SECTION 4.0 PERVIOUS PAVEMENT

Pervious pavement is a permeable alternative to conventional asphalt and concrete, which can be constructed in pedestrian paths, parking areas, or residential settings with low traffic speeds (less than 30 miles per hour (mph)) and volumes. Pervious pavements typically include materials such as pervious concrete or asphalt, pervious aggregates, paver systems (Figure 4.1) and modular paver systems.

Figure 4.1 Modular interlocking paver installation (Source: City of Seattle)

Pervious pavements can be designed as retention systems due to their high surface void ratio which allows precipitation to pass through the pavement and aggregate base. Pervious pavements can also be designed to provide groundwater recharge through infiltration and water quality treatment. They also provide a reduction in imperviousness and provide storage volume within the aggregate subbase. Pervious pavements provide water quality treatment from infiltration through pavement and subbase materials. The effectiveness of pervious pavement relies on the design of storage volume within the pavement system and the underlying soil permeability, as well as routine maintenance.

Figure 4.2 Pervious asphalt (Source: Geosyntec)

4.1 TYPES OF PERVIOUS PAVEMENTS

There are two types of pervious pavements: pour-in-place and modular systems. Pour in place systems are poured where they will ultimately be used and allowed to setup (cure) in place. Typically, the pore spaces in the pavement make up about 10% of the total surface area. Pervious asphalt (Figure 4.2) and pervious concrete (Figure 4.3) are similar to each other in that the porosity is created by removing the small aggregate or fine particles from the conventional recipe, which leaves stable air pockets (gaps through the material) for water to drain through into the subsurface. Porous concrete is slightly rougher than its conventional counterpart, and, unlike oil-based asphalt, will not release harmful chemicals into the environment. These types of pervious pavements should only be used in areas of low traffic speed, and volumes (e.g., parking lots, low traffic streets, pedestrian areas, etc…) due to their lower relative structural strength.

Figure 4.3 Pervious concrete (Source: Geosyntec)

There are several varieties of pavers that allow for infiltration, including (but not limited to) grass pave (Figure 4.4), interlocking concrete pavers (Figure 4.5), and gravel-pave (Figure 4.6). Interlocking concrete pavers are not porous themselves, rather the mechanism that allows them to

interlock creates voids and gaps between the pavers that are filled with a pervious material and can withstand heavy loads. Grass pave and gravel-pave are nearly identical to each other in structure (rigid grid of concrete or durable plastic) but differ in their load bearing support capacities. The grids are embedded in the soil to support the loads that are applied, thereby preventing compaction, reducing rutting and erosion. Grass pave is generally filled with a mix of sand, gravel, and soil to support vegetation growth (e.g., grass, low-growing groundcovers, etc.). This provides habitat, removes pollutants, and reduces stormwater runoff volumes and rates. Grass pave is good for low-traffic areas; while gravel pave is good for high-frequency, low speed traffic areas. Gravel-pave differs from grass pave in that they are filled with gravel (often underlain with a geotextile fabric to prevent the migration of the gravel into the sub-base), which support greater loads and higher traffic volumes.

Figure 4.4 Grass pave (Source: Stone Age Pavers)

Figure 4.5 Interlocking concrete pavers (Source: CT DEP)

Figure 4.6 Gravel-pave (Source: NDS Inc.)

Pervious pavement surfaces can be designed as volume-based, to provide water quality treatment, or infiltrated, to provide groundwater recharge. Depending on site slope and soil conditions, pervious pavements can provide high volume reduction. Where site conditions allow for infiltration (i.e., underdrain), the volume reduction capability of pervious pavement surfaces can be used to provide storage for small, most frequent storms. In addition, for pervious pavement areas where underdrains are used with an impervious liner, additional depth may be added to the sub-base gravel layer to provide additional storage and detention capacity. Pervious pavement areas can also be used to help meet peak runoff discharge requirements.

Pervious pavement areas remove pollutants through physical, chemical, and biological mechanisms. The sub-base gravel layer and subsoil beneath the facility (if designed for infiltration) adsorb pollutants by binding to the aggregate and soil particles. In addition, biological degradation and chemical precipitation also lower pollutant concentrations. As the water filters through the pervious pavement layer, the sub-base gravel layer, and the subsoil, particulates and suspended solids are physically removed through filtration. The degree of infiltration, filtration, and absorption in the subsoil is dictated by the soil type (i.e., clayey soils will adsorb and filter more pollutants than sandy soils, while sandy soils will infiltrate the water more quickly). The removal of nitrogen depends on the degree of infiltration into the subsoil where microbial activity can convert nitrogen. Vegetation present in grass pavers increases the amount of biological treatment by providing treatment within the structure itself. Other pervious pavement surfaces can also provide biological treatment within the structure itself, and the degree of treatment depends on the level of pollutants in the source water and the pervious pavement type. Microbial

bacteria will begin forming over time within the pavement pore spaces providing treatment as the water flows through.

4.2 SITE SUITABILITY

Table 4.1 provides a summary of BMP applicability, advantages and limitations for pervious pavement. Pervious pavement surfaces may be used for non-residential applications, such as parking stalls or low traffic parking areas, for residential driveways and sideways, low-volume, low-speed streets or emergency vehicle access lanes and in open space areas, such as walking or biking paths. While these surfaces provide aesthetic value, runoff storage and water quality treatment, there are limitations to this practice which must be considered.

Table 4.1 Pervious pavement applicability, advantages, and limitations

Applications	*Advantages*	*Limitations*
• Non-residential: (commercial/office) parking areas • Residential: driveways and sidewalks • Low-volume, low-speed areas • Open space area: sidewalks or bike paths	• Reduces stormwater volume and peak flow rates • Reduces sediment and particulate-bound pollutants • Reduces need for large-scale stormwater management systems • Reduces flooding and standing water in parking areas • Reduces particulate-bound pollutants through filtration	• Reduced infiltration capacity if not maintained • Compacting of underlying soils is common • Limited removal of dissolved constituents when underdrains are used • Restriction on use by heavy vehicles • Not applicable in environmental hotspot areas (gas stations, industrial sites, or other potential sites that may have adverse discharges) • Not applicable in areas with heavy sediment loads (i.e., unstabilized sand/soils) • Cost of installation

Pervious pavements can be used in multi-use areas and in treatment train approaches. These multi-use applications may include:

- Single family home driveways, walkways;
- Parking lots and overflow parking areas;
- Low-traffic roads;
- Golf cart paths;
- Within right-of-ways along roadways; and
- In parks and along open space edges.

4.3 POLLUTANT REMOVAL EFFICIENCIES

Pervious pavements can improve stormwater quality; however, research has shown moderate removal efficiencies for soluble and particulate pollutants. Due to clogging potential, pervious pavement shall not be used for removal of sediment or other coarse particulate in stormwater. Table 4.2 presents conservative pollutant reduction percentages, which can be used for design purposes and are derived from sampling data, modeling and professional judgment. Refer to Attachment B to compare pervious pavements with other LID practices.

Table 4.2 Pollutant reductions for pervious pavement

Pollutant	*Treatment Effectiveness*	*Source*
Total Suspended Solids (TSS)	85%	PA Stormwater BMP Manual
Total Phosphorus (TP)	85%	PA Stormwater BMP Manual
Total Nitrogen (TN)	80%	Knox County, TN Stormwater Manual
Nitrate (NO_3)	30%	PA Stormwater BMP Manual
Metals	90%	Knox County, TN Stormwater Manual
Bacteria	Insufficient Data	-

4.4 DESIGN CRITERIA

General design criteria for pervious pavements are presented in Table 4.3 with more detailed information on pervious asphalt, pervious concrete and concrete pavers presented in Table 4.4.

Table 4.3 Pervious pavement general design criteria

Design Parameter	*Unit*	*Criteria*
Drainage Area	acres	Less than 5
Underlying soil group	-	A and B, some C type soils with clay content less than 30% (to provide groundwater recharge/infiltration) For water quality treatment and volume reduction, all soil groups, size gravel drainage layer to meet drawdown and volume requirements and provide underdrain.
Underlying soil infiltration rate (to achieve water quality treatment)	in/hr	Between 0.5 and 2.4
Minimum depth to aquitard	ft	3
Minimum depth to seasonal high water table	ft	2
Maximum site slope	%	5
Offsets (for infiltrating practice)	ft	50 - drinking water well or structural foundation (up-gradient) 10 - structural foundation (down-gradient)
Treatment volume	ft^3	Per Water Management District
Pretreatment	-	Runoff from pervious areas shall be minimized but, if provided, a vegetated swale or filter strip with level spreader shall be provided for all runoff from off-site sources that are not directly adjacent to the pervious pavement.
Drawdown time of gravel drainage layer	hrs	72 (maximum)
Vertical hydraulic conductivity	in/hr	≥ 2 (minimum)
Void Space	%	10 - pervious asphalt or concrete 40 - sub-base material
Underdrain	-	As needed (geotextile wrap), provide cleanout

Table 4.4 Detailed design criteria by pervious pavement type

Design Parameter	*Pervious Asphalt*	*Pervious Concrete*	*Concrete Pavers*
Filter fabric	Non-woven geotextile shall be placed on the top of the base soil, to prevent fine material from moving in the gravel drainage layers	See FL DOT specifications	Non-woven geotextile shall be placed on the top of the base soil, to prevent fine material from moving in the gravel drainage layers
Gravel drainage layer	Typically comprised for open graded stones (0.75 to 2.5 inches in diameter) to store water. Depth varies, depending on treatment volume required.		No. 2 stone, thickness dependent on the treatment volume
Choker layer	Washed, small, open-graded aggregate		4 inch layer of single size stone
Depth of sub-base layers	1.5 feet (minimum) 3.0 feet (maximum)		Dependent on treatment volume
Surface layer thickness	2.5 inch (minimum) 4.0 inch (maximum)		1 inch thick 3/8 inch aggregate (pavers are set on this layer and voids filled with this stone)
Surface layer void	16% (minimum)		10-20% (typical)
Other	Bituminious asphalt must make up 5.75 - 6% of the mix by dry weight	Comprehensive strength shall be 1700 lb/ft^2	-

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

4.5 Construction Considerations

The following construction considerations shall be required to assure that the pervious pavement is installed as designed and the design components such as infiltration rate are obtained:

1) Pervious pavement systems shall be installed by a contractor with qualifications including certification to install pervious surfaces.
2) The pavement shall be the last installation done at a development site. Landscaping shall be

completed and adjacent areas stabilized before pavement installation to minimize risk of clogging.

3) Pervious pavement installation areas shall not be used to store site materials during construction, unless the surface is well protected from accidental spillage or other contamination. The location of these areas shall be clearly marked prior to any construction to keep construction vehicles away from the area.

