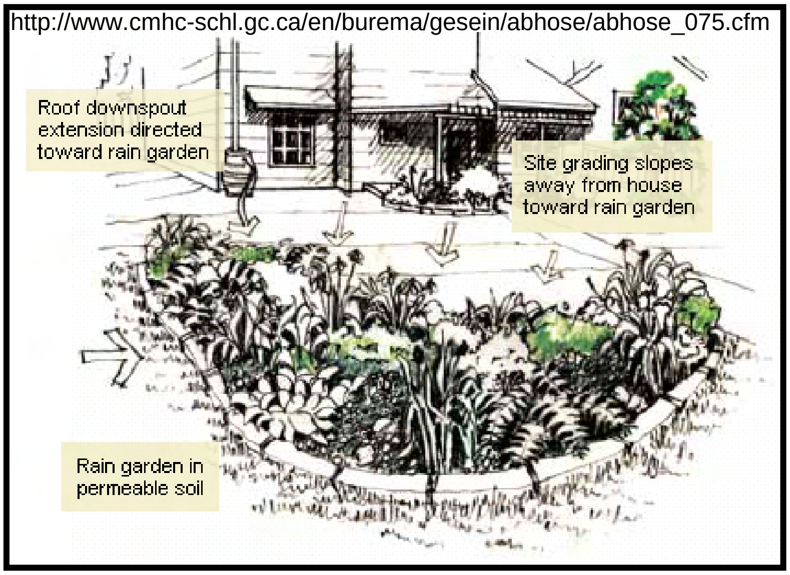

Figure 1: Layout of a typical rain garden

Benefits

Rain gardens can have many benefits when applied to redevelopment and infill projects in urban settings. The most notable include:

- Effective pollutant treatment for residential rooftops and driveways, including solids, metals, nutrients and hydrocarbons
- Groundwater recharge augmentation
- Micro-scale habitat
- Aesthetic improvement to turfgrass or otherwise hard urban surfaces (Figure 2)
- Ease of maintenance, coupling routine landscaping maintenance with effective stormwater management control
- Promotion of watershed education and stewardship


http://www.urbanwaterquality.org/RainGardens/rgindex1.htm

Figure 2: Rain gardens also have aesthetic value.

Feasibility/Limitations

Rain gardens have some limitations, similar to bioretention, that restrict their application. The most notable of these include:

- Steep slopes. Rain gardens require relatively flat slopes to be able to accommodate runoff filtering through the system. Some design modifications can address this constraint through the use of berms and timber or block retaining walls on moderate slopes.

- Compacted and clay soils. Soils compacted by construction and heavy clay soils need more augmentation than sandy soils, though all soils should be prepared to specification. In compacted soils and clay, additional excavation is necessary, along with a gravel bed and, under some circumstances, an underdrain system.

- A single rain garden system should be designed to receive sheet flow runoff or shallow concentrated flow from an impervious area or from a roof drain downspout with a drainage area equal to or less than 1,000 square feet. Because the system works by filtration through a planting media, runoff must enter at the surface.

- The rain garden must be sited in a location that allows overflow from the area to sheet flow or be otherwise safely conveyed to the formal drainage system. Rain gardens should be located downgradient and at least 10 feet from basement foundations.

- Rain gardens require a modest land area to effectively capture and treat residential runoff from storms up to approximately the 1-inch precipitation event.

- Rain gardens should not be located in areas with heavy tree cover, as the root systems will make installation difficult and may be damaged by the excavation.

Sizing and Design Guidance

Stormwater quantity reduction in rain gardens occurs via evaporation, transpiration, and infiltration, though only the infiltration capacity of the soil and drainage system is considered for water quality sizing. The storage volume of a rain garden is achieved within the gravel bed, soil medium and ponding area above the bed. The size should be determined using the water quality volume (WQv), where the site area is the impervious area draining to the rain garden. The following sizing criteria should be followed to arrive at the surface area of the rain garden, based on the required WQv:

$$WQv \leq V_{SM} + V_{DL} + (D_P \text{ x } A_{RG})$$

$$V_{SM} = A_{RG} \text{ x } D_{SM} \text{ x } n_{SM}$$

$$V_{DL} \text{ (optional)} = A_{RG} \text{ x } D_{DL} \text{ x } n_{DL}$$

where:
V_{SM} = volume of the soil media [cubic feet]
V_{DL} = volume of the drainage layer [cubic feet]
A_{RG} = rain garden surface area [square feet]
D_{SM} = depth of the soil media, typically 1.0 to 1.5 feet [feet]
D_{DL} = depth of the drainage layer, typically .05 to 1.0 feet [feet]
D_P = depth of ponding above surface, maximum 0.5 feet [feet]

n_{SM} = porosity of the soil media (≥20%)
n_{DL} = porosity of the drainage layer (≥40%)
WQv = Water Quality Volume [cubic feet], as defined in Chapter 4 of the New York Stormwater Management Design Manual

A simple example for sizing rain gardens based upon WQv is presented in Table 1.

Table 1: Rain Garden Simple Sizing Example

Given a 1,000 square foot impervious drainage area (e.g., rooftop), a rain garden design has been proposed with a 200 square foot surface area, a soil layer depth of 12 inches, a drainage layer depth of 6 inches, and an allowable ponding depth of 3 inches. Evaluate if the proposed rain garden design satisfies site WQv requirements

Step 1: Calculate water quality volume using the following equation:

$$\text{WQv} = \frac{(P)\,(Rv)\,(A)}{12}$$

where:

P = 90% rainfall number = 0.9 in

Rv = 0.05+0.009 (I) = 0.05+0.009(100) = 0.95

I = Percentage impervious area draining to site = 100%

A = Area draining to practice (treatment area) = 1,000 ft^2

$$\text{WQv} = \frac{(0.9)(0.95)(1{,}000)}{12} \qquad \text{WQv} = 71.25\ ft^3$$

Step 2: Solve for drainage layer and soil media storage volume:

$V_{SM} = A_{RG} \times D_{SM} \times P_{SM}$

$V_{DL} = A_{RG} \times D_{DL} \times P_{DL}$

where:

A_{RG} = proposed rain garden surface area = 200 ft^2

D_{SM} = depth soil media = 12 inches = 1.0 ft

D_{DL} = depth drainage layer = 6 inches = 0.5 ft

P_{SM} = porosity of soil media = 0.20

P_{DL} = porosity of drainage layer = 0.40

$V_{SM} = 200\ ft^2 \times 1.0\ ft \times 0.20 = 40\ ft^3$

$V_{DL} = 200\ ft^2 \times 0.5\ ft \times 0.40 = 40\ ft^3$

D_P = ponding depth = 3 inches = 0.25 ft

$\text{WQv} \le V_{SM}+V_{DL}+(D_P \times A_{RG}) = 40\ ft^3 + 40\ ft^3 + (0.25\ ft \times 200\ ft^2)$

$\text{WQv} = 71.25\ ft^3 \le 130.0\ ft^3$, OK

Therefore, the proposed design for treating an area of 1,000 ft^2 satisfies the WQv requirements .

Siting Rain gardens should be located within approximately 30 feet of the downspout or impervious area treated. Rooftop conveyance to the rain garden is through roof leaders directed to the area, with stone or splash blocks placed at the point of discharge into the rain garden to prevent erosion. Runoff from driveways and other paved surfaces should be directed to the rain garden at a non-erosive rate through shallow swales, or allowed to sheet flow across short distances (Figure 3).


http://www.metrocouncil.org/directions/water/MEPgrantsOct03.htm

Figure 3: This rain garden treats road and driveway runoff.

Sizing The following considerations should be given to design of the rain garden (after PA Stormwater Design Manual, Bannerman 2003 and LID Center):

- Ponding depth above the rain garden bed should not exceed 6 inches. The recommended maximum ponding depth of 6 inches provides surface storage of stormwater runoff, but is not too deep to affect plant health, safety, or create an environment of stagnant conditions. On perfectly flat sites, this depth is achieved through excavation of the rain garden and backfilling to the appropriate level; on sloping sites, this depth can be achieved with the use of a berm on the downslope edge, and excavation/backfill to the required level.

- Surface area is dependent upon storage volume requirements but should not exceed a maximum loading ratio of 5:1 (drainage area to infiltration area, where drainage area is assumed to be 100% impervious; to the extent that the drainage area is not 100% impervious, the loading ratio may be modified)

- A length to width ratio of 2:1, with the long axis perpendicular to the slope and flow path is recommended.

Soil The composition of the soil media should consist of 50% sand, 20-30% topsoil with less than 5% clay content, and 20-30% leaf compost. The depth of the amended soil should be approximately 4 inches below the bottom of the deepest root ball.

Construction Rain gardens should initially be dug out to a 24" depth, then backfilled with a 6 - 10 inch layer of clean washed gravel (approximately 1.5-2.0 inch diameter rock), and filled back to the rain garden bed depth with a certified soil mix.

Environmental/Landscaping Elements

The rain garden system relies on a successful native plant community to stabilize the ponding area, promote infiltration, and uptake pollutants (Figure 2). To do that, plant species need to be selected that are adaptable to the wet/dry conditions that will be present. The goal of planting the rain garden is to establish an attractive planting bed with a mix of upland and wetland native shrubs, grasses and herbaceous plant material arranged in a natural configuration starting from the more upland species at the outer most zone of the system to more wetland species at the inner most zone. Plants should be container grown with a well established root system, planted on one foot centers. Table 2 provides a representative list of possible plant selections. Rain gardens should not be seeded as this takes too long to establish the desired root system, and seed may be floated out with rain events. The same limitation is true for plugs. Shredded hardwood mulch should be applied up to 2” to help keep soil in place.

