Stormwater Best Management Practice

Bioretention (Rain Gardens)

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Filtration

Description

Bioretention practices, such as rain gardens, are landscaped depressions that treat on-site stormwater discharge from impervious surfaces such as roofs, driveways, sidewalks, parking lots and compacted lawns. They are used to collect stormwater and filter it through a mixture of soil, sand and/or gravel. The designs of bioretention practices mimic volume reduction and pollutant removal mechanisms that work in natural systems. The filtered stormwater soaks into the ground, provides water to plants and can help recharge the local groundwater supply. Through these processes, bioretention practices reduce peak flows within downstream sewer systems and allow pollutant removal through filtration and plant uptake.

Applicability

Bioretention practices are well suited to small sites in urbanized settings and can filter stormwater from small to medium storms. Designers generally bypass stormwater discharges from larger storms past a bioretention practice to a larger stormwater control or the storm drain system.

Urban Areas

Developers can easily install bioretention practices in densely developed urban areas with few pervious surfaces. Bioretention practices can fit into existing parking lot islands, along roads, at intersections or in other landscaped areas as part of a retrofit, redevelopment or new construction. Bioretention practices generally need a footprint of approximately 5 to 10 percent of the surrounding drainage area (Tetra Tech, Inc., 2011).

Stormwater Hot Spots

Stormwater hot spots are areas where certain land uses or related activities generate highly contaminated discharges with pollutant concentrations exceeding those typical of stormwater. Typical examples include gas stations and some industrial areas. Design engineers can tailor a bioretention practice to treat a stormwater hot spot by adding an impervious liner to the bottom of the gravel layer to prevent groundwater or surface water contamination.

A bioretention practice in a suburban road median, capturing stormwater during a rain event.

Photo Credit: Image reproduced with permission from Montgomery County, MD Department of Environmental Protection

Cold Water (Trout) Streams

Heat from paved surfaces like parking lots and roads can increase the temperature of stormwater discharge as it flows into nearby surface waters. Some wildlife species in cold water streams like trout are sensitive to temperature changes. Bioretention practices can decrease the temperature of stormwater by temporarily detaining stormwater discharge beneath the ground surface.

Regional Applicability

Bioretention practices are applicable almost anywhere in the United States. A three-year study in the Twin Cities, Minnesota, region concluded that bioretention practices perform well in cold climate conditions (LeFevre et al., 2009). In this study, soil type was the most important design consideration. In addition, the presence of frost only influenced performance in cases where pore spaces became frozen, halting infiltration.

In arid and semiarid climates, drought-tolerant plants are the best landscaping option for bioretention practices. Houdeshel et al. (2015) evaluated the effectiveness of three bioretention practices in a semiarid climate and concluded that by increasing native vegetation densities or by using gray water to irrigate vegetation during dry periods, nutrient retention performance in this climate was similar to that of other wetter climates.

Siting Considerations

Important site conditions to consider when designing bioretention practices include the size of the drainage area, slopes, soil and subsurface conditions, and the depth of the seasonal high groundwater table. Design engineers can incorporate design features that improve the longevity and performance of the bioretention practice while minimizing maintenance.

Drainage Area

Design engineers typically use bioretention practices to treat small drainage areas that are less than 5 acres. When treating areas larger than one-half acre, bioretention practices often use pretreatment systems such as forebays or filter strips to prevent clogging. In addition, it can be difficult to convey flow from a large drainage area to a bioretention practice. In these cases, multiple successive bioretention practices may work better than a single large system.

Slope/Topography

Parking lots or residential landscaped areas with gentle slopes around 5 percent are ideal for bioretention practices. A design engineer should include sufficient elevation difference between the bioretention practice inflow and outflow to ensure that water can flow through the filtering media in a specified amount of time, typically less than 24-48 hours (design requirements vary by location). Depending on the design variation, the bioretention practice may need 2 to 6 feet of elevation difference to meet this requirement.

Soils

Design engineers can use bioretention practices with almost any soil type. In soils with poor infiltration rates, adding underdrains allows stormwater to percolate through the media and move downstream. In soils with naturally high infiltration rates, design engineers may exclude underdrains from the plans. In all cases, preliminary design steps should include site-specific soil testing by a qualified professional and should adhere to local design standards that specify when conditions warrant an underdrain.