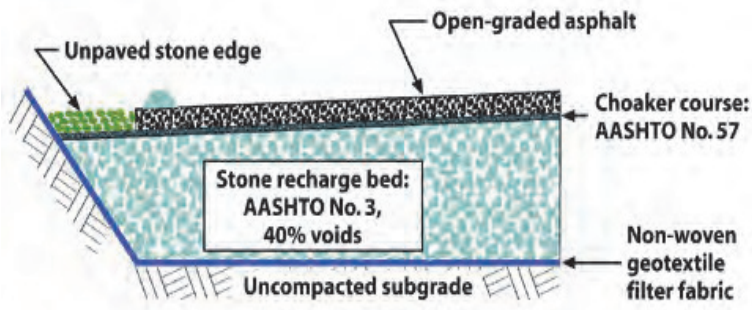


Figure 4.7 Typical pervious asphalt cross section (Source: Public Works Magazine)

4) To prevent/minimize soil compaction in the area of the pervious pavement installation, use light equipment with tracks or oversized tires. Scarify / rake areas as needed. Divert stormwater from the area as needed (before and during installation). Rake or disc soil as needed prior to installation.

5) Pervious pavement shall be laid close to level, the bottom of the base layers must be leveled to ensure uniform infiltration.

6) With the exception of pervious walks and bicycle paths, the installation of Embedded Ring Infiltrometer Kit (ERIK) is required. A minimum of one (1) embedded ring infiltrometer kit (ERIK) is required for each section of pervious pavement installed. Documentation of construction and post-construction testing shall be required with submittal of necessary construction completion documentation.

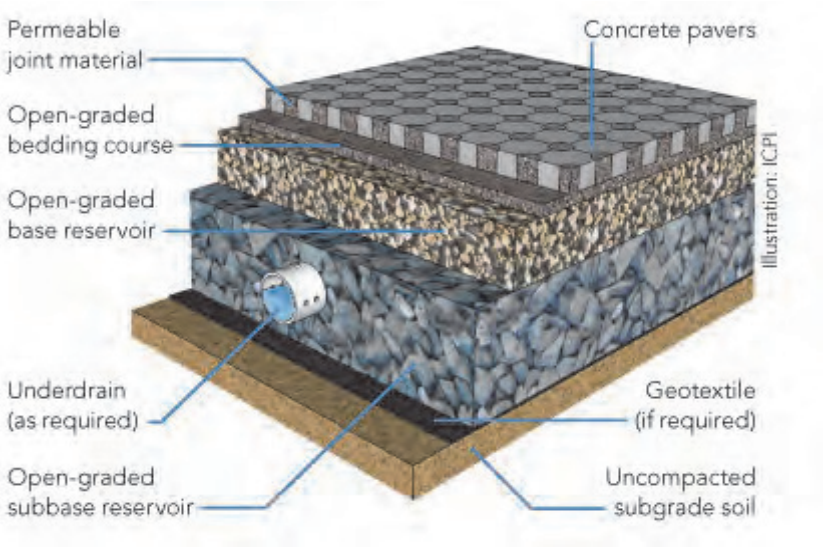


Figure 4.8 Typical pervious concrete paver cross section (Source: Interlocking Concrete Pavement Institute)

7) After reaching subgrade elevation, area shall be inspected prior to installing filter fabric to ensure no materials could puncture or inhibit integrity of filter fabric are present.

8) Geotextile shall be installed in accordance with manufacturer's specifications.

9) Inspect aggregate material(s) prior to placement to ensure these materials meet engineering specifications. Inspect to ensure materials have been washed prior to delivery to minimize the fines in the sub-base which can decrease infiltration rate. Aggregate material should be

spread to specified thickness, as determined by the licensed civil engineer.

10) Prior to placing pervious pavement surface, ensure material is installed by certified contractor, and it is certified by the manufacturer and meets engineering specifications. Ensure curing time (if appropriate) is obeyed prior to moving any vehicles onto the area or stormwater runoff.

4.6 OPERATION AND MAINTENANCE

Pervious pavement mainly requires vacuuming and management of adjacent areas to limit sediment contamination and prevent clogging by fine sediment particles; therefore, little special training is needed for maintenance crews. Inspection and maintenance activities for pervious pavements are summarized in Table 4.5.

Table 4.5 Pervious pavement inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect area for trash and debris accumulations	Monthly or as needed (dependent on site conditions)	Remove trash and debris from pavement area using laborers with brooms and dust pans
Inspect pavement for ponding water	Minimum 3 times annually: prior to wet season and after the wet season and after major storm events (>0.75 inches/24 hours)	Monitor these areas to determine if surface infiltration rates have been compromised. If so, vacuum area to reduce the risk of clogging
Inspect pavement for accumulated sediment		Remove accumulated sediment with vacuum truck. Identify source of sediment and repair area
Inspect outlets		Remove accumulated sediment from outlet and repair areas of erosion
Inspect adjacent areas for		Stabilize bare areas
Inspect for vegetation growth between pervious pavers		Remove vegetation between pavers
Conduct surface vacuuming with street sweeper	Once per year (prior to wet season)	Vacuum with street sweeper pervious pavement and surrounding contributing pavement
Conduct infiltration testing		Using ERIK procedures[1], determine the infiltration rate through the pervious pavement. If rate is less than 2.0 inches per hour, rehabilitate accordingly.

Notes:
1. ERIK is an Embedded Ring Infiltrometer with a measurement kit. It consists of inner embedded 6 inch diameter pipe, an outer embedded 12 inch diameter pipe, a 2 inch graduated "reservoir cylinder with red marks indicating every inch drop in water level within the embedded ring, and a timing device with a recoding pad. There are two manually adjusting valves located near the bottom to control flow of water out of the reservoir cylinder

SECTION 5.0 SHALLOW BIORETENTION AREAS/ BIORETENTION SWALES

Shallow bioretention areas are shallow depressions used as structural stormwater controls to capture, treat, and infiltrate stormwater runoff (Figure 5.1). Within the bioretention area, nutrient-absorption media, soils, mulch, and planted vegetation facilitate treatment and remove pollutants from the runoff. Shallow bioretention is used instead of regular bioretention in locations with a seasonal high groundwater table near the surface. Multiple bioretention areas are often distributed throughout a larger catchment, providing numerous treatment and water storage areas. Although any one treatment area may be small, the cumulative effect can be significant. This distributed approach also better mimics predevelopment hydrologic conditions by promoting stormwater infiltration, thereby reducing runoff and recharging groundwater.

Figure 5.1 Bioretention area in parking lot
(Source: City of Santa Barbara Manual)

Shallow bioretention areas are designed as retention systems infiltrating stormwater runoff into underlying soils and recharging groundwater. The effectiveness of shallow bioretention areas relies on the storage volume within the soil media and the underlying soil permeability, as well as annual maintenance. Shallow bioretention areas retain and infiltrate stormwater runoff and are highly effective at reducing runoff flow rate, volumes, and pollutants carried by stormwater.

Figure 5.2 Bioretention swale adjacent to roadway
(Source: NRCS)

Bioretention swales or bioswales (Figure 5.2) are conveyances which contain vegetation and engineered media designed to remove silt and pollutants from surface runoff. Bioswales improve water quality by enhancing infiltration of the first flush of stormwater and filter the large storm flows they convey. Wherever possible, bioswales should be incorporated into existing or natural drainage swales and enhanced with native plants and soils amended with engineered media.

5.1 BACKGROUND ON BIORETENTION

Bioretention areas are engineered facilities that can be designed to temporarily capture and store the treatment volume for water quality treatment (filtration) or to provide groundwater recharge

(infiltration). Bioretention facilities use soils and vegetation in shallow basins or landscaped areas to remove pollutants from stormwater runoff. Shallow bioretention areas allow stormwater to slowly seep into the engineered media rather than flow directly to a stormwater conveyance system. For infiltration practices, the bottom of the bioretention area is typically leveled to ensure uniform distribution for infiltration. For filtration or storage of the treatment volume, the bottom of the systems contain underdrains and are slowed to allow for positive flow. For all applications, the surface of the bioretention area is bowl shaped and should gently slope up to the ground level along the edges to minimize the risk of erosion. Bioretention areas should be landscaped with Florida-Friendly Landscaping Plant species that can withstand innundation as well as drought and also provide an attactive landscape that is similar to a garden. A list of these plants is provided in Attachment E.

Shallow bioretention areas shall not be considered ponds and should not retain water for more than 72 hours after rain ceases. To promote infilration, it may be necessary to fill the bottom of the bioretention area with a layer of sand and/or amend the soils with sand, organic material or top soil. Underdrains and overflows should be installed to convey stormwater runoff from larger storm events.

5.2 Site Suitability

Table 5.1 provides a summary of BMP applicability, advantages and limitations for shallow bioretention areas and bioswales.

Table 5.1 Shallow bioretention/bioswales applicability, advantages, and limitations

Applications	*Advantages*	*Limitations*
Shallow Bioretention: • Non-residential: commercial/ office • Residential: parking areas, street edges, rooftop runoff, adjacent to sidewalks and walking paths • Urban: parking areas, rooftop runoff Bioswales: • Street: within existing roadway ditch, curb cuts to bioswale, roadway median • Non-residential (commercial/office): adjacent to parking areas	• Reduce stormwater volume and peak flow rates • Reduce sediment and particulate-bound pollutants • Aesthetically pleasing • Can be incorporated into existing landscapes or natural drainage features	• Reduced infiltration capacity if not maintained or as pores plug • Seasonal high groundwater • Greater maintenance requirement than conventional stormwater practices

5.3 Pollutant Removal Efficiencies

Bioretention practices are highly effective at removing sediment, bacteria and heavy metals, and are moderately effective at removing nutrients from stormwater runoff. Table 5.2 presents conservative average pollutant reduction percentages, which can be used for design purposes and

are derived from sampling data, modeling and professional judgment. Refer to Attachment B to compare bioretention with other LID practices.

Table 5.2 Pollutant reductions for bioretention practices

Pollutant	*Treatment Effectiveness*	*Source*
Total Suspended Solids (TSS)	80%	GA Stormwater Manual
Total Phosphorus (TP)	60%	GA Stormwater Manual
Total Nitrogen (TN)	50%	GA Stormwater Manual
Metals	90%	LID Center
Bacteria	High (dependent on exposure to sunlight)	NC LID Manual

5.4 DESIGN CRITERIA

Bioretention practices typically are comprised of four layers (from surface of practice to bottom, Figure 5.4):

- **Retention (Ponding) Area** provides temporary storage of water prior to infiltration. It is typically between 6 and 12 inches. The overflow weir or riser pipe orifice is installed within this area to convey larger storm flows to an outfall.
- **Organic Layer** is wood mulch, typically 2 to 3 inches thick, which provides initial filtration of water, retains moisture for plants and is a good source of organic matter to the soil.
- **Engineered Media (Filter bed)** is the primary storage volume area with the greatest thickness (ranging from 6 inches upward). Plants are typically rooted in this zone. Specifications for engineered media are summarized below and shall be verified during construction to ensure grain size distribution matches specifications.
- **Nutrient Layer (Absorption media)** provides additional storage and filtration. It is typically comprised of sand, 6 inches thick at the bottom of the practice.