Table 2: Suggested Plant List

Shrubs	**Herbaceous Plants**
Witch Hazel *Hamemelis virginiana*	Cinnamon Fern *Osmunda cinnamomea*
Winterberry *Ilex verticillata*	Cutleaf Coneflower *Rudbeckia laciniata*
Arrowwood *Viburnum dentatum*	Woolgrass *Scirpus cyperinus*
Brook-side Alder *Alnus serrulata*	New England Aster *Aster novae-angliae*
Red-Osier Dogwood *Cornus stolonifera*	Fox Sedge *Carex vulpinoidea*
Sweet Pepperbush *Clethra alnifolia*	Spotted Joe-Pye Weed *Eupatorium maculatum*
	Switch Grass *Panicum virgatum*
	Great Blue Lobelia *Lobelia siphatica*
	Wild Bergamot *Monarda fistulosa*
	Red Milkweed *Asclepias incarnata*

Adapted from NYSDM Bioretention Specifications, Bannerman, Brooklyn Botanic Garden.

Maintenance

Rain gardens are intended to be relatively low maintenance. Weeding and watering are essential the first year, and can be minimized with the use of a weed free mulch layer. Rain gardens should be treated as a component of the landscaping, with routine maintenance provided by the homeowner or homeowners’ association, including the occasional replacement of plants, mulching, weeding and thinning to maintain the desired appearance. Homeowners and landscapers should be educated regarding the purpose of the rain garden, so the desirable aspects of ponded water are recognized and maintained.

Cost

The cost of a rain garden is typically $10-$12 dollars per square foot of surface area (Bannerman 2003).

References

Bannerman, Roger. 2003. Rain Gardens, A How-to Manual for Homeowners. University of Wisconsin. PUB-WT-776.

Brooklyn Botanic Garden. 2004.Using Spectacular Wetland Plantings to Reduce Runoff.

Low Impact Development Center, Inc. (LID)
http://www.lid-stormwater.net/intro/sitemap.htm#permpavers

Pennsylvania Stormwater Best Management Practices Manual. Draft 2005.

Section 9.5.2 Alternative Stormwater Management Practices Cisterns

Description

Cisterns capture and store stormwater runoff to be used later for irrigation systems or filtered and reused for household activities such as toilet flushing and clothes washing. Cisterns can be constructed of any water-retaining material and their size can vary from hundreds of gallons for residential uses to tens of thousands of gallons for commercial and/or industrial uses. They can be located either above or below ground and can be constructed on-site or pre-manufactured.

The basic components of a cistern include: a secure cover, a leaf/mosquito screen, a coarse inlet filter with clean-out valve, an overflow pipe, a manhole or access hatch, a drain for cleaning, and an extraction system (tap or pump). Additional features might include a water level indicator, a sediment trap, or an additional tank for extra storage volume.

Recommended Application of the Practice

Cisterns can be used in most areas (residential, commercial, and industrial; Figure 1) due to their minimal site constraints relative to other stormwater management practices. They can be applied to manage almost every land use type from very dense urban to more rural residential areas. The sizes of cisterns are directly proportional to their contributing drainage areas and intended use.

http://www.lid-stormwater.net/raincist/raincist_benefits.htm

Copyright Prakash Patel, 2001

Figure 1: Cisterns can be designed for smaller residential uses (left) or for large business operations (right).

Benefits

Cisterns provide many stormwater management benefits, among them:

- Cisterns can reduce stormwater runoff volumes, and delay and reduce peak runoff flow rates.

- Stored water from cisterns can help reduce water consumption, which ultimately reduces the demand on municipal water systems. Water from cisterns can be used for irrigation or other non-potable uses.

- Cisterns can also be used in urban redevelopment scenarios to reduce runoff volumes in areas where soils are compacted, groundwater levels are high or hot-spot conditions exist that preclude infiltration.

Feasibility/Limitations

The biggest limitation to the installation and use of cisterns to capture and reuse stormwater is the need for active management/maintenance and initial capital cost. Generally, the ease and efficiency of municipal water supply systems and the low cost of water prevent people from implementing on-site water conservation and reuse systems. Specific limitations include:

- Cisterns require periodic maintenance and cleaning to ensure effective stormwater treatment. If water from a cistern is intended for non-potable household use, adequate design and maintenance on the part of the homeowner are necessary to ensure all water is appropriately treated before use.

- A supplementary water source may be needed if water captured in a cistern does not fulfill the intended water demand. Alternatively if captured water is not used as anticipated, the extra water entering the cistern will need to be managed to prevent overtopping.

- To achieve significant community wide acceptance, an active community education program and a high profile public site demonstration will likely be necessary.

- In cold climates specific design or maintenance strategies will need to be considered to prevent freezing such as providing insulation or disconnecting the system.

Sizing and Design Guidance

Depending on the intended use, cistern sizing is a function of the impervious area that drains to the device and the amount of water required for the reuse activity (e.g., laundry or toilet flushing). The basic equation for sizing a cistern based on the contributing area is as follows:

$\text{Vol} = \text{WQv} * 7.5\ \text{gals/ft}^3$

where:
Vol = Volume of cistern [gallons]
WQv = Water Quality Volume [cubic feet], as defined in Chapter 4 of the New York Stormwater Management Design Manual
7.5 = Conversion factor [gallons per cubic foot]

A simple example for sizing cisterns using WQv is presented in Table 1.

Table 1: Simple Cistern Sizing Example

Given a 3,000 square foot impervious surface area draining to a cistern, calculate the water quality volume and required cistern volume.

Step 1: Calculate water quality volume using the following equation:

$$WQv = \frac{(P)(Rv)(A)}{12}$$

where:

P = 90% rainfall number = 0.9 in

Rv = 0.05+0.009 (I) = 0.05+0.009(100) = 0.95
I = the percentage of impervious area draining to site = 100%

A = the Area Draining to Practice = 3,000 ft^2

$$WQv = \frac{(0.9)(0.95)(3,000)}{12} \qquad WQv = 213.75\ ft^3$$

Step 2: Calculate cistern volume using equation above: Vol = (WQv) (7.5 gals/ft^3)

Vol = WQv x 7.5 gals/ft^3

Vol = 1603 gal

Therefore, to treat the water quality volume for the area draining to the practice, a 1,650-gallon cistern is required.

Siting

A cistern can be located beneath a single downspout or one large cistern can be located such that it collects stormwater from several sources. Due to the size of rooftops and the amount of contributing impervious area, increased runoff volume and peak discharge rates for commercial and industrial sites may require large capacity cisterns. Cisterns designed to capture small, frequent storm events need to be either actively or passively drained to provide storage for subsequent storm events or located in an area where overflow runoff can be conveyed to a suitable area such as open yard, swale, a rain garden or the storm drain system.

In cold climates where cisterns are designed for use throughout the year, cisterns placed on the ground require extra insulation on the exposed surfaces (Stensrod, *et al*., 1989). For cisterns placed on rock, the bottom surface will also need to be insulated. For underground systems it may be cost-prohibitive to place the cistern below the freezing depth, so alternatively, insulation can be placed below the surface and above the underground cistern to prevent freezing. Other methods to prevent freezing include lining the intake pipe and cistern with heat tape and closing the overflow valve (Stensrod, *et al*., 1989). Water levels should also be lowered at the beginning of winter to prevent possible winter damage and provide needed storage for spring snow melt.

Environmental/Landscaping

An effort should be made to meet property owners' preferences in providing attractive above ground cisterns. The likelihood of continued use of the cistern is increased if they are an attractive part of the landscape (Figure 3). Landscaping should be used to shade cisterns to reduce algae growth and to provide visual screening.

Maintenance

Maintenance requirements for cisterns vary depending on if the water will be used domestically or only for irrigation. Depending on the design and use of the cistern, winterization maintenance may also be necessary. Generally, cisterns inspections should be conducted semi-annually and the following components inspected and either repaired or replaced as needed:


http://www.terrain.org/essays/16/calhoun.htm

Figure 3: Cisterns can be incorporated into the overall landscaping of the site.

- Roof catchments should be inspected to ensure that no particulate matter or other parts of the roof are entering the gutter and downspout to the cistern.
- Gutters and downspouts should be inspected to ensure that no leaks or obstructions are occurring.
- Roof washers, cleanout plugs, screens, covers, and overflow pipes should be inspected and replaced as needed.
- Inspections should also include inflow and outflow pipes as well as any accessories, such as sediment traps.

Cost

The cost for cisterns can vary greatly depending on its size, material and location (above or below ground). Costs range from a low of about $0.50 per gallon for large fiberglass tanks to up to $4.00 per gallon for welded steel tanks (TWDB, 2005). The following are representative costs for pre-manufactured cisterns, not including labor and accessory costs (Table 2).

