United States Environmental Protection Agency

BIORETENTION DESIGN HANDBOOK

Designing Holistic Bioretention for Performance and Longevity

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EPA United States Environmental Protection Agency

TETRA TECH

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DISCLAIMERS

This document serves as a guide to designing, implementing, and maintaining bioretention facilities; selection of and specifications for individual facility designs should be based on a thorough analysis of site conditions and awareness of local regulations.

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CONTENTS

TABLES

ACRONYMS

ADA	Americans with Disabilities Act
BSM	bioretention soil media
CCD	City and County of Denver
CDA	contributing drainage area
CWA	Clean Water Act
DOT	Department of Transportation
DDOT	District of Columbia Dept. of Transportation
EJSCREEN	Environmental Justice Screening and Mapping Tool
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GAO	Government Accountability Office
GSI	green stormwater infrastructure
HDPE	high-density polyethylene
IDF	intensity-duration frequency
IPM	integrated pest management
IWS	internal water storage
LR	loading ratio
MOU	memorandum of understanding
MSC WMO	Middle St. Croix Watershed Management Organization
MPCA	Minnesota Pollution Control Agency
MC DEP	Montgomery County Dept. of Environmental Protection
NACTO	National Association of City Transportation Officials
NRCS	Natural Resources Conservation Service
NYC DEP	New York City Dept. of Environmental Protection
OLIN	Olin Partnership Limited Labs
O&M	operation and maintenance
PVC	polyvinyl chloride
PWD	Philadelphia Water Department
ROW	right-of-way
SOP	standard operation procedure
SWMM	Storm Water Management Model
UDFCD	Urban Drainage and Flood Control District
USDA	U.S. Department of Agriculture
VFS	vegetated filter strip
WTR	wastewater treatment residual
WINSLAMM	Source Loading and Management Model for Windows
WQV	water quality volume

PREFACE

Bioretention is one of the most widely implemented green stormwater infrastructure (GSI) practices. Nationally, the design for bioretention varies based on factors such as local requirements, climate, site conditions, and land use. At the state and local levels, much innovation in bioretention design and management has occurred in the recent past. However, this information is not compiled and readily available to inform practitioners about the latest trends, designs, and approaches to optimizing bioretention design and management.

The *Bioretention Design Handbook* (the handbook) compiles the current state of knowledge from a combination of literature, interviews, and site visits with leading municipalities and practitioners across the United States to document approaches for bioretention design, construction, inspection, and operation and maintenance (O&M). The handbook is organized into three main sections: the introduction, the design phase, and the post-construction phase. The introduction defines each bioretention design element discussed in detail in the handbook and highlights the important holistic design concepts such as urban heat mitigation and material reuse. The design phase section walks readers through each design element, working in the order from the inlet to the outlet. The design phase section also discusses strategies to help build community acceptance and incorporate design aspects that accommodate multimodal transportation and public safety concerns. The handbook also includes a post-construction phase section that covers considerations associated with the O&M of bioretention facilities and recommendations for longevity. The handbook describes various resources and tools to assist with bioretention design.

A unique feature of the handbook is the numerous photographs of bioretention facilities from across the contiguous United States that showcase the diversity of design techniques and approaches. The photographs show sites from more than 20 municipalities visited as part of an ORISE fellowship research project or provided by other credited sources. Hopefully, these images will inspire new ideas and further advance the GSI field. Please note that the handbook is not intended to be used for design specifications but rather as a starting point to help designers and planners consider various design elements and approaches to improve the functionality and management of bioretention systems.

Chapter 1 INTRODUCTION

In this chapter

Chapter 1 provides an overview of this handbook's scope, purpose, and intended audience. According to the U.S. Government Accountability Office (GAO), a recent survey revealed that municipalities found the process of developing green stormwater infrastructure (GSI) to be more difficult than developing gray infrastructure. The municipalities identified design and engineering as the most challenging aspects (GAO 2017). An overarching goal of this handbook is to highlight lessons learned and design concepts to help municipalities overcome these challenges.

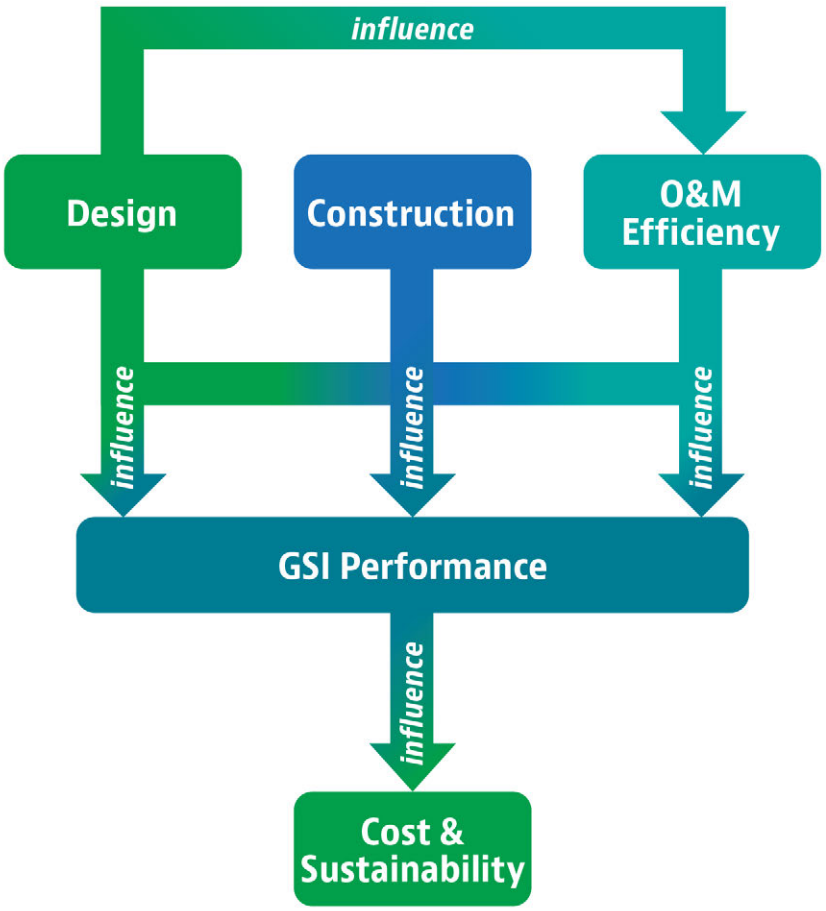
Photo: NYC Department of Environmental Protection

1.1 Handbook Scope, Purpose, and Audience

Municipal stormwater programs have been installing GSI for several decades. In contrast to gray infrastructure, which relies on piped networks and engineered components to convey stormwater, GSI instead depends on natural physical, chemical, and biological processes to manage stormwater quality and quantity.

GSI, the term used in this handbook, is synonymous with the term **green infrastructure** defined in the Clean Water Act[1] (CWA) as the range of measures that use plant or soil systems; permeable pavement or other permeable surfaces or substrates; stormwater harvest and reuse; or landscaping elements to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters. Some use other terms to reference the same practices as **green infrastructure for stormwater management**. Other terms include **low impact development**, **natural infrastructure**, and **nature-based solutions**. The definitions of these terms might vary slightly among organizations and industry professionals; however, these concepts are generally captured in the CWA definition of green infrastructure. GSI and green infrastructure are both terms used in planning and research to achieve various ecosystem services.

Bioretention is one of the most popular GSI practices implemented in urban areas. For example, as explained in the GAO's 2017 report, *[Stormwater Management: EPA Pilot Project to Increase Use of Green Infrastructure Could Benefit from Documenting Collaborative Agreements]()*, a survey found that



Influence of design and post-design phases on GSI performance, cost, and sustainability

[1] Water Infrastructure Improvement Act, 2019. https://www.congress.gov/115/plaws/publ436/PLAW-115publ436.pdf

municipalities most frequently installed, encouraged, or required three main types of GSI: downspout disconnection, bioretention (also referred to as rain gardens), and permeable pavements (GAO 2017). A correctly designed, constructed, and maintained GSI practice can be a more effective, economical, and sustainable choice over its service life when compared to gray infrastructure (TNC and TX A&M 2021).

Despite the popularity of GSI, the 2017 GAO report noted that 15 of the 27 municipalities surveyed reported that less than 5% of the area subject to their municipal stormwater permit or consent decree drained into GSI. The remaining area drained into either gray infrastructure (i.e., combined or storm sewers) or directly into receiving waters. Municipalities indicated that implementing some GSI tasks were more challenging compared to gray infrastructure, including developing capital expenditure, identifying operation and maintenance (O&M) costs, and designing practices (GAO 2017).

The overarching goal of this bioretention design handbook—referred to as "the handbook" throughout this document—is to help you successfully implement bioretention projects. In addition to sharing lessons learned from across the country, the handbook offers recommendations for design, construction, inspection, and O&M practices that will help you achieve performance goals, reduce project costs, and effectively integrate bioretention into your built environments. We will highlight common obstacles that can cause a project to incur added expenses. For example, undersized inlets can lead to runoff bypassing the system and require reconstruction. The top photo shows an inlet that was constructed incorrectly without a drop in elevation; as a result, runoff ponds at the inlet. The bottom photo shows an inlet constructed with a change in grade between the roadside and the practice; it functions properly during a storm.

Darren Distefano

Incorrectly installed inlet.

NYC Department of Environmental Protection

A well-designed inlet.

Robert Goo

A street-side bioretention planter in Washington, DC.

The second overarching goal of the handbook is to promote adaptive management in GSI projects. Adaptive management is the process of observing how a system performs over time and using that knowledge to adapt O&M strategies, retrofits, or future designs. Applying adaptive management can also extend beyond the physical boundary of a GSI site. Incorporating lessons learned can improve future GSI implementation in public settings, enhancing social benefits such as green space.

This handbook is intended for a multidisciplinary audience of GSI professionals, including design professionals, municipal officials, developers, planners, contractors, and inspectors across states, territories, and Tribes.[2] This document compiles current knowledge from published resources detailing how to approach bioretention design and post-construction activities. As recognized in the acknowledgments, this handbook also conveys the experiences and expertise of many municipalities and GSI practitioners who generously shared information during interviews and site visits.

Bioretention facilities used throughout this document encompass bioretention, rain gardens, bioswales, bioretention planters/boxes, and tree pits. Design elements specific to each of these practices are called out when applicable. As highlighted later in the handbook, GSI offers benefits beyond stormwater control—it can also be implemented for programmatic reasons, such as traffic calming, urban greening, carbon sequestration, and heat island mitigation.

[2] For the purposes of this handbook, Tribe is used as a collective term encompassing Tribes, Nations, Pueblos, and other similar entities.

1.2 Handbook Organization

The handbook includes three parts, described in detail below. Chapters 1–3 offer background information. Chapters 4–12 describe the GSI design phase, and Chapters 13–14 discuss the GSI post-construction phase.

Part 1: Introduction – Provides background details:

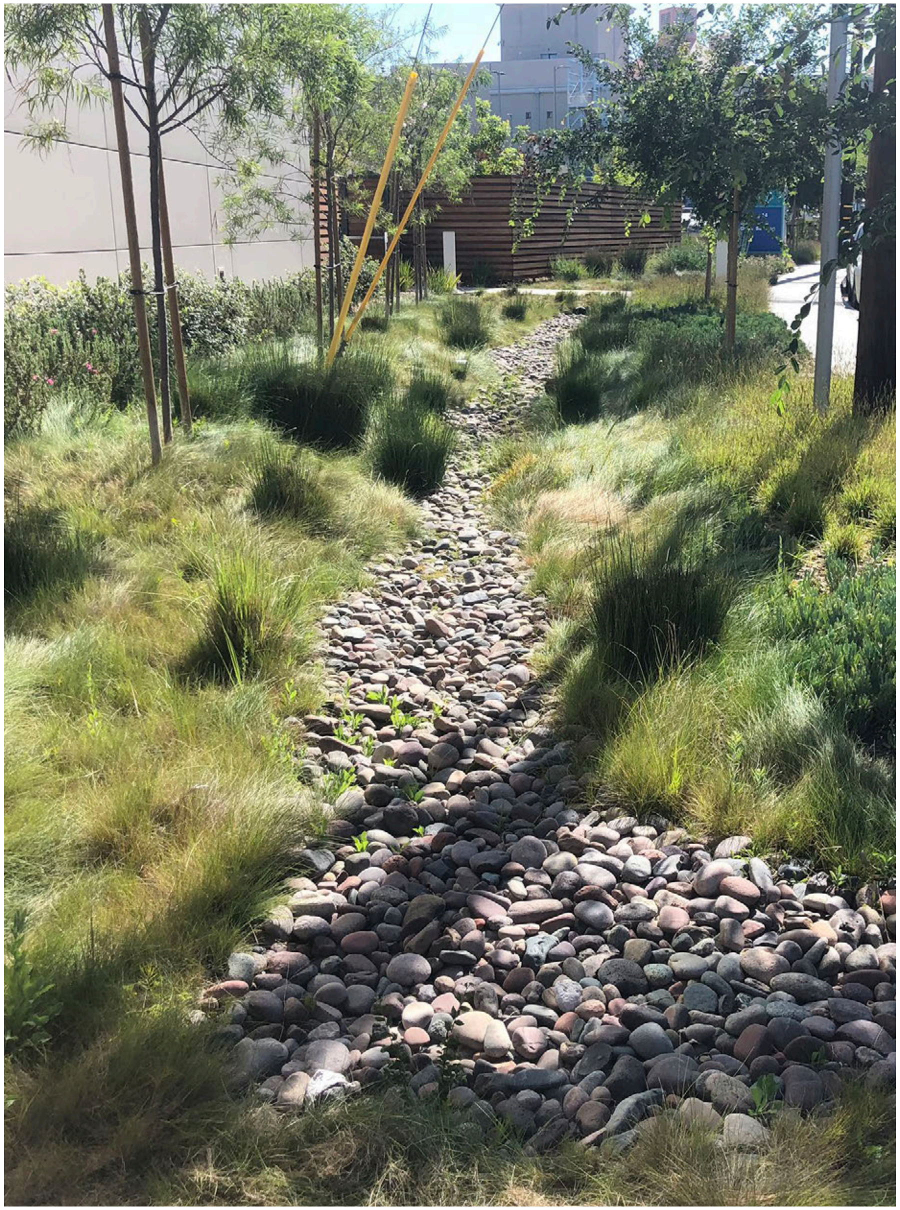
- Chapter 1: Handbook Introduction
- Chapter 2: Bioretention Design Elements
- Chapter 3: Holistic Design Concepts

Part 2: Design Phase – Describes various design considerations and lessons learned:

- Chapter 4: Managing Drainage Areas
- Chapter 5: Bioretention Geometry and Sizing
- Chapter 6: Runoff Capture
- Chapter 7: Pretreatment
- Chapter 8: Bioretention Media
- Chapter 9: Vegetation
- Chapter 10: Underdrains and Outflows
- Chapter 11: Multimodal Transportation and Public Safety
- Chapter 12: Promoting Community Acceptance

Part 3: Post-Construction Phase – Describes post-design considerations:

- Chapter 13: Managing the Construction Process
- Chapter 14: Long-Term O&M and Asset Management



Rhea Thompson

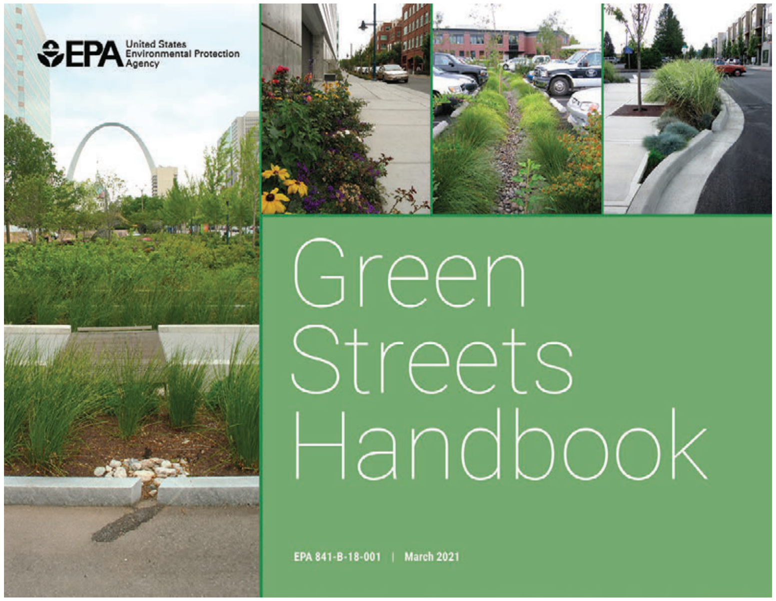
Bioretention in San Diego, CA.

1.3 Using the Handbook

This design handbook complements EPA's *Green Streets Handbook*, which guides state and local transportation agencies, municipal officials, tribal staff, designers, stakeholders, and others as they select, design, and implement site design strategies and GSI facilities for streets, alleys, and parking lots.

This design handbook focuses on efforts to implement bioretention in right-of-way (ROW) areas for stormwater management. Using ROWs for GSI alleviates concerns about access and O&M because these areas are already under the municipality's control. However, the *State of the Public Sector Green Stormwater Infrastructure 2022* surveyed 52 public sector entities and found that the GSI they implemented in the public ROW accounted for less than a third of acres they managed compared to projects implemented on parcels and redevelopment projects (Greenprint Partners 2022a). The report also notes that GSI in the public ROW is an expected growth area between 2022 and 2027. This handbook aims to expand the use of ROWs for GSI.

This document is not a design manual; instead, it provides recommendations and resources for bioretention design approaches—especially where technical expertise might be lacking. Furthermore, this document does not replace construction, inspection, or O&M manuals, which are necessary to ensure project success. Planning and design professionals are responsible for developing projects using sound judgment and following applicable laws and regulations. Always consult local or municipal specifications for design, construction, and O&M.



EPA's *Green Streets Handbook* focuses on GSI in transportation networks.

Portland Bureau of Environmental Services

Street-side bioretention in Portland, OR.

Chapter 2
BIORETENTION DESIGN ELEMENTS

In this chapter

Chapter 2 defines and illustrates the bioretention design elements referenced and discussed in detail throughout the handbook. The practices defined in this chapter include inflows, pretreatment components, energy dissipaters, mulch layers, vegetation, existing soil, soil media for bioretention, choker layers, liners, drainage/storage layers, underdrains, outflows, and overflows.

Photo: Maryland Department of the Environment

2.1 Bioretention Design Elements

Bioretention facilities generally include many of the following design elements. Some elements are optional (i.e., the amount of water stored), and the bioretention design will vary based on regional and site-specific conditions. Many design elements presented for bioretention are translatable to other GSI practices, such as vegetated swales and permeable pavements.