To maximize performance, design of these practices shall include pretreatment to reduce velocity and filter out particulates that can clog these practices over time. These practices are designed with a ponding area, which provides temporary storage of stormwater runoff prior to evaporation, infiltration or uptake. The organic mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The engineered media also acts as a filtration system and provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants. As the water filters through the engineered media and the subsoil, particulates and suspended solids are physically removed through filtration. The degree of infiltration, filtration, and adsorption in the subsoil is dictated by the soil type (i.e., clayey soils will adsorb and filter more pollutants than sandy soils, while sandy soils will infiltrate the water more quickly). The removal of nitrogen depends on the degree of infiltration into the subsoil where microbial activity can convert nitrogen. Vegetation present increases the amount of biological treatment by providing treatment within the structure itself. Microbial bacteria will begin forming over time within the soil media providing treatment as the water flows through.

The design criteria for shallow bioretention and bioretention swales is summarized in Table 5.3, and based on the intended use. The total depth of the system shall be determined by a licensed civil engineer based on analyses of not only the hydrology and hydraulics, but also the structural requirements of the site.

Figure 5.3 Plan view illustrating a shallow bioretention system (Source: Sarasota LID Manual)

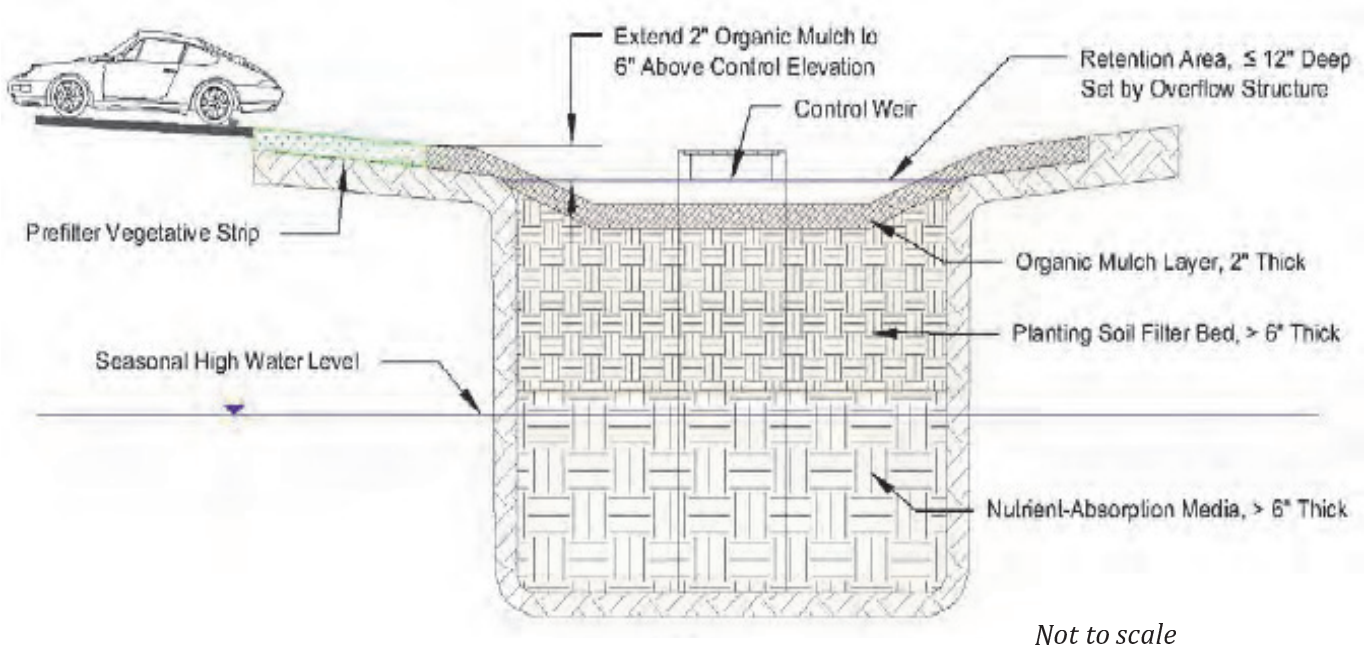


Figure 5.4 Cross section view of a shallow bioretention system (Source: Sarasota LID Manual)

Table 5.3 Bioretention practices general design criteria

Design Criteria	*Filtration Practice*	*Infiltration Practice*	*Treatment Volume Practice*
Drainage Area	2 acre maximum; 1 acre maximum impervious area	1 acre maximum; ½ acre maximum impervious area	1 acre maximum, ½ acre maximum impervious area
Minimum depth to seasonal high water table	0.5 feet	2 feet	0.5 feet
Infiltration rate of subsoils	0.5 to 2.0 in/hr	0.5 to 2.0 in/hr	0.5 to 2.0 in/hr
Set backs	> 100" water supply well >50' septic system >10' foundation	> 100" water supply well >50' septic system >25' foundation	> 100" water supply well >50' septic system >10' foundation
Pretreatment	Surface BMP: vegetated or grassed channel with level spreader or riprap level spreader	Required to control sediment (i.e., sediment trap with vegetated filter strip). Provide storage for 10% of treatment volume.	Required to control sediment (i.e., sediment trap with vegetated filter strip). Provide storage for 10% of treatment volume.
Surface pool	3-4 hours (maximum)	3-4 hours (maximum)	3-4 hours (maximum)
Drawdown time of soil media	72 hours (maximum) (with factor of safety = 2)	72 hours (maximum) (with factor of safety = 2)	72 hours (maximum) (with factor of safety = 2)
Side slopes	3:1 (H:V) (maximum)	3:1 (H:V) (maximum)	3:1 (H:V) (maximum)
Retention Area	0.5 to 1.0 foot	0.5 to 1.0 foot	0.5 to 1.0 foot
Organic Mulch Layer	2 to 3 inches	2 to 3 inches	2 to 3 inches
Engineered Media	0.5 to 2 feet	0.5 to 2 feet	0.5 to 2 feet
Nutrient-Absorption Layer	0.5 feet (minimum)	0.5 feet (minimum)	0.5 feet (minimum)
Overflow/ Underdrain	4 inch minimum diameter; 0.5% slope Sized to convey flows in excess of treatment volume Geotextile wrap as needed, provide cleanouts	N/A	4 inch minimum diameter; 0.5% slope Sized to convey flows in excess of treatment volume

Additional design specifications for shallow bioretention and bioretention swales include:

- Place in location receiving full to partial sun for growth of plants.
- Do not locate over shallow utilities.
- The engineered media must be at least 6 inches thick and should be sandy loam, loamy sand, or loam texture with a clay content between 3 and 5% and a soil pH between 5.5 and 6.5. The soil organic matter content must be between 3% and 10% by volume and be uniform, free of stones, stumps, roots, or other similar material greater than 2 inches in size.
- The nutrient-adsorption layer must be at least 6 inches thick and the unit weight should be more than 80 pounds per cubic foot when dry and be used in place of filter fabric. Greater than 15% but less than 30% of the particles should pass through the #200 sieve and the media should be more than 50% uniformly graded sand by volume, and the sand must not contain shale. The media water holding capacity should be at least 35% as measured by porosity and the specified unit weight noted above the vertical permeability must be at least 0.03 in/hr but less than 0.25 in/hr.
- Gravel shall be double washed, #57 stone, 1-1/2" in size or equivalent.
- Mulch shall be shredded hardwood mulch, well aged and uniform in color and free of foreign material including plant material. Well aged is referred to mulch that has been stockpiled or stored for at least twelve (12) months
- Use a variety of Florida-Friendly Landscaping Plants (Attachment E), which are tolerant to flooding, as well as drought.
- Overflow from bioretention practices must be safely conveyed to a suitable discharge point (storm sewer system, stream channel or swale).
- Longitudinal slope shall not exceed ~6%; otherwise check dams shall be provided.

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

5.5 CONSTRUCTION CONSIDERATIONS

The following construction considerations shall be required to assure that bioretention practices are installed as designed, and the design components, such as infiltration rate, are obtained:

- Shall be installed by a contractor with required qualifications.
- Avoid compacting soils to maintain underlying soil infiltration capacity.
- During construction, direct only runoff from stabilized areas to bioretention practice. Direct construction runoff elsewhere to prevent accumulating silt and sediment within area, causing clogging.
- Place soil media in 1 to 2 foot lifts to avoid compaction.
- Specifications for engineered soil media shall be provided to ensure media meets engineer's specifications.
- Plant shrubs at least 6 to 8 feet apart and at least 3 species of herbaceous perennials and grasses to prevent monoculture.

- Provide vegetated or grassed channel at each concentrated inlet point to prevent erosion.
- If site soils are impermeable and outfall is provided for system, amend the bioretention soils to facilitate infiltration and promote plant growth.
- Provide skimmer to contain trash and mulch on outfall/overflow.
- Utilize temporary irrigation as needed to establish vegetation.

5.6 Operation and Maintenance

Bioretention practices mainly require management of adjacent areas and practices to limit sediment contamination and prevent clogging by fine sediment particles. Maintenance activities for the bioretention practices are summarized in Table 5.4, and an inspection and maintenance checklist is provided as Table 5.5.

Table 5.4 Bioretention practices inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect area for trash and debris accumulations	Monthly or as needed (dependent on site conditions)	Remove trash and debris from bioretention practices using laborers
Inspect for standing water after rain event	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Monitor these areas to determine if surface infiltration rates have been compromised. If area does not drain within 72 hours, engineered media may need to be replaced
Inspect for accumulated sediment		Remove accumulated sediment using laborers. Identify source of sediment and repair area. Refresh mulch if necessary
Inspect inlets , outlets and overflow structures		Remove accumulated sediment from inlets and outlets and repair areas of erosion
Inspect adjacent areas for erosion		Stabilize bare areas
Inspect for weeds or dead plants		Remove weeds and replace plants as necessary
Depth of mulch present is equal to design depth		Add additional mulch if less than design depth
Check underdrain cleanout for debris, roots, or sediment that may clog underdrain pipe	Annually, during wet weather event	Remove clogs as necessary, pressure washer as necessary
Inspect change in infiltration during storm event and ponding after event		Replace media if ponding or loss of infiltration capacity persists

SECTION 6.0 RAINGARDENS

Raingardens are landscaped depressions that collect and store stormwater runoff allowing it to infiltrate, evaporate, and nourish plants. Raingardens mitigate the environmental impacts of land development and provide attractive landscaping and habitat for many animals. While rainwater may be used to irrigate any garden, raingardens are intended to provide storage and water quality treatment with engineered media. Therefore, they require sloped sides, berms, and hardy plants that can withstand periods of flooding as well as drought.

Figure 6.1 Raingarden installed on a residential lot (Source: Geosyntec)

Raingardens are designed as retention systems infiltrating stormwater runoff into underlying soils and recharging groundwater. The effectiveness of raingardens relies on the storage volume within the ponding area, soil media, and the underlying soil permeability as well as annual maintenance. Raingardens are a type of bioretention BMP that retains and infiltrates stormwater runoff, and they are highly effective at reducing runoff flow rate, volumes, and pollutants carried by stormwater.