Table 2: Cost Guide – Pre-manufactured Cisterns (LID Center)

Material	Cost (small system)	Cost (large system)
Galvanized Steel	$225 for 200 gallons	$950 for 2,000 gallons
Polyethylene	$160 for 165 gallons	$1,100 for 1,800 gallons
Fiberglass	$660 for 350 gallons	$10,000 for 10,000 gallons
Fiberglass/Steel Composite	$300 for 300 gallons	$10,000 for 5,000 gallons

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The Urban Garden Center (UGC) http://www.urbangardencenter.com/products/rainbarrel/index.html

Section 9.5.3 Alternative Stormwater Management Practices Green Roofs

Description

Green roofs consist of a layer of vegetation and soil installed on top of a conventional flat or sloped roof (Figure 1). The rooftop vegetation captures rainwater allowing evaporation and evapotranspiration processes to reduce the amount of runoff entering downstream systems, effectively reducing stormwater runoff volumes and attenuating peak flows. There are two types of green roof designs, *extensive* and *intensive*. *Extensive* green roofs have a thin soil layer so are lighter, less expensive, and generally require low maintenance. *Intensive* green roofs often have pedestrian access and are characterized by a deeper soil layer with greater weight, higher capital cost, increased plant diversity, and more maintenance requirements.

The general components of any green roof system include a:

- roof structure capable of supporting the weight of a green roof system
- waterproofing system designed to protect the building and roof structure;
- drainage layer consisting of a porous media capable of water storage for plant uptake
- a geosynthetic layer to prevent fine soil media from clogging the porous media
- soil with appropriate characteristics to support selected green roof plants
- plants with appropriate tolerance for harsh rooftop conditions and shallow rooting depths.

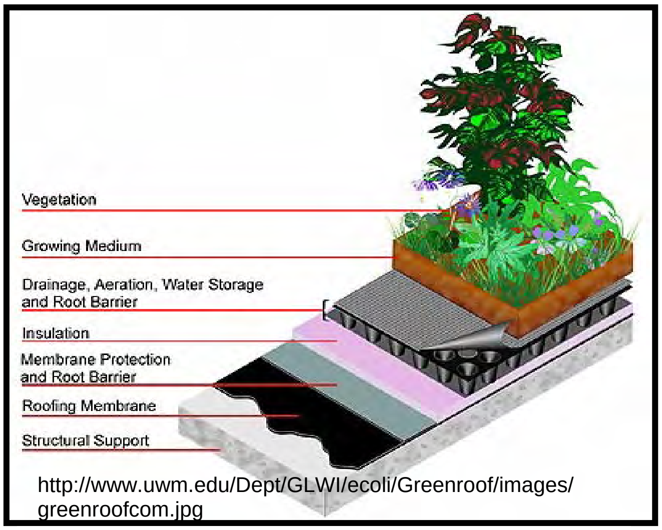

http://www.fcwc.org/WEArchive/010203_wbj/rain.htm

Figure 1: Green roof installed on a sloped roof

Figure 2 is a schematic of the various layers included in a typical green roof system.

Recommended Application of Practice

Green roofs are suitable for retrofit or redevelopment projects as well as new buildings, and can be installed on small garages or larger industrial, commercial and municipal buildings. Green roofs present an above ground management alternative when the on-site space availability for stormwater practices is limited. Green roofs can be installed on flat roofs or on roofs with slopes up to 30% provided special strapping and erosion control devices are used (Peck and Kuhn, 2003). Generally, extensive green roofs can be built on flat or sloped roofs; where as intensive systems are built on flat or tiered roofs.



http://www.uwm.edu/Dept/GLWI/ecoli/Greenroof/images/greenroofcom.jpg

Figure 2: Green roof layers

Green roofs are most effective in reducing runoff volume and rates for land uses with high percentages of rooftop coverage such as commercial, industrial and multifamily housing (Stephens *et al.*, 2002). Green roofs on lots with approximately 70% impervious area have been shown to retain as much as 80% of the total annual runoff in regions with low total annual rainfall and 30% in areas with high total annual rainfall (Stephens *et al.*, 2002), which likely brackets the range of performance likely to be observed in New York State.

Benefits

Green roofs reduce runoff volumes and delay peak flows while providing a number of other benefits to the urban environment, private building owners, and the public. The most notable include:

- Green roofs help achieve stormwater management goals by reducing total annual runoff volumes (Roofscapes, Inc., 2005).

- The layers of soil and vegetation on the rooftop moderate interior building temperatures, and provide insulation from the heat and cold. As a result the amount of energy required to heat and cool the building is reduced, providing energy savings to the owner. The increased insulation reduces HVAC infrastructure requirements, and therefore building construction costs.

- The additional rooftop insulation protects rooftop materials from ultraviolet radiation and extreme temperature fluctuations, which deteriorates standard roofing materials. It is estimated that green roofs can extend the life of a roof by as long as 20 years (Velazquez, 2005).

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

- Fully saturated green roofs can provide fire resistance and inhibit the spread of fire from adjacent buildings.

- Green roofs reduce the urban heat island effect by cooling and humidifying the surrounding air.

- Green roofs help filter and bind airborne dust and other particulates, improving air quality (Barr Engineering Company, 2003).

- The additional rooftop vegetation within an urban or suburban environment creates habitat for birds and butterflies.

- With thoughtful design, green roofs can be aesthetically pleasing and improve views from neighboring buildings as illustrated in Figure 3, with a high-rise residential building in Manhattan.

- A benefit specific to extensive green roofs is pedestrian access to a scenic space within an urban environment (Figure 4).


Photo courtesy of Cesar Pelli & Associates

Figure 3: A green roof installed on an apartment building in Manhattan along the Hudson River.

Figure 4: Extensive roofs increase aesthetics in the urban environment.

Feasibility/Limitations

The primary limitation to the implementation of green roofs is increased design and construction costs. Green roof designs need to include any structural requirements necessary to support the additional weight of soil, vegetation, and possibly pedestrians. For retrofit projects, a licensed structural engineer or architect must conduct a structural analysis of the existing structure, which will dictate the type of green rooftop system and any necessary structural reinforcement. Other limitations include:

- Damage to or failure of waterproofing elements present a risk of causing water damage. However, similar to traditional roof installations, a warranty can help guarantee that any damage to the water proofing system will be repaired.

- Extreme weather conditions can impact plant survival.

- Green roof maintenance is higher than for traditional roofs.

- The need to provide safe access to the rooftop for construction and maintenance.

- Supplemental irrigation during the first year may be necessary to establish vegetation, and a long-term supplemental irrigation system may be required for some intensive systems.

- In cold climates, snow loads need to be accounted for when determining the structural capacity required to install a green roof system.

- In many building designs it will likely be more feasible to incorporate an extensive green roof design versus an intensive system.

Sizing and Design Guidance

Green roofs can be counted as pervious area that can be applied towards meeting the total impervious cover reduction target for redevelopment sites that can be accepted as a deviation from the technical standards. Simple sizing calculations can also be made to check the actual storage volume provided by a proposed green roof design. The following sizing guidelines are based upon providing a stormwater treatment volume equal to the New York Unified Stormwater Sizing Criteria for water quality volume. Stormwater treatment in green roofs occurs via evaporation, transpiration, and filtration. A simplified (and conservative) approach to estimating the volume of water that can be effectively managed and treated by a green roof system is outlined below and based on an instantaneous volume that can be stored in the soil media, drainage layer, and surface ponding area together.

$$\mathrm{WQv} \leq V_{SM} + V_{DL} + (D_P \times A_{GR})$$

$$V_{SM} = A_{GR} \times D_{SM} \times n_{SM}$$

$$V_{DL} = A_{GR} \times D_{DL} \times n_{DL}$$

where:
V_{SM} = volume of the soil media [cubic feet]
V_{DL} = volume of the drainage layer [cubic feet]
A_{GR} = green roof surface area [square feet]
D_{SM} = depth of the soil media [feet]
D_{DL} = depth of the drainage layer [feet]
D_P = depth of ponding above surface [feet]
n_{SM} = porosity of the soil media (~20%)
n_{DL} = porosity of the drainage layer (~25%)
WQv = Water Quality Volume [cubic feet], as defined in Chapter 4 of the New York Stormwater Management Design Manual

A simple example for sizing green roofs based on WQv is presented in Table 1.

Table 1: Simple Green Roof Sizing Example

A green roof has been designed for a 1,100 square foot rooftop. The proposed system has a 900 square foot surface area, a 3 inch soil media layer, and a 2 inch drainage layer. Given the proposed design, evaluate if the proposed green roof design satisfies site WQv requirements:

Step 1: Calculate water quality volume using the following equation:

$$WQv = \frac{(P)(Rv)(A)}{12}$$

where:

P = 90% rainfall number = 0.9 in

$Rv = 0.05+0.009\ (I) = 0.05+0.009(100) = 0.95$
I = the percentage of impervious area draining to site = 100%

A = area draining to practice = 1,100 ft^2

$$WQv = \frac{(0.9)(0.95)(1{,}100)}{12}$$

$WQv = 78.4\ ft^3$

Step 2: Calculate the drainage layer and soil media storage volume:

$V_{SM} = A_{GR} \times D_{SM} \times P_{SM}$

$V_{DL} = A_{GR} \times D_{DL} \times P_{DL}$

where:

A_{GR} = green roof surface area = 900 ft^2

D_{SM} = depth soil media = 3 inches = 0.25 ft

D_{DL} = depth drainage layer = 2 inches = 0.17 ft

P_{SM} = porosity of soil media = 0.20

P_{DL} = porosity of drainage layer = 0.25

$V_{SM} = 900\ ft^2 \times 0.25\ ft \times 0.20 = 45.0\ ft^3$

$V_{DL} = 900\ ft^2 \times 0.17\ ft \times 0.25 = 38.25\ ft^3$

D_P = ponding depth = 0.5 inches = 0.04 ft

$WQv \leq V_{SM}+V_{DL}+(D_P \times A_{GR}) = 45.0\ ft^3 + 38.25\ ft^3 + (0.04\ ft \times 900\ ft^2)$

$WQv = 78.4\ ft^3 \leq 119.25\ ft^3$, OK

Therefore, the proposed design satisfies the WQv requirements.

