Design Considerations

- Soil for Infiltration
- Tributary Area
- Slope
- Aesthetics
- Environmental Side-effects

Targeted Constituent	Removal
Sediment	High
Nutrients	Med
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

Description

The bioretention cell functions as a soil and plant-based filtration device that removes pollutants, including trash, through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, ponding area, organic layer or mulch layer, planting soil, and native vegetation. Runoff velocity is reduced by passing over or through a buffer strip, which can increase sedimentation and debris capture in heavily trafficked areas. Stormwater is infiltrated through engineered media to the native soils or can be directed to an underdrain.

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California Experience

Bioretention areas have been widely implemented across California in a variety of configurations to meet a full suite of regulatory requirements in Los Angeles, San Diego, San Francisco, and many of the surrounding areas. Bioretention areas have been implemented in the right-of-way as a green street, in medians in parking lots, and incorporated into landscaped areas. Figure 1 and Figure 2 show how bioretention areas have been implemented around the state.

Bioretention areas have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water

Figure 1. Bioretention incorporated in a green street in San Diego, CA.

Boards. Additionally, the Water Boards have determined that bioretention can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

Figure 2. Bioretention in the parking lot of the LA Zoo.

Advantages

- Bioretention provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape and aesthetic.
- Can be used in any soil type. When infiltration rates are too low, underdrains are installed.

Limitations

- Not recommended for areas with slopes greater than 20%.
- Bioretention is not suitable where the water table is within 3 feet of the ground surface.
- Creates an attractive habitat for mosquitoes and other vectors if drainage is insufficient.

Performance

Bioretention removes stormwater pollutants through numerous processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Media depth can have an impact on the removal of certain pollutants, particularly nitrogen and phosphorus (Hunt et al. 2012, Hunt et al. 2006; Hunt and Lord 2006). Table 1 below details expected effluent concentrations and removal processes for each pollutant constituent.

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Sediment	High	9.9 mg/L	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet of media	Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Geosyntec Consultants and Wright Water Engineering 2012; Stander and Borst 2010
Metals	High	TCd: 0.07 μg/L, TCr: 0.35 μg/L, TCu: 5.33 μg/L, *TFe: 1027 μg/L,* TPb: 0.19 μg/L, *TNi: 4.53 μg/L,* TZn: 12.0 μg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet of media	Hsieh and Davis 2005; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012
Hydrocarbons	High	N/A	Removal and biodegradation in mulch.	3 inches of mulch	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium -240% - 99%	*0.240 mg/L*	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal can result from media containing high organic matter or high background concentrations of phosphorus.	2 feet of media	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; ; Li et al. 2010
Total nitrogen	Medium TKN: -5% - 64%, Nitrate: 1% - 80%	TN: 0.92 mg/L, TKN: 1.34 mg/L, $NO_{2,3}$-N: 0.37 mg/L	Sorption and settling (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet of media	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006, 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009
Bacteria	High	*Enterococcus*: 235 MPN/ 100 mL, *E.coli*: 101 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet of media	Hathaway et al. 2009, 2011; Hunt and Lord 2006; Hunt et al. 2008, 2012; Jones and Hunt 2010; Geosyntec Consultants and Wright Water Engineering 2012
Trash	High	*N/A*	Filtration	1.5 feet of media	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Performance Considerations

Bioretention areas provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most sediment removal occurs in pretreatment practices, in the mulch layer, and in the top 2 to 8 inches of soil media (Hatt et al. 2008; Li and Davis 2008; Stander and Borst 2010). Metals are commonly sediment-bound and are removed in the top 8 inches of media (Hsieh and Davis 2005; Hunt et al. 2012).

Nitrogen and phosphorus removal is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal). The significant increase is suspected to be the result of excessive phosphorus levels in the furnished soil media (Hsieh and Davis 2005; Hunt et al. 2006; Davis 2007). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 parts per million (ppm) (Hunt and Lord 2006). A study in Texas indicated that nutrient export can also occur when bioretention soils are amended with excessive compost (Li et al. 2010). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). Total Kjeldahl nitrogen (TKN) has been found to vary between a 5 percent increase and 64 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate in the planting soil to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Nitrate removal can be improved by incorporating a saturated layer in the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009).