6.1 BACKGROUND ON RAINGARDENS

On the surface raingardens look like typical, attractive landscaping features. However, below the garden surface is soil media, which allows for potential contaminates in stormwater to be filtered. Plants also provide additional water quality benefits. Raingardens can collect and store runoff from roof downspouts, driveways, sidewalks and pathways. Raingardens allow water to slowly seep into the ground rather than flow directly to a stormwater conveyance system. The bottom of the garden is leveled to ensure uniformly distributed infiltration; however, the surface of the garden should be bowl shaped and should gently slope up to the ground level along the edges to minimize risks of erosion. Native plants which can withstand periodic inundation, as well as periods of drought, shall be used.

Raingardens are similar to shallow bioretention areas (Section 3.4.2). However, where shallow bioretention practices have shallow depths of bioretention soil, raingarden practices typically tend to have deeper soil media, which allows them to capture and retain more than the treatment volume, therefore, reducing flooding impacts downstream and the size of the stormwater management conveyance system.

6.2 SITE SUITABILITY

Table 6.1 provides a summary of BMP applicability, advantages and limitations for raingardens.

Table 6.1 Raingarden applicability, advantages, and limitations

Applications	*Advantages*	*Limitations*
• Non-residential: (commercial/office) and residential: adjacent to parking areas, driveways, sidewalks, walking paths and rooftops • Streets: adjacent to parking spaces • Urban: rooftop drainage • Open space: adjacent to parking areas and walking paths	• Reduces stormwater volume and peak flow rates • Reduces sediment and particulate-bound pollutants • Aesthetically pleasing • Blends in with natural drainage patterns and existing landscaping • Good retrofit BMP	• Reduced infiltration capacity if not maintained • Seasonal high groundwater • Greater maintenance requirement

6.3 POLLUTANT REMOVAL EFFICIENCIES

Raingardens are highly effective at removing sediment and heavy metals, and are moderately effective at removing nutrients from stormwater runoff. Table 6.2 presents conservative average pollutant reduction percentages, which can be used for design purposes and are derived from sampling data, modeling and professional judgment. Refer to Attachment B to compare raingardens with other LID practices.

Table 6.2 Pollutant reduction for raingardens

Pollutant	*Treatment Effectiveness*	*Source*
Total Suspended Solids (TSS)	80%	GA Stormwater Manual
Total Phosphorus (TP)	60%	GA Stormwater Manual
Total Nitrogen (TN)	50%	GA Stormwater Manual
Metals	90%	LID Center
Bacteria	High (dependent on exposure to sunlight)	NC LID Manual

6.4 DESIGN CRITERIA

A raingarden is typically comprised of three layers (from surface to bottom of practice, Figure 6.2)

- **Retention (ponding) Area** provides temporary storage of water prior to infiltration and is typically 6 inches.
- **Organic (mulch) Layer** is wood mulch, typically 2 to 3 inches thick, which provides initial filtration of water, retains moisture for plants and is a good source of organic matter to the soil.
- **Engineered Media (amended soil / filter bed)** is the primary storage volume area with the greatest thickness (ranging from 1.5 feet up to 4 feet). Plants are typically rooted in this zone. Specifications for engineered media are summarized below and shall be verified during construction to ensure grain size distribution matches specifications. Much like bioretention areas, the pollutant removal efficiency of the raingarden depends on the soil media mixture. Generally, the soil mix should be uniform, free of stones, stumps, roots, or similar materials larger than 2 inches to prevent clogging of the system. To allow for adequate nutrient removal and microbial growth, the soil pH should be between 5.5 and 7.5, and it should consist of about 40% sand, 20% - 30% topsoil, and 30% - 40% compost.

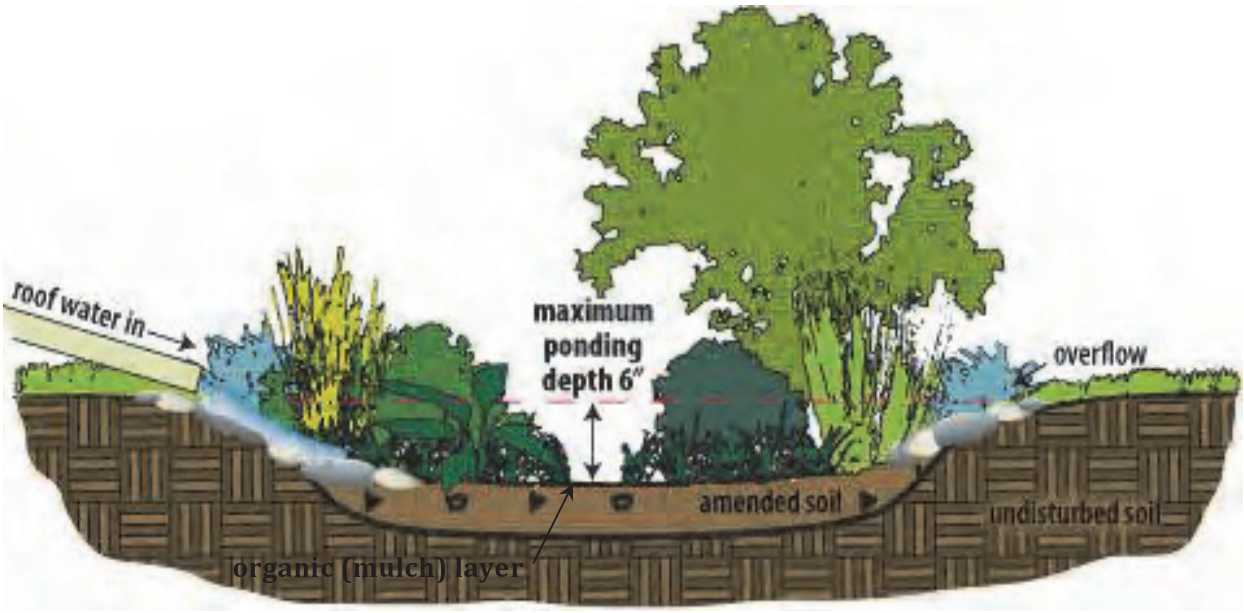


Figure 6.2 Typical cross section of a raingarden (not to scale)
(Source: Adapted from Oregon Environmental Council)

To maximize their performance, design of these practices shall include pretreatment to reduce velocity and filter out particulates which can clog these practices over time. These practices are designed with a ponding area which provides temporary storage of stormwater runoff prior to evaporation, infiltration or uptake. The organic mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The engineered media also acts as a filtration system and provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants. As the water filters through the

engineered media and the subsoil, particulates and suspended solids are physically removed through filtration. The degree of infiltration, filtration, and adsorption in the subsoil is dictated by the soil type (i.e., clayey soils will adsorb and filter more pollutants than sandy soils, while sandy soils will infiltrate the water more quickly). The removal of nitrogen depends on the degree of infiltration into the subsoil where microbial activity can convert nitrogen. Vegetation present increases the amount of biological treatment by providing treatment within the structure itself. Microbial bacteria will begin forming over time within the soil media providing treatment as the water flows through.

Design criteria for raingardens are listed in Table 6.3. The total depth of the system shall be determined by a licensed civil engineer based on analyses of not only the hydrology and hydraulics, but also the structural requirements of the site.

Additional design specifications for raingardens include:

- Place in location receiving full to partial sun for growth of plants.
- Raingarden longitudinal slope shall not exceed 6%; otherwise check dams shall be provided.
- Use without an underdrain in Hydrologic Soil Groups A and B. If subsoils are Hydrologic Soil Groups C and D, an underdrain may be required for adequate draining.
- Use a variety of Florida-Friendly Landscaping Plants (Attachment E) suitable to tolerate flooding as well as drought.
- Planting media should be uniform, free of stones, stumps, roots, or similar materials larger than 2 inches to prevent clogging of the system. To allow for adequate nutrient removal and microbial growth, the soil pH should be between 5.5 and 7.5 and consists of about 60% - 70% sand, 15% - 25% compost and 10% - 20% clean topsoil with an organic content around 8% - 12%.
- Gravel shall be double washed, #57 stone, 1-1/2" in size or equivalent.
- Mulch shall be shredded hardwood mulch, well aged and uniform in color and free of foreign material including plant material. Well aged is referred to mulch that has been stockpiled or stored for at least twelve (12) months.
- Provide skimmer to contain trash and mulch on outfall/overflow.

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

Table 6.3 Raingarden design criteria

Design Criteria	*Filtration Practice*	*Infiltration Practice*	*Treatment Volume Practice*
Drainage Area	2 acre maximum; 1 acre maximum impervious area	1 acre maximum, ½ acre maximum impervious area	1 acre maximum, ½ acre maximum impervious area
Minimum depth to seasonal high water table	0.5 feet	2 feet	0.5 feet
Infiltration rate of subsoils	0.5 to 2.0 in/hr	0.5 to 2.0 in/hr	0.5 to 2.0 in/hr
Set backs	> 100' water supply well >50' septic system >10' foundation	> 100' water supply well >50' septic system >25' foundation	> 100' water supply well >50' septic system >10' foundation
Pretreatment	Surface BMP: vegetated or grassed channel with level spreader or riprap level spreader	Required to control sediment (i.e., sediment trap with vegetated filter strip). Provide storage for 10% of treatment volume.	Required to control sediment (i.e., sediment trap with vegetated filter strip). Provide storage for 10% of treatment volume.
Surface pool dewater	3-4 hours (maximum)	3-4 hours (maximum)	3-4 hours (maximum)
Drawdown time of soil media	72 hours (maximum) (with factor of safety = 2)	72 hours (maximum) (with factor of safety = 2)	72 hours (maximum) (with factor of safety = 2)
Side slopes	3:1 (H:V) (maximum)	3:1 (H:V) (maximum)	3:1 (H:V) (maximum)
Retention Area	0.5 to 1.0 foot	0.5 to 1.0 foot	0.5 to 1.0 foot
Organic Mulch Layer	2 to 3 inches	2 to 3 inches	2 to 3 inches
Engineered Media	1.5 to 4 feet	1.5 to 4 feet	1.5 to 4 feet
Nutrient-Absorption	0.5 feet (minimum)	0.5 feet (minimum)	0.5 feet (minimum)
Overflow/ Underdrain	4 inch minimum diameter; 0.5% slope Sized to convey flows in excess of treatment volume Geotextile wrap as needed, provide cleanout	N/A	4 inch minimum diameter; 0.5% slope Sized to convey flows in excess of treatment volume

6.5 CONSTRUCTION CONSIDERATIONS

The following construction considerations shall be required to assure that the raingarden is installed as designed, and the design components, such as infiltration rate, are obtained:

- Avoid compacting soils to maintain underlying soil infiltration capacity.
- During construction, direct only runoff from stabilized areas to raingarden. Direct construction runoff elsewhere to prevent accumulating silt and sediment within area, causing clogging.
- Place soil media in 1 to 2 foot lifts to avoid compaction.
- Plant one tree or shrub per 50 square feet and at least 3 species of herbaceous perennials and shrubs to prevent monoculture.
- Provide energy dissipation and a flow spreader at each concentrated inlet point if necessary.
- If site soils are impermeable, amend the raingarden soils to facilitate infiltration and promote plant growth.
- Utilize temporary irrigation as needed to establish vegetation.