Inflow. For a bioretention facility to capture and treat stormwater runoff, the runoff must enter the practice. Runoff entering bioretention facilities, also called inflow, can travel in the form of sheet flow or concentrated flow that moves through engineered inlet structures (curb cuts, gutters, etc.). Other methods of runoff capture, such as runnels and depressional channels, are discussed. (See Chapter 6 for more details.)

Pretreatment components. Pretreatment (e.g., forebays, vegetated filters) is typically used for inflow that enters a bioretention facility as concentrated flow via inlets such as curb cuts, trench drains, and pipes. Pretreatment components prevent erosion by slowing inflow velocities and dissipating the energy. Reducing the inflow speed promotes the settling out of suspended solids, debris, and trash in a localized area. Pretreatment also prevents downstream clogging. (See Chapter 7 for more details.)

Energy dissipator. Including pretreatment techniques, such as weirs, check dams, and rock rundowns, can reduce runoff velocities and dissipate energy. Energy dissipation reduces the likelihood of erosion and vegetation disturbance. Additionally, slower flow velocities within the facility enhance infiltration. (See Chapter 7 for more details.)

Mulch layer. Mulch retains water, traps pollutants, prevents erosion, suppresses weed growth, and provides a favorable environment for beneficial soil organisms to thrive at the mulch/soil interface. However, mulch can be susceptible to suspension and washout during intense storms and can leach dissolved organic carbon, which can stimulate unwanted biological activity in lakes and streams. Therefore, other alternatives, such as expanded shale, gravel, or crushed rock, may be used. (See Chapter 7.4 for more details.)

Vegetation. Bioretention vegetation includes native noninvasive grasses, perennials, shrubs, and trees. Vegetation can reduce runoff velocities, improve infiltration rates, and enhance water quality through phytoremediation and nutrient uptake (via plant roots and biological processes). Vegetation selection is influenced by site conditions, such as soil type, available water, light, climate, road salt application, and other environmental stressors. Other factors to consider are the plant locations and intended plant functions (e.g., aesthetics, nutrient removal, infiltration, wildlife value). (See Chapters 3 and 9 for more details.)

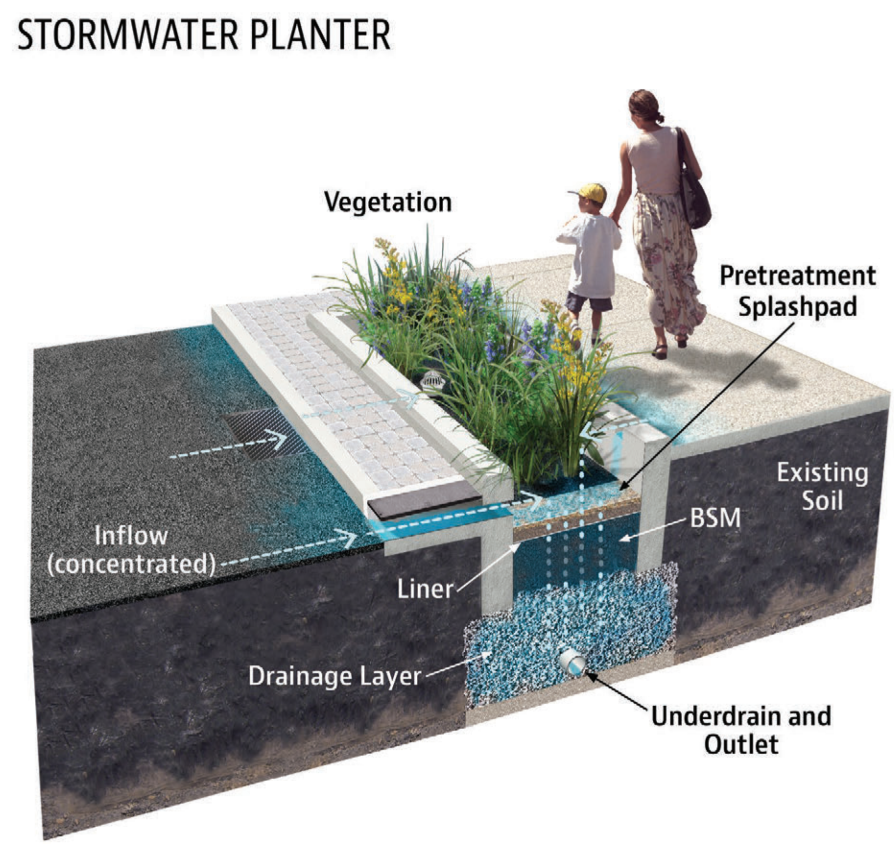
Existing soil. A site's existing soil refers to soil conditions before site disturbance or bioretention implementation. Existing soil may consist of the area's native soil (a mixture of sand, silt, clay, and organic matter) or historical fill (a mixture of dirt, debris, and construction material). Existing soils are evaluated to determine whether they are suitable for the bioretention practice design and have the desired porosity, nutrient content, compaction resilience, and other properties to support plant growth and the overall performance goals. In many cases, well-draining, existing soils can be used in the bioretention facility, or the soils can be amended to meet design goals. (See Chapter 8.2 for more details.)

Bioretention soil media (BSM). BSM refers to the media mix used in the bioretention facility. Often BSM mixes may be required to meet local government specifications. If existing soils do not meet the design criteria, designers can use engineered BSM to improve infiltration rates and achieve other goals, such as pollutant removal or carbon sequestration. BSM can include media amendments (e.g., biochar, wastewater treatment residuals) to enhance the removal of specific dissolved pollutants. (See Chapter 8 for more details.)

Choker layer. A choker layer separates different media layers. It is usually placed between the BSM and the drainage layer. The choker layer generally consists of 3 inches (minimum) of sand and gravel that prevents BSM from migrating into the underlying gravel drainage layer. (See Chapter 8.6 for more details.)

Liner. A liner can be a permeable or impermeable geotextile fabric used to prevent weed growth, separate media layers to prevent migration of material (as an alternative to a choker layer), or restrict exfiltration. Liners can clog, particularly in areas with clay soils, and thus are not recommended in some circumstances. Impermeable geotextiles are suitable along slopes for blocking exfiltration and preventing interactions with structure foundations or preventing the mobilization of pollutants (e.g., underlying soil that contains a hot spot from a contaminant spill). Lastly, bioretention facilities implemented with an impermeable liner at the bottom can increase the systems' hydraulic residence time and prevent water from interacting with groundwater or contaminated areas in the soil below. (See Chapter 8.5 for more details.)

Stone storage/drainage layer. A washed stone layer added beneath the BSM promotes drainage and exfiltration. This design element may be practical when it is impossible to store the total water quality volume (WQV) on the surface of the practice, such as in constrained bioretention systems (e.g., planter boxes) or when designers wish to minimize surface storage. (See Chapter 8.6 for more details.)



Philadelphia Water Department

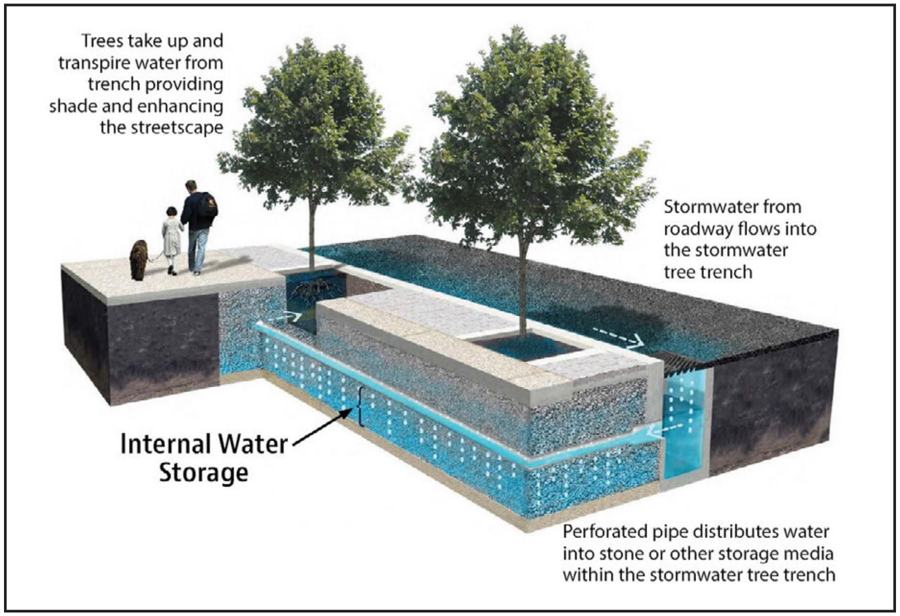
Underdrain. Underdrains are generally required when underlying soils have an insufficient infiltration capacity. In such cases, designers may incorporate underdrains to reduce the failure potential. To maximize retention volumes, designers can include caps or valves on the underdrain that stay in place unless the practice experiences a drainage problem. Underdrains consist of a perforated pipe set in a gravel bed installed along the bottom of the filter bed (this design separates the BSM from the underdrain). Underdrains collect and convey effluent stormwater back into the sewer, surface conveyance system, or the surface of another GSI practice area. (See Chapter 10 for more details.)

Internal water storage (IWS). IWS is a zone in the practice designed to hold water. IWS can be added to increase overall storage capacity or enhance nitrate removal. A typical IWS design includes a gravel layer with a perforated underdrain. The elevation of the underdrain outlet is raised to create a saturated layer during storm events. When denitrification is desired, the IWS layer must include a carbon source such as woodchips. (See Chapter 10 for more details.)

Outlet. The outlet is where the treated runoff exits the bioretention facility. They are placed downgradient of the inflow structure. Outlets may be on the surface (e.g., curb cut, riser) or subsurface (underdrain). They can convey water to another GSI practice, treatment train, or storm sewer (or approved discharge point, such as a waterbody). (See Chapter 10 for more details.)

Overflow. Overflow refers to the water volumes associated with storms that exceed the design volume. Overflow structures are sized to safely manage larger storms and allow flows to bypass the practice during extreme storm events. Designers can include a positive overflow that enables stormwater to flow back out of the system when the water level reaches the maximum design subsurface elevation or surface ponding depth. Flow that moves out through the positive overflow can connect to another GSI practice or an approved discharge point. (See Chapter 10 for more details.)

**Note:* Because the bioretention design terms are defined in this chapter, they are not repeated in the glossary.



Philadelphia Water Department

Design schematic for a stormwater tree trench.

Rhea Thompson

Trees as part of bioretention in Kansas City, MO.

Chapter 3
HOLISTIC DESIGN CONCEPTS

In this chapter

While most of this handbook describes each bioretention design element in detail, Chapter 3 introduces holistic design concepts. Holistic design integrates existing site conditions, multiple performance goals, and other life cycle factors into the design process to maximize a bioretention facility's performance and longevity. Consider these concepts as you start a project and carry them through the construction and maintenance phases.

Photo: Rhea Thompson

3.1 Consider the Site Context

Although GSI can be implemented at a network scale, adapting practices to the site scale takes advantage of existing conditions and prevents over-design. The planning and design phases should be multidisciplinary and engage municipal officials, landscape architects, local community leaders, and professionals from transportation, stormwater management, and public utilities. The following holistic design concepts and engagement opportunities should be considered during planning and design.

Site-specific design optimizes performance. A single standard bioretention design does not apply in all cases. Conducting a site assessment is critical for ensuring the constructed facility meets stormwater management program requirements and accounts for site-specific conditions and local needs. When creating a system, designers should consider the characteristics of the site and its surrounding areas, such as topography, available space, slope, microclimate (aspect, shading, wind exposure, and thermal gain from adjacent buildings), proximity to utilities, conditions of local soils (contamination and infiltration capacity), and the presence of nearby materials that could clog the system. Designers should also consider other programmatic goals, such as incorporating multimodal transportation opportunities, meeting accessibility needs, and improving community aesthetics.

Portland Bureau of Environmental Services

This GSI design treats runoff while guiding pedestrians safely to the crosswalk.

Understand the existing soil conditions at the site. Identifying the infiltration capacity of existing soils allows designers to correctly size and model facilities. For example, San Francisco Water Power Sewer conducts surveys and collects existing site data (e.g., local infiltration capacity) to see if the existing infiltration rates will satisfy stormwater quantity goals (NACTO 2017). If so, planners can adjust the design and save money. If existing soils do not meet acceptable infiltration rates, the design can use BSM and/or an underdrain.

Use the site to restore connections to the natural water cycle. One of the biggest contrasts between GSI and gray stormwater infrastructure is how water is viewed and managed. GSI relies on natural processes, such as infiltration, groundwater recharge, and evapotranspiration. Alternatively, gray infrastructure simply conveys the runoff to treatment plants or receiving waters. To create conditions that mimic the natural hydrological cycle, designers should account for the nature of storms (frequency and intensity) and how water flows naturally (predevelopment). When all the runoff cannot be managed using natural processes alone, the design can emphasize detention—the capture and slow release of water.

CCD, Division of Green Infrastructure

Aerial image showing impermeable liners at the bottom of two bioretention cells under construction in Denver, CO.

Rhea Thompson

A bioswale includes gentle grades and low-growing vegetation, which fits the parking lot site in Minneapolis, MN.

Groundwater interactions with bioretention media should be avoided. The bottom elevation of a bioretention facility should be at least 2 feet above the seasonally high groundwater table (USEPA 2004). Groundwater interactions with BSM can mobilize stormwater contaminants. Additionally, groundwater interactions reduce the available void space for runoff capture. In areas with a high year-round or seasonal water table, noninfiltration practices are preferred. If a bioretention facility is sited near industrial areas with existing soil contamination (i.e., potential hotspots), the design should incorporate pretreatment and/or an impermeable liner. EPA's *The Influence of Stormwater Management Practices and Wastewater Infiltration on Groundwater Quality: Case Studies* discusses the results of three field studies investigating the potential impacts on groundwater quality due to using GSI (Beak et al. 2020). Bioretention facilities that emphasize exfiltration should also be carefully sited in areas with karst geology to avoid contamination of aquifers and potential de-stabilization of geology. The *Minnesota Stormwater Manual* outlines design considerations for karst areas (MPCA 2023a).

Consider whether coupling bioretention facilities with other GSI practices maximizes impact. Space constraints in the ROW may limit the available surface area for bioretention. Other GSI practices, such as permeable pavement for sidewalks or bike lanes, can be incorporated to meet hydrologic performance goals.

Disconnect impervious surfaces and apply GSI planning and design approaches. Impervious areas within the area draining to a bioretention facility should be disconnected from each other (e.g., ensure that roof runoff does not flow across the sidewalk and directly into a storm sewer). Instead, route flow over the natural landscape to slow runoff to reduce the quantity of water entering the combined or separate sewer system. When possible, route flow directly into a bioretention facility.

Consider other opportunities to manage runoff beyond the project area. Look beyond a single project site to determine if GSI could be designed to benefit a larger drainage area. For example, in one scenario described by the National Association of City Transportation Officials (NACTO) (2017), designers in one city realized that large bioretention facilities installed in a project could manage runoff from the adjacent street as well as another area three to five times larger. The added treatment capacity allowed for a system that would accept runoff from cross streets and other nearby streets; therefore, these streets did not need costly reconstruction for stormwater control.

Avoid impacts to utilities. Utility lines are a common and necessary part of suburban and urban infrastructure, running overhead and under streets, sidewalks, and tree spaces. Emergency responders should always have access to utilities. Thus, bioretention designs should avoid utility lines, even if it means moving the practice or designing it to coexist (i.e., providing protective elements within facilities). Maintaining the facility will help prevent impacts to utilities through the facility's life span (e.g., trimming trees prevents interference with overhead wires).

Preserve existing trees where possible. Many urban settings balance bioretention areas with the need for improved tree canopy. Street trees are often protected as part of a city's efforts to improve greening/urban canopy coverage. Trees and bioretention both supply the benefits of stormwater management, air quality, and urban heat mitigation. If possible, avoid disrupting mature trees when siting bioretention. If this is not possible, assess and evaluate the benefit and trade-offs of removing trees before doing so. Consult with local experts to understand the tree species, growth patterns, and on-site root systems that may exist for the site's mature trees, for these will affect the recommended proximity of bioretention practices. Proper planning can allow existing trees and new bioretention facilities to coexist and contribute to a successful green street.

3.2 Strive to Provide Multiple Benefits

Holistic bioretention design meets performance goals (e.g., state or local regulatory requirements) and aims to maximize environmental and social benefits. Table 3-1 summarizes performance goals and benefits that are reiterated in later chapters.

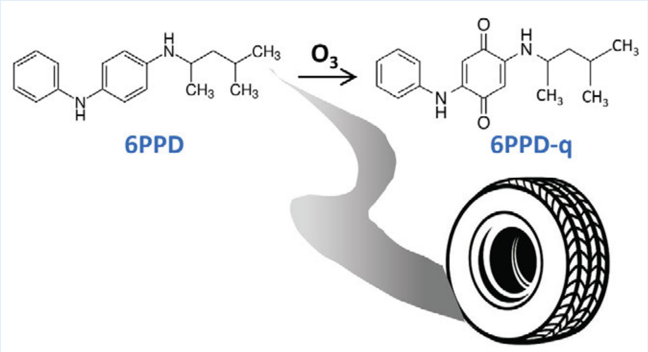
Table 3-1. Opportunities to increase environmental and social benefits using bioretention.