Each green roof project is unique, given the purpose of the building, its architecture and the preferences of its owner and end user. However, several key design features should be kept in mind during the design, of any green rooftop systems.

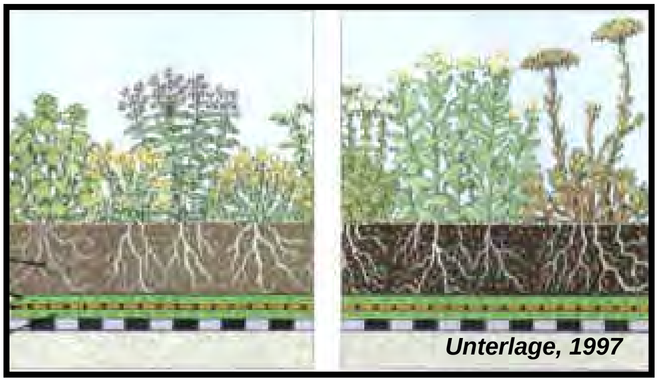


Figure 5: Extensive Cross-Section

Extensive systems are characterized by low weight, lower capital cost, and minimal plant diversity (Figure 5). The growing medium is usually a mixture of sand, gravel, crushed brick, peat, or organic matter combined with soil. The soil media ranges between two and six inches in depth and increases the roof load by 16 to 35 pounds per square foot when fully saturated. Since the growing medium is shallow and the microclimate is harsh, plant species used in extensive systems should be low and hardy, which typically involves alpine, arid, or indigenous species.

Intensive systems have a deeper soil layer and a corresponding greater weight (Figure 6). The growing medium is often soil based and ranges in depth from eight to 24 inches, with a saturated roof loading of between 60 and 200 pounds per square foot. Designers can use a diverse range of trees, shrubs and groundcover because the deeper growing medium allows longer root systems. This allows the designer to develop a more complex ecosystem. Both a structural engineer and an experienced installer are recommended for design and installation of intensive systems (Magco, 2003).

The four principle components of any green roof system are the roof structure, waterproofing, drainage system, and soil media. General design guidelines for each of these components are described below.

<u>*Roof Structure*</u> The load bearing capacity of the roof structure is critical for the support of soil, plants, and any people who will be accessing the green roof (for either maintenance or recreation). Generally, green roofs weighing more than 17 pounds per square foot saturated require consultation with a structural engineer (Barr Engineering, 2003). As a fire resistance measure, non-vegetative materials, such as stone or pavers should be installed around all rooftop openings and at the base of all walls that contain openings (Barr Engineering, 2003). On sloped roofs additional erosion control measures, such as cross-battens, may be necessary to stabilize drainage layers.

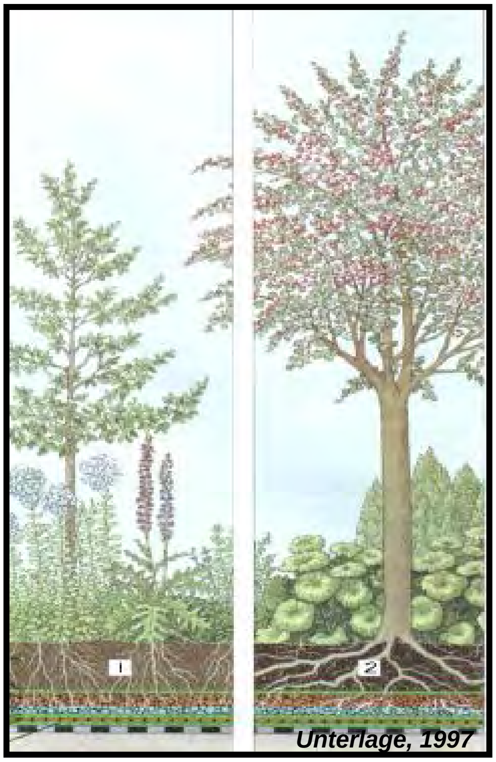


Figure 6: Intensive Cross-Section

Waterproofing In a green roof system the first layer above the roof surface is a waterproofing membrane. Two common waterproofing techniques used for the construction of green roofs are monolithic and thermoplastic sheet membranes. An additional protective layer is generally placed on top of either of these membranes followed by a physical or chemical root barrier. Once the waterproofing system has been installed it should be fully tested prior to construction of the drainage system.

Drainage System The drainage system includes a porous drainage layer and a geosynthetic filter mat to prevent fine soil particles from clogging the porous media. The drainage layer can be made up of gravels or recycled-polyethlylene materials that are capable of water retention and efficient drainage. The depth of the drainage layer depends on the load bearing capacity of the roof structure and the stormwater retention requirements. Once the porous media is saturated excess water should be directed to a traditional rooftop storm drain system. The porosity of the drainage system should be greater than or equal to 25% (Cahill Associates, 2005).

Soil The soil layer above the drainage system is the growing media for the plants in a green roof system. Soils used in green roofs are generally lighter than standard soil mixes, and consist of 75% mineral and 25% organic material (Barr Engineering, 2003), and no clay size particles. The chemical characteristics of the soil (e.g., pH, nutrients, etc.) should be carefully selected in consideration with the planting plan. The porosity of the soil layer, measured as non-capillary pore space at field capacity, should be greater than or equal to 15% (Cahill Associates, 2005).

Environmental/Landscape Elements

Plant selection for green rooftops is an integral design consideration, which is governed by local climate and design objectives. A qualified botanist or landscape architect should be consulted when choosing plant material. For extensive systems, plant material should be confined to hardier or indigenous varieties of grass and *sedum*. Root size and depth should also be considered to ensure that the plants stabilize the shallow depth of soil media. Plant choices can be much more diverse for intensive systems. The location of the roof plays an important role in the design process. The height of the roof, its exposure to wind, snow loading potential, its orientation to the sun and shading by surrounding buildings all have an impact on the selection of appropriate vegetation. It is estimated that approximately 5 years is required for a green roof to reach its optimum performance (Cahill Associates, 2005 - Draft Pennsylvania Stormwater Management Manual).

Maintenance

Green roof maintenance may include watering, fertilizing and weeding, and is typically greatest in the first two years as plants become established. Maintenance largely depends on the type of green roof system installed and the type of vegetation planted. Maintenance requirements in intensive systems are generally more costly and continuous, compared to extensive systems. The use of native vegetation is recommended to reduce plant maintenance in both extensive and intensive systems.

A green roof should be monitored after completion for plant establishment, leaks and other functional or structural concerns. Vegetation should be monitored for establishment and viability, particularly in the first two years. Irrigation and fertilization is typically only a consideration during the first year before plants are established. After the first year, maintenance consists of two visits a year for weeding of invasive species, and safety and membrane inspections (Magco, 2003).

Cost

Green roof costs are variable and have been estimated at $5.00 to $12.00 per square foot for a new green roof and $7.00 to $20.00 per square foot for a retrofit (Liptan and Strecker, 2003). Operation and maintenance costs for extensive systems are estimated to be between $1.00 to $1.60 per square foot for the first two years, and for intensive systems $1.00 to $1.60 per square foot annually (Canadian currency converted to U.S. from Peck and Kuhn, 2003). Design costs typically run five to ten percent of the total project cost and administration and site review costs are two and a half to five percent of the total project cost (Peck and Kuhn, 2003). Irrigation systems in intensive systems typically cost between $1.60 and $3.20 per square foot (Canadian currency converted to U.S. from Peck and Kuhn, 2003).

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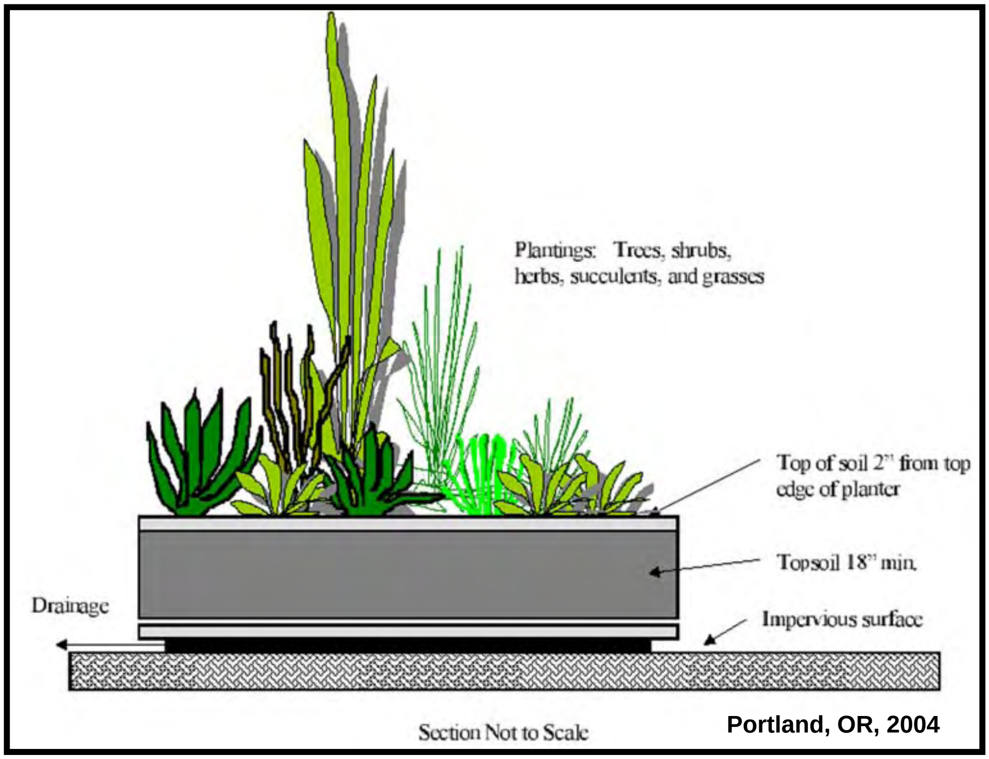
Section 9.5.4 Alternative Stormwater Management Practices Stormwater Planters

Description

Stormwater planters are small landscaped stormwater treatment devices that can be placed above or below ground and can be designed as infiltration or filtering practices. Stormwater planters use soil infiltration and biogeochemical processes to decrease stormwater quantity and improve water quality, similar to rain gardens and green roofs. Three versions of stormwater planters include contained planters, infiltration planters, and flow-through planters.