6.6 OPERATION AND MAINTENANCE

Raingardens mainly require management of adjacent areas to limit sediment contamination and prevent clogging by fine sediment particles. Inspection and maintenance activities for raingardens are summarized in Table 6.4, and an inspection and maintenance checklist is provided as Table 6.5.

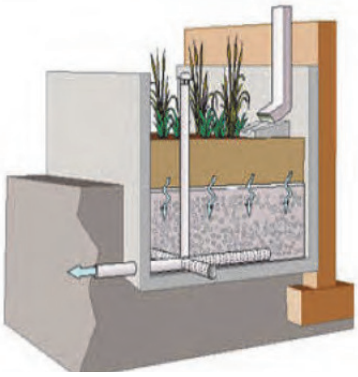
Table. 6.4 Raingarden inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect area for trash and debris accumulations	Monthly or as needed (dependent on site conditions)	Remove trash and debris from raingarden practices using laborers
Inspect for standing water after rain event	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Monitor these areas to determine if surface infiltration rates have been compromised. If area does not drain within 72 hours, engineered media may need to be replaced
Inspect for accumulated sediment		Remove accumulated sediment using laborers. Identify source of sediment and repair area. Refresh mulch if necessary
Inspect inlets and outlets		Remove accumulated sediment from inlets and outlets and repair areas of erosion
Inspect adjacent areas for erosion		Stabilize bare areas
Inspect for weeds or dead plants		Remove weeds and replace plants as necessary
Depth of mulch present is equal to design depth		Add additional mulch if less than design depth
Underdrain cleanout for debris, roots, or sediment that may clog underdrain pipe	Annually, during wet weather event	Remove clogs as necessary
Inspect change in infiltration during storm event and ponding after event		Replace media if ponding or loss of infiltration capacity persists

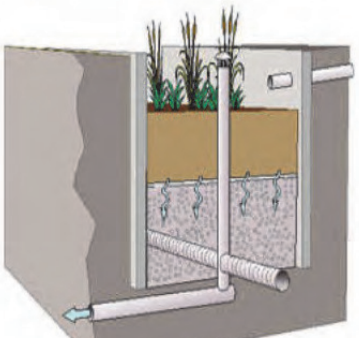
SECTION 7.0 PLANTER BOX

Planter boxes (Figure 7.1) are bioretention treatment control measures that are completely contained within an impermeable structure with an underdrain or open on the bottom to allow for infiltration. The boxes can be comprised of a variety of materials, such as brick or concrete (usually chosen to be the same material as the adjacent building or sidewalk), and are filled with gravel on the bottom (to house an underdrain system), planting soil media, and vegetation. Planter boxes may also require splash blocks for flow energy dissipation and geotextile filter fabric or chocking stone to reduce clogging of the underdrain system. The stormwater infiltrates into the soil where it is used by the plants, stored, and filtered. If runoff volume is large, the stormwater may even pond on the surface for a limited period of time. Planter boxes are intended to be placed next to buildings. Once the soil becomes saturated, the excess water collects in the underdrain system where it may be routed to a stormwater conveyance system or another stormwater runoff BMP, such as a vegetated swale. Planter boxes are very similar in design to bioretention areas but are more practical for steep slope applications where the planter box can be terraced. Planter boxes are very effective at peak flow mitigation and at removing heavy metals, bacteria, sediment, and nutrients from stormwater runoff, and they may provide runoff volume reduction through retention of runoff within the soil media.

Figure 7.1 Planter box designed to capture and treat rooftop runoff
(Source: Geosyntec)



Flow-through planter box



In-ground planter box with (perforated underdrain) or without (solid underdrain) infiltration

Figure 7.2 Types of planter boxes
(Source: NRCS)

Planter boxes sometimes are referred to as raingardens in a box. These practices can be designed as one of the three types of a planter box (as illustrated in Figure 7.2):

- **Flow-through planter boxes** are raised boxes which do not provide infiltration and are typically designed with a perforated underdrain system;
- **In-ground planter boxes without infiltration** are flow through planter boxes in the ground as opposed to raised above ground; and
- **In-ground planter box with infiltration** look the same as in-ground without infiltration; however, underdrains are solid and only convey flows when ponded water exceeds invert of overflow riser and have underlying soils with high permeability (typically HSG A).

7.1 SITE SUITABILITY

Table 7.1 provides a summary of BMP applicability, advantages and limitations for Planter Boxes.

Table 7.1 Planter box applicability, advantages and limitations

Applications	*Advantages*	*Limitations*
• Adjacent to non-residential (commercial/office) and residential buildings	• Accommodates high groundwater tables • Highly effective at removing nutrients, bacteria, sediment, and heavy metals • Aesthetically pleasing • May provide runoff volume reduction through retention of runoff within soil media	• Limited capture volume • High maintenance requirement • Typically above ground structures • May required additional support on steep slopes • May require to be constructed with underdrain system

7.2 POLLUTANT REMOVAL EFFICIENCIES

Planter boxes have moderate removal efficiencies for nutrients and high removal efficiencies for sediment, bacteria, and heavy metals. Table 7.2 presents conservative average pollutant reduction percentages, which can be used for design purposes and are derived from sampling data, modeling and professional judgment.

Table 7.2 Pollutant reduction for planter boxes

Pollutant	*Treatment Effectiveness*	*Source*
Total Suspended Solids (TSS)	80%	GA Stormwater Manual
Total Phosphorus (TP)	60%	GA Stormwater Manual
Total Nitrogen (TN)	50%	GA Stormwater Manual
Metals	90%	LID Center
Bacteria	Moderate (dependent on exposure to sunlight)	NC LID Manual

7.3 DESIGN CRITERIA

Planter boxes are generally intended for reducing peak runoff discharge rates and providing water quality treatment. Planter boxes remove pollutants through physical, chemical, and biological mechanisms. The designed soil media adsorb pollutants by binding to the aggregate and soil particles. In addition, biological degradation and chemical precipitation also lowers pollutant concentrations. As the water filters through the soil media, particulates and suspended solids are physically removed through filtration. The removal of nitrogen depends on the runoff retention time within the soil media, where microbial activity can convert nitrogen. Vegetation increases the amount of biological treatment by providing treatment within the structure. Microbial bacteria will begin forming over time within the soil media providing treatment as the water flows through.

Planter boxes are typically designed in layers as follows (top to bottom - Figure 7.3):

- Overflow riser shall be connected to underdrain.
- Maximum of 1 foot of ponding above the mulch.
- 2 to 3 inches of mulch.
- Minimum depth of 2 to 3 feet of soil media (see soil media specification below) to provide sufficient root zone for plant palette.
- Minimum 12 inch gravel layer with underdrain, which shall be slotted, polyvinyl chloride (PVC) pipe or equivalent.
- Concrete or brick exterior lined with or without impermeable geomembrane.

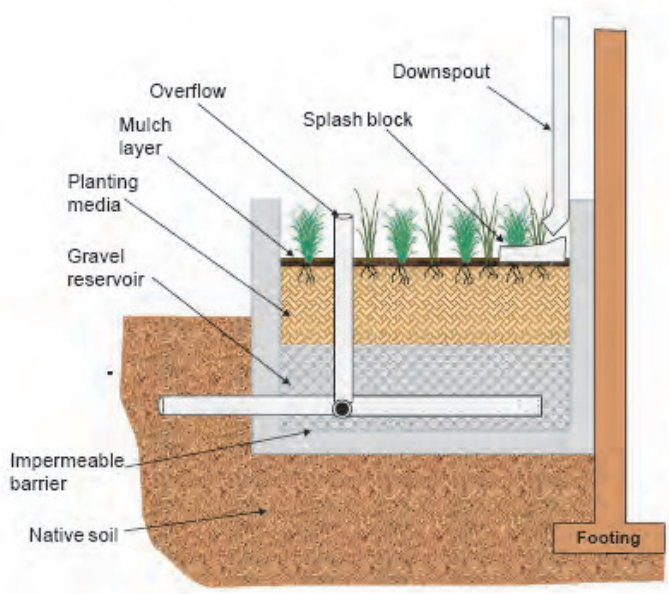


Figure 7.3 Illustration of typical planter box cross section (Source: Bayou Land RC&D BMP Guidance Manual)

Design criteria for planter boxes are presented in Table 7.3.

Table 7.3 Planter box design criteria

Design Parameter	*Unit*	*Design Criteria*
Drainage Area	acres	< 0.25
Pretreatment	-	Pretreatment not required; however energy dissipation may be required through the use of splash blocks.
Minimum depth to seasonal high water table	ft	None
Drawdown time of planting soil	hrs	48 (with factor of safety = 2)
Ponding depth	ft	0.5 to 1
Minimum depth to seasonal high water table	ft	None
Mulch layer	in	2 to 3
Planting soil depth	ft	2 (minimum); 3 preferred
Gravel reservoir	ft	1 (minimum) (geotextile if needed)
Underdrain	-	4 inch. minimum diameter; 0.5% slope (geotextile wrap as needed, provide cleanout)
Overflow device	-	Required

Additional design specifications for planter boxes include:

- Planting media should be uniform, free of stones, stumps, roots, or similar materials larger than 2 inches to prevent clogging of the system. To allow for adequate nutrient removal and microbial growth, the soil pH should be between 5.5 and 7.5 and consist of about 60% - 70% sand, 15% - 25% compost and 10% - 20% clean topsoil with an organic content around 8% - 12%.
- Gravel shall be double washed, #57 stone, 1-1/2" in size or equivalent.
- Mulch shall be shredded hardwood mulch, well aged and uniform in color, and free of foreign material including plant material. Well aged is referred to mulch that has been stockpiled or stored for at least twelve (12) months.
- Can be installed in all Hydrologic Soil Groups.
- Site must have adequate relief between land surface and stormwater conveyance system to allow vertical percolation through the planting media and underdrain to the stormwater conveyance system.
- Use a variety of Florida-Friendly Landscaping Plants (Attachment E) which are tolerant to flooding as well as drought.

- Shall not be located near large trees that may drop leaves or needles. Excessive tree debris may clog the soil media.

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

7.4 CONSTRUCTION CONSIDERATIONS

The following construction considerations shall be required to assure that the planter box is installed as designed and the design components are obtained:

- Planter box shall be installed by a contractor with required qualifications.
- Provide energy dissipation (e.g. splash block) at each concentrated inlet point.
- The use of treated wood or galvanized metal anywhere within the planter box should be avoided.
- Inspect soil media mix prior to placement to ensure the media meets engineering specifications. Inspect to ensure gravel materials have been washed prior to delivery to minimize the fines in the sub-base which can decrease infiltration rate.
- Material of planter boxes should be selected carefully to blend in and enhance aesthetics of adjacent structures (buildings and sidewalks).
- Plants should be selected carefully to minimize maintenance and function properly. Native plant species and/or hardy cultivars are preferred.
- Prior to placing the planter box, ensure material is installed by certified contractor and certified by the manufacturer, and that the material meets engineering specifications.

7.5 OPERATION AND MAINTENANCE

Planter boxes require annual plant, soil, and mulch layer maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. Planter box maintenance requirements are typical of landscape care procedures. Inspection and maintenance activities for planter boxes are summarized in Table 7.4, and an inspection and maintenance checklist is provided as Table 7.5.