Groundwater

Design engineers should separate the bottom layer of a bioretention practice from the seasonal high groundwater table by a minimum of 2 feet. This separation ensures that the groundwater table does not intersect with the bed of the bioretention practice, maintains infiltration rates throughout the system, and prevents possible groundwater contamination from contaminated stormwater. In areas where groundwater contamination is a concern, design engineers should add an impervious liner around the bottom of the bioretention practice. Bioretention practices without underdrains and with high infiltration rates may also help maintain groundwater recharge rates.

Design Considerations

Bioretention practice designs can vary considerably, depending on site constraints or preferences of the design engineer or community. Some consistent design features fall into five basic categories described below: pretreatment, treatment, conveyance, maintenance reduction and landscaping.

Pretreatment

Bioretention practices that treat large drainage areas greater than one-half acre use pretreatment, which includes design features that settle coarse sediment particles and their associated pollutants. Pretreatment can reduce the maintenance burden and the likelihood that the soil bed will clog over time. Design engineers can use several different mechanisms to provide pretreatment in bioretention practices, including grass channels or filter strips and pea gravel diaphragms. The system directs stormwater to these pretreatment features to reduce flow rates and filter out coarse materials before the stormwater flows into the filter bed. Larger systems often use wet or dry forebays as pretreatment.

Treatment

Treatment design features help enhance a bioretention practice’s ability to remove pollutants. Design engineers should consider several basic design features to enhance the bioretention practice’s pollutant removal:

1. A footprint whose size is between 5 and 10 percent of the impervious area draining to it (Tetra Tech, Inc., 2011).

2. A soil bed that is a sand/soil matrix to serve as plant growing media.
3. A design to temporarily pond a small amount of water (typically 6 to 12 inches) above the filter bed.

In addition to the standard features above, design engineers may add various media amendments to the soil bed layer to enhance specific pollutant removal performance. For example, a literature review by Hirschman et al. (2017) found that adding iron and aluminum amendments can reduce total phosphorus in bioretention practice effluent.

Conveyance

Stormwater flow into and through a bioretention practice is a critical component of its design. If surrounding soils have low infiltration rates, bioretention practices should include a perforated underdrain system to collect and convey filtered stormwater to the storm drain system. Design engineers should place the underdrain in a gravel bed at the bottom of the filter bed. Design engineers should also provide an overflow structure to convey flows that are too large for the system to handle.

Landscaping

Landscaping with appropriate plants is vital to the function and aesthetic value of bioretention practices. Using native plants that also provide wildlife habitat provides multiple benefits and can help boost plant survival, given these plants should tolerate the local hydrologic regime. For example, plants on the bottom of the bioretention practice should tolerate both wet and dry conditions. At the edges, upland species used to dry conditions can thrive. Finally, it is best to plant a combination of shrubs and herbaceous vegetation where site conditions allow. Design engineers can include trees after considering any overhead or underground infrastructure such as power lines or pipes.

Design Variations

Design engineers can implement multiple design variations for bioretention practices to serve different objectives. Some variations promote percolation into the native soil and groundwater recharge, while others exclusively focus on filtration. The Minnesota Pollution Control Agency offers examples of bioretention design variations. The main differences pertain to the presence or absence of an underdrain, an impermeable liner or an internal water storage chamber. One common design variation is the rain garden, a shallow depression containing a layer for planting media. However, rain gardens do not have sand or gravel layers to treat stormwater through infiltration.

Limitations

Bioretention practices are not suitable for treating large drainage areas. Surface soil layers can clog over time in areas with excessive sediment loadings. Although bioretention practices typically have small footprints, incorporating them into a parking lot design may reduce the number of parking spaces available if the design did not previously include islands. In addition, bioretention practices should leave space between the system and permanent structures, including buildings (with the exception of the bioretention planter box design variation).

Bioretention practices can reduce local flooding but may not provide flood control during extreme storms. They can, however, alleviate the stress on other flood control measures by reducing peak flows and stormwater volumes within their drainage areas.