Goal	Description	Design considerations and resources
Reduce Combined Sewer Overflows	Minimizing the occurrence of combined sewer overflows involves capturing, retaining, and infiltrating as much volume as possible. When infiltration is not possible, stormwater volume is managed by detention and controlled release to the existing sewer.	• Design bioretention with permeable soils that promote infiltration. • Add IWS to increase storage volume and exfiltration. • Use stone wells if layers of more-permeable soil lie beneath an impermeable layer.
Pollutant Removal	In areas where storm sewers convey runoff to an open water body, the primary goal of bioretention is water quality. As a result, tailor bioretention treatment to watershed-specific pollutants. The first flush of a rain event is often characterized by a higher concentration of pollutants than later flushes. Bioretention media can capture and remove common pollutants (e.g., nutrients, bacteria, metals) as well as more emerging contaminants like microplastics and 6PPD-quinone (see box, next page).	• Add IWS to remove nitrates when soils have low infiltration rates. • Consider inflow and outflow configuration, soil permeability, and check dams to allow ponding, maximize storage volume, and increase runoff residence time. • Select compost blends or mulch to prevent pollutant leaching. • Incorporate vegetation and soil amendments to enhance pollutant removal. • Including forebays can localize sediment capture near inlets.
Improve Flood Resilience	Localized flooding, not riverine or coastal flooding, is a concern in areas with poor drainage, overwhelmed pipe networks, and impervious cover. Bioretention can retain, infiltrate, or move stormwater to reduce risks.	• Design systems with permeable soils that promote infiltration. • Design systems to safely manage volumes from larger storm events.
Urban Heat Island Mitigation	GSI that incorporates canopy cover and other vegetation can reduce urban heat island effects via processes like evapotranspiration and shading. Maximizing these benefits will be a function of the local site and climate.	• Find opportunities to include native trees and other vegetation to provide a canopy for evaporative cooling and shade.
Air Quality	Where appropriate, design bioretention to help improve air quality through the use of vegetation for air filtration.	• Find opportunities to include native vegetation and supporting soil media that filter air pollutants and sequester carbon emissions. Refer to *Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality* for best practices when adding trees along roadsides for air quality benefits (Baldauf 2016). • Design systems with local, sustainable materials to offset emissions.
Green Space & Wildlife Habitat	When a community has tree canopy, habitat creation, or greening compliance requirements, add green space into designs. Planting vegetation helps to improve native wildlife habitat.	• Consider native vegetation and supporting soil media that enhance biodiversity and attract wildlife. • Refer to EPA's *Stormwater Trees: Technical Memorandum* for information on planting and maintaining trees in urban areas.

Goal	Description	Design considerations and resources
Community-Focused & Equitable Access	Green streets are part of healthy, equitable urban designs and are vital to creating viable public spaces. When implementing GSI, such as bioretention, ensure the benefits are supplied equitably, especially in communities that lack green space or have historically had disproportionately high air and water pollution levels.	• Identify environmental justice communities with the greatest need for GSI projects or communities that currently lack GSI projects. EPA's EJSCREEN: Environmental Justice Screening and Mapping Tool combines environmental and demographic indicators. • Engage residents and property owners early in the process to ensure projects are collaborative. • Support urban tree planting decisions using American Forests' Tree Equity Score (environmental, climate, and demographic data). • Review the *Equity Guide for Green Stormwater Infrastructure Practitioners* to build equity into stormwater management. • Create a sense of community and ownership with artistic and functional elements like seating and bike racks.
Public Health & Safety	Bioretention elements in the ROW (e.g., bumpouts) can calm traffic and help pedestrians by creating a visual and physical buffer and reducing crossing distances. GSI improves public health by connecting people to natural spaces and adding safe, accessible, and active modes of transportation.	• Integrate crosswalks/pathways for pedestrians and bikes. • Design and maintain vegetation to protect sight lines. • Design systems to minimize tripping hazards. • Incorporate proper barriers around facilities to prevent pedestrians from stepping into ponded water.

Using Bioretention to Address Emerging Contaminants

Several emerging contaminants are gaining research interest, such as microplastics and 6PPD-quinone (N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone). The contaminant 6PPD-quinone, a transformation product of the tire additive 6PPD, has demonstrated acute toxicity to several salmonid species (ITRC 2023). Data have shown bioretention to be a viable option for removal of 6PPD-quinone (Rodgers 2023).



3.3 Design for Longevity

If well-designed, constructed, and maintained, a bioretention facility can operate for decades. The City of Portland is a notable example of a municipality with functional systems up to 25 years old. Holistic design considers future development, snow impacts, maturing vegetation, and other factors that could affect the practices' long-term performance.

Incorporate material reuse with life cycle and sustainability in mind. GSI is an asset for cities—consider sustainability, life-cycle costs, and benefits when planning, designing, and implementing GSI. Ensure systems are properly designed, operated, and maintained, and consider ways to use less material, reuse local materials, recycle construction waste, and close waste loops where possible. For example, Olin Partnership Limited (OLIN) Labs is leading the Soilless Soil Initiative, a phased research project exploring ways to close the loop of Philadelphia's glass and food waste streams. In fall 2022, OLIN Labs and its partners retrofitted an existing bioretention facility to test the efficacy of glass-based soil.

Bigger doesn't mean better. Some people think bioretention must be extensively engineered to meet performance goals. However, smaller footprints and simple designs can be effective. For

ThinkGreen LLC

Soilless Soil Initiative project site during construction.

ThinkGreen LLC

Soilless Soil Initiative project site after vegetation establishment.

example, researchers compared the catchment-to-bioinfiltration surface area ratios for the bioinfiltration units at EPA's Edison Environmental Center, which included small (22:1), medium (11:1), and large (5.5:1) test units. The vegetation included native grasses, perennials, shrubs, and trees. This research showed that the larger oversized units did not engage the entire surface area during runoff capture and were less efficient in using all of the bioretention media for volume control. As a result, plant growth was slower and less dense compared to the small units (O'Connor 2022).

Design with redundancy. Including multiple ways for runoff to enter a practice is beneficial in case of water flow changes, clogging, or high water volumes. Drainage can flow through multiple entrances, which helps ensure runoff does not bypass the system. Designing bioretention practices in a series might be more beneficial than relying on a single system to manage runoff from a drainage area—if the runoff misses or overflows the first system, it can be captured and treated by the next one.

Allow flexibility for adaptive management. Consider designing systems to be adaptable in case of performance issues and to mitigate potential impacts of natural hazards and climate change. For example, designers can plan the systems so they can adjust the size, curb-cut widths, vegetation, weirs, and other elements to accommodate larger storm volumes in the future. Continuous monitoring and experimentation will ultimately provide the best data on which design elements work best. Designers may also consider setting aside space that can be used for bioretention if runoff volumes increase due to changing climatic or site conditions.

Be mindful of where water will flow if the system overflows. Designers must anticipate where water will flow if the system backs up or clogs, which is especially important if the water will affect nearby critical infrastructure or create public safety hazards. Designers should plan for the possibility that a system does not operate as intended and add elements to reduce the potential for unintended consequences (e.g., by incorporating bypass elements).

Portland Bureau of Environmental Services

This facility in Portland, OR, illustrates how the placement of seating and other features can help create a sense of place.

Consider current and future uses of the space and its relationship to the surrounding area. Once built, city streets are generally not reconstructed for many decades. Therefore, when a reconstruction opportunity arises, carefully consider future needs and capitalize on the opportunity. To extend the street's useful life, account for expected changes in mobility patterns, local climate and precipitation, and land use. Proactive planning can prevent many performance and maintenance problems and minimize costs for reconstructing or retrofitting systems as sites evolve. For example, if an area is proposed for future development, consider how it could affect the catchment area of the bioretention facility and if the site is still feasible.

Incorporate design elements that allow for efficient maintenance. Maintain GSI to ensure its long-term functioning as a treatment facility and part of the community. Conducting routine maintenance—removing trash, debris, dead vegetation, leaves, and sediment—can prevent costly performance problems and increase public acceptance. When designing facilities, consider the O&M needs upfront (type, intensity, and frequency) and the budget. Consider local factors, such as snow removal and storage, deicing salt use, street sweeping, and the presence of clogging materials that could damage bioretention health and longevity. Also, review the types of maintenance equipment (e.g., shovels) needed and include access routes in the design. Ensure any grates, outlets, runnels, or other runoff conveyances allow maintenance access. Remember that simpler systems are generally easier for company staff or private owners to maintain, given possible turnover and a lack of technical expertise.

Portland Bureau of Environmental Services

A bioretention facility after a snowfall in Portland, OR.

Rhea Thompson

This grassy street-side bioswale is easy to clean and maintain and fits in with the community aesthetic in Fort Lauderdale, FL.

Chapter 4
MANAGING DRAINAGE AREA

In this chapter

This chapter highlights resources to assist drainage area delineation as well as considerations for grading and site location.

Photo: Kary Phillips

4.1 Drainage Area Delineation

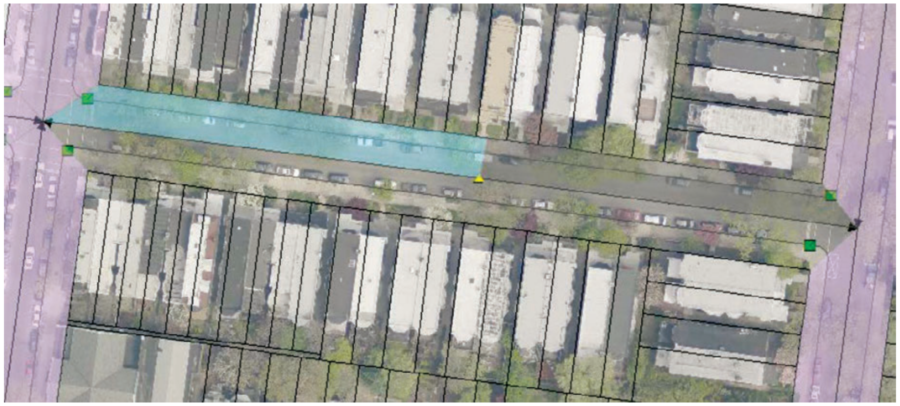
The drainage area is the quantified surface area draining to a single point or location. In this handbook, the contributing drainage area (CDA) refers to the total area (both pervious and impervious) draining to a bioretention facility. **Maximizing the capture efficiency of runoff from impervious surfaces increases bioretention's benefits.**

Drainage area delineation allows designers to understand stormwater drainage patterns in a study area and quantify the runoff volumes. A delineation will also inform the design of bioretention elements such as pretreatment, inlet size, erosion control measures, and outflow structures. A drainage area delineation is conducted during the site assessment. Delineating a drainage area requires creating a representation of the drainage area boundary, drainage pattern based on flow direction, and the different contributing land use types. A combination of publicly available data sources, software programs, or site surveys can be used. These resources are described in more detail below.

Publicly available or local data sources. Topographic maps, elevation data, aerial imagery, and existing roadway plans are often available. On a national scale, the USGS National Map is the primary online viewing source of USGS's geospatial data, which includes topographic maps (digital and print) (USGS 2023). USGS has updated the National Map with high-resolution elevation data developed from nationwide LiDAR (i.e., Light Detection and Ranging, a remote sensing method using light to measure ranges to the Earth); these data can be used for catchment delineation. One-meter resolution data sets are available for portions of the United States. Aerial imagery provides a resource to identify

NYC Department of Environmental Protection

A bioretention practice manages drainage from a street in New York City, NY.



The Philadelphia Water Department performs in-house drainage area delineation using a geographic information system. The delineation is completed for the entire study area being analyzed, including ROWs and parcel locations (PWD 2018a). This graphical example of a Philadelphia city block CDA delineation shows a split drainage area (indicated by the colored layers in the software output). The high point is denoted by the yellow triangle, and drainage inlets are denoted by the green squares. Other examples are available in Philadelphia Water Department's *Green Infrastructure Planning and Design Manual* **(PWD 2021).**

specific land use types and site features such as roofs or parking lots. Local, as-built plans for roadways also offer information on slopes, dimensions, and existing inlet locations.

Software programs. Autodesk and ArcGIS (closed sources) offer tools to calculate the CDA. In Autodesk Civil3D, the catchment area command determines the runoff flow paths and quantifies the CDA. In ArcGIS, Digital Elevation Models (DEMs) can be used to determine the CDA. For example, Villanova University researchers coupled one-meter-resolution DEMs with a model developed by ArcGIS Pro software to create urban micro-subbasins. This resulted in an automated workflow for urban watershed delineation that incorporated GSI, building roof drainage, and inlets by altering the DEM to make these features part of the hydrologic landscape (Hosseiny et al. 2020; Jahangiri et al. 2020). Lastly, some municipalities may have ROW CDAs already delineated in-house for GSI design use, such as the Philadelphia Water Department (see image at left).

Site surveys. Use topographic surveys to determine elevation; contours; and site features such as trees, buildings, or streams (when this information is unknown). Alternatively, a site survey may simply include visiting a site to verify the information collected from other sources. Field verification activities could consist of observing flow patterns during a storm and obtaining photo and video documentation. In the absence of rain, practitioners can place a ball on the ground to identify grade changes. Conducting field verification of site drainage patterns and features is important because publicly available data sources might not reflect current site conditions.

Once the CDA is known, planners and designers determine the surface area of a bioretention facility using the loading ratio (LR). LR is a design parameter equal to the impervious CDA divided by the bioretention infiltration surface area. LR is an important design consideration because LRs that are too high (i.e., greater than 25:1) can lead to maintenance problems (e.g., excessive sediment accumulation) or LRs that are too low can hinder plant growth and result in nonuniform infiltration (O'Connor 2022). Follow local or state guidelines for LRs when available; they are often found in local stormwater management design manuals.

4.2 Determining Grade

The grade of a CDA determines the direction of water flow and velocity (discussed in subsequent chapters) and influences what percentage of the targeted drainage area is captured. For example, larger CDAs and steeper grades contribute to higher runoff volumes and velocities. When assessing the grade and flow paths of a CDA, consider the factors described below.

Slope. Bioretention generally requires a relatively flat site and is generally best applied when the grade of the contributing slopes is greater than 1% and less than 5%. For slopes greater than 5%, the interior of the bioretention facility may need to be terraced or include check dams or other energy dissipators. Alternatively, another approach could shift the design from a single bioswale to a series of terraced bioswales. Avoid sites with steep slopes (more than 20%) that cause erosive inflows and reduce capture efficiency.

Site grading. If the targeted CDA is not adequately graded, consider opportunities to regrade the roadbed or incorporate design elements such as berms and runnels to improve flow routing into the facility. Grading combined with diverters, inlet design, and bioretention sizing can ensure that flow enters the facility, which can accept or bypass flow without damage. Regrading can be difficult in retrofit cases. Additionally, some people involved in the construction process might not understand GSI principles. Including details such as flow path arrows on design drawings, schematics, and construction plans can help ensure proper construction and avoid drainage problems.

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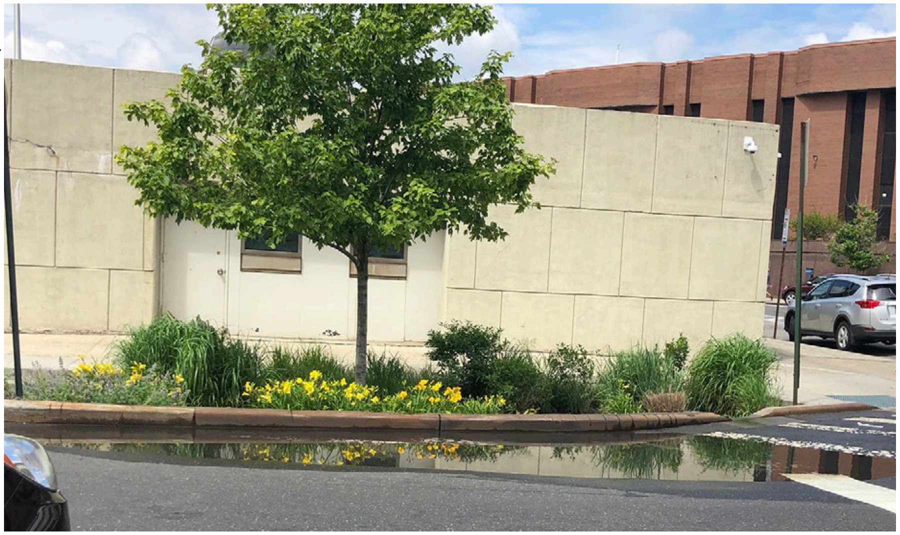
A road is graded toward a bioretention practice in Washington, DC.

Cecelia Lane

Improper grading causes water to build up at the edge and not flow into this facility.

Rhea Thompson



Poor grading allows water to build up on the road adjacent to a bioretention practice.

Use of medians. Medians (when present) can support linear practices such as bioswales and infiltration trenches. Medians tend to be at the high point of a road's cross-slope; thus, the flow path is typically not toward the median. As a result, using bioretention facilities in medians might require reversing a street's cross-slope. If the street's cross-slope cannot be modified, seek opportunities to intercept stormwater in an upstream conveyance system (from another street) and daylight the collected flow into a series of bioretention facilities in the median. To maximize the amount of ROW available for bioretention and provide more area to treat offsite water from upstream, either reverse the street crown to direct flow to the median or change the roadbed to slope to one side of the street.

4.3 Selecting the Optimal Site Location

Siting a bioretention facility is not limited to the commonly thought of site characteristics such as groundwater depth, infiltration rate, and topography but also requires balancing other factors such as utilities, space constraints, and roadway safety. During the planning phase, performing a desktop analysis of the drainage area using Google Earth or ArcGIS provides a first cut at determining the feasibility of a particular location. Using additional data layers, such as city utility maps, bike lanes, the 100-year flood plain, and sewer networks, can also influence siting decisions. Consulting the community as part of this analysis can help uncover functional aspects of the project, such as incorporating benches because a school bus stop is nearby. (Chapter 12 discusses community engagement in more detail.)

When conducting this type of site feasibility analysis, consider the bioretention facility siting factors below.

Existing utilities and public use corridors. Utility conflicts affect decisions regarding how runoff is conveyed to the site and the facility's footprint. For example, a conveyance pipe directing runoff across a street could be a way to minimize impacts to a bike lane or to route runoff to a parcel that accommodates more of the drainage area.

The number of facilities implemented. Choosing whether to implement fewer facilities that manage the entire drainage area or multiple smaller units in series may be influenced by available land type. For example, a park may offer sufficient space to implement a single facility, while a congested city block may need multiple bioretention planters implemented in the ROW.

NYC Department of Environmental Protection

Darren Distefano

Bioretention can be configured as a series of individual facilities (top) or a single, street-length facility with multiple inlets (bottom).

Available partnerships. Working with partners may provide opportunities to incorporate GSI into other projects, such as new recreational fields or transportation improvements. Seeking partners with a stormwater interest may yield more options for siting. The RainScapes Project in Montgomery County, Maryland, offers technical and financial help to property owners who install bioretention and other GSI practices.

Variable siting costs. Investigating the costs of different siting options influences placement. For example, the Philadelphia Water Department found that managing runoff in parcels such as city-owned parks, facilities, and schools was more cost-effective than building in the ROW (PWD 2014a).

Philadelphia Water Department

The Philadelphia Water Department installed GSI and other stormwater management facilities at the city-owned Venice Island Performing Arts and Recreation Center in Philadelphia, PA.

Chapter 5 BIORETENTION GEOMETRY AND SIZING

The configuration of bioretention facilities can range from relatively large and open vegetated basins to small-scale facilities contained within flow-through planter boxes. They can also be designed as a series of multiple cells along roadways or parking lots or combined with other GSI to meet flood control requirements. This chapter defines the different sizing elements of bioretention facilities and presents various methods that can be used for bioretention sizing.