Table 7.4 Planter box inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect area for trash and debris accumulations	Monthly or as needed (dependent on site conditions)	Remove trash and debris from planter box using laborers
Inspect for standing water after rain event	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Monitor these areas to determine if surface infiltration rates have been compromised. If area does not drain within 72 hours, engineered media may need to be replaced
Inspect for accumulated sediment		Remove accumulated sediment using laborers. Identify source of sediment and repair area. Refresh mulch if necessary
Inspect downspouts, gutters, splash blocks and outlets		Remove accumulated sediment from inlets and outlets and repair areas of erosion
Inspect for weeds or dead plants		Remove weeds and replace plants as necessary
Depth of mulch present is equal to design depth		Add additional mulch if less than design depth
Inspect planter box to ensure there are no cracks or leaks	Annually, during wet weather event	Repair cracks or plug leaks
Inspect change in infiltration during storm event and ponding after event	Annually, during wet weather event	Replace media if ponding or loss of infiltration capacity persists

SECTION 8.0 TREE BOX FILTERS

Tree box filters (Figure 8.1) are an increasingly common type of proprietary biotreatment device that are installed at curb level and filled with a bioretention type soil. For low to moderate flows they operate similarly to raingarden systems and are bypassed during high flows. Tree box filters are highly adaptable solutions that can be used in all types of development and in all types of soils, but are especially applicable to dense urban parking lots, street, and roadways (Figure 8.2).

Figure 8.1 Tree box filter to receive runoff from an adjacent parking lot (Source: Geosyntec)

Tree box filters are devices that are manufactured to mimic natural systems, such as bioretention areas, by incorporating plants, soil, and microbes engineered to provide treatment. Tree box filters typically provide treatment for greater flow rates and volumes, with a smaller footprint, when compared to their natural counterparts. Incoming flows are typically filtered through a planting media (mulch, compost, soil, plants, microbes, etc) and either infiltrated or collected by an underdrain and delivered to the stormwater conveyance system. Similarly to bioretention areas, tree box filters are very effective at removing sediment, nutrients, and heavy metals from stormwater runoff and providing peak flow mitigation; however, their performance may be limited due to depth to groundwater table.

8.1 Background on Tree Box Filters

Tree box filters are relatively new compared to the other types of proprietary treatment devices; therefore, fewer third party studies on tree box filters have been conducted and available performance information is mostly vendor-supplied. Tree box filters remove pollutants through the same processes as bioretention, reduce runoff volumes and peak discharge rates for small, frequently occurring storms, and they are not intended to capture or detain large volumes. Like their natural counterparts, tree box filters, are highly efficient at mitigating dissolved metals, nutrients, and suspended solids.

Figure 8.2 Tree box filter along road edge (Source: Geosyntec)

This practice consists of an open bottom or closed bottom concrete box or barrel filled with a porous soil media and designed to capture and temporarily store stormwater runoff. The

captured runoff infiltrates through the bottom of the depression and a layer of soil media that has an infiltration rate capable of draining the tree box filter within 72 hours. Tree box filters also treat the stormwater as it passes through the soil media. After the stormwater infiltrates through the soil media, it infiltrates into the subsoil; the filtered water might also be directed towards a stormwater conveyance system or other stormwater runoff BMP via underdrain pipes. Tree box filters are designed to capture a specified design volume and the planting soil is a mixture that includes mostly sand with smaller fractions of fines and organic matter. As stormwater passes through the planting soil, pollutants are filtered, absorbed, biodegraded, and uptaken through evapotranspiration by the tree. A cross section of a tree box filter can be found in Figure 8.3.

Figure 8.3 Illustration of tree box filter cross section (Source: Contech, Inc.)

Modular wetland units are available from numerous vendors and may provide a site specific alternative to traditional tree boxes depending on site conditions. The design concept is similar with flow of stormwater through a vegetative media for treatment. These units are often configured in a manner to facilitate easier maintenance and replacement of vegetative media.

8.2 SITE SUITABILITY

Table 8.1 provides a summary of BMP applicability, advantages and limitations for tree box filters.

Table 8.1 Tree box filter applicability, advantages and limitations

Applications	*Advantages*	*Limitations*
• Non-residential: commercial/office • Residential/Urban: parking areas, street edges, sidewalks • Open space: walking paths	• Reduces stormwater volume through retention and infiltration • Reduces stormwater peak flow rates • High pollutant removal effectiveness • Small space requirement	• Seasonal high groundwater • Type of tree due to resilience and size of box

8.3 POLLUTANT REMOVAL EFFICIENCIES

Tree box filters like other proprietary biotreatment devices, are relatively new compared to the other types of proprietary treatment devices; therefore, fewer third party studies on proprietary biotreatment devices have been conducted, and available performance information on them is mostly vendor-supplied. Tree box filters have high removal efficiencies for sediment and moderate removal efficiencies for soluble and particulate pollutants. Table 8.2 presents conservative average pollutant reduction percentages (from Filterra®), which can be used for design purposes and were derived from sampling data, modeling and professional judgment.

Table 8.2 Pollutant reduction for tree box filters

Pollutant	*Treatment Effectiveness*	*Source*
Total Suspended Solids (TSS)	85%	Filterra®
Total Phosphorus (TP)	65%	
Total Nitrogen (TN)	45%	
Metals	58-82%	
Bacteria	Insufficient Data	

Tree box filters remove pollutants through physical, chemical, and biological mechanisms. The designed soil media and subsoil beneath the facility adsorb pollutants by binding to the aggregate and soil particles. In addition, biological degradation and chemical precipitation also lower pollutant concentrations. As the water filters through the soil media and the subsoil, particulates and suspended solids are physically removed through filtration. The degree of infiltration, filtration, and adsorption in the subsoil is dictated by the soil type (i.e., clayey soils will adsorb and filter more pollutants than sandy soils, while sandy soils will infiltrate the water more quickly). The removal of nitrogen depends on the degree of infiltration into the subsoil where microbial activity can convert nitrogen. Presence of vegetation increases the amount of biological treatment by providing treatment within the structure itself. Microbial bacteria will begin forming over time within the soil media providing treatment as the water flows through.

8.4 DESIGN CRITERIA

Tree box filters can be designed to provide peak flow rate reduction, runoff volume reduction and water quality treatment. Where site conditions allow for infiltration (i.e., omitting underdrain), the volume reduction capability of tree box filters can be used to provide groundwater recharge and storage for small, most frequent storms. In addition, for tree box filters where underdrains are used, runoff may be diverted to an additional BMP in a "treatment train" to provide additional infiltration and pollutant removal during large storm events.

Tree box filters are typically designed in layers as follows (top to bottom - Figure 8.4):

- Use a deciduous tree (saturation tolerant) centered in the concrete barrel

- Design curb cut to act as inlet to tree box filter, with rip rap pad at inlet for energy dissipation
- Design an overflow riser pipe with grate, connected to perforated underdrain
- Minimum 6 inches of ponding depth
- Minimum 1 to 2 feet of soil media (see manufacturers specification)
- Pack a perforated underdrain pipe in a clean, washed crushed stone layer (minimum 24-inch layer)
- Install precast concrete barrel (minimum 6 feet in diameter), approximately 4 feet deep
- Line bottom of excavation with filter fabric

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

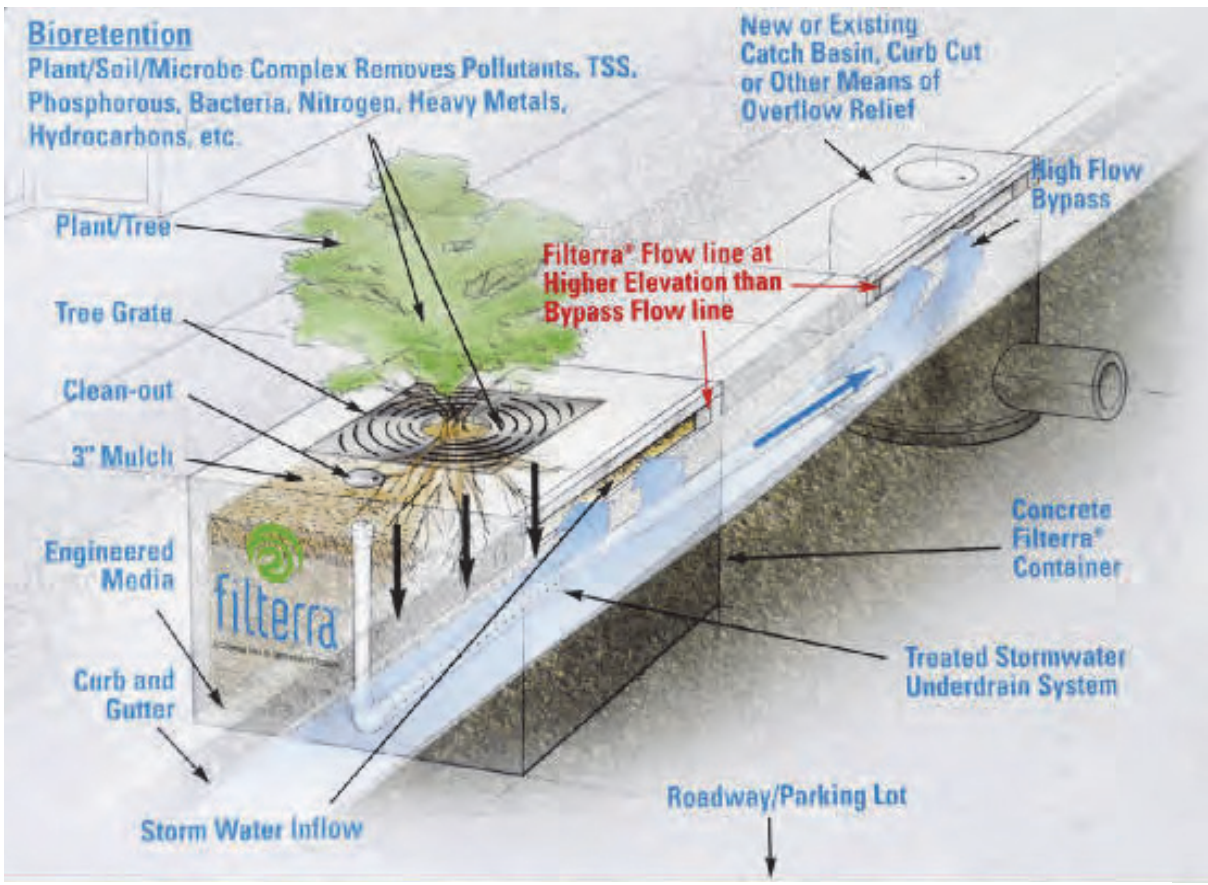


Figure 8.4 Illustration of typical tree box filter cross section (Source: Filterra)

Design criteria for tree box filters are listed in Table 8.3.