Bioretention represents a technology to mitigate pathogens from urban watersheds (especially when volume reduction is considered), although limited data exist for bacteria, virus, and protozoa removal. Most scientists and engineers agree that bacteria die-off occurs at the surface where organisms are exposed to solar radiation and dry (desiccating) conditions; dense vegetation in the bioretention area can limit the penetration of sunlight, but it can provide habitat for bacterivores and other beneficial pathogen predators (Hunt and Lord 2006; Hunt et al. 2008; Hathaway et al. 2009). Microbes are also sequestered by sedimentation and sorption; therefore, 2 feet minimum media depth and slower infiltration rates (1–2 in/hr) are recommended to enhance pathogen removal (Hathaway et al. 2011; Hunt et al. 2012).

In addition to chemical and biological pollutant removal, bioretention can be designed to reduce thermal loading to waterways. Thermally enriched runoff can increase stream temperatures and have adverse impacts on stream biota and dissolved oxygen (Booth et al. 2013; USEPA 1986). Research suggests that deep media beds (generally four feet or greater) can buffer extreme temperatures and that infiltration of stormwater can decrease overall thermal loading (Hunt et al. 2012; Jones and Hunt 2009; Winston et al. 2011; Wardynski et al. 2013). Thermal mitigation can likely be enhanced by shading bioretention areas with tree canopy cover and including IWS (Hunt et al. 2012; Jones et al. 2012).

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which bioretention meets (see Section 5.6.1 for FCS details).

It is worth noting that the numerous treatment processes provided by bioretention, particularly filtration, means bioretention performance far exceeds the 5 mm or greater FCS definition for particle trapping. So bioretention systems are not only trapping all particles of 5 mm or greater but effectively all particles less than 5 mm, including microplastics and "nurdles" (pre-production plastics).

Suitability and Design

Figure 1 and Figure 2 illustrate the flexibility of bioretention design in new or existing infrastructure. The constraints of each site dictate the appropriate siting and footprint. Fundamental bioretention design components are as follows:

- A fully stabilized drainage area of less than 20% slope.
- 2.5 to 3.5 inch minimum elevation difference in head between inlet and outlet.
- Typical ponding depth of 3 to 12 inches or more with 9 inches recommended.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.
- Geotechnical investigation required to identify soil infiltration rate. If known soil contamination is present, line restricting infiltration is not allowed.

Bioretention design is highly dependent on the constraints of the considered site. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations. Retrofitting can increase costs because of demolition of existing pervious surfaces.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation		Underdrain required if subsoil infiltration rate < 0.5 in/hr or when contamination present. When infiltrating ensure that subgrade compaction is minimized.
Without underdrains (unlined)	$2.75–$5.00/ft^2	
With underdrains (lined)	$3.90–$6.15/ft^2	
Soil Media		1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and rooting depths) at minimum 5 in/hr infiltration. Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil. Organic Matter Content < 5% by weight. 65% sand, 20% sandy loam, and 15% compost (from vegetation-based feedstock) by volume.
Recommended mix	$2.40–$4.75/ft^2	
With engineered media	$3.40–$6.80/ft^2	
Soil Media Barrier		When utilizing an underdrain, separate media from underdrain with 2 to 4 inches of washed sand (ASTM C-
Geotextile	$0.45/ft^2	

Component	Cost	Design Consideration
Washed sand (2-inch layer) No. 8 aggregate (min 2 inches thick) No. 57 stone (1.5 + feet)	$0.20/ft² $0.28/ft² $2.49/ft²	33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Underdrain Pipe (includes drainage stone, with 5-foot spacing)	$3.60/ft²	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Curb and Gutter	$18/ft	When installed adjacent to road, provide stabilized inlets at least 12 inches wide
Mulch Native hardwood	$0.24–$0.39/ft²	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3-inches-deep.
Hydraulic Restriction Layer Filter fabric Clay 30-mil liner Concrete barrier	 $0.45/ft² $0.65/ft² $0.35/ft² $12.00/ft²	If non-infiltrating, use hydraulic restriction layer. If infiltrating may use on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.
Vegetation	$0.20–$3.50/ft²	Native, deep rooting, drought tolerant plants. Apply one-time spot fertilization upon planting. Water until plants are established.