Maintenance Considerations

Bioretention practices require landscaping maintenance as well as measures to ensure that the practice is functioning properly. Bioretention practices may initially require more labor for maintenance than a traditional landscaped island, but maintenance needs generally decrease over time. If they contain appropriate vegetation, landscaping maintenance may require fewer resources than traditional landscaped islands in parking areas.

Table 1 below provides a general overview of the typical maintenance activities, frequency and maintenance notes for bioretention practices. Local stormwater manuals often include specific maintenance considerations.

Bioretention Planter Box

A *bioretention planter box* can be designed to infiltrate stormwater and act as a bioretention practice. This type of practice is typically a concrete box that contains planting media, sand and gravel layers that promote infiltration. Bioretention planter boxes can be used in rights of way. If used beside buildings, then designers should consider potential impacts of infiltration on building foundations.

Table 1. Typical maintenance activities for bioretention practices (consult local stormwater manuals for specific considerations).

Activity	Frequency	Maintenance Notes
Pruning	1 to 2 times per year	Vegetation often grows vigorously during rainy seasons. Prune vegetation to maintain capacity and flow rates.
Mowing	2 to 12 times per year	Frequency depends on location and desired aesthetic appeal. Providing clarity as to the timing is important so that maintenance staff do not include these areas as part of more regular mowing procedures.
Watering	Once every 2 to 3 days for first 1 to 2 months; sporadically after establishment	If drought conditions exist, plants may need watering after the initial year. Native vegetation may flourish without watering.
Fertilization	Once initially	One-time spot fertilization for *first-year* vegetation.
Dead plant removal and replacement	Once per year	Within the first year, 10 percent of plants can die. Survival rates increase with time. Removing dead plants also removes nutrients that would otherwise enter the system.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioretention practice is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet, and remove any accumulated mulch or sediment.
Miscellaneous upkeep	Once per month	Tasks include collecting trash, checking plant health, spot weeding, removing invasive species and removing mulch from the overflow device.
Replacement of top few inches of filter media	If ponding occurs for more than 48 hours	Replace top few inches of filter media. Sediment accumulation reduces the bioretention practice's performance and the facility's ability to drain.

Sources: Tetra Tech, Inc., 2011; MDE, 2009

Effectiveness

Effective bioretention practices reduce stormwater flows and remove pollutants. Bioretention practices reduce stormwater discharge from smaller-storm events, though they can also remove a limited amount of pollutants from larger events under the right conditions. Like most stormwater treatment systems, bioretention practices by design capture a specific treatment volume associated with local climate conditions. For example, Maryland defined this volume as the stormwater produced from a 1-inch storm event (MDE, 2009). Treatment performance generally diminishes for larger storm events above the design capacity, though these events tend to be less frequent and often make up a small fraction of the total annual rainfall and stormwater discharge to a given location.

Bioretention practices reduce stormwater discharge by enhancing infiltration and evapotranspiration. Infiltration enhancement depends on the design variation. Figure 1 shows the results of an analysis looking at the volume reduction performance of 20 different bioretention practices with underdrains (left) and without underdrains (right) (Geosyntec Consultants and Wright Water Engineers, Inc., 2012). Both design variations consistently provided volume reduction, though systems without underdrains (right) provided greater volume reduction (as measured by zero-discharge events) due to increased infiltration losses. Systems with underdrains provided an average volume reduction of 56 percent across all measured storm events, while those without underdrains provided an average volume reduction of 89 percent.

These areas enhance evapotranspiration (the sum of evaporation and vegetation transpiration) by providing prolonged storage of stormwater discharge within bioretention media and gravel layers where plant roots have greater access.