Photo: Robert Goo, Washington, DC

5.1 Cell Sizing and Geometry

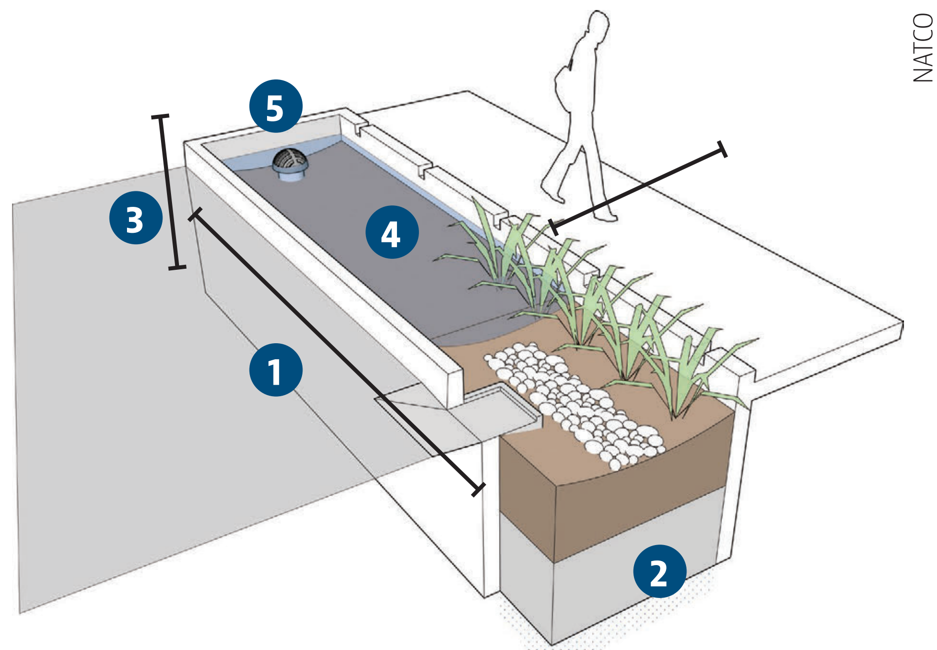
Bioretention surface area, ponding depth, and infiltration rate of BSM and underlying soils influence the effectiveness of bioretention facility to temporarily store and infiltrate runoff. When siting bioretention in the ROW, external factors such as sidewalk widths, the presence of utilities, and surrounding land use may constrain or limit bioretention dimensions. Additionally, the local drainage systems will influence whether design goals emphasize water quantity or water quality. For example, for combined sewer systems, bioretention design emphasizes runoff volume reductions and minimizing combined sewer overflows. Alternatively, in settings where storm sewer systems exist, bioretention design emphasizes water quality improvements related to pretreatment, treatment, and maintenance to protect the health of receiving waters.

Bioretention facility sizing is an important design element—one that is discussed thoroughly in the National Association of City Transportation Officials' (NACTO's) 2017 *Urban Street Stormwater Guide*. The following section leans heavily on NACTO's resource, which was developed to help cities design and construct sustainable streets (NACTO 2017).

The bioretention planter design schematic (right) illustrates five key concepts applicable to many bioretention facilities in the ROW, including the sizing elements of length, width, BSM depth, ponding depth, and freeboard depth. Table 5-1 (next page) describes these sizing elements and provides suggested dimensions and other considerations.

Planter Boxes: Small Size, Big Impact

Bioretention planter boxes are an application of bioretention used to handle volume and peak flow requirements for smaller CDAs such as roofs or sidewalks. Planter boxes are contained in a concrete box with an impermeable liner to prevent impacts to a building foundation or utilities.



1 Cell Length
2 Cell Width
3 BSM Depth
4 Ponding Depth
5 Freeboard Depth

Bioretention planter design schematic.

Table 5-1. Description of sizing elements for bioretention facilities (planters and boxes).

Sizing element[1]	Sizing element information
1, 2. Cell length, cell width (surface area)	***Description:*** The surface area is equal to the length multiplied by the width, and it represents the surface area available for infiltration and temporary surface storage. Greater surface area increases the surface available for infiltration. ***Typical range:*** Length: Ranges from 10 feet to the length of a city block (260–400 feet); Width: A minimum of 4 feet ***Design considerations:*** • If sidewalk access is a priority, several short cells can be used in place of one long cell. Short cells could increase hydraulic efficiency and require the use of BSM. • Check dams provide flow control on sloped surfaces.
3. BSM depth	***Description:*** BSM depth refers to the thickness of the soil media that extends from the surface of the facility to the bottom of the cell or other media layer, such as IWS or a gravel drainage layer. Deeper media increases the storage capacity and pollutant-removal benefits. ***Typical range:*** 2–4 feet ***Design considerations:*** • Pollutants such as total suspended solids, metals, hydrocarbons, and particulate phosphorus are generally captured within the top 2–8 inches of BSM. • Targeting dissolved phosphorus, nitrogen, and temperature pollution requires a minimum BSM depth of 2–3 feet; 4 feet is sometimes preferred for targeting elevated temperatures. • Including IWS in the design would increase the total cell depth. IWS-specific design considerations are presented in Chapter 10.
4. Ponding depth (surface storage)	***Description:*** Ponding depth refers to the depth of runoff that is temporarily stored—to meet local draw-down requirements—on the surface of a bioretention facility before infiltration. ***Typical range:*** Maximum ponding depth is based on soil infiltrate rates, local guidelines, and public safety requirements: 6–12 inches; 18 inches maximum ***Design considerations:*** • 6 inches is recommended for areas with high foot traffic, next to sidewalks, or when a fence is not included in the design. • For depths of 12–18 inches, consider including safety features (e.g., fencing). • Incorporate check dams and weirs to control the desired ponding depth.
5. Freeboard depth	***Description:*** Freeboard depth equals the distance between the top of the facility's overflow elevation and the maximum ponding depth. Freeboard provides a margin of safety for larger storm events. ***Typical range:*** 2–6 inches ***Design considerations:*** • A freeboard more than 6 inches high might be needed for sites with frequent overflows.

Sources: NATCO 2017; Hunt et. al. 2012; DOEE 2020
Note: [1] Refer to the design schematic on page 5-2 for a diagram of the sizing element numbers.

MD Department of Environmental Protection

A bioretention practice with side slopes in Montgomery County, MD.

5.2 Side Slopes and Geometry

The side slopes of a bioretention facility provide a transition from the adjacent roadway or sidewalk to the bioretention surface. Designers can increase the ponded storage volume of the bioretention facility by using deeper side slopes. Design considerations include:

- Cross-sections of the bioretention surface depression can be parabolic, trapezoidal, or flat (with a minimum 2-inch freeboard).
- Side slopes allow for sidewall infiltration. For facilities with graded side slopes, the cell-wetted area includes the surface of the cell and the area on the sides when inundated (i.e., maximum ponding depth plus freeboard).
- Typical recommendations specify a 2% or less longitudinal slope and side slopes of 4:1 horizontal:vertical, with a maximum slope of 3:1 (some resources recommend that a maximum side slope of 2:1 not be exceeded). Where feasible, use gradual side slopes of 5:1 for graded surface facilities.
- The Philadelphia Water Department recommends a maximum side slope of 4:1 for mowed facilities to prevent damage from mower blades and a side slope of 3:1 for facilities that are not mowed (PWD 2018b).
- To prevent erosion, design the facility’s side slopes based on expected stormwater flow rates. Applying jute or coir erosion control mats can help stabilize soils until vegetation is established.

- For street conditions, use a 12-inch flat shelf transitioning between the curb or pavement and the slope when used next to a parking lane, bicycle facility, or sidewalk.
- Where space is available, using bioretention swales with graded side slopes provides gentler transitions from the pedestrian path to the bioretention facility, offers safer conditions compared to vertical walls, and allows for more plant choices.

5.3 Sizing Methods and Considerations

Various methods and models are available to guide the design of bioretention facilities to ensure they are adequately sized.

> When sizing and designing the bioretention facility's size, understand the facility's purpose, review the stormwater management goals, and ensure you're conforming with the state and local codes. For example, state and local codes might dictate that bioretention facilities be designed to mimic an area's original hydrological (pre-development) conditions or to infiltrate a specified volume of water (e.g., the first inch of precipitation or runoff).

Runoff and Water Quality Volume

The necessary cell size can also depend on the pollutant load and desired pollutant removal targets, which are more difficult to evaluate. WQV generally refers to the stormwater runoff volume created from a given precipitation event that be captured and treated to remove most of the pollutants on an average annual basis (Ohio EPA 2018).

Alternatively, the sizing of bioretention can be guided by tools such as performance curves. For example, the *New England Retrofit Manual* (SNEP 2022) provides performance curves for various stormwater control measures and pollutants (total phosphorus, total nitrogen, total suspended solids, metals, and bacteria). The performance curves can be used to identify the percent removal of a pollutant based on a design runoff depth or determine the runoff depth that must be captured to achieve a specific pollutant reduction target.

Planners and designers can estimate the runoff volume (V, in acre-inches) by multiplying the impervious cover (IC, in acres) of the CDA by the design rainfall depth (P, in inches).

$$V = IC \times P$$

The bioretention surface area can then be estimated as a function of the runoff volume managed divided by the bioretention ponding depth. The bioretention surface area is typically sized to equal 5% to 10% of the CDA (Tetra Tech 2011).

The Rational Method and Curve Number Method can also be used to calculate the size of a facility needed to manage a specific runoff volume. When applying runoff coefficients or curve numbers, note that grass strips or highly compacted areas can be considered impervious unless they are modified with soil improvements (such as sand) as part of the proposed work. Most municipalities generally design facilities to manage 1 inch of precipitation. EPA's *Compendium of MS4 Permitting Approaches* provides other examples of post-construction performance standards to meet on-site retention requirements from cities and towns (USEPA 2022a).

Rhea Thompson

Effective sizing is a common challenge for communities, with many bioretention facilities being undersized or oversized for the site. In this example, large oversized bioretention can be perceived as giant pits to the surrounding community.

Modeling

EPA's Storm Water Management Model (SWMM) is used worldwide for planning, analyzing, and designing systems for stormwater runoff, combined and sanitary sewers, and other types of drainage (USEPA 2022c). SWMM can be used to size detention facilities to control flooding and protect water quality.

EPA's National Stormwater Calculator is a simple screening tool that uses EPA SWMM to calculate hydrology for sites up to 12 acres. The tool allows users to test the impact of implementing different GSI practices for runoff capture. The tool can also provide planning-level estimates of capital and O&M costs and account for future climate change scenarios.

The Source Loading and Management Model for Windows (WINSLAMM) considers both runoff quantity and water quality. The program evaluates GSI performance for specific sources in urban land use areas during a range of rainfall events.

The Water Environment Federation's *Stormwater, Watershed, and Receiving Water Quality Modeling* document provides straightforward guidance for modeling tools and their capabilities. The document offers past, present, and future perspectives on stormwater quality modeling and outlines criteria for model selection based on project needs (WEF 2020).

Other Sizing Considerations

Weather. Local climate and weather conditions (e.g., precipitation, temperature) affect how quickly water soaks into the ground. Many factors influence the sizing and modeling coefficients used for runoff and infiltration, including the annual precipitation, storm frequency, and evaporation and infiltration rates.

Available space. In many urban settings, retrofitted bioretention often cannot be fully sized to manage the expected runoff volumes or WQVs because of space constraints. The length-width-depth dimensions of practices might be restricted by adjacent land uses; surrounding topography; pedestrian volumes; and proximity to trees, utilities, and buildings and other structures. **Under space-constraint scenarios, size the bioretention facilities to capture and treat as much water as possible**. Consider reducing the size of facilities to supply sufficient setbacks from any conflicts. In constrained spaces (e.g., ROWs), bioretention facilities could be narrow and deep; in open areas, they could be wide and shallow. If undersized, consider designing the practice as an offline system; as part of a connected series to prevent overloading; or with design elements such as flow splitters/diverters, underdrains, and overflow structures.

Margin of safety. In jurisdictions with limited or unreliable maintenance, consider designing oversized bioretention facilities to supply a margin of safety if performance deteriorates. For example, some states require that 100% of WQV be captured within the surface storage rather than allowing some of it to be stored in the media; this ensures adequate storage volume in case of over-mulching (poor maintenance) or faulty construction.

Effective sizing. Consider the total cost and feasibility of maintaining bioretention at a given size. For example, the Philadelphia Water Department (2018a) found that systems are cost-effective when they manage an area of at least 8,000 square feet overall, and the individual drainage areas entering each inlet are at least 5,000 square feet.

Public use. Consider public safety and multimodal transportation access when needed. Refer to Chapter 12 for design considerations related to public safety and transportation.

Rhea Thompson

In this example, a series of bioretention practices in Kansas City, MO, were sized appropriately and constructed on once-vacant land to manage a very large CDA.

Adrienne Donaghue

Adrienne Donaghue

A bioretention facility (left) within Oklahoma City's Scissortail Park is situated alongside public benches and a playground (right), which encourage community gathering.

Chapter 6
RUNOFF CAPTURE

In this chapter

Runoff must flow into a bioretention facility to be effective. This chapter provides a comprehensive overview of the various inlet designs used to manage sheet flow or concentrated flow via inlets. Many different inlet types are presented in detail, along with photographs illustrating various design modifications from across the country.

Photo: NYC Department of Environmental Protection

6.1 Stormwater Conveyance

The best design choice for capturing and conveying stormwater runoff into bioretention facilities depends on various factors, such as location, land use, grade, and flow velocity. Curbless bioretention facilities are designed without a curb and gutter, while curbed bioretention facilities incorporate a curb and gutter in the design.

A curbless design allows sheet flow—runoff that flows uniformly over the ground surface—to drain freely into the practice. Curbless bioretention facilities in low-density areas are associated with larger footprints and little or no vertical separation from the sidewalk and street. Curbless bioretention facilities are also often used along major arterials and highways where sidewalks are absent or separated from the roadway. Bioretention designed with gentle side slopes are amendable to curbless practices. More structured facilities, such as straight-sided bioretention planter boxes, are less common in this context.

Curbed bioretention designs are prevalent in high-density urban environments with space limitations or other site constraints. Stormwater curb extensions and bioretention planter boxes are generally more appropriate for this context. Curbed bioretention facilities require inlets to convey runoff to practices from the surrounding catchment area. Proper inlet design is essential for ensuring runoff is effectively captured.

Design Challenges and Considerations

Table 6-1 summarizes the challenges often encountered in curbless and curbed bioretention facilities and the design options that help overcome those challenges.

Rhea Thompson

Curbless bioretention in Kansas City, MO.

Rhea Thompson

Curbed bioretention with inlets for runoff in College Park, MD.

Table 6-1. Curbless and curbed design challenges and considerations.

Design challenge	Design consideration
Low Capture Efficiency for inlets occurs when runoff flows across the pavement and does not enter the bioretention facility; low capture efficiency is a common problem for both curbless and curbed systems. For curbless systems, a slight elevation difference between the edge of the pavement and the edge of the bioretention facility can contribute to low capture efficiency; debris buildup and plant growth along the edges can also be factors that reduce runoff capture. For curbed systems, problems such as too-small inlets, improperly placed and/or numbered inlets, 90-degree turns, and debris buildup can prevent runoff capture.	Regrade the roadbed to improve the capture efficiency of runoff (i.e., gentle grading affects the capture of small flows). Regrading will depend on existing development and whether grades can be adjusted at the property line. Design the inlets to meet stormwater capture requirements. Understand the hydrology to inform inlet design and enhance overall system performance (i.e., preventing erosion). Design inlets to function in concert with pretreatment to capture most incoming debris and sediment, allowing for easier maintenance. Consider how ice and snow may block inlets and design to minimize these impacts to the extent practical. Specify routine visual inspections and maintenance every few months or after large storms to minimize impacts from vegetation and debris.
Erosion occurs due to fast-flowing water. In curbless systems, the slope or land cover can direct sheet flow to form channels within the practice. Although the inlets of curbed practices are designed to capture high-velocity runoff flows, incorrect or inadequate designs can lead to erosion around the inlet or within the practice.	Protect the system with pretreatment, energy dissipators, and erosion control devices (e.g., forebays). Design inlet width, number, and placement to mitigate erosive flows that could scour the surface of bioretention facilities.
Damage, such as compaction from pedestrians and vehicles, can occur in bioretention facilities.	Consider measures such as visual barriers, low fencing, and bollards to protect the system from damage. Include elements to minimize vehicle entry. Wheel guards (e.g., steel plates, concrete lids) reduce the risk of incursion.
Ease of Maintenance ensures inlets allow access for cleaning and clearing of debris.	Check inlets 3–4 times per year for accumulated grit, leaves, and other debris that could block inflow. Clear blockages as necessary. Use inlets that are wide, free of enclosures, and allow for access by maintenance tools to ensure efficient long-term maintenance.

= sheet flow = inlets

6.2 Sheet Flow Conveyance

A bioretention facility receiving sheet flow (without inlets) takes advantage of how water drains naturally across the land, uses a simpler design, and is less prone to failure. Sheet flow enters the facility uniformly, evenly distributing sediment, so bioretention erosion-control measures can often be omitted.

Suitability

Sheet flow conveyance is often associated with smaller drainage areas where runoff can be safely conveyed via overland flow over short distances (e.g., 400 feet or less), such as parking lots, residential areas, or curbless roadway sections (PDHonline 2020).

Design and Maintenance Considerations

A grass filter strip or gravel filter strip are common pretreatment for sheet flow. A grass filter strip is a uniformly graded vegetated buffer that traps sediment and reduces runoff velocities entering the bioretention facility. A gravel filter strip consists of a trench (2–4 feet wide by 1 foot deep) placed between the edge of the pavement and the edge of the bioretention side slope.

A catchment area's grade, length, and roughness influence the *time of concentration*, or how long it takes for a raindrop to travel from the furthest point of the catchment area to the collection point (the bioretention facility). Gently sloped grades (1%–5% for paved surfaces) help maintain a thin, even sheet flow across level entrance areas (PDHonline 2020). Sheet flow conveyance is unsuitable for travel distances more than about 400 feet because the water concentrates into erosive flows. For transitioning from the catchment surface to the bioretention facility, a 3:1 side slope allows runoff to enter and encourages even sediment distribution.

Portland Bureau of Environmental Services

Sheet flow is directed off a residential street by using a gentle slope along the street crown and a curbless gutter (valley gutter) in Portland, OR.

Portland Bureau of Environmental Services

A valley gutter concentrates sheet flow from upstream and can cause localized deposition of debris as it flows into a bioswale in Portland, OR.