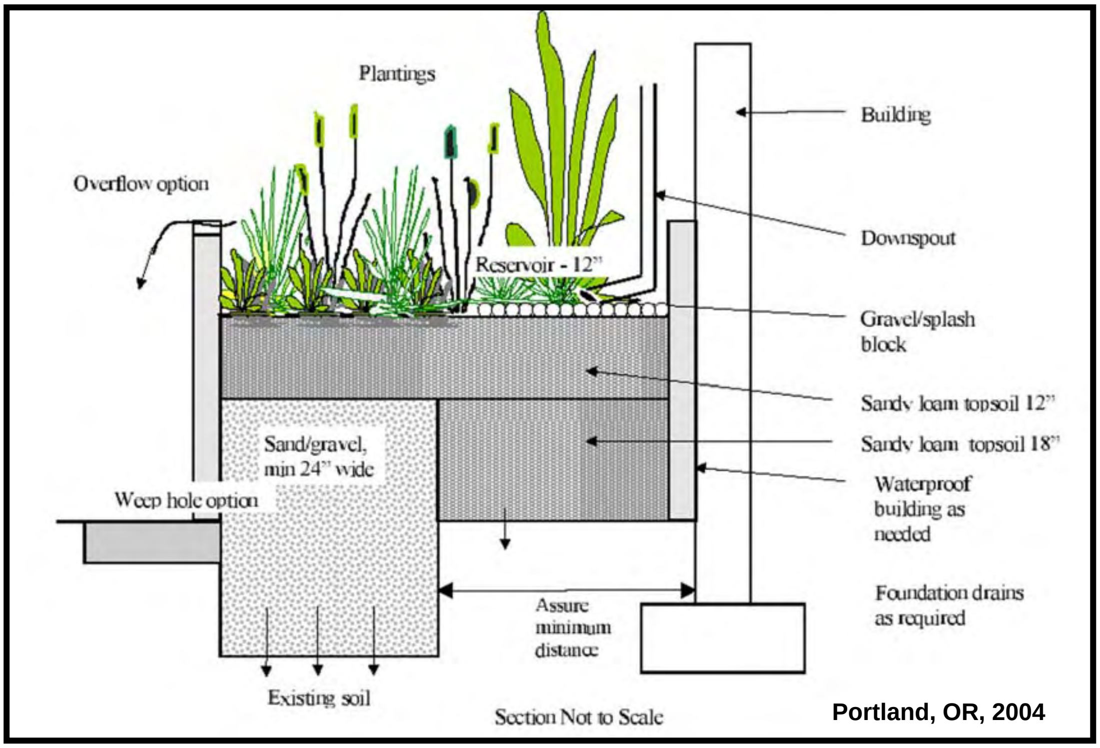
Contained planters are essentially potted plants placed above impervious surfaces (Figure 1). Stormwater infiltrates through the soil media within the container, and overflows when the void space or infiltration capacity of the container is exceeded. Infiltration planters are contained planters with a pervious bottom that allows stormwater to infiltrate through the soil media within the planter and pass into the underlying soil matrix (Figure 2). Flow-through planters are contained planters with an under drain system that conducts filtered stormwater to the storm drain system or downstream waterway (Figure 3).

All three types of stormwater planters include three common elements: planter "box" material (e.g., wood or concrete); growing medium consisting of organic soil media; and vegetation. Infiltration and flow-through planters may also include splash rock, filter fabric, gravel drainage layer, and perforated pipe.



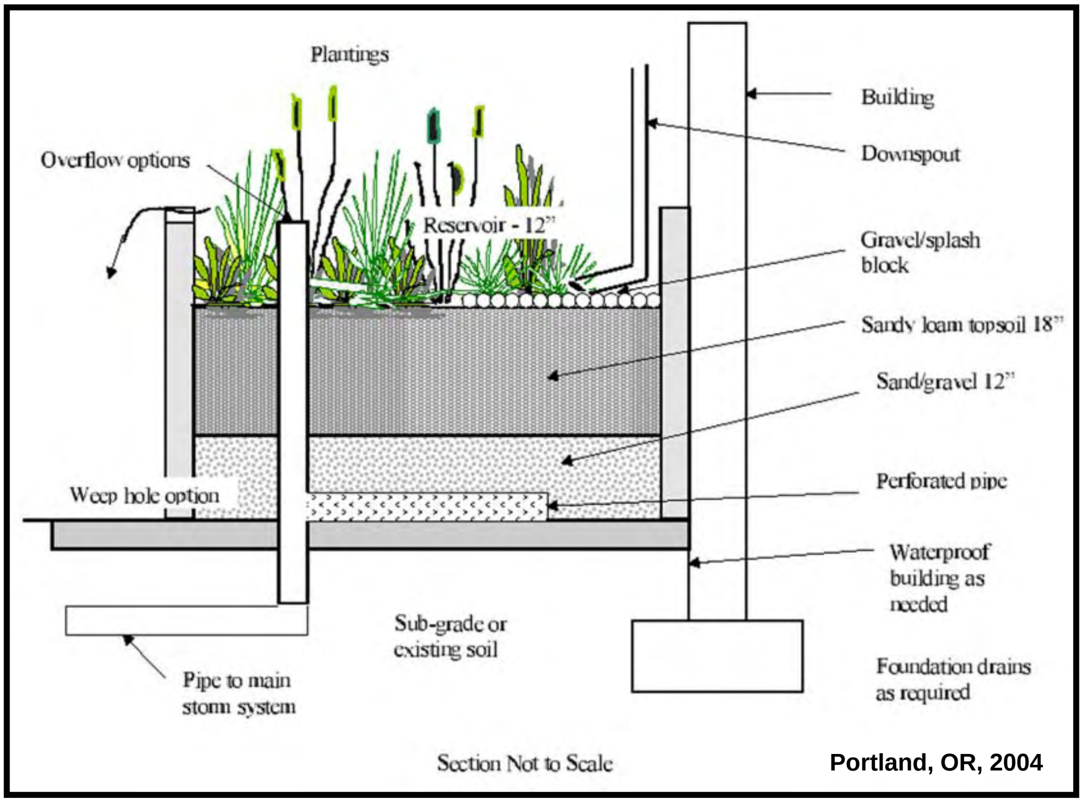
Portland, OR, 2004

Figure 1: Contained stormwater planter



Portland, OR, 2004

Figure 2: Infiltration stormwater planter



Portland, OR, 2004

Figure 3: Flow-through stormwater planter

Recommended Application of the Practice

The versatility of stormwater planters makes them uniquely suited for urban redevelopment sites. Depending on the type, they can be placed adjacent to buildings, on terraces or rooftops. Building downspouts can be placed directly into infiltration or flow-through planters; where as contained planters are designed to capture rainwater, essentially decreasing the site impervious area. The infiltration and adsorption properties of stormwater planters make them well suited to treat common pollutants found in rooftop runoff, such as nutrients, sediment and dust, and bacteria found in bird feces. Stormwater planters are most effective at treating small storm events because of their comparatively small individual treatment capacity.

Benefits

Stormwater planters provide many stormwater management benefits, among them:

- If on-site soils or a high seasonal groundwater table are not suitable for infiltration practices (e.g. rain garden or infiltration trench), flow-through or contained stormwater planters make filtration treatment possible.

- Reduction of stormwater volumes and velocities discharging from treated impervious areas.

- Flow-through or contained planters do not require a setback from a building foundation, though appropriate waterproofing technology should be incorporated into the design.

- Creates an aesthetic landscape element, as well as providing micro-habitat within an urban environment.

Feasibility/Limitations

The primary limitation to the use of stormwater planters is their size. They are by definition small-scale stormwater treatment cells that are not well suited to treat runoff from large storm events, or large surface areas. They can however be used in series or to augment other stormwater management practices. Other limitations include:

- Stormwater planters are not designed to treat runoff from roadways or parking lots and are ideally suited for treating rooftop or courtyard/plaza runoff. Flow-through and infiltration stormwater planters should not receive drainage from impervious areas greater than 15,000 square feet.

- For all three types of stormwater planters, if the infiltration capacity of the soil is exceeded, the planter will overflow. Excess stormwater needs to be directed to a secondary treatment system or released untreated to the storm drain system.