Vegetation

Figure 3. Bioretention in a landscaped area in San Diego, CA.

Vegetation is an integral component of bioretention and has been shown to provide some increase in metals reduction (Sun and Davis 2007, Li, et al. 2011) and a significant increase in nutrient reduction (Glaister, et al., 2014; Henderson, et al., 2007; Barrett, et al., 2013; Limouzin, et al., 2011; Li, et al., 2011; Houdeshel, et al., 2015). Three species each of trees, shrubs, and perennials are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For instance, a 15 foot (4.6 meter) by 40 foot (12.2 meter) bioretention area (600 square feet or 55.75 square meters) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1.

Drought tolerant native species are recommended and should be planted when conditions are most favorable. Vegetation should be watered at the end of each day for fourteen days following planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the bioretention area. The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures, such as providing a soil breach to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities.

Figure 4 Bioretention in San Francisco, CA. Source: Jim Hook

The designers should evaluate the best placement of vegetation within the bioretention area. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site. Following placement of the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted at the beginning of the growing season. Mulch should be placed immediately after trees and shrubs are planted. Two to 3 inches (5 to 7.6 cm) of commercially available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion.

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The bioretention area must be configured to allow trash to enter the system and for trash to remain in the bioretention area until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in a bioretention area. An open curb cut is recommended for high traffic areas (Figure 5). A minimum 2 inch drop from the gutter line of the curb to the inlet is recommended as demonstrated in Figure 6 to ensure that flow is routed into the bioretention area and trash will not clog the inlet.

Figure 5. Example of an open curb cut.