Grade and Routing of Inflow

When stormwater flow is routed incorrectly and results in low capture efficiency, the problems are usually related to variations in microtopography (landscape irregularities) or errors in construction or design. Minor elevation differences between the edge of the pavement and the curb's edge can greatly influence inflow capture. For example, an elevation increase of as little as one-fifth of an inch (5 mm) between the asphalt and the invert of a concrete inlet can lead to suboptimal capture efficiencies. A small expansion gap between the asphalt and the curb's edge will also interfere with runoff capture. Moreover, routing water into bioretention facilities can be challenging when stormwater flows from different slopes converge and cause variable velocities.

The pavement's slope next to the curb or the gutter might need to be adjusted to orient flow paths toward the bioretention facility. Typically, curb cuts sloped (2%) toward the bioretention facility or designed with a minimum 2–3 inch drop in grade between the curb entry point and the bioretention facility's finishing grade provide optimal conditions for conveyance and minimal sediment buildup. Also, consider whether multiple inlets or curb cuts will improve runoff routing into the facility (see photos at right).

Darren Distefano

An inlet design where water cannot turn 90 degrees, resulting in low capture efficiency.

Montgomery County, MD, DEP

A design that allows water to turn 90 degrees and flow through the inlet, resulting in high capture efficiency.

6.3 Inlet Types for Concentrated Flow

Inlets can be open, closed, precast, cut, retrofitted, or cast in place. Inlet construction materials vary and include stone, concrete, steel, and aluminum steel. Choose the best design for a site based on your desired inflow, cost and feasibility, community aesthetics, pedestrian safety, functionality, durability, and ease of maintenance.

Inlets can generally be classified into the following types:

1. Curb cuts
2. Covered inlets
3. Trench drains
4. Pipes and downspouts
5. Curb extension inlets
6. Depressed drains
7. Inlet sumps


Curb Cut (Rhea Thompson)


Covered Inlet (Rhea Thompson)


Trench Drain (City of Seattle and MIG/SvR)


Pipe (City of Seattle and MIG/SvR)


Curb Extension Inlet (Rhea Thompson)


Depressed Drain (Portland Bureau of Environmental Services)


Inlet Sump (ACF Environmental)

Curb Cuts

A curb cut is any break along a uniform curb that allows runoff from the street or sidewalk to enter a stormwater management practice next to the back edge of the curb break. For the purposes of this handbook, **curb cuts are defined as curb openings that are poured, cast, or cut into an existing curb**.

Suitability

- Curb cuts convey both street and sidewalk runoff to the surface of a bioretention facility.
- Curb cuts work well for relatively shallow facilities that do not have steep side-slope conditions.
- Curb cuts are generally an easy retrofit for existing neighborhoods and provide a way to implement bioretention facilities without major reconstruction.

Design and Maintenance Considerations

- Consider designing wide openings and angling the curb cuts to help facilitate stormwater entry. For example, curb cut openings placed parallel to the gutter's stormwater flow typically result in a lower capture efficiency because the water must make a 90-degree turn into the facility.
- Space the curb cut openings to distribute inflow evenly within the bioretention facility.
- The bottom of the concrete curb cut generally is sloped toward the GSI practice.
- Depressed or angled curb cut geometries help facilitate the flow of stormwater into bioretention facilities.

Rhea Thompson

A curb cut on the sidewalk side of a bioretention practice in San Francisco, CA.

Depressed Curb Cut

Depressed curb cuts are often used to convey runoff into bioretention facilities next to curbed roadways. A depressed curb cut is one that is poured with one or more sides tapered down, which allows stormwater to enter a facility directly behind the back edge of the depressed curb. Cuts are usually made at 45 degree angles (forming a trapezoidal channel shape), but the dimensions vary by location.

NYC Department of Environmental Protection

Flow enters a well-designed curb cut in New York City, NY.

City of Seattle and MIG/SvR

Water flows through a curb cut in Seattle, WA.

Depressed curb cuts have been documented for their effectiveness by NYC DEP (2011). After evaluating the first generation of inlets, the city replaced some of them with depressed curb cuts to increase stormwater conveyance. Some inlets were retrofitted to include either a depressed curb or a modified back-plate on the cast iron curb pieces to increase clearance (minimum of 3 inches). These modifications increased the overall conveyance of stormwater to the underground storage areas without affecting vegetation.

Angled Curb Cuts

Angled curb cuts are constructed by angling or bending the curb cut in an orientation towards the facility to help route flow and increase capture efficiency. Many variations of angled curb cuts are illustrated in the following photographs.

Covered Inlet

Covered inlets are openings in sidewalks that direct runoff from streets or parking lots into a bioretention facility located directly behind the back edge of the opening.

Suitability

- Covered inlets are useful for sidewalks with high pedestrian volume, such as parking zones, because they allow runoff to flow underneath the sidewalk into the bioretention facility.

Design and Maintenance Considerations

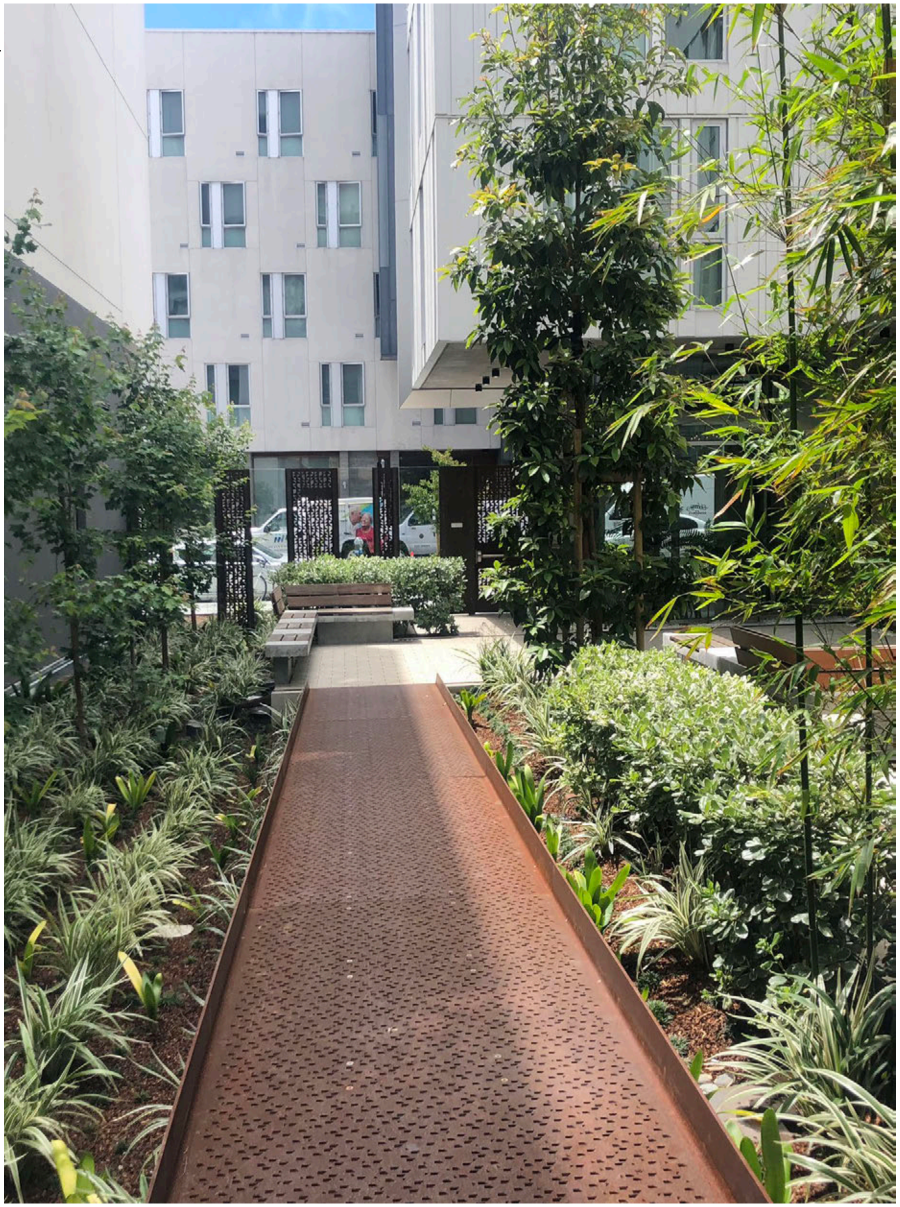
- Openings are often placed parallel to the stormwater flow along the curb, which can reduce capture efficiency.
- Covered inlets are prone to clogging from trash and debris and are difficult to clean.

Rhea Thompson

Rhea Thompson

These examples illustrate how covered inlets can become easily clogged with trash and debris and are difficult to clean.

Rhea Thompson



A trench drain crosses a bioretention practice in San Francisco, CA.

Trench Drain

A trench drain, also called a grated curb cut, is a long, shallow channel with a grate or solid cover over the top. This drain collects stormwater and directs it into a stormwater management practice. Trench drains convey stormwater over a distance while the grate or solid cover maintains the grade of the ground surface.

Suitability

- Trench drains can be installed over an existing runoff channel or gutter.
- On sidewalks they support pedestrian traffic along the surface.
- Aesthetically they are less attractive in residential neighborhoods.

Design and Maintenance Considerations

- Trench drains are manufactured and sized for many different site conditions and can be selected accordingly. The choice of trench drain depth depends on the volume of runoff expected (i.e., more runoff requires deeper trench drains). Note that deeper trench drains can accumulate sediment and must be maintained frequently.
- Trench drain channels are usually concrete and covered with a heavy-duty bolted metal grate or a solid cover.
- The concrete strength required for trench drains will vary by municipality. For example, the Philadelphia Water Department and the City of Columbus specify 3,500 and 4,000 pounds per square inch, respectively (PWD 2018c; City of Columbus 2022).
- Grate and covers can include decorative patterns or colors.

- All bolts are typically stainless or galvanized steel (or as the manufacturer recommends).
- Although the length varies, it is recommended that trench drains be less than 20 feet long. Trench drain grate covers are typically cast in 2-foot sections (with varying widths); therefore, design the trench drain length in 2-foot increments to avoid the need to cut grate castings to fit.
- Trench drains may be placed across or parallel to the flow direction to collect and direct the runoff to a single inlet point in the bioretention facility.
- Review current Americans with Disabilities Act (ADA) codes for grate requirements if trench drains are within sidewalk zones and/or ADA travel paths. All grates or covers used must be heel-safe and have sufficient slip resistance. Consider using slip-resistant materials, textured surfaces, or other measures to minimize slippery surfaces and enhance safety.
- To support accessibility and address safety concerns, a trench drain can serve as part or all of a detectable edge treatment (i.e., to indicate pedestrian street crossing is not intended). They can also provide a visual separation on a roadway, especially on curbless or shared streets (i.e., a road with a designated bicycle lane).
- If projects use federal funds (e.g., state revolving funds), American Iron and Steel requirements apply.
- Avoid grade changes in the location of trench drain grates.
- Trench drains generally work well; however, if not maintained, debris can get trapped in the covered zone and block runoff flow. When the trench drain is installed with a removable cover, debris can typically be extracted with a shovel. Trench drains with permanent covers usually require washing/flushing to clear.

Cory Rayburn

A trench drain across a sidewalk in Atlanta, GA.

Rhea Thompson

A trench drain allows for runoff conveyance and pedestrian circulation in Seattle, WA.

Rhea Thompson

A pipe conveys and discharges roof runoff in San Diego, CA.

City of Seattle and MIG/SvR

A pipe discharges runoff over an energy-reducing concrete splash pad in Seattle, WA.

Pipes and Downspouts

Pipes are commonly used to convey surface runoff from roadways, rooftop surfaces, and other impervious areas before discharging it directly to a bioretention facility. A downspout is a pipe that conveys runoff from a rooftop to a ground drainage system.

Suitability

- Pipes carry runoff to a bioretention facility when the practice can't be fed by sheet flow or when flow comes from different subcatchments.
- Pipes and downspouts are useful in areas where water needs to be intercepted from rooftops. Many buildings, especially in commercial districts, have existing buried downspout connections that discharge to the street curb line or a curb and gutter underdrain. The downspouts from rooftops can be reconfigured to route stormwater into a GSI facility, such as a bioretention planter.
- Pipes convey runoff over a distance from an upstream source.
- Pipes work well in high-traffic areas because they do not interfere with multimodal transportation. However, existing underground utility infrastructure might prohibit the installation of additional storm drain pipes.

Design and Maintenance Considerations

- Existing downspouts can be modified to divert runoff to a GSI practice. Coordination with property owners is needed when downspouts are on privately owned buildings (City of Columbus DPU 2015).

- Modify downspouts according to their distance and elevation in relation to the GSI practice.
  - For downspouts discharging directly to a bioretention facility, cut the existing downspout pipe parallel to the adjacent grade and smooth the edges.
  - For downspouts located away from the practice but at a higher elevation, add piping that carries the water and discharges it at or above the surface of the practice.
  - For downspouts with an elevation lower than the proposed GSI surface, fit the downspout with a perforated pipe that discharges into a gravel layer in the subsurface of the practice (City of Columbus DPU 2015).
- Use check valves when connecting downspouts to bioretention to prevent stormwater backflow due to ponding in the GSI during storm events (City of Columbus DPU 2015).
- Bubble-up risers, also called pop-up emitters, are internal downspouts that may be used as an alternative to below-grade distribution piping. They function by allowing water to back up from underneath the ground. Although they can direct roof runoff to bioretention, they can be problematic because they need significant pressure for water to flow. Moreover, they are not suitable near building foundations.
- The use of energy dissipation is generally needed to mitigate erosion.
- Monitor and maintain pipes to avoid blockages. Also, consider installing grates over pipe openings to exclude pests.

City of Seattle and MIG/SvR

A pipe under a street conveys runoff between bioretention practices in Seattle, WA.

Philadelphia Water Department

Stormwater curb extension in Philadelphia, PA.

NYC Department of Environmental Protection

Stormwater curb extension in New York City, NY.

Curb Extension Inlet

A curb extension inlet is a type of opening found on a curb extension, which is a bioretention facility in the ROW that extends into the street (often referred to as a bump-out) to capture runoff and calm traffic.

Suitability

- They are suitable for any stormwater curb extension practice.

Design and Maintenance Considerations

- Some inlet designs have been modified to be stormwater curb extensions. The most common design allows water to flow straight along the gutter, such as in the image to the left.

- Curb extensions placed in the street can be susceptible to damage from drivers, especially in locations near parking spaces. Consider adding elements such as bollards or metal bars secured across the top of the inlet for protection when designing practices.

All photos: Portland Bureau of Environmental Services

Lessons Learned

The City of Portland's preferred stormwater curb extension inlet design has evolved over time to meet local needs. In Portland's early curb extension design (right), **the water had to turn to flow into the curb cut** and most runoff flowed past the opening and bypassed the practice completely. To prevent inlet bypass, the City of Portland modified the curb extension inlets so the opening was offset and intercepted runoff within the flow path along the gutter (bottom left). However, the City of Portland then realized that vehicles could drive into the facilities through the opening. To solve this problem in the existing inlets of this type, Portland retrofitted the inlets with a metal bar extension that prevented vehicles from entering the facilities (bottom middle). The current standard for new stormwater curb extension inlets is to include a metal "staple" bar across the top and install a splash pad for sediment collection just downgradient (bottom right).

An early curb extension inlet design allowed flow bypass.

An inlet design that extends into the gutter to intercept flow.

Metal bars added across inlet opening prevents vehicle access.

A metal bar is included in all new curb extension designs.

Depressed Drain

In depressed drains, the runoff flowing along the gutter drains down through a grate-covered inlet and discharges into a bioretention facility.

Suitability

- Depressed drains are helpful when water flows parallel to a cell because the water drops in without needing to make a 90-degree turn.
- They are useful for bioretention facilities on sloped streets, where directing runoff into cells can be challenging.

Design Considerations

- Drain cover design must be safe for bicyclists and pedestrians. Grid-type covers are generally preferred.
- Depressed drains can be shallow or deep. Deep depressed drains generally use pipes to convey runoff to the facility, making them challenging to maintain.
- If retrofitting a site to implement a depressed drain, consider the cost and labor needed to cut into the road.

Portland Bureau of Environmental Services

Portland Bureau of Environmental Services

Shallow depressed drains include inlet openings to maintain runoff capacity into the cell if debris accumulates on the grate, Portland, OR.

Rhea Thompson

Water flows into a depressed drain and through a pipe to a bioretention facility in Minneapolis, MN.

Rhea Thompson

A pipe conveys runoff from a depressed drain to a bioretention facility in San Francisco, CA.

Inlet Sump

Inlet sumps, also known as manufactured inlets, include pretreatment for sediment and erosion control. They are designed to route runoff into a catch basin to collect debris. After pretreatment, water is directed into the bioretention facility.

Suitability

- When a lot of debris is expected in stormwater flows, inlet sumps are especially useful because they settle and separate the sediment from the runoff before it enters a bioretention facility.
- Avoid siting inlet sumps where pedestrians will interact with them, such as at intersections or next to a curb ramp.

Design Considerations

- Many inlet sumps are proprietary devices; some municipalities have replicated and modified these designs.
- The pretreated runoff typically drains out of the catch basin through a pipe or opening and into the bioretention facility. Some inlet sumps are designed to release pretreated runoff through a perforated underdrain directly into the subsurface of bioretention facilities (NACTO 2017).
- The grate, filter, and chamber of inlet sumps capture sediment and debris. Maintenance efforts can remove accumulated sediment and debris from the chamber with a shovel and clean the drop-in filter with a broom or hose.

Middle St. Croix Watershed Management Organization (MSC WMO)

Proprietary inlet sump in Minneapolis, MN.

MSC WMO

A bioretention practice in Minneapolis, MN, with a proprietary inlet sump often used in residential areas.

MSC WMO

The Middle St. Croix Watershed Management Organization developed this low-cost shallow sump to capture runoff and debris.

6.4 Inlet Number, Placement, and Frequency

During the design phase, pay careful attention to the proposed number, placement, and frequency of inlets.

Use multiple inlets to maximize capture efficiency and minimize erosion. Placing inlets at intervals along a bioretention facility helps to capture more stormwater and evenly distribute the flow within a GSI practice. Installing multiple inlets also ensures water can enter the cell if an upstream inlet becomes blocked.

Position inlets to capture the majority of runoff. Ensure they are placed in the pathway of stormwater flow and alongside the gutter line at the upstream end of the facility. Placing an inlet at a low point or depression in a road or parking lot might be necessary. As previously noted, stormwater flows can be altered by small factors in the landscape (e.g., pavement cracks or divots), which could direct runoff away from the inlets.

Review the slope of the street when siting inlets. On a street that is higher in the middle and drains to the sides (i.e., a crested/crowned street), note that one side of the street could be at a slightly higher elevation and might affect runoff flow.