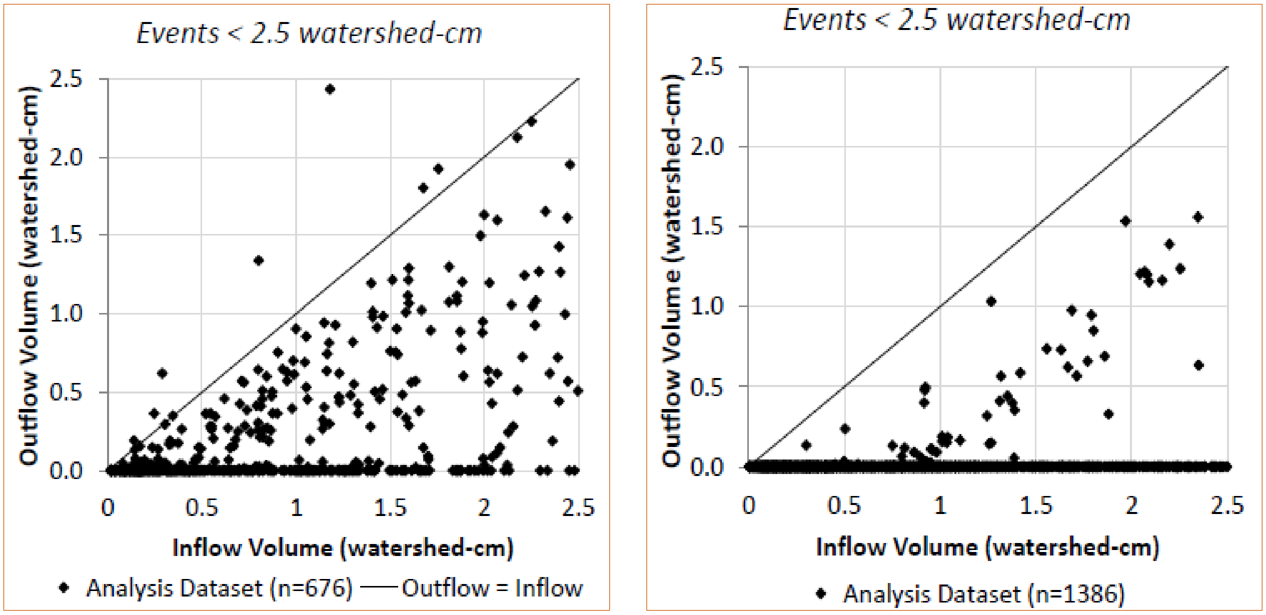

Figure 1. Discharge volume versus inflow volume for bioretention areas with and without underdrains. Tile A shows results for 676 monitored events across 14 individual systems with underdrains. Tile B shows results for 1,386 monitored events across six individual systems without underdrains.

Source: Geosyntec Consultants and Wright Water Engineers, Inc. 2012. Reprinted with permission. © Water Environment Research Foundation.

Pollutant removal performance is more variable and, due to volume losses described above, can be misleading when looking at influent and effluent concentrations. For example, data summaries in the National Pollutant Removal Database (Clary et al., 2017) indicate positive removals for metals, bacteria, total suspended solids and total nitrogen but negative removals for total phosphorus when measured using concentration. However, to determine actual mass removal performance, analysts should incorporate the volume reduction performance discussed above. For example, in a detailed assessment of a subset of the same National Pollutant Removal Database data, Leisenring et al. (2013) found that bioretention systems with underdrains showed statistically significant removal of total suspended solids but not total nitrogen or total phosphorus.

Cost Considerations

Bioretention practices can vary depending on size, maintenance required and cost of materials. Costs can range from $50,000 to $200,000 per acre of impervious surface treated,[1] with smaller systems being more expensive per acre. In addition, retrofits with complex existing infrastructure may be more expensive than new construction (King and Hagan, 2011).

An important consideration when evaluating bioretention practice maintenance costs is that they are often in areas that already require landscape maintenance, such as parking lot islands or rights-of-way. Maintenance activities for bioretention practices are similar to traditional landscaping and may cost less than typical vegetative cover—such as turfgrass or ornamental vegetation—because they require less watering and less frequent mowing.

Like other volume reduction practices, bioretention practices can save costs compared to the use of traditional structural stormwater conveyance systems. For example, the use of bioretention practices can decrease the cost of constructing stormwater conveyance systems and reduce the required size of traditional stormwater detention ponds.

Helpful EPA Resources

- What is Green Infrastructure?
- What is EPA Doing to Support Green Infrastructure?
- Green Infrastructure Modeling Tools
- Green Infrastructure Design and Implementation
- Green Infrastructure Funding Opportunities
- Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects
- Manage Flood Risk
- Build Resiliency to Drought
- Green Infrastructure Webcast Series

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

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[1] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site https://data.bls.gov/cgi-bin/cpicalc.pl. Reference dates for the calculation are October 2011 and September 2019.

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