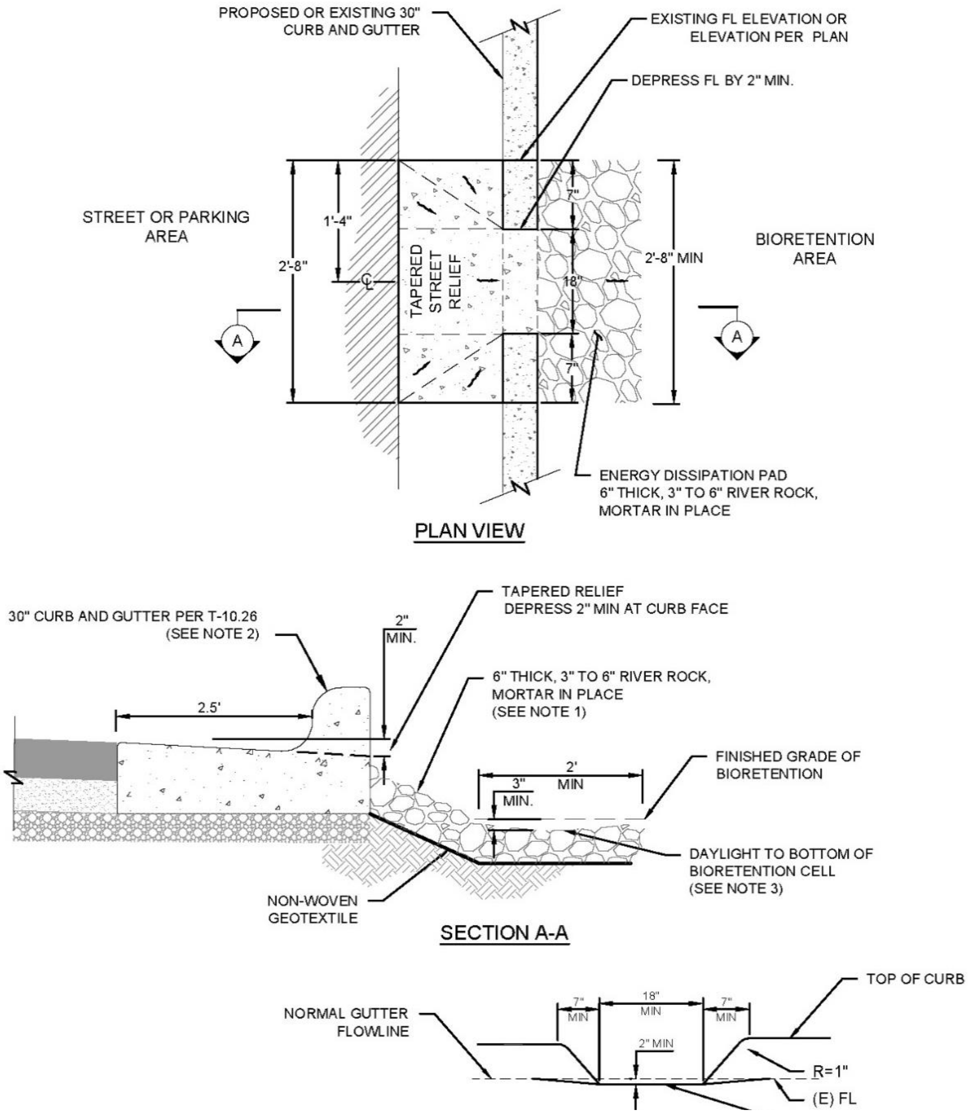

Figure 6. Example Inlet Detail

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. A forebay (Figure 7), filter strip (Figure 8), or mortared cobble inside the curb cut (Figure 9) can slow flow and allow trash and gross solids to settle out while consolidating at the edge of the bioretention area to make it easier for maintenance crews to collect and remove.

Figure 7. Example of a forebay as pretreatment for a bioretention area.

Figure 8. Example of filter strip as pretreatment for a bioretention area.

Figure 9. Example of mortared cobble for pretreatment in a bioretention inlet with a curb cut.

Trash Containment

Once trash has been captured in the bioretention area it must be contained so trash does not escape the bioretention area. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or

Figure 10. Example of an outlet with 5 mm screen.

- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Figure 10 shows an example of an outlet with a screen to contain trash.

Maintenance

The primary maintenance requirement for bioretention areas is inspection and repair or replacement of the treatment area's components. Appropriately selected plants will aid in reducing fertilizer, pesticide, water, and overall maintenance requirements. Bioretention system components should blend over time through plant and root growth, organic decomposition, and the development of a natural soil horizon. These processes will lengthen the facility's life and reduce the need for extensive maintenance. Maintaining soil porosity and basic housekeeping practices such as removal of debris accumulations and vegetation management are necessary to ensure that the system dewaters completely (recommended 72-hour or less residence time) to prevent creating mosquito and other vector habitats. If a bioretention cell has an underdrain, the functionality of the underdrain needs to be maintained to ensure that the drainage and drawdown of stormwater is not hindered. Bioretention requires monthly landscaping maintenance, including measures to ensure that the area is functioning properly, and irrigation during dry periods. In many cases, bioretention areas initially require intense maintenance, but less maintenance over time. Maintenance tasks can be conducted by a landscaping contractor, who might already be hired at the site. Additionally, a bioretention cell's efficacy to reduce pollutant loads and provide hydrologic benefits is severely diminished when frequent and complete maintenance is not conducted. For typical maintenance activities, Table 3 provides recommended frequencies and associated costs.

Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
As needed		• Irrigate area during dry periods. Make structural changes or repairs as needed to eliminate pools of water, particularly during the warmer months of the year. Coordinate with the local mosquito and vector control agency to control mosquitoes.
Biweekly, at project completion		Water plants daily for 2 weeks.
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Pruning and mowing overgrown vegetation that interferes with access, or safety. Remove and replant dead or dying plants. Replace tree stakes and wires. If there is an underdrain, unclog drainage structure.
Routine (small)	$7.62/ft^2$	
Routine (medium)	$1.91/ft^2$	
Routine (large)	$1.91/ft^2$	
Intermediate Maintenance (required every 6 to 10 years)		Remove and replace mulch upon decomposition. Replace soil media for areas receiving especially
Intermediate (small)	$5.62/ft^2$	

Frequency	Cost	Activity
Intermediate (medium)	$2.94/ft^2	high pollutant loads. Repair erosion at inflow points and outflow structures.
Intermediate (large)	$2.50/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$10.52/ft^2	
Replacement (medium)	$10.17/ft^2	
Replacement (large)	$10.11/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Bioretention Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the bioretention area in the subsequent rain events (see Table 3). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance interval is best determined by observing the BMP in operation for a wet season.