Use hydrological modeling tools to help place inlets. Various municipalities and researchers are studying how to design inlets to accept desired volumes and velocities based on the hydrology (i.e., the volume, velocity, time of concentration, and direction of water flow) of the modeled drainage area. Although effective, modeling can be costly and impractical for many municipalities.

City of Seattle and MIG/SvR

This bioretention facility in Seattle, WA, has multiple inlets that allow runoff to enter if an upstream inlet gets clogged or is at capacity. Although some bypass is expected, designing inlets with redundancy can help maximize conveyance.

Lessons Learned

Examine examples of the number, placement, and frequency of inlets in existing bioretention facilities to determine if the designs could be improved. Incorporate these lessons into future designs. In Example 1, a bioretention facility has a single undersized and enclosed inlet downstream of an existing catch basin draining to the city's sewer system. Stormwater easily bypasses the inlet, especially when clogging occurs. The design could be improved by placing the bioretention inlet upstream of the catch basin, designing a wider and more open structure, or converting the catch basin into an inlet by adding a flow splitter. In Example 2, a street-side bioswale is isolated from the street runoff. The design could be improved by adding multiple curb cut inlets to increase runoff capture efficiency.

Photos: Rhea Thompson

Example 1. Arrow shows an undersized, poorly functioning inlet.

Example 2. Arrows show possible locations for new curb inlets.

6.5 Inlet Size

The following factors should be considered when designing the size of the inlet opening, which is the key to ensuring water flows into the practice.

Inlet size varies based on the type of bioretention facility. Inlet size can allow some (i.e., an offline system) or all (i.e., an online system) the stormwater to enter the facility. In offline systems, fewer, smaller inlets would allow storm flows that exceed the design storm to bypass the system. This excess runoff would continue downgradient to another bioretention facility or flow into a storm drain. In online systems, using wide, frequently spaced inlets would allow all stormwater to enter the practice. Include overflow structures to manage excess flows and add pretreatment to slow flow and minimize erosion.

Inlet size varies based on drainage area. The flow rate, longitudinal slope, and the number and frequency of inlets placed along a bioretention facility affects the size needed. The following resources are available to help with inlet sizing:

- The City and County of Denver (CCD) and the Urban Drainage and Flood Control District (UDFCD) developed the *Ultra-Urban Green Infrastructure Guide*—a resource for determining inlet width when the upstream drainage area is assumed to be 100% impervious (CCD and UDFCD 2016).
- The Philadelphia Water Department requires the use of the Rational Method to determine inlet capacity (PWD 2018a). Once the flow is known, the inlet width (specifically, for type R inlets) can be identified using equation 3 in *Hydraulic Efficiency of Street Inlets Common to UDFCD Region* (UDFCD 2011).


Cory Rayburn

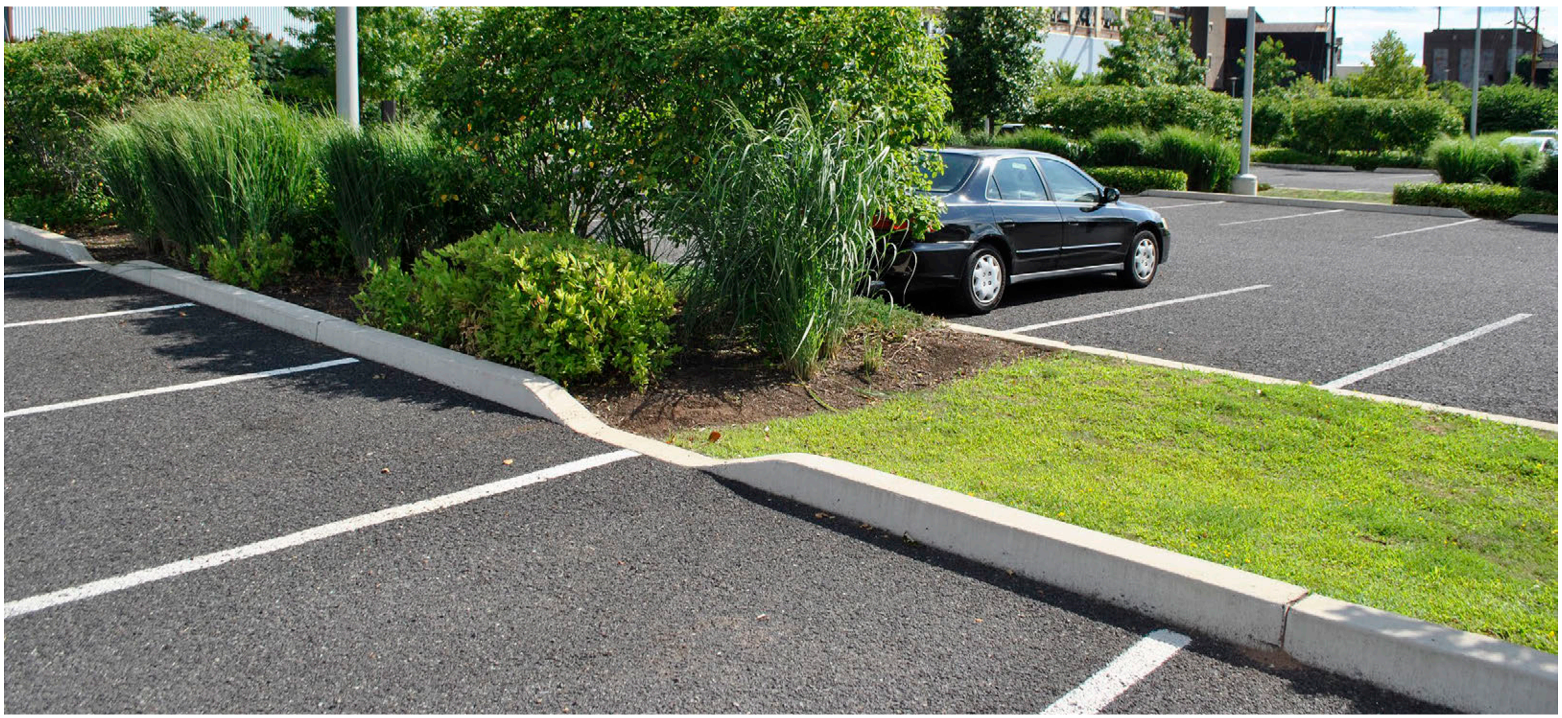
Small inlet openings convey runoff into a bioretention practice within a traffic median in Atlanta, GA.

- The District of Columbia Department of Transportation (DDOT) recommends using the method in the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 22 to determine the size of the inlet opening that achieves 100% interception for a 15-year storm (DDOT 2017; FHWA 2009).

Avoid small inlets where water must turn 90 degrees to flow into the bioretention facility. To prevent clogging with trash or street debris, ensure inlets are wide enough to accommodate the expected stormwater volume and debris. Curb opening widths of 18–24 inches (and no smaller than 12 inches) have been recommended to reduce the chance of sediment and debris clogging an entry point. Moreover, designing curb openings with angles and other modifications can facilitate inflow. Several examples are discussed in the remaining pages of this chapter.

Oversized inlets can accommodate high volumes and may exacerbate erosion. Oversized inlets can also be hazardous to pedestrians and drivers.

Pretreatment type and maintenance plans (e.g., the use of shovels or vac trucks) can influence inlet size. Inlet size can be influenced by pretreatment type and maintenance plans and capabilities (e.g., the use of shovels or vac trucks). Chapter 7 provides details on pretreatment and maintenance considerations.



Philadelphia Water Department

A bioretention practice in Philadelphia, PA, with a wide curb opening and angled edges to facilitate runoff capture.

City of Seattle and MIG|SvR

A depressed curb cut in Seattle, WA.

City of Seattle and MIG|SvR

An angled curb cut in Seattle, WA.

Rhea Thompson

An angled inward curb cut at Villanova University, PA.

Darren Distefano

An angled inward curb cut in Washington, DC.

6.6 Inlet Flow Path Modifications and Retrofits

Enhancing an inlet's design (e.g., incorporating gutter aprons and saw cuts) or changing the road surface (e.g., adding berms and speed bumps) can help guide stormwater runoff into inlets. These modifications are useful where flows are potentially erosive or inlets require runoff to make 90-degree turns. Additionally, modifying an existing inlet (i.e., retrofitting it) may be needed to improve stormwater runoff capture. When considering the following options, note the added cost they may incur. Additionally, modifications and retrofits can be viewed as an adaptive management approach that responds to changes or lessons learned and helps maintain the functionality of a facility long-term.

Channels and Runnels

Channels and runnels are surface depressions designed to convey concentrated flow to a bioretention facility or a drain. Channels are used to collect and carry moderate-to-large flows. Runnels are typically shallow systems designed for small spaces and small-to-moderate flows.

Suitability

- Channels and runnels are beneficial because they quickly and unobtrusively direct water where desired and are easily combined with GSI. They are useful in commercial or mixed-use areas with high traffic where runoff along paths of travel (e.g., sidewalks) must be conveyed to a GSI facility.
- They are placed along the surface, so they are suitable in areas where underground utility infrastructure prohibits installing buried drainpipes.

Rhea Thompson

Retrofitted inlet in Montgomery County, MD.

Montgomery County, MD, DEP

Retrofitted inlet in Montgomery County, MD.

- Channels and runnels are not appropriate across designated ADA pathways or emergency egresses. A covered trench drain is necessary when traversing a pedestrian travel path.
- On low-volume streets such as alleys, runnels can be combined with bioretention in the center of the roadway. The road must be graded and crowned to direct runoff to the roadway's center.

Rhea Thompson

A runnel directs runoff to a bioretention practice in San Diego, CA.

Design Considerations

- Artistic or educational stormwater designs can incorporate channels and runnels.
- Where pedestrian crossing or accessibility is needed, cover channels or runnels with durable ADA-compliant linear covers such as steel grates, trench drain grates, boardwalks, or other walkable surfaces at least 4 feet wide, or fill them with stone to reduce tripping hazards. Consider American Iron and Steel requirements if projects use federal funding, including state revolving funds.
- Channels and runnels are commonly constructed using concrete or stone. Appropriate materials include pavers, bricks, recycled cobblestone, river rock, or any other durable, impermeable material. In highly urban areas, concrete-mortared work well for durability.
- Channels and runnels installed using contrasting material to the main path of travel enhance visibility for pedestrians.
- Maintain the bottom of the covered channel at or below the grade of a pre-existing gutter pan to maintain drainage to the storm drain inlet.
- Channels and runnels are typically 10–36 inches wide with gentle slopes (0.5%–3%) to move water effectively toward the discharge point.
- Runnels design typically incorporates a smooth, sloping cross-section with maximum depths of 2–2.5 inches for safety.

Gutter Apron

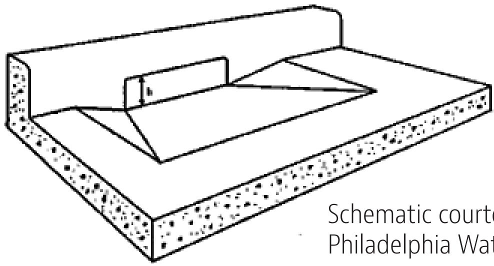
A gutter apron, also known as an inlet apron, is a depressed gutter section of concrete placed along the gutter line in front of curb openings to increase inlet capacity. It helps to guide concentrated flow towards the curb opening.

Suitability

- Gutter aprons are usually placed in front of inlets that are closed along the top of the opening (e.g., trench drains, wheel guard in place).

Design Considerations

- A depressed concrete apron can be cast in place or retrofitted by grinding down the existing concrete pavement. Cast-in-place gutter aprons provide an increased cross-slope and tapered sides that slope toward the curb opening.
- Aprons typically drop 2 inches into the bioretention facility, with another 2-inch drop behind the curb to maintain inflow as debris collects.
- Stormwater capture requirements and design entrance velocities typically govern a gutter apron's cross-slope. The slope of aprons parallel to the curb is recommended to be a maximum of 8% (City of Columbus DPU 2015).
- Limit the slope and extent of gutter aprons to prevent hazards to pedestrians or bikers.
- To give bicyclists adequate clearance from the curb and any pavement seams, protected bike lanes along concrete aprons are typically implemented with a minimum widths of 6 feet.



Schematic courtesy of Philadelphia Water Department

City of Seattle and MIG|SvR

Top: A schematic of a gutter apron. Bottom: A depressed curb cut in Seattle, WA, showing how concrete aprons can be created (retrofitted) by grinding down the existing concrete pavement.

- Aprons that create a drop of more than 8 inches along a parking lane can cause a vehicle wheel to drop below the curb, preventing the door from opening.
- For aprons leading into bioretention swales, the curb may angle into the facility to improve the conveyance of flow.

Flow Splitters

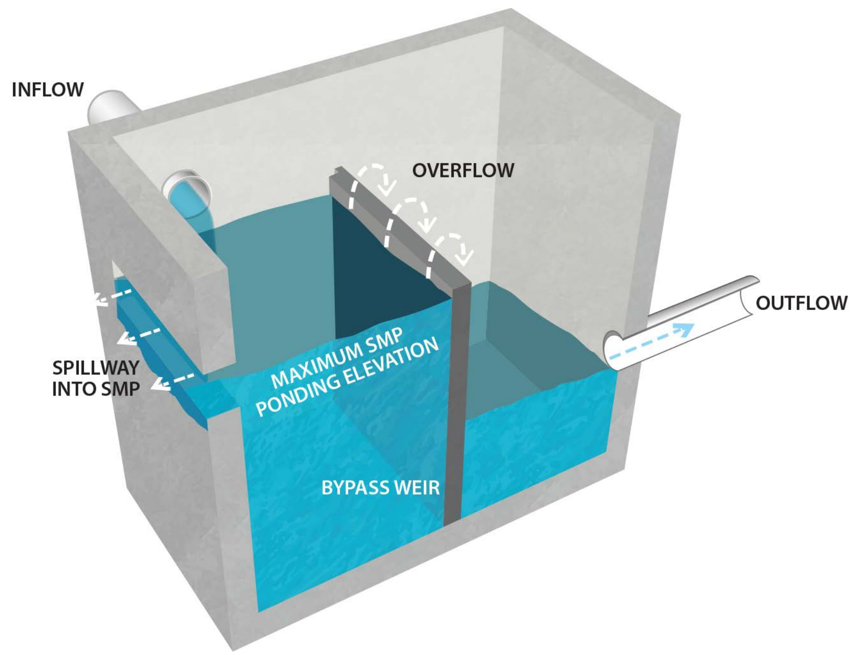
Flow splitters are devices used to direct the design WQV into a GSI practice while splitting flows from larger events and routing them around the practice into a bypass pipe or channel. The bypass typically connects to another GSI practice, storm sewer, or receiving water and will vary depending on the design and management requirements.

Suitability

- Flow splitters can divide runoff volume and divert it to different destinations to alleviate downstream flooding.
- Flow splitters can also be used to separate the first flush volume, which contains the majority of the runoff pollutants. Flow splitters allow the first flush to be sent to a facility offering more intensive treatment or allowing treatment over a longer duration without being diluted by additional runoff (which can be diverted downstream or to another GSI practice).

Design Considerations

- They can be constructed by installing bypass weirs in stormwater control structures, such as manholes.
- Flow splitter design components include the elevation of the bypass weir, the capacity of the pipe routing to the GSI practice, and the capacity of the pipe bypassing flow that discharges over the weir.
- The elevation of the bypass weir dictates the maximum elevation of the water in the GSI practice. The bypass elevation typically equals the design storage elevation in the practice. The flow will begin to bypass the facility once it exceeds the design storage elevation of the practice. The design storage elevation is the water surface elevation at which the facility storage area contains the runoff volume from a design storm event (for example, the WQV or the first 1.5 inches of precipitation).
- Flow splitters are sized to provide enough capacity to transmit larger flows over the bypass weir without surcharging (i.e., overflowing) the top of the flow-splitter control structure.
- When designing flow splitters, construction materials that are corrosion resistant are best (e.g., reinforced concrete, galvanized steel, brick and epoxy mortar).



Philadelphia Water Department

A schematic of a flow splitter for a stormwater management practice (SMP).

- Flow splitters have the potential to cause flow reversal under certain circumstances (e.g., due to lack of a backflow preventer or one-way valve) in which water will flow from a facility back through the flow splitter.

Saw Cuts

Saw cuts are ridges cut into the surface next to the inlet and are often used on offline stormwater retrofits to direct water into bioretention facilities. While effective, saw cuts may not be appropriate in colder climates because the uneven surface can catch plows during snow removal.

Rhea Thompson

Saw cuts help direct water flow into an inlet.

Berms

An optional 1- to 2-inch high asphalt or concrete berm placed on the downstream side of a curb opening can help direct runoff into a bioretention facility. Berms are particularly useful in areas with steep slopes.

Alisha Goldstein

A berm on the downstream side of a curb opening directs runoff.

Speed Bumps

Speed bumps are a simple and inexpensive retrofit strategy to convey water to bioretention. They can be installed as a "backstop" near curb cut entries to direct water into practices. They can also be installed near the beginning of a facility to increase treatment time. In the example pictured below, without the speed bump in place, runoff would enter the bioswale much lower within the system, bypassing some of the area available for treatment. A 2-inch speed bump is typically adequate for directing stormwater flow, and it can be set on a diagonal to further facilitate stormwater capture.

Nevue Ngan Associates, courtesy of C/CAG of San Mateo County

A speed bump intercepts and redirects runoff.

6.7 Inlet Protection

Inlet protection includes measures along concrete curb cuts and gutters that protect at-grade inlets from damage. This section reviews wheel guards, grates, and winged curb cuts.

Wheel Guard

Wheel guards, or wheel stops, consist of a steel plate or bar extending along the top of a curb opening that allows water to pass through while protecting the entrance—they help to prevent car wheels from unintentionally entering curb openings.

Suitability

- Wheel guard plates protect at-grade inlets from damage caused by vehicles; thus, they are useful on high-traffic streets or in areas where parking is common along the curb.
- Wheel guard installation occurs on the curb cuts on the street side of a bioretention facility.

Design Considerations

- The Philadelphia Water Department recommends using steel-plate wheel guards but notes that other materials (e.g., strong composite plastics), patterns, and colors can add aesthetic interest (PWD 2014).
- Wheels guards are prone to damage as shown; thus, entrance protection that can withstand the expected loading from vehicles or pedestrians will be more durable (i.e., a tensile strength greater than 35,000 pounds per square inch).
- Consider American Iron and Steel requirements if projects use federal funding (e.g., state revolving funds).

Robert Goo, EPA

A damaged wheel guard over a curb cut in Washington, DC.

Rhea Thompson

Wheel guards are installed over inlets that are parallel to traffic, such as on this median bioswale in Prince George's County, MD.