Sizing and Design Guidance

Stormwater planters should initially be sized to satisfy the WQv requirements for the impervious surface area draining to the practice. This does not apply to contained planters because they are designed to decrease impervious area, not receive additional runoff from adjacent surfaces. The basis for the sizing guidance is the same as that for bioretention (see Chapter 6 of the New York Stormwater Management Design Manual) and relies on the principles of Darcy's Law, where water is passed through porous media with a given head, a given hydraulic conductivity, over a given timeframe (Flinker, 2005). The equation for sizing an infiltration or flow-through stormwater planter based upon the contributing area is as follows:

$A_f = WQv \text{ x } (d_f)/\ [k \text{ x } (h_f + d_f)(t_f)]$

where:
A_f = the required surface area [square feet]
Vol = the treatment volume [cubic feet]
d_f = depth of the soil medium [feet]
k = the hydraulic conductivity [in ft/day, usually set at 4 ft/day, but can be varied depending on the properties of the soil media]
h_f = average height of water above the planter bed [maximum 12 inches]
t_f = the design time to filter the treatment volume through the filter media [usually set at 3 to 4 hours]
WQv = water quality volume [cubic feet], as defined in Chapter 4 of the New York Stormwater Management Design Manual

A simple example for sizing a stormwater planter using WQv is presented in Table 1. The ultimate size of a stormwater planter is a function of either the impervious area or the infiltration capacity of the media.

Table 1: Flow-through Stormwater Planter Simple Sizing Example

Determine the required surface area of a stormwater planter that will be installed to treat stormwater runoff from an impervious area of 3,000 square feet, given the depth of the soil medium is 1.5 feet.

Step 1: Calculate the WQv

$$WQv = \frac{(P)\ (Rv)\ (A)}{12}$$

where:

P = 90% rainfall number = 0.9 in

Rv = 0.05+0.009 (I) = 0.05+0.009(100) = 0.95
I = percentage impervious area draining to site = 100%

A = Area draining to practice = 3,000 ft^2

$$WQv = \frac{(0.9)(0.95)(3{,}000)}{12} \qquad WQv = 213.75\ ft^3$$

Table 1 (cont.): Flow-through Stormwater Planter Simple Sizing Example

Step 2: Calculate required surface area:

$A_f = WQv*(d_f) / [k*(h_f + d_f)(t_f)]$

where:
$WQv = 213.75 \text{ ft}^3$

d_f = depth of soil medium = 1.5 ft

k = hydraulic conductivity = 4 ft/day

h_f = height of water above planter bed = 0.5 ft

t_f = filter time = 0.17 days

$$A_f = \frac{(213.75)(1.5)}{[(4)(0.5+1.5)(0.17)]} \qquad \mathbf{A_f = 235.75\ ft^2}$$

Therefore, a 240 square foot stormwater planter with a soil medium depth of 1.5 feet will be needed to treat stormwater from a 3,000 square foot area.

There are a number of sizing, siting, and material specification guidelines that should be consulted during stormwater planter design.

Siting Flow-through and infiltration stormwater planters should not receive drainage from impervious areas greater than 15,000 square feet, and for infiltration planters should be located a minimum distance of ten feet from structures. To prevent erosion, splash rocks should be placed below downspouts or where stormwater enters the planter.

Sizing Stormwater planters should be designed to pond water for less than 12 hours, with a maximum ponding depth of 12 inches. An overflow control should redirect high flows to the storm drain system or an alternative treatment facility. Generally, flow-though and infiltration planters should have a minimum width of 1.5 and 2.5 feet, respectively.

Soil Soil specifications for the stormwater planter growing medium should allow an infiltration rate of 2 inches per hour, and 5 inches an hour for the drainage layer. The growing medium depth for all three stormwater planter types should be at least 18 inches. For infiltration and flow-through planters the drainage layer should have a minimum depth of 12 inches.

Specific considerations for the design of infiltration planters are the depth and infiltration rate of the native soil. The infiltration rate of the native soil should be a minimum of 2 inches per hour, and a minimum infiltration depth of 3 feet should be provided between the bottom of the infiltration practice and any impermeable boundaries, such as the seasonal high groundwater level. Infiltration planters should also be designed and constructed with no longitudinal or lateral slope.

Construction Materials suitable for planter wall construction include stone, concrete, brick, clay, plastic, wood, or other durable material (Figure 4). Treated wood may leach toxic chemicals and contaminate stormwater, and should not be used. Flow-through planter walls can be incorporated into a building foundation, with detailed specifications for planter waterproofing (Figure 5).


http://www.lcrep.org/fieldguide/examples/containedplanter.htm

Figure 4: Contained stormwater planters made of concrete

Figure 5: This flow-through planter collects runoff from a parking garage and is incorporated into the structure

Environmental/Landscaping

In an attempt to replicate the functions of a forested ecosystem, vegetation selected for stormwater planters should be relatively self-sustaining and adaptable. Native plant species are recommended, and fertilizer and pesticide use should be avoided whenever possible. Tree planting is encouraged in and adjacent to infiltration and flow-through planters for the infiltration, habitat and interception benefits they can provide.

Maintenance

A regular and thorough inspection regime is vital to the proper and efficient function of stormwater planters. Following completion, planters should be inspected after each storm event greater than 0.5 inches, and at least twice in the first six months. Subsequently, inspections should be conducted annually and after storm events equal to or greater than the 1-year storm event. Routine maintenance activities include pruning and replacing dead or dying vegetation, plant thinning, and erosion repair.

Cost

Stormwater planters are generally considered cost effective stormwater treatment practices. For one redevelopment project where detailed project records exist stormwater planter costs tallied $2.10 per square foot of managed impervious area or approximately $32.70 per square foot of the practice. For this project, management, design, and permitting costs comprised 25% of the total budget, and construction the remaining 75% (PBES, 2004). The cost of proprietary stormwater planters, or tree box filters, is approximately $24,000 per acre ($0.55 per square foot) of impervious surface. Annual maintenance cost is approximately 2% to 8% of the system cost or in the range of $200 to $2,000 per impervious acre treated (Flinker, 2005).

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Section 9.5.5 Alternative Stormwater Management Practices Permeable Paving

Description

Permeable paving is a broadly defined group of pervious types of pavements used for roads, parking, sidewalks, and plaza surfaces. Permeable paving provides an alternative to conventional asphalt and concrete surfaces and are designed to infiltrate rainfall through the surface, thereby reducing stormwater runoff from a site. In addition, permeable paving reduces impacts of impervious cover by augmenting the recharge of groundwater through infiltration, and providing some pollutant uptake in the underlying soils. Due to the potential high risk of clogging the pavement voids and the underlying soils, permeable paving should be limited in its use and should require strict adherence to manufacturer’s specifications for installation and maintenance.

The different types of paving can be broken into two basic design variations: porous pavement and permeable pavers. *Porous pavement* is a permeable asphalt or concrete surface that allows stormwater to quickly infiltrate to an underlying stone reservoir. Runoff then percolates directly into the underlying soil, which recharges groundwater and removes stormwater pollutants. Runoff can also be drained out of the stone reservoir through an underdrain system connected to the stormdrain system. Porous pavement looks similar to conventional pavement, but is formulated with larger aggregate and less fine particles, which leaves void spaces for infiltration. *Permeable pavers* include concrete grid and grass pavers, interlocking concrete modules, and brick pavers (Figure 1). Often, these designs do not have an underground stone reservoir, but can provide some infiltration and surface detention of stormwater to reduce runoff velocities.

Recommended Application of Practice

Permeable paving can be used to treat low traffic roads (i.e., a few houses or a small cul-de-sac), single-family residential driveways, overflow parking areas, sidewalks, plazas, and courtyard areas. Good opportunities can be found in larger parking lots, spillover parking areas, schools, municipal facilities, and urban hardscapes. Permeable paving is intended to capture and manage small frequent rainfall events. These events can include as much as 30 – 50% of the annual precipitation (Schueler, 1987). The system does not readily work for storms greater than 1-inch or with high rainfall intensities.

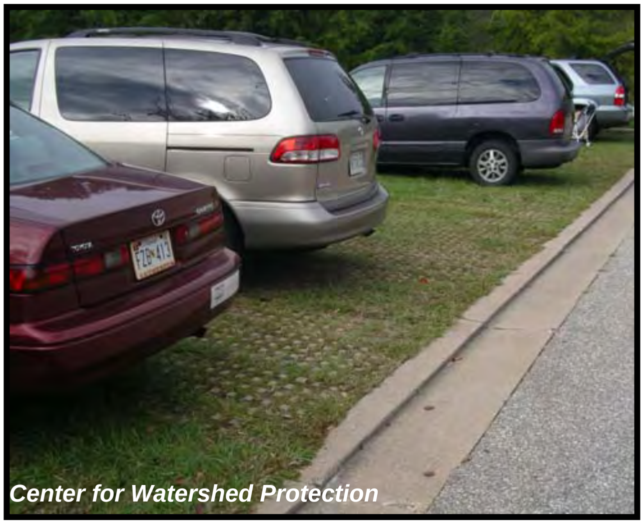

Center for Watershed Protection

Figure 1: Application of Permeable Pavers

Benefits

Permeable paving can have many benefits when applied to redevelopment and infill projects in urban centers. The most notable benefits include:

- Groundwater recharge augmentation
- Runoff reduction to ease capacity constraints in storm drain networks
- Effective pollutant treatment for solids, metals, nutrients, and hydrocarbons (see pollutant removal performance, Table 1)
- Aesthetic improvement to otherwise hard urban surfaces (e.g., interlocking permeable pavers, lattice pavers)

Two long-term monitoring studies of porous pavement systems conducted in Rockville, MD, and Prince William, VA, indicated high removal efficiencies for sediments and nutrients (see Table 1). The Rockville study also reported high removals for zinc (99%), lead (98%), and chemical oxygen demand (82%) (Schueler, 1987).