Trash maintenance not only plays a role in the functionality of the bioretention area but also in the aesthetics and public perception of the bioretention area (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic

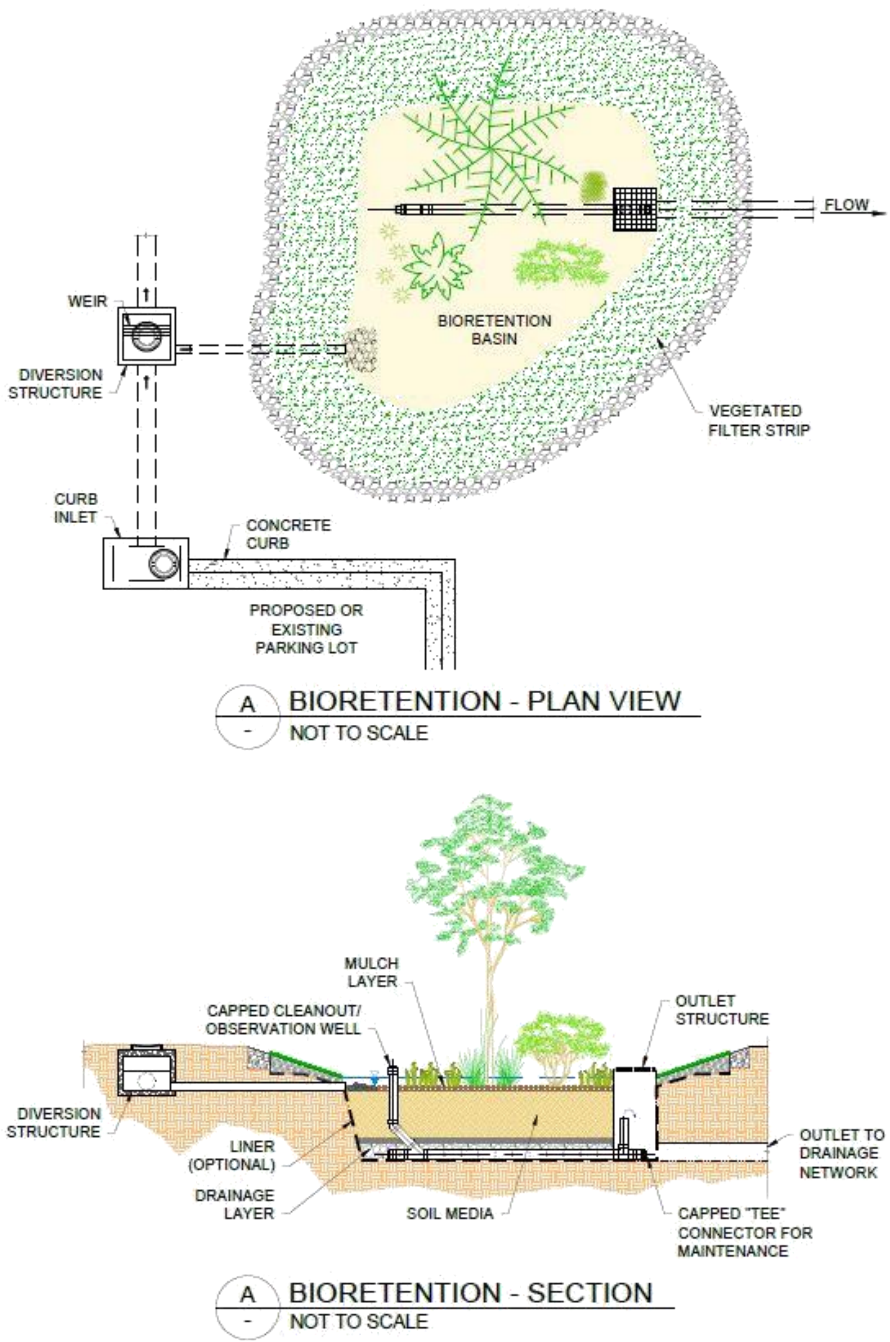

Figure 11. Schematic of a Bioretention Area.

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