Montgomery County, MD, DEP

Wheel guards protect openings from vehicles on this stormwater curb extension in Montgomery County, MD.

Grates

Grates are often applied over inlets to remove floatables. Although they can be effective, they must be maintained, or they will clog. The Philadelphia Water Department generally recommends that grated inlets use a clogging reduction factor of 0.5 (assuming only half of the opening is available for the conveyance of stormwater to the practice) (PWD 2018). This factor must be applied to the unclogged inlet capacity of the inlet and the resulting clogged interception capacity compared to the design intensity flow rate.

Winged Curb Cut

A curb cut with wings helps retain the side-slope grade on each side of the opening while directing concentrated runoff into the bioretention facility. Winged curb cuts are particularly good for routing runoff into bioretention without eroding the sides. Curb-cut wing walls also allow soil to be pulled up to the top of the curb. They work well with relatively shallow bioretention facilities that do not have steep side-slope conditions. Designs vary, but openings are usually at least 18 inches wide.

Darren Distefano

Debris clogs a grate leading into a bioretention facility.

Rhea Thompson

A winged curb cut in San Mateo County, CA.

Chapter 7 PRETREATMENT

In this chapter

Inlets opening into a bioretention facility are often coupled with pretreatment to capture solids and dissipate the energy of the incoming flow. This chapter presents pretreatment options for both sheet flow and concentrated flow. Various forebay pretreatment design options are discussed in more detail.

Photo: Rhea Thompson

7.1 Importance of Pretreatment

Pretreatment consists of an aboveground area or a belowground structure designed to capture solids from runoff and dissipate flow velocities before the water contacts the BSM and vegetation. As a result, **pretreatment is not a standalone practice** but an upstream design component; the pretreatment type will differ depending on whether the facility is receiving sheet flow or concentrated flow. Pretreatment provides the following benefits when included in bioretention facilities.

Reducing sediment. Pretreatment can work together with in-practice erosion control measures, such as check dams and weirs, to reduce flow velocities, collect water, and promote sedimentation. Settling sediment-bound pollutants, such as metals and phosphorus, in pretreatment can increase the treatment lifespan of BSM and reduce the pollution entering municipal stormwater and natural drainage systems.

Prolonging the service life of BSM. Pretreatment plays a critical role in removing substances from runoff (leaves, coarse sediment, trash, etc.) that can cause bioretention clogging, which shortens the lifespan of BSM and can result in costly repairs.

Protecting vegetation. Pretreatment reduces inflow velocities and protects vegetation from erosive flows.

Localizing maintenance efforts. Pretreatment concentrates sediment and debris at the upstream end of the facility, where it can be easily accessed and removed.

Kary Phillips

Inadequate pretreatment allowed sediment and debris to accumulate on the surface of a facility in Baltimore, MD.

Rhea Thompson

Accumulated sediment and trash needs to be removed from this forebay to ensure proper function.

When is Pretreatment Necessary?

The pretreatment type used is influenced by factors such as the CDA, land use, slopes, and soils. Some bioretention may not require pretreatment, such as facilities that drain small stabilized tributary drainage areas. Alternatively, an urban site with a large LR would benefit from adding pretreatment practices to minimize clogging and focus maintenance efforts. Other examples may include areas with leaf drop or high traffic or truck volumes (NACTO 2017). Areas with CDAs of more than 0.5 acre and steep slopes also need pretreatment to mitigate erosion by inlet and sheet flows.

Check local requirements and guidelines. Some cities or municipalities may provide specific guidance for pretreatment. For example, the *Minnesota Stormwater Manual* recommends that flow entering a pretreatment vegetated filter strip (VFS) should not exceed 1 foot per second (MPCA 2013).

The pretreatment design types described in the following sections are categorized into pretreatment for sheet flow and pretreatment for inlets or concentrated flow. Using multiple pretreatment elements together can yield multiple benefits, such as energy dissipation (i.e., splash pad) and sedimentation (i.e., forebay).

7.2 Pretreatment for Sheet Flow

Sheet flow pretreatment is designed to manage incoming flows that enter the practice as a diffuse layer. Thus, it is important to avoid concentrated flow, which can cause channelization or erosion in the pretreatment device. Designing for sheet flow pretreatment emphasizes sedimentation, energy dissipation, and the redistribution of concentrated flow, if needed.

Vegetated Filter Strip

VFS, also called grass filter strips or buffer strips, are often used to pretreat sheet flow entering a bioretention facility. They are suitable alongside roadways or parking lots where the contributing area is uniform and the flow path is less than 150 feet. A VFS is a common pretreatment application for sheet

Rhea Thompson

A VFS in a curbless bioretention facility treats incoming sheet flow in Kansas City, MO.

Rhea Thompson

Curbless bioretention with a VFS that treats sheet flow in Fort Lauderdale, FL.

flow conditions. Adding a gravel diaphragm or level spreader—described below—at the upstream end of a VFS can improve pretreatment effectiveness. Conducting street sweeping also helps reduce sediment loads entering the VFS in sheet flow.

Design and Maintenance Considerations

The length of the VFS needed from the edge of the drainage area to the bioretention practice is a function of the VFS slope, the vegetation type, and the drainage area's soil type. The CDA's vegetation and soil type also determines the needed VFS slope; typical values are 4%–8% slope. The *New Jersey Stormwater Best Management Practices Manual* (see Chapter 9.10; NJDEP 2021) provides lookup curves for VFS slopes, VFS lengths, and the maximum slopes for different vegetation types (turf grass, meadow cover, or forest).

Design a VFS to fall at least 2 inches below the contributing impervious surface. If, over time, the grade of the VFS rises above the adjacent impervious catchment, regrade the VFS to restore proper drainage.

Debris buildup and plants growing along the edge can cause performance issues. For example, small incongruities or pieces of debris can alter flow paths and result in flow diversions. Perform visual inspections every few months to inform maintenance needs. Maintenance crews should clear the accumulated sediment and trash from the VFS's edges at the same time they remove debris from the bioretention practice—approximately twice per year. Maintenance staff should also check for erosion in the VFS. If erosion is visible, it should be repaired with topsoil and revegetated.

VFS may not be practical for retrofit projects and urban sites constrained by small footprints.

Gravel Diaphragms

Gravel diaphragms consist of a gravel trench (1 foot deep by 2 feet wide) positioned between the CDA and the VFS. The gravel diaphragm's primary purpose is to remove sediment, maintain sheet flow, and reduce erosion potential. It's important to note that this device is not a conveyance practice but rather a measure to distribute flow evenly before it enters the VFS.

Level Spreader

Level spreaders are an engineered practice that discharge sheet flow evenly into a bioretention facility. It can be used to convert concentrated flow into sheet flow; for example, when added just downgradient of a curb cut. Typically, the design includes a rigid material, such as concrete, wood, or metal, where runoff collects in a trench on the upstream side and spills over the lip of the level spreader as diffuse flow. The level spreader is situated between the CDA or conveyance pipe and the GSI practice. Gravel can be placed immediately downgradient of the level spreader to provide a transition to the VFS or bioretention practice.

City of Omaha

Curbless bioretention with a level spreader and VFS in Omaha, NE.

Portland Bureau of Environmental Services

Curbless bioretention with a level spreader in Portland, OR.

7.3 Pretreatment for Inlets and Concentrated Flow

Pretreatment is generally a necessary element for practices with concentrated flow and inlets. A pretreatment practice on the ground surface is sometimes referred to as a presettling zone, which consists of a designated area for collecting debris, dissipating energy, and preventing erosion of BSM directly downgradient of the inlet. The following design and maintenance considerations apply to all pretreatment options selected for concentrated flow through inlets.

Ideally, install pretreatment at the primary inlet of a single bioretention facility or at the inlet of the first facility in a series. This design focuses the maintenance efforts in one location and dissipates energy in the first cell before the flow moves to other cells in a series.

Consider the land use when selecting the pretreatment type for inlets. Runoff from busy urban streets can contribute high loads of sediment and debris, which necessitates installing larger presettling zones at inflow points. Also, design the pretreatment areas to withstand the flow velocities expected from the design storm.

Ensure regular maintenance of the inlet pretreatment area. Minimizing the buildup of sediment or debris is important for maintaining system performance. The pretreatment type selected will influence the maintenance tasks and equipment needed, so consider a town or city's operations and available maintenance equipment during the design phase. For example, city agencies using vacuum trucks might prefer forebays with concrete pads rather than rocks or cobbles.

Kary Phillips

Stone presettling zones collect debris and dissipate the energy of runoff entering a bioretention facility in Olney, MD.

Table 7-1 provides photos of and describes the various methods available to pretreat concentrated flow, along with method-specific design and maintenance considerations. Forebays and splash pads—two of the most common pretreatment methods—are presented in more detail after the table.

Table 7-1. Pretreatment options for concentrated flow.

Pretreatment type	Description	Design and maintenance considerations
Cory Rayburn  **Forebay**	• An aboveground pretreatment area separated from the BSM by a berm or gabion. It is the first compartment of a bioretention practice; often used when a stormwater pipe or swale discharges directly into bioretention. *Note:* More detailed information about forebays is provided on pages 7-10 to 7-20.	• Surface material options include vegetation, stone, pavers, or concrete pads next to the inlet. • Helps to maximize sedimentation and localize maintenance efforts.
Adrienne Donaghue  **Splash pad or splash block**	• Dissipates energy to prevent erosion and channelization. • Often used directly below conveyance pipes connecting into a bioretention facility or at the bottom of downspouts. *Note:* More detailed information about splash pads and blocks is provided on page 7-21.	• Typically made of concrete; can be designed with embedded stones, cobbles, rocks, or bricks. • The roughness of surface materials slows the stormwater, reducing erosive potential.
City of Omaha  **Catch basin (sump or chamber of inlet sump)**	• An underground chamber or sump connected to conveyance piping. Debris and sediment collect in a sump; oil and grease float on the surface. • After pretreatment, water drains into the facility via a piped discharge or an opening in the catch basin's walls. *Note:* See Chapter 6 for more details about inlet sumps.	• Suitable for ultra-urban settings where aboveground space is limited. • Can be paired with a splash pad for energy dissipation (as pictured). • Routine maintenance prevents foul odors. • Size will vary depending on the land use (e.g., residential versus commercial).

Table 7-1. Pretreatment options for concentrated flow.

Pretreatment type	Description	Design and maintenance considerations
Rhea Thompson  **Leaf screen or inlet filter guard**	• Consists of a grate over the inlet opening. • Useful in residential settings with high leaf drop.	• Can prevent larger debris (plastic bottles, leaves, trash) from entering the practice. • Can be used in conjunction with forebays and/or splash pads.
City of Omaha  **Trash rack/screen**	• Placed across curb cuts or between the presettling zone and the BSM. • Suitable in areas where trash and large debris is expected.	• Can protect outlet structures. • Screen's small footprint allows trash to collect in one location for easy removal.

Table 7-1. Pretreatment options for concentrated flow.

Pretreatment type	Description	Design and maintenance considerations
Rhea Thompson  **Vortex chambers or hydrodynamic separators**	• Underground flow through pretreatment chamber that can be installed online or offline. • Capable of reducing sediment and floatables (e.g., oil and grease).	• Primarily proprietary structures. • Several types are available using varied separation methods (swirl/vault systems). • Requires routine maintenance. Sediment is removed using a vacuum truck.
NYC DEP  **Pretreatment cell**	• Typically above ground with a check dam or weir at the downstream end. • Larger than a forebay; designed to detain 15% of the design volume (VA DEQ 2011). • Not often used in small-scale or residential applications.	• Place next to the inlet pipe or curb cut to dissipate concentrated flow. • No need for underlying engineered BSM, unlike the main bioretention practice. If the bioretention storage volume includes the pretreatment cell's volume, the cell must dewater between storm events to avoid permanent ponded volume.

Forebays for Pretreatment

Forebay pretreatment is the most diverse and common type of pretreatment device. The following section describes the suitability and design considerations common across all forebay design variations and highlights examples.

Suitability

- Forebays can be used in most curb cut settings or when a stormwater pipe or swale discharges directly into the bioretention facility.
- Forebays are acceptable in ultra-urban environments when space allows and there are no strict aesthetic requirements.
- Forebays can enhance suspended solids removal within the bioretention facility when total suspended solids removal is a priority.
- In colder climates, forebays can offer dual functionality and be used to store plowed snow.

Design and Maintenance Considerations

Typically, a forebay is sized to capture and temporarily detain a portion of the water quality volume to satisfy sedimentation. For example, the Georgia Department of Transportation sizes its forebays to hold 0.1 inch of runoff per impervious area managed (GDOT, n.d.). Local guidance documents should be consulted for specific sizing requirements.

An effective design technique includes an energy dissipation zone followed by a sedimentation zone. The energy dissipation zone is a deeper pool (2–18 inches) that transitions to a shallow zone

Jason Wright

Stone forebay along Elmer Avenue in Los Angeles, CA.

separated from the BSM by an earthen berm, gabion, or concrete structure. The berm structure at the edge of the sedimentation zone allows water to spill over into the main bioretention area. Be mindful of the forebay's depth near pedestrian or public access areas.

Select the material for the energy dissipation zone so it withstands incoming flow velocities and resists erosion or scouring. Where cobblestones are the desired material, using a mortar treatment secures the cobblestones in place and reduces the need to replace cobbles during maintenance. The choice of forebay material may also be influenced by the setting. For example, stone or gravel forebays might not be the best choice for schools and playgrounds, as children can climb or pick up stones. Concrete offers a good alternative for these types of site conditions.

A routine maintenance schedule helps maintain the functionality of the pretreatment practice, prevents the accumulation of too much sediment, and minimizes the resuspension of sediment.

Robert Goo

Forebay stones near playground were moved by children.

Forebay Types

Forebay pretreatment design options are diverse. This handbook discusses 10 main forebay types, including stone, gravel, limestone, concrete, curb well, shallow sump, flagstone, utility box, vegetated bag, and inlet sump forebays. A photo comparison of forebay types is presented on this page; the following pages provide a detailed description of each type.

Stone Forebay (Steve Epting, EPA)

Gravel Forebay (Rhea Thompson)

Limestone Forebay (City of Omaha)

Concrete Forebay (Kansas City Water)

Curb Well Forebay (City of Omaha)

Shallow Sump Forebay (MSC WMO)

Flagstone Forebay (City of Omaha)

Utility Box Forebay (City of Omaha)

Vegetated Bag Forebay (City of Omaha)

Inlet Sump Forebay (Rhea Thompson)

Stone Forebay

Stone-filled forebays, also referred to as stone spreaders, rock rundowns, or rock aprons, are often found at the end of conveyance pipes or other concentrated inflow points. Orienting them perpendicular to the flow path promotes settling, with an allowable ponding depth of 2–4 inches from the pavement or other hard-edged surface to the top of the stone. Select the stone size according to the expected rate of discharge. A typical design for the bottom of the presettling area includes large rocks (streambed or round cobbles, 2–4 inches in diameter) with a porous berm or weir that ponds the water to a maximum depth of 12 inches. When stone forebays are the same width as the curb cut or greater, place the stone 1–2 inches below the curb opening to prevent soil erosion. Stone forebays are not an optimal pretreatment for facilities expected to receive high sediment loads. The cracks and crevices in stone forebays clog easily and are more cumbersome to maintain.

Steve Epting, EPA

A stone forebay dissipates the energy of incoming flow.

Rhea Thompson

A sediment-clogged stone forebay.

Gravel Forebay

Gravel forebays are similar to a gravel diaphragm or gravel flow spreader. Gravel forebays are usually designed as a small shallow-graded, non-planted area with stone that can be placed at curb cuts, downspouts, or other concentrated inflow points. For concentrated flow applications, attention should be given to stone size to avoid washout at high inflow rates. The gravel should extend the entire width of the opening and create a level surface to distribute flow.

Rhea Thompson

A gravel forebay receives runoff flow and distributes it evenly across this bioretention facility in New York City, NY.

Limestone Forebay

The City of Omaha uses limestone slabs positioned at the base and slabs oriented vertically, with the sides higher than the inlet, to create a forebay sump and weir. Open-graded stone is installed below the base for drainage. A critical component of this design is the free-draining rock under the forebay that requires regular maintenance. Limestone is readily available in some areas and is durable, which can be an advantage. If implementing this design in locations with pedestrians, be mindful of elevation changes.

City of Omaha

A limestone forebay captured significant amounts of sediment (see inset for typical depth of a newly installed forebay) and needs maintenance in Omaha, NE.

Concrete Forebay

Concrete forebays are common because they are easy to vacuum. The example pictured below shows an older forebay in Kansas City, MO, which was retrofitted because it was not draining well. For 56 sites where this was implemented in Kansas City, 27 of the concrete forebays had documented drainage problems. The initial design included weep holes that clogged, causing ponded water that contributed to a mosquito problem. The retrofit design raised the pretreatment base elevation to facilitate drainage and mitigate the ponded water. Paver joints and gravel were also added to the downstream end to allow infiltration of ponded water.

Kansas City Water

Kansas City Water

A poorly draining concrete forebay (left) was retrofitted in Kansas City, MO (right).

Rhea Thompson

Concrete forebay in New York City, NY.

Cory Rayburn

Concrete forebay in New York City, NY.

Rhea Thompson

Concrete forebay in New York City, NY.

NYC Department of Environmental Services

Concrete forebay in New York City, NY.

Curb Well Forebay

A curb well forebay resembles a window well design with a custom stainless steel settling area that collects runoff. Curb wells are generally designed so that the bottom of the presettling area is a volume of large rock (2–4 inch streambed or round cobbles) or a concrete pad with a porous berm or weir that ponds the water to a maximum depth of 12 inches. The original design used by the City of Omaha used a porous concrete bottom with clean open graded stone, and perforated pipe connected to an underdrain. This type of forebay is typically 2 feet long by 4 feet wide and 8–10 inches deep. Curb well forebay materials are readily accessible, and installation is quick and straightforward. Regular maintenance will typically suffice to ensure long-term performance. To improve runoff dissipation, small baffles can be incorporated on the sides of the forebay.

City of Omaha

Curb well forebay in Omaha, NE.

Shallow Sump Forebay

Shallow sumps are a low-cost forebay alternative used in Minneapolis, MN. The design consists of pavers on the ground surface and bricks to create a shallow pan as shown in the picture. The pan creates a zone for sediment collection, and they are relatively easy to maintain (crews can manage a large number of system clean-outs in a day) with a flat shovel and a broom. The limited capacity requires frequent clean outs for systems with larger CDAs and to maintain aesthetics. Shallow sump forebays are less durable and may require replacement in the spring, but the costs are low and the materials are readily available.

MSC WMO

Facility with a retrofitted shallow sump in Minneapolis, MN.