Table 1: Estimated Pollutant Removal Performance of Porous Pavement (Porous Asphalt) (EPA, 1999)

Pollutant Parameter	% Removal
Total Phosphorus	65
Total Nitrogen	80 – 85
Total Suspended Solids	82 – 95

Feasibility/Limitations

Major limitations to this practice are suitability of the site grades, subsoils, drainage characteristics, and groundwater conditions. Proper site selection is an important criteria in reducing the failure rate of this practice. Areas with high amounts of sediment-laden runoff and high traffic volume are likely causes of system failure. High volume parking lots, particularly parking drive aisles, high dust areas, and areas with heavy equipment traffic, are not recommended for this practice. Ownership and maintenance responsibility should also be considered in determining the potential for success.

Soil It is important to confirm that local soils are permeable and can support adequate infiltration, since past grading, filling, disturbance, and compaction can greatly alter the original infiltration qualities. The underlying parent soils should have a minimum infiltration rate of 0.5 inches per hour. To maintain effective pollutant removal in the underlying soils organic matter content in the subsoils is important.

Permeable pavers are typically not installed over a gravel chamber, but can be placed on a sand bed to facilitate drainage. Pavers generally provide more surface storage than infiltration capacity, but have the same limitations in terms of clogging. Permeable paving should generally have a drainage time of at least 24 hours.

Cold Climate Considerations Permeable paving practices can be used effectively in cold-climate areas, but should not be used where sand or other materials are applied for winter traction since they quickly clog the pavement. Care should be taken when applying salt to permeable pavement, since chlorides can easily migrate into the groundwater. Care should also be taken to select a surface material that can tolerate undulations from frost movements, or to protect pavements from frost damage (Ferguson, 2005).

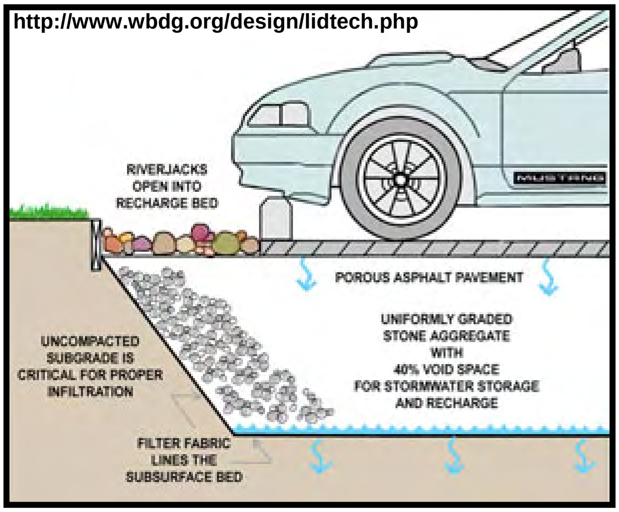
Land Use Like any stormwater infiltration practice, there is a possibility of groundwater contamination. Therefore, permeable paving should not be used to treat stormwater hotspots, areas where land uses or activities have the potential to generate highly contaminated runoff. These areas can include: commercial nurseries, auto recycling and repair facilities, fleet washing facilities, fueling stations, high-use commercial parking lots, and marinas. Additionally, certain types of permeable pavers, such as block, grid pavers, and gravel, are not ideal for areas that require handicap accessibility.

Sizing and Design Guidance

The two types of permeable paving, *porous pavement* and *permeable pavers*, have specific sizing guidelines, which are described below.

Porous pavement areas are generally designed to accommodate a 1-inch or less design storm. Storms greater than that will either sheet flow off the site, or if not graded properly, will pond on-site. Other design considerations for porous pavement include:

- Soils permeability should be between 0.5 and 3.0 inches per hour. Soil testing is required as defined in this Design Manual.
- Clean, washed aggregate must be specified for the gravel bed/stone reservoir (Figure 2).
- The bottom of the stone reservoir should not exceed a slope of 5 percent. Ideally it should be completely flat so that the infiltrated runoff will be able to infiltrate through the entire surface. Perforated pipes may be used to distribute runoff through the reservoir evenly.



http://www.wbdg.org/design/lidtech.php

Figure 2: Porous pavement with a gravel bed/stone reservoir

- Located at least 3 feet above the seasonally high groundwater table, and at least 100 horizontal feet away from drinking water wells and 25 feet down gradient from structures and septic systems

- As a back-up measure in case of clogging, permeable paving practices can be designed with a perimeter trench to provide some overflow treatment should the surface clog. The trench may be connected to the stone reservoir

- The contributing drainage area should generally be less than 5 acres, and where feasible, water should sheet flow onto the practice.

- If stormwater flows onto a permeable paving surface the use of pretreatment practices should be considered so effective pollutant removal can be achieved.

The basic equation for sizing the required porous surface area is as follows:

$A_p = Vw / (n \times d_t)$

where:
A_p = the required porous pavement surface area [square feet]
Vw = the design volume [cubic feet]
n = porosity of gravel bed/reservoir (assume 0.4)
d_t = depth of gravel bed/reservoir (maximum of four feet, and separated by at least three feet from seasonally high groundwater) [feet]

An example calculation for porous pavement is provided in Table 1.

Table 1: Porous Pavement Simple Sizing Example
A porous pavement area is being designed to treat a 20,000 square foot drainage area. Based on the water quality volume required to treat this area, an assumed gravel bed/reservoir porosity of 0.4, and a gravel bed/reservoir depth of one foot, the following calculations were completed to determine the required porous pavement surface area.
Step 1: Calculate the WQv WQv = (P) (Rv) (A) / 12 where: P = 90% rainfall number = 0.9 in Rv = 0.05+0.009 (I) = 0.05+0.009(100) = 0.95 I = percentage impervious area draining to site = 100% A = Area Draining to Practice (i.e., treatment area) = 20,000 ft^2 WQv = [(0.9)(0.95)(20,000)] / 12 = 1,425 ft^3
Step 2: Calculate porous pavement surface area: $A_p = WQv / (n \times d_t)$ where: n = assumed porosity = 0.4 d_t = gravel bed/reservoir depth = 1 ft A_p = 1,425 ft^3 / (0.4 x 1 ft) **A_p = 3,562.5ft^2**
Therefore, to treat the 20,000 square feet, the porous pavement area needed is approximately 3,560 ft^2.

Permeable paver (e.g., interlocking block, concrete gird pavers, etc.) areas are most effective when designed to accommodate small rainfall depths (e.g., less than 1 inch) that fall directly on the paver areas. They are less effective and more prone to clogging when used to also receive runoff from other areas. Unless underlying soils are extremely permeable, larger storms will either sheet flow off the site, or if not graded properly, will pond on the site.

For permeable pavers, treatment level will be based on the area covered by permeable pavers multiplied by a "discount factor" (F), that reduces the accounts for the likely effectiveness of the paver based on the application, as described below.

TA = (permeable paver surface area) x (F)
where:
TA = Treatment Area
F = 0.5 or 0.75 (based on high or low usage area designation, respectively)

High-usage areas: 0.5 discount factor

> This includes sites where permeable pavers are likely to receive fairly high levels of traffic, potential compaction, or where the underlying soils have poor infiltration capacity (e.g., hydrologic soil groups C and D). Examples include multi-family and commercial overflow parking, urban

plazas and hardscapes. The assumption is that these areas will be more prone to clogging and compaction of the void spaces and decreased function over time.

Low-usage areas: 0.75 discount factor

This includes low-traffic areas such as single family residential uses, institutional overflow parking with only periodic use, emergency access areas, grass paving systems, and schools, and includes sites with sandy parent materials. The assumption is that these areas will maintain some infiltration capacity and will have minor compaction and clogging issues.

An example calculation for permeable pavers is provided in Table 2.

Table 2: Permeable Pavers Simple Sizing Example
Area covered by permeable pavers = 10,000 ft^2 of commercial overflow parking and 2,000 ft^2 of emergency access road/path
Solving for treatment area (TA): TA = 10,000 ft^2 x 0.5 + 2,000 ft^2 x 0.75 **TA = 6,500 ft^2**

Environmental/Landscaping Considerations

Stringent sediment controls are required during the construction stage, and all adjacent land areas should be stabilized prior to installing permeable paving practices. Where feasible, a grass filter strip is recommended to pre-treat adjacent land areas that drain to porous pavement areas.

Maintenance

The type of permeable paving and the location of the site dictate the required maintenance level and failure rate. Concrete grid pavers and plastic modular blocks require less maintenance because they are not clogged by sediment as easily as porous asphalt and concrete. Areas that receive high volumes of sediment will require frequent maintenance activities, and areas that experience high volumes of vehicular traffic will clog more readily due to soil compaction. Typical maintenance activities for permeable paving are summarized below (Table 3).

Table 3: Typical Maintenance Activities for Permeable Paving (WMI, 1997)

Activity	Schedule
Ensure that paving area is clean of debris	Monthly
Ensure that paving dewaters between storms	Monthly and after storms >0.5 in.
Ensure that the area is clean of sediments	Monthly
Mow upland and adjacent areas, and seed bare areas	As needed
Vacuum sweep frequently to keep surface free of sediments	Typically 3 to 4 times a year
Inspect the surface for deterioration or spalling	Annual

When maintenance of permeable paving areas is required, the cause of the maintenance should be understood prior to commencing repairs so unnecessary difficulties and recurring costs can be avoided (Ferguson, 2005). Generally, routine vacuum sweeping and high-pressure washing (with proper disposal of removed material and washwater) can maintain infiltration rates when clogged or crusted material is removed. Signs can also be posted visibly within a permeable paving area to prevent such activities as resurfacing, the use of abrasives, and to restrict truck parking.