Table 8.3 Tree box filter design criteria

Design Parameter	*Unit*	*Design Criteria*
Drainage area	acres	less than 0.25 (or see manufacturers specifications)
Pretreatment	-	Pretreatment is not required. However, tree box filters should not be used in areas that generate large sediment loads (i.e., unstabilized areas)
Drawdown time of filter media	hrs	72 (maximum) (with factor of safety = 2)
Minimum depth to seasonal high water table	ft	0.5 to 2
Infiltration rate of subsoil	in/hr	0.5 (minimum); 2.0 (maximum)
Underdrain (where required)	-	6 inch diameter perforated PVC or HDPE set in 1 to 2 inch diameter stone or gravel free of fines and organic material (provide cleanout)
Overflow device	-	Required

Additional design specifications for tree box filters include:

- Maximum infiltration, volume reduction, and peak flow rate mitigation are achieved through sandy subsoils.
- Tree box filters shall be carefully integrated into drainage area to provide optimal number of units in suitable locations to capture stormwater treatment volume.
- Do not use Tree box filters to treat runoff from high sediment load areas.
- Tree box filters can be used to meet groundwater recharge objective where underlying soils are suitable and allowed by land use and receiving water characteristics.
- Soil media shall be uniform, free of stones, stumps, roots, or similar materials larger than 2 inches to prevent clogging of the system. To allow for adequate nutrient removal and microbial growth, the soil pH should be between 5.5 and 6.5, and it should consist of about 80% concrete sand and 20% organic material with 5% passing through a #200 Sieve.
- The total depth of the system shall be determined by a licensed civil engineer based on analyses of not only the hydrology and hydraulics, but also the structural requirements of the site.

8.5 CONSTRUCTION CONSIDERATIONS

The following construction considerations shall be required to assure that the tree box filter is installed as designed and the design components are obtained:

- Tree box filter systems shall be installed by a contractor with required qualifications.
- Tree box filter shall be the last installation done at a development site. Landscaping shall be completed and adjacent areas stabilized prior to installing the tree box filter to minimize risk of clogging.
- To prevent/minimize soil compaction in the area, perform excavation with equipment positioned outside the limits of the system.
- To prevent/minimize clogging of the soil, do not discharge sediment-laden water from construction activities to the tree box filter.
- Inspect soil media mix prior to placement to ensure the media meets engineering specifications. Inspect to ensure gravel materials have been washed prior to delivery to minimize the fines in the sub-base which can decrease infiltration rate.
- Prior to placing the tree box filter, ensure the material is installed by certified contractor, it is certified by the manufacturer and it meets engineering specifications.
- Provide energy dissipation (e.g. riprap), within tree box filter, at each concentrated inlet point to prevent erosion of soil media.

8.6 OPERATION AND MAINTENANCE

Tree box filters mainly require management of adjacent areas to limit sediment contamination and prevent clogging by fine sediment particles; therefore, little special training is needed for maintenance crews. Inspection and maintenance activities for tree box filters are summarized in Table 8.4 and a checklist provided as Table 8.5.

Table 8.4 Tree box filter inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect under grate for trash and debris	Monthly or as needed (dependent on site conditions)	Remove trash and debris from tree box using laborers
Inspect for standing water after rain events	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Monitor these areas to determine if surface infiltration rates have been compromised. If area does not drain within 72 hours, engineered media may need to be replaced
Inspect adjacent areas for erosion		Stabilize bare areas with sod or gravel as needed
Inspect for accumulated sediment		Remove accumulated sediment using laborers. Identify source of sediment and repair area. Refresh mulch if necessary
Depth of mulch present is equal to design depth		Add additional mulch if less than design depth
Inspect change in infiltration during storm event and ponding after event	Annually, during wet weather event	Replace media if ponding or loss of infiltration capacity persists
Inspect tree and filter area for weeds or dead plants	Annually	Remove weeds and replace plants as necessary. Prune tree as necessary.

SECTION 9.0 CURB CUTS AND INVERTED MEDIANS

Curb cuts (Figure 9.1) are a break in a roadway curb that allows runoff to drain to pervious surfaces adjacent to a roadway, allowing for filtration and retention. Curb cuts reduce the volume of water entering the storm sewer system. Curb cuts typically are not a stand-alone practice and can be designed in conjunction with raingardens, vegetated swales and shallow bioretention systems.

Inverted medians (Figure 9.2) provide stormwater retention for runoff from impervious surfaces while providing an aesthetically pleasing landcaped area and water quality treatment. Inverted medians are typically designed in the center of two- or four-laned roads and in parking areas, and they can be designed with curb cuts. Inverted medians can contain bioretention practices or vegetated swales to convey stormwater.

Figure 9.1 Curb cut along road is providing drainage to raingarden
(Source: Geosyntec)

Figure 9.2 Curb cuts and inverted median along four lane road
(Source: City of Arlington Virginia)

9.1 SITE SUITABILITY

Table 9.1 provides a summary of applicability, advantages and limitations for curb cuts and inverted medians.

Table 9.1 Curb cuts and inverted medians applicability, advantages and limitations

Applications	*Advantages*	*Limitations*
• Non-residential (commercial/office): parking decks and rooftops • Streets	• Reduce parking area and roadside flooding • Good for retrofits • Aesthetically pleasing • Reduce storm sewer infrastructure • Cost	• Maintenance to prevent clogging on inlets • Not a stand-alone practice • Does not provide water quality or volume reduction • May require additional grading • Potential frequent replacement of vegetative material

Curb cuts, while not stand-alone practices, are typically used in the following site applications:

- **Parking areas** where vegetated areas exist outside of current curb line. Curb cuts can allow water to flow into existing pervious areas, reducing flooding in parking areas and promoting groundwater recharge.

(Source: NRCS)

- Along **roadways**, conveying flows to roadside vegetated or landscaped areas.

(Source: US EPA)

- **Removal of curb line along one-side of residential roads**, to allow drainage to flow onto grassed areas, reducing volume into stormwater conveyance system.

Inverted medians, while not stand-alone practices either, are typically used in the following site applications:

- **Parking islands**, which can be used as bioretention areas or landscaped areas with overflow devices.

(Source: North Central Texas)

- **Roadway medians**, which can also function as vegetated conveyances of bioretention swales to provide stormwater retention and water quality treatment.

- **Bioretention cul-de-sac** medians, which reduce the amount of imperviousness and provide stormwater volume retention and water quality treatment.

(Source: State of Massachusetts)

9.2 DESIGN CONSIDERATIONS

<u>Curb Cuts</u>

- Curb cuts shall be designed in a manner to create positive flow, and they shall be spaced so that water does not bypass during rain events. Design will be such to accommodate the capacity of the receiving area for handling larger storm events.
- Curb cuts shall be sized to be less than the width of a car (≤4 feet) to prevent vehicles from driving into pervious areas.

- Energy dissipation shall be installed at downstream end of curb cut to prevent erosion to vegetation.
- Curb cuts shall be installed with other BMPs to provide water quality treatment, including vegetated filter strips, vegetated swales, and bioretention.
- Ensure that during large storm events, if flow bypasses curb cut, appropriate storm sewer infrastructure is in place to capture flow preventing flooding of streets and parking areas.

Inverted Medians

- Inverted medians shall be designed as depressions that allow for ponding of water (6" minimum, 8" maximum).
- In parking areas, consider curbs with curb cuts to prevent vehicles from driving into inverted medians.
- Inverted medians can be designed as bioretention areas or vegetated swales to provide water quality treatment. Consider an underdrain in these systems to convey larger storm events to other practices or into the storm sewer system.
- Clearly mark edge of road to ensure vehicles do not compromise edge of pavement.
- Pre-treatment includes filtration system and screens to filter debris and reduce pollutants. Where screens and filtration systems are used, an effective maintenance plan must be developed to ensure clogging does not occur which would prevent proper drainage.

Note that the use of this LID practice in conjunction with other BMPs should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

9.3 Construction Considerations

The following construction considerations shall be required to assure that the curb cuts and inverted medians are installed as designed and the design components are obtained:

- Construct curb cuts and inverted medians in right-of-ways.
- Do not install curb cuts or inverted medians adjacent to building or other structures with foundations.
- Keep equipment away from pervious areas where drainage from curb cut is directed and out of inverted medians, to prevent compaction of soils.

9.4 Operation and Maintenance

Since curb cuts and inverted medians are not stand-alone practices, their operation and maintenance requirements are typically in conjunction with other practices. The specific inspection and maintenance activities associated with these practices are summarized in Tables 9.2 and 9.3.

Table 9.2 Curb cuts inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect curb cuts for trash and debris	Monthly or as needed (dependent on site conditions)	Remove trash and debris from curb cuts using laborers or vacuum truck
Inspect for accumulated sediment	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Remove accumulated sediment using laborers. Identify source of sediment and repair area
Inspect downstream of curb cuts for erosion	Annually	Repair vegetation downstream of curb cut or install energy dissipation
Inspect during wet weather condition and make observations of ponding	Annually	Determine if size of curb cut can adequately convey flows during storm event

Table 9.3 Inverted medians inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect inverted medians for trash and debris	Monthly or as needed (dependent on site conditions)	Remove trash and debris from inverted median using laborers
Inspect for accumulated sediment	2 to 3 times per year or after major storm events (>0.75 inches/24 hours)	Remove accumulated sediment using laborers. Identify source of sediment and repair area
Inspect during wet weather condition and make observations of ponding	Annually	Conduct infiltration testing (if infiltration practice) or refresh soil or stone if clogged

SECTION 10.0 STORMWATER HARVESTING

Stormwater harvesting systems consist of structural tanks and pipe networks designed to capture stormwater runoff from impermeable surfaces, such as rooftops and parking decks, and temporarily store the water for intended uses, such as irrigation, washing of vehicles, or flushing toilets (Figure 10.1). Stormwater harvesting systems can also consist of converting an existing detention pond to a retention pond with a supply system to divert water for industrial use or for irrigation.

Figure 10.1 Stormwater harvesting system adjacent to a children's museum (Source: Geosyntec)

Stormwater harvesting systems are most often used as the wet detention part of a BMP treatment train and their effectiveness relies on storage volume design and use of the stored stormwater. Through detention and re-use of stormater runoff, stormwater harvesting systems are very effective at peak flow mitigation and reduction of wet weather discharges. Stormwater harvesting systems do not provide water quality treatment; however, through the re-use of captured stormwater, pollutant loads are reduced through runoff volume reduction.

10.1 COMPONENTS OF STORMWATER HARVESTING SYSTEMS

Two types of stormwater harvesting systems are cisterns or rainbarrels. Cisterns are large storage containers installed either above or below ground and are designed to hold large volumes of water (about 500 gallons or more). Cisterns may be built of fiberglass, concrete, plastic, brick, or other materials. Rainbarrels (typically less than 100 gallons) are smaller containers installed above the ground surface, and they are generally used in residential applications. Cisterns and rainbarrels collect runoff from rooftops during rain events. Stormwater harvesting systems consist not only of a cistern or rainbarrel, but also a pipe network diverting runoff to the storage tank, an overflow bypass for when the storage tank is full, and a pump and distribution network to deliver water to its intended use or downstream BMP (Figure 10.2 shows a basic above ground

Figure 10.2 Above ground cistern used for irrigation purposes (Source: Duke University)

cistern used to supply a building with grey water and Figure 10.3 illustrates the components of an underground cistern used to supply an adjacent building with grey water). Pumps used to distribute water from cisterns tend to be low head, high flow pumps, like centrifugal pumps.

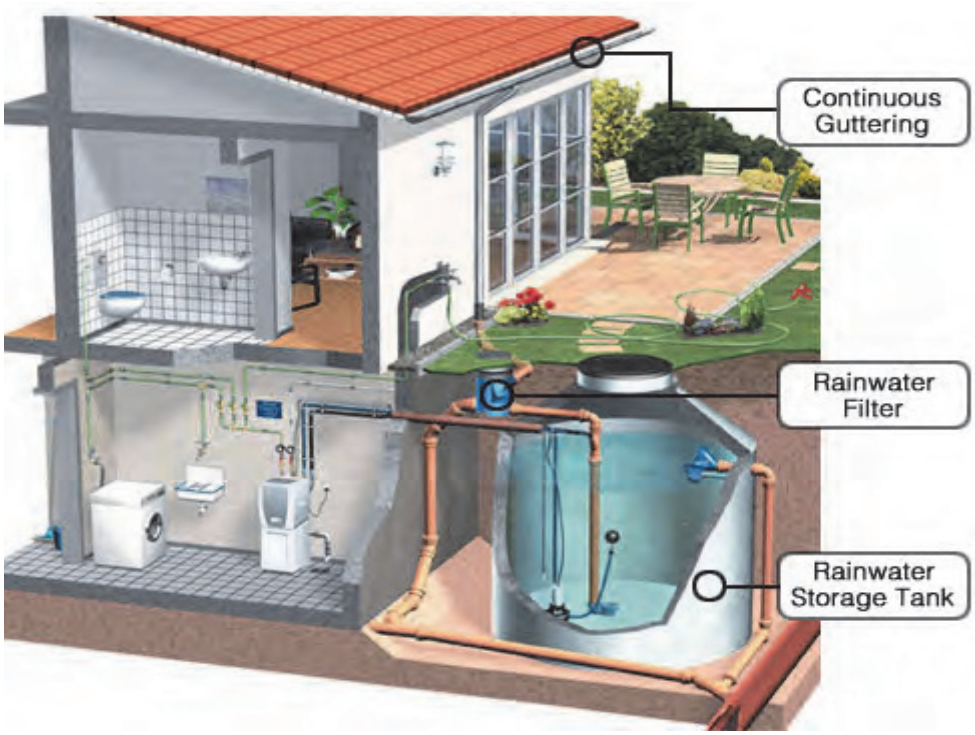


Figure 10.3 Schematic of an underground cistern supplying adjacent building with grey water (Source: All Things Rainwater)

10.2 Site Suitability and Design Specifications

Table 10.1 provides a summary of BMP applicability, advantages and limitations for stormwater harvesting systems

Table 10.1 Stormwater harvesting systems applicability, advantages and limitations

Applications	*Advantages*	*Limitations*
• Non-residential (commercial/office): parking decks and rooftops • Residential rooftops	• Reduces stormwater volume through re-use • Reduces stormwater peak flow rates • Provides additional water source for demands, such as irrigation, washing of vehicles, and flushing of toilets • Reduces pollutant loads	• Performance depends on use of captured stormwater runoff • Cost

Stormwater harvesting systems are volume-based and provide peak flow rate and runoff volume reduction depending on re-use of stored stormwater between rain events. When the cistern or rainbarrel contains enough storage volume to fully capture runoff from storms, runoff during wet weather events may be eliminated. However, if stored stormwater is not used between events and the cistern or rain barrel is full at the beginning of the storm, the stormwater harvesting system will act as a flow-through device, providing minimal volume or peak flow rate reduction, if any. When the cistern or rainbarrel does not contain enough storage volume to fully capture runoff from the storm (design capacity of the system is less than runoff volume of storm event), the system will fill up at the beginning of the storm, reducing runoff volumes downstream and potentially peak flow rate of the storm event. The performance of a stormwater harvesting system is heavily dependent of the re-use of stored stormwater between rainfall events.

10.3 POLLUTANT REMOVAL EFFICIENCIES

Stormwater harvesting systems as stand-alone practices do not provide water quality treatment; however, they do provide pollutant load reductions through volume reductions. In order to provide volume reductions, the stored stormwater runoff must be used between rainfall events. The decrease in nutrient load reductions will be proportional to the decrease in stormwater volumes.

The nutrient removal credits associated with stormwater harvesting shall be calculated using the Rate-Efficiency-Volume (REV) curves for Zone 2 (Orange County) (Figure 10.4) and calculated removal efficiencies of other BMPs in the BMP treatment train. The use rate and runoff volumes values are based upon inches over the project's equivalent impervious area (EIA).

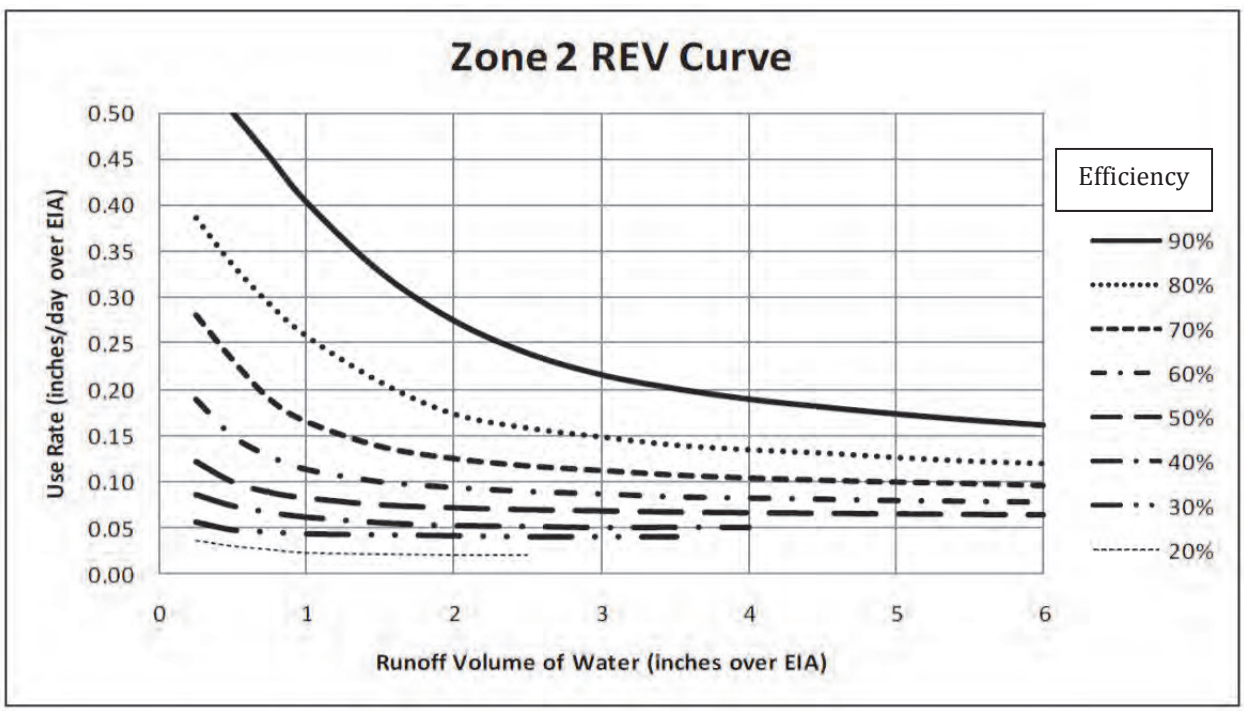


Figure 10.4 REV Curve for Meteorological Region 2

10.4 DESIGN CRITERIA

Design criteria for stormwater harvesting systems are presented in Table 10.2.

Table 10.2 Stormwater harvesting system design criteria

Design Parameter	*Unit*	*Design Criteria*
Drainage Area	Acres	Tank size varies on required treatment volume
Pretreatment	-	Install first flush diverter and filtration system on storage unit. If used with parking lots, absorbent socks or other oil absorbent filters should be included.
Drawdown time of cistern	hrs	48 – 60 (with factor of safety = 2) (may vary seasonally)
Minimum depth to aquitard	ft	None; however, a foundation for storage unit must be designed to support weight of storage unit and stored water
Overflow device	-	Required. Designed a few inches from the top of the storage unit and sized to accommodate the 100-year, 24-hour design storm if designed as an on-line system.

Additional design specifications for stormwater harvesting systems include:

- Screens may be used to filter debris from units. If intended use of stored stormwater is for irrigation purposes, use of filtration device is highly recommended.
- Should be designed to minimize clogging from leaves and other debris from rooftops.
- Storage unit should be installed and secured on level foundation.
- Pipes or storage units should be clearly marked with signs to indicate non-potable water and not for drinking use.
- Storage elements should be protected from direct sunlight by positioning and landscaping to limit algae growth.
- The proximity to building foundations should be considered for overflow conditions.
- Units should be watertight (joints sealed with nontoxic waterproof material) with a smooth interior surface.
- Covers (lids) should have a tight fit to keep out surface water, animals, mosquitoes, dust, and light.
- Reuse may require pressurization. Water stored has a pressure of 0.43 psi per foot of water elevation. Most irrigation systems require at least 15 psi. To add pressure, a pump, pressure tank and fine mesh filter can be used.

Note that this LID BMP should not be used in areas of high pollutant loading (i.e., sediments, oils & greases, chemicals, etc.) without incorporation of pre-treatment features into the practice.

10.5 Construction Considerations

The following construction considerations shall be required to assure that the stormwater harvesting system is installed as designed and the design components are obtained:

- The location and dimension of the stormwater storage unit shall be verified on-site prior to installation. All design requirements including stormwater storage unit dimensions and distances to foundations, septic systems, and wells need to be verified.
- All inlets and outlets shall be stabilized to prevent erosion, scour, and sedimentation.
- Construct stormwater harvesting system and the associated irrigation system (if required) in accordance with all permitted design specifications and irrigation system design standards.
- Assure that all irrigation components are properly sited and that irrigation spray heads are working properly and not spraying irrigation water onto impervious areas.
- Assure foundation for above ground cistern or rain barrel is capable of supporting storage unit weight and stored water to prevent soil consolidation.

10.6 Operation and Maintenance

Stormwater harvesting mainly requires removal of debris collected on inlet screen from drainage area; therefore, little training is needed for maintenance crews. Inspection and maintenance activities for stormwater harvesting systems are summarized in Table 10.3 and an inspection checklist provided as Table 10.4.

Table 10.3 Stormwater harvesting inspection and maintenance activities

Inspection Activity	*Frequency*	*Maintenance Activity*
Inspect cover, inlets, downspouts and outlets for debris	Monthly or as needed (dependent on site conditions)	Remove sediment and debris using laborers
Inspect pump (if applicable)	Annually or as needed	If not functioning properly, consult manufacturers specifications for troubleshooting
Inspect for sediment depth in tank and algae growth, mosquitos or other insects		Empty tank and clean. Remove accumulated sediment
Inspect tank for leaks		Determine severity of leak, and patch appropriately – replace if warranted.