Cost

Costs for permeable paving are significantly more than traditional pavement (Table 4). However, incorporating savings from not having to build a separate stormwater infrastructure in addition to paving, the overall project costs are often reduced.

The estimated annual maintenance cost for a porous pavement parking lot is $200 per acre per year (EPA, 1999). This cost assumes four inspections each year with appropriate jet hosing and vacuum sweeping.

Table 4: Cost Guides for Permeable Pavement System (LID)

Paver System	Cost Per Square Foot (Installed)
Asphalt	$0.50 to $1.00
Porous Concrete	$2.00 to $6.50
Grass/gravel pavers	$1.50 to $5.75
Interlocking Concrete Paving Blocks	$5.00 to $10.00

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Section 9.5.6 Alternative Stormwater Management Practices Proprietary Practices

Description

Proprietary practices encompass a broad range of manufactured structural control systems available from commercial vendors designed to treat stormwater runoff and/or provide water quantity control. The focus of this profile sheet is on those proprietary practices that provide some level of water quality treatment and are accepted for redevelopment applications as a standard practice. Manufactured treatment systems are often attractive in redevelopment scenarios because they tend to take up little space, often installed underground, and can usually be retrofitted to existing infrastructure.

Common proprietary systems include:

- Hydrodynamic systems such as gravity and vortex separators –devices that move water in a circular, centrifugal manner to accelerate the separation and deposition of primarily sediment from the water. They are suitable for removal of coarse particles, small drainage areas, and are more effective in an offline configuration.

- Wet vaults –water-tight “boxes” that include a permanent pool and promote settling of particulates through detention and use of internal baffles and other proprietary modifications. Manufacturers recommendation may base the sizing of the vaults based on water quality volume or flow rate, incorporate bypass, and sediment capacity.

- Media filters –surface or subsurface practices that contain filter beds containing absorptive filtering media that promotes settling of particulates as well as adsorption and absorption of other pollutants attracted to the characteristics of the proprietary filter media. Similar to traditional filtering systems, they are flow through systems which function based on contact of polluted stormwater with the filtering media, commonly contained in prefabricated devices. Commercially available media range from fabrics, activated carbon, perlite, zeolite, and combination of multiple media mixes, with varied treatment performances.

- Underground infiltration systems- prefabricated pipes and vaults designed as alternative treatment systems to capture and infiltrate the runoff. Various proprietary products are marketed as space saving structures utilizing the infiltration capacity of the sites. The offline underground infiltration modular structures have potential to perform at an acceptable treatment level when designed according to all the technical specifications of the standard infiltration systems. Manufactured infiltration systems are considered standard practices when all the required elements, design guidance, soil testing, siting, and maintenance requirements, as defined in the Design Manual, are followed.

Evaluation of Alternative Practices

As a group, the performance of manufactured stormwater management practices (SMPs) have been verified thus far only to a limited extent, with a majority of the verification studies limited to laboratory testing. Where verification data does exist, they generally indicate that these practices do not meet both an 80% total suspended solids (TSS) and 40% total phosphorus (TP) removal efficiency target that is specified in Chapter 5 of this Manual. However, selected proprietary practices that provide some level of water quality treatment meet criteria for redevelopment applications as follows. Those practices, which have demonstrated a minimum TSS removal efficiency of 50% with an average d50 particle size < 100 microns under laboratory testing, are allowed to be used in redevelopment applications. This allowance is conditioned upon the system being operated at the specific tested design flow rate, defined based on the verified performance of each specific system. Based on the conclusions of the verification sources, it is believed that these treatment systems have the capability of achieving a TSS removal efficiency of 50% in field applications.

NYSDEC's evaluation of proprietary systems for demonstration of minimum removal efficiency for redevelopment application are based on one of the following stormwater management practice evaluation systems: The U.S. Environmental Protection Agency (EPA) Environmental Technology Verification Program, the state of Washington Technology Assessment Protocol - Ecology (TAPE), the Technology Acceptance Reciprocity Partnership Protocol (TARP), the International Stormwater Best Management Practices Database, and several other evaluation systems.

The proposed manufactured treatment systems that are verified or certified through ETV, TAPE, or TARP (primarily New Jersey Corporation for Advanced Technology*)* process and meet the criteria stated above are allowed for redevelopment applications in NY. Proposed manufactured treatment systems that are not verified yet may be considered for acceptance in NY if verified at any time through one these verification sources.

All the manufactured treatment systems must be sized appropriately to provide treatment for the water quality volume or the runoff from the entire contributing area. Due to the proprietary nature of the practices, designers are responsible to ensure that manufacturer's recommendations concerning all the design details such as structural integrity, configuration, assembly, installation, operation, and maintenance of the units are followed. Designers are also responsible to address, at minimum, all the relevant requirements set by NYS standards such as quantity controls, pretreatment, bypass, overflow, head configuration, inflow/outflow rates, maintenance, separation distance, accessibility, and safety issues concerning the selected practice.

Recommended Application of Practice

Many proprietary systems are useful on small sites and space-limited areas where there is not enough land or room for other structural control alternatives. Proprietary practices can also be reasonable alternatives where there is a need to tie in to the existing drainage infrastructure, where site elevations limit the head for certain stormwater management practices (SMPs). Hydrodynamic separators are generally more effective on sites with potential loading of coarse particulates. While specific media filters may be suitable in most conditions, infiltration systems must be limited to sites with the A or B hydrologic soil groups.

Benefits

The benefits of using proprietary practices will vary depending on the type of practice, but may include:

- Reduced space requirements for practices located below grade.
- Reduced engineering and design due to prefabricated nature of systems and design support and tools provided by manufacturer.
- Spill containment and control capabilities

Feasibility/Limitations

Depending on the proprietary system, the following factors may be considered as a limitation:

- Limited performance data. Data that do exist suggest these practices don't perform at the same level as the suite of standard practices in the NY Design Manual, particularly with regard to nutrient load reduction.
- Application constraints such as limits to area draining to a practice, due to pre-manufactured nature of products.
- High maintenance requirements (e.g., need for specialized equipment, confined space entry training, frequency of recommended maintenance, and cost of replacement components) that often are ignored or forgotten because many practices are underground and out of sight.
- Higher costs per treated area than other structural control alternatives, but this can be offset by value of land not needed due to subsurface nature of many proprietary practices.
- Concern over mosquito breeding habitat being provided by practices that have wet sumps as design components.

Sizing and Design Guidance

Sizing and design guidance will vary based on the product being used. Since sizing criteria is integral to the verified performance of manufactured practices, designers should refer to the capacities and flow rates associated with the models (sizes) of the manufactured SMPs identified by the verification source.

The New York State design standards calls for small storm hydrology and the use of Simple Method for hydrology calculation. For practices with volume-based sizing approaches, sizing should be performed to meet the water quality volume as defined in Section 4.2 of this Manual.

For rate or flow-based sizing approaches, sizing should be performed based on the peak rate of discharge for the water quality design storm, as described in Appendix B of this Manual.

Some proprietary practices can be designed on-line or off-line. On-line practices typically have built-in bypass capabilities. Flow through systems, which do not have built-in bypass must be designed as off-line systems

It is important for designers to specify proprietary practices based on their treatment capacities (CASQA, 2003). Since hydraulic capacity can be as much as ten times that of the treatment capacity, designer must ensure that hydraulic load does not exceed the performance rate defined in the verification process. The above applies to all design elements that affect the performance rate. Some examples of such design elements are head, orifice sizing, oil storage or sediment storage capacities, baffle configuration, or screen size.

Practices with a volume-based sizing approach must be sized to capture and treat 75 % of the WQv as defined in Chapter 4 of the Manual. Flow through practices must be sized to the peak rate of runoff as defined in Chapter 4 and Appendix B of this Manual. For off-line practices, the installation must include flow diversion that protects the practice from exceeding design criteria. The list of verified technologies on DEC's website provides references to the key elements of the design for each SMP. This list includes type of the system, proper applications, design methods, treatment capacity and accepted operation rate for each SMP.

Environmental/Landscape Elements

There are few or no environmental or landscaping elements that designers can consider with most proprietary treatment practices. They are frequently absent or predetermined by the manufacturer. The use of land area above the facility needs to be selective and manufacturer design codes must be strictly followed.

Maintenance

Maintenance is a critical component to ensure proper functioning of proprietary practices. Most manufacturers provide maintenance recommendations. When these schedules are not followed, proprietary practices can be expected to fail. Maintenance is often overlooked with proprietary products because they are underground and out of view. Most proprietary practices require a quarterly inspections and cleanouts at a minimum. In addition, specialized equipment (e.g., vactor trucks and boom trucks) may be required for maintaining certain proprietary products. Similar to standard practices, a maintenance agreement between the municipality and the property owner should be executed to clearly identify required or recommended maintenance activities, schedules, reporting, and enforcement procedures.

Cost

Proprietary systems are often more costly than other SMPs on a per-area-treated basis, but this is sometimes made up for in space savings. Manufacturers should be contacted directly for unit pricing, which will vary based on size of unit specified. As a rule of thumb, installation cost of most proprietary practices will range from 50 to 100% of the unit cost (CASQA, 2003). Other proprietary practices, may not have high initial capital or installation costs, but require frequent (i.e., at least quarterly) replacement of component parts for proper operation.

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