City of Omaha

A flagstone forebay in Omaha, NE.

City of Omaha

A vegetated bag forebay in Omaha, NE.

City of Omaha

A utility box forebay in Omaha, NE.

Flagstone Forebay

Flagstone forebays are a design used by the City of Omaha. They are designed with high sides and an engineered v-notch weir to pond and drain water slowly. Alternatively, a retaining wall block can be used to create a shallow 2-inch sump. Materials for the design can be expensive and are susceptible to deterioration due to salt and grime and can be easily broken. In areas with pedestrians, be mindful of ponded water depth to avoid safety issues.

Vegetated Bag Forebay

Vegetated bags with planting media can be used as a simple, low-cost, and green pretreatment method. In the example pictured, vegetated bags were placed at the back (three bags) and downgradient side (two bags) of the forebay. The forebay was then planted with lily turf to promote water filtration. Vegetated bags can break down quickly and as a result are not as durable as other pretreatment methods and will require more frequent maintenance/replacement.

Utility Box Forebay

Off-the-shelf utility boxes are a low-cost, accessible, and durable means of pretreatment in Omaha, NE. They are usually designed with no bottom, over a clean stone, and can be connected to an underdrain. A screen can be placed on top if desired. They pair well with large curb cuts (as pictured). Ensure that plastic applications can withstand the sun's ultraviolet radiation; inspect them periodically to assess degradation and the need for replacement.

Inlet Sump Forebay

Inlet sumps were described in Chapter 6 as an inlet type. Note that these structures serve a dual functionality as an inlet flow (i.e., the grate or screen that serves as an inlet) and a pretreatment device (i.e., the underground chamber or sump). Proprietary pretreatment systems such as inlet sumps or catch basins are becoming increasingly common. Although these systems have high upfront costs, they tend to be cost effective long-term due to more efficient maintenance. Maintenance simply requires removing the top grate, scooping out sediment and debris, and scrubbing any fines from the filter.

Rhea Thompson

Rhea Thompson

Example of proprietary inlet sump forebays with demonstrated capability of reducing sediment and hydrocarbons to provide pretreatment.

Rhea Thompson

Rhea Thompson

Maintenance requirements include removing the grate, scooping out sediment and debris (left), and scrubbing fines off the filter (right).

MSC WMO

Inlet sump forebay paired with a rock forebay in Minneapolis, MN.

Splash Pads for Pretreatment

A splash pad or splash block is an energy dissipation method to reduce inflow velocities. The splash pad is a rigid material able to withstand inflows at the inlet point (i.e., concrete, larger stones, or pavers). Energy dissipation is helpful for instances when concentrated stormwater flows entering a GSI facility might cause erosion of planting media within the facility. Concrete can be considered for situations where the entrance velocity exceeds 6 feet per second.

Design and Maintenance Considerations

- Splash pads are typically concrete, but they can also be designed with stones, cobbles, rocks, or bricks embedded in concrete at the entrance of the GSI practice. The roughness of the surface material reduces the stormwater velocity. Material for a splash pad can be installed over an aggregate bedding with a media liner or may be embedded in concrete.
- Widths and lengths of energy dissipation will vary based on the type and size of inlet used and the velocity of stormwater entering the bioretention practice. At a minimum, it is recommended the energy dissipation method extend the full width of the concentrated flow path.
- Refer to local construction and material specification guidelines for concrete mix, placement, and testing.
- Typical design elements include the following:
  - A minimum separation of 3 inches of freeboard between the top of the energy dissipation material and the inlet grade elevation allows for sediment accumulation between maintenance events.

Rhea Thompson

Concrete splash pad in San Mateo, CA

Portland Bureau of Environmental Services

A concrete pad in a stormwater curb extension system in Portland, OR.

Rhea Thompson

A concrete splash pad is paired with a stone forebay in Kansas City, MO.

- Splash pads that are not embedded in concrete can be loose surface stone, such as local washed gravel or river rock, which is well-graded with stone sizes of 1–4 inches. Additionally, stones that are not embedded in concrete can be surrounded with a permanent edging (e.g., concrete, anchored angle irons) to prevent the materials from migrating into the planting area of the facility.

7.4 In-Practice Erosion Control

In some situations, forebays and other pretreatment devices may not adequately prevent the erosion and scouring of surface layers containing soil, mulch, vegetation, or other materials. In such cases, adding in-practice erosion control devices, such as check dams (discussed below), can help to slow stormwater velocity and promote the settling of coarser materials. In-practice erosion control devices can encourage water to pond to promote infiltration or detention. Other available in-practice erosion control practices that will not be featured in this document include berms, elevated terraces, rock rundowns, and rip rap.

Check Dams

A check dam is a small structure constructed across a GSI practice that helps to reduce velocities, pond water, and maximize sedimentation and infiltration. By ponding water in a segment of the facility, water maintains contact with more surface area and experiences longer residence times through the system, maximizing treatment efficiency.

Suitability

- Bioretention may be built in steeper/sloped areas with check dams that create ponded areas and step-down points to adjust to street slopes. These designs effectively serve as terraced infiltration systems.

- On streets with longitudinal slope (more than 5%), consider installing check dams at intervals to help slow the water flow to avoid wash-out from occurring and allow runoff ponding and infiltration throughout the entire cell area rather than flowing directly to the downstream end.

- Check dams can be applied to sites with minimal longitudinal slopes to promote infiltration where soils are suitable. Underdrains can be used in areas with poorly draining soils.
- Terraced or check dam designs can be used in systems where more filtering and settling of nutrients, sediment, and other pollutants is desired.
- Check dams can be a suitable to incorporate when slopes range between 3% and 10% (MPCA 2023b).

MIG/SvR

Check dams in a bioretention facility in Paso Robles, CA. These types of in-practice erosion control measures create terraces on the steep grades of sloped streets, prevent erosive flows from entering and damaging bioretention practices, and help control the desired ponding depth. This example also illustrates how check dams can be designed in an artistic manner.

Rhea Thompson

Check dam used for energy dissipation in a bioretention planter box in Kansas City, MO.

Design and Maintenance Considerations

- Check dams are often concrete walls with v-notch weirs spanning the width of the cell perpendicular to the flow. Weirs can be designed with adjustable heights to provide flexibility on sites with variable soil conditions.
- Check dam material options include wood, metal, waterproof membrane, polyvinyl chloride (PVC) sheeting, acrylic sheeting, and permeable materials (e.g., rocks, stone, soil berms). Membranes and sheeting are the most cost-effective and generally preferred options. Using more durable materials is advised on steeper slopes.
- Place check dams in sloped facilities at intervals to maintain ponding and facility depth within allowable limits. Space the check dams based on channel slope and ponding requirements.
- Check dams can create a series of small, temporary pools along the length of the facility, and they should drain down effectively within 24–48 hours (depending on local requirements).
- Bioretention cells on steep slopes with check dams that are not stabilized in the BSM or sidewalls are likely to be less effective than a bioretention surface without check dams, unless: (1) the check dam extends deep into the soil profile, forcing the "upstream" media to saturate or (2) the bioretention practice is "over excavated" on the upstream end of the cell.

Cory Rayburn

Check dam in a bioretention facility in Atlanta, GA.

Rhea Thompson

Rock check dams on a steep facility in Kansas City, MO.

Portland Bureau of Environmental Services

Rock check dam in a bioretention facility in Portland, OR.

Chapter 8
BIORETENTION MEDIA

In this chapter

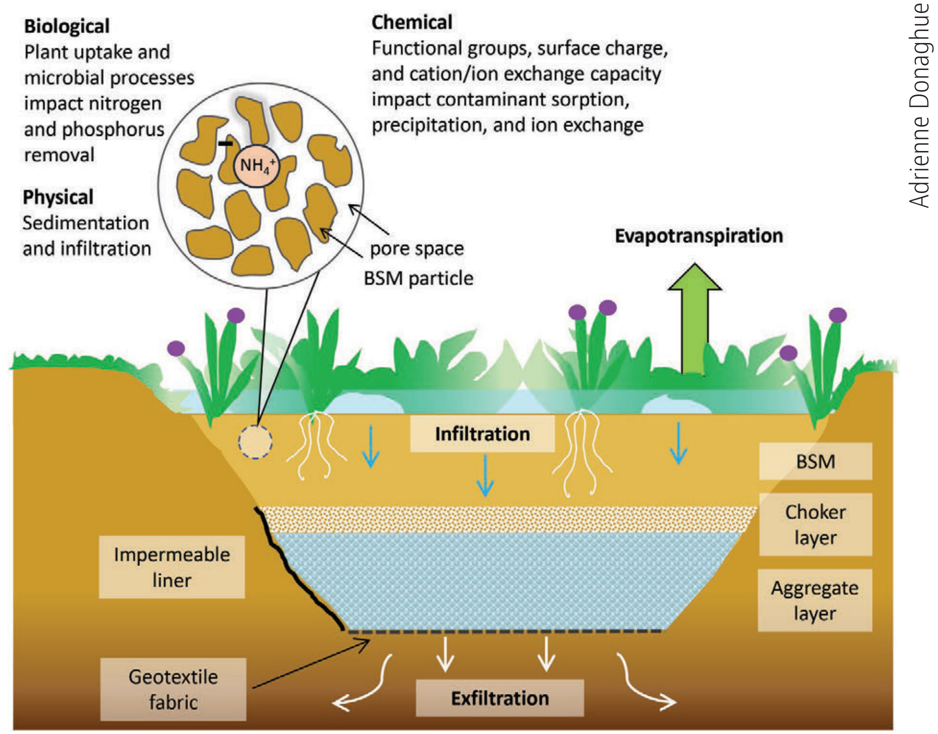
Bioretention media selection and design influences infiltration rates, water quality, and plant health. Chapter 8 presents methods for assessing and testing existing soil media and notes considerations for achieving hydrologic and water quality performance goals. Media amendments, such as biochar and wastewater treatment residuals, are also introduced.

Photo: Adrienne Donaghue

8.1 Bioretention Soil Media Function and Composition

BSM typically includes a soil media layer for filtration and plant growth and sometimes an aggregate layer for more water storage or underdrain placement. Additionally, design elements may include liners to restrict water flow (impermeable liner) or create a barrier that separates BSM layers while allowing water to flow between them (permeable liner). When runoff flows into a bioretention facility, it ponds on the surface and then infiltrates through the BSM. Captured runoff leaves the bioretention facility through exfiltration (i.e., slow drainage) into the underlying subsurface or by slow release via the system's underdrain or outlet. Additionally, evapotranspiration (the sum of evaporation and transpiration) moves captured runoff from the soil and surface to the air. The intended hydrologic function of the bioretention facility, such as storage or peak discharge mitigation, will influence design choices regarding BSM, liners, and the presence or absence of an underdrain. Hydrologic performance goals are discussed in Chapter 10.

BSM is a blend of sand, silt, and clay mixed with organic material to promote infiltration and influence the physical, biological, and chemical processes affecting pollutant fate and removal (see the bioretention schematic). For example, solids are generally removed through the physical processes of sedimentation and filtration, whereas nitrate is removed via plant uptake or the microbial pathway of denitrification. In addition to providing volume retention and pollutant removal, the chosen BSM should have the chemical and physical properties necessary for soil and plant health. Although BSM can be derived from the site's existing soils, designers might need to include amendments or use engineered soils to ensure adequate infiltration rates and optimize treatment—particularly for dissolved pollutants. This chapter highlights considerations for BSM selection and design.



Bioretention facility schematic showing media layers, hydrologic processes, and pollutant-removal mechanisms.

8.2 Assessment and Testing of Existing Soils

Because soil characteristics vary between sites, evaluating the existing soil in the proposed location is important for determining the feasibility of bioretention. The following steps are typically used when testing and assessing soils; however, consult your local guidelines for the specific required testing protocols in your area.

1. **Use publicly available soil survey data.** Consult resources such as the Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (also known as the SSURGO Database) to assess potential conditions during the planning phase (NRCS, n.d.). The NRCS Web Soil Survey, an online mapping application, provides soil surveys with digital spatial data (see the Soil Availability Map for data in your area) (NRCS 2019). You may also download the Web Soil Survey data from the NRCS Geospatial Data Gateway (NRCS 2023). Your local NRCS or soil and water conservation district office or local library might also have soil survey information available.

2. **Analyze the existing soil composition.** Many municipalities specify required ranges for soil media composition. For example, in its *Urban Storm Drainage Criteria Manual: Volume 3, Best Management Practices*, the Urban Drainage and Flood Control District in Denver, Colorado, specifies a blend of 80%–90% sand, 3%–17% silt, and 3%–17% clay (UDFCD 2010). Analyzing existing soil composition can reveal if changes are needed to satisfy media blend requirements. When possible, use existing soils to help reduce earth-moving costs.

3. **Confirm the site's existing infiltration potential.** Typically, soil textures that facilitate infiltration include sand, loamy sand, sandy loam, and silty sands. Minnesota's stormwater manual recommends using infiltration-based practices for hydrologic soil groups A (0.8–1.6 inches/hour) and B (0.3–0.45 inches/hour) (MPCA 2023a). PWD (2014) recommends infiltration-based practices when infiltration rates are equal to or greater than 0.25 inches/hour. When soils have infiltration rates of less than 0.25 inches/hour, PWD (2014) recommends using temporary storage and slow water release, typically via an underdrain. Regardless of the facility's intended function, the drawdown times of ponded water should follow local requirements (typically 24–48 hours).

Cory Rayburn

Bioretention facility under construction in Atlanta, GA.

> "In North Carolina, construction can reduce infiltration rates by as much as a factor of 10. Thus, a pre-construction infiltration rate of 2 inches per hour is required to forego the use of underdrains. Infiltration rates of 0.25–0.5 inches per hour may be good as long as that is the rate post-construction."
>
> — *William Hunt, North Carolina State University*

4. **Perform a test boring to determine the depth to groundwater or the presence of restrictive layers.** Test borings provide valuable information on subsurface conditions such as restrictive layers (e.g., bedrock) and changes in infiltration conditions (e.g., presence of clay). Additionally, test borings also indicate the water table depth. As previously noted, the bottom of the bioretention facility should maintain a separation of at least 2 feet from the seasonally high groundwater table (USEPA 2021b).

5. **Verify if soil contamination is a concern.** The areas around the potential location might show visual evidence of possible soil contamination, such as stressed vegetation. Checking historical records might uncover previous activities on and around the site that warrant soil testing. Alternatively, inspecting soil cores from the test boring could reveal an odor or sheen that suggests contamination. If contaminated soil is present, the designer can change the practice goal from infiltration to detention and release (by adding an impermeable liner) or relocate the practice to prevent contaminants from moving into surrounding soils or groundwater.

6. **Amend soils to target specific pollutants, increase water retention capacity, or improve soil fertility.** Organic matter soil amendments, such as biochar, can be added to BSM to increase porosity, improve water retention, and enhance pollutant removal. Additionally, amending soils with organic material promotes plant growth and microbiological processes. Tables 8-1 and 8-2 provide more information on biochar and other media amendments.

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Installing BSM amended with biochar, zeolite, and coconut coir in Denver, CO.

Table 8-1. Organic media amendment characteristics and applications.

Media amendments	Description	Target pollutant(s)/ benefit(s)	Operational considerations	Source[a]
Organic				
Compost	Substrate produced from biological decomposition of organic material. Provides nutrients (N, P, and C) to support soil health and plant growth.	• Metals • Soil fertility • Plant growth	Not all compost is created equal and can contribute to nutrient leaching under saturated conditions. The BSM specification for compost will vary by jurisdiction.	1, 5
Biochar	Biochar is a carbon-rich and porous absorbent produced from the pyrolysis of biomass (crop residues and wood). In addition to pollutant removal, biochar provides benefits of water holding capacity, organic carbon content, and carbon sequestration.	• Plant growth • Soil fertility • Organic contaminants • Metal/metalloids • NO_3^-, NH_4^+, PO_4^{3-}	Like compost, not all biochar is equal. Properties vary based on feedstock and pyrolysis temperature, which affect contaminant specificity (e.g., metals and nutrients noted at left). Feedstock also influences whether biochar is a sink or source for NO_3^- or PO_4^{3-}.	3, 4
Coconut Coir	Is a byproduct of processing/recycling of coconut fibers. Provides a rich carbon source, and the surface functional groups make it effective for metal binding.	• Heavy metals • Soil fertility • Plant growth • Organics	Susceptible to leaching of dissolved organic C; has demonstrated limited effectiveness for lead or copper. Application in the top 5 centimeters of media can replace mulch.	2, 5

Notes: C = carbon; Ca = calcium; Fe = iron; N = nitrogen; P = phosphorus; = PO_4^{3-} = phosphate; NH_4^+ = ammonium; NO_3^- = nitrate

[a] Information sources:

1 Hurley, Stephanie, Paliza Shrestha, and Amanda Cording. "Nutrient Leaching from Compost: Implications for Bioretention and Other Green Stormwater Infrastructure." *Journal of Sustainable Water in the Built Environment* 3, no. 3 (August 2017): 04017006. https://doi.org/10.1061/JSWBAY.0000821.

2 Lim, H.S., W. Lim, J.Y. Hu, A. Ziegler, and S.L. Ong. "Comparison of Filter Media Materials for Heavy Metal Removal from Urban Stormwater Runoff Using Biofiltration Systems." *Journal of Environmental Management* 147 (January 2015): 24–33. https://doi.org/10.1016/j.jenvman.2014.04.042.

3 Marvin, Jeffrey T., Elodie Passeport, and Jennifer Drake. "State-of-the-Art Review of Phosphorus Sorption Amendments in Bioretention Media: A Systematic Literature Review." *Journal of Sustainable Water in the Built Environment* 6, no. 1 (February 2020): 03119001. https://doi.org/10.1061/JSWBAY.0000893.

4 Mohanty, Sanjay K., Renan Valenca, Alexander W. Berger, Iris K.M. Yu, Xinni Xiong, Trenton M. Saunders, and Daniel C.W. Tsang. "Plenty of Room for Carbon on the Ground: Potential Applications of Biochar for Stormwater Treatment." *Science of The Total Environment* 625 (June 2018): 1644–58. https://doi.org/10.1016/j.scitotenv.2018.01.037.

5 Tirpak, R. Andrew, ARM Nabiul Afrooz, Ryan J. Winston, Renan Valenca, Ken Schiff, and Sanjay K. Mohanty. "Conventional and Amended Bioretention Soil Media for Targeted Pollutant Treatment: A Critical Review to Guide the State of the Practice." *Water Research* 189 (February 2021): 116648. https://doi.org/10.1016/j.watres.2020.116648.

Table 8-2. Inorganic media amendment characteristics and applications.

Media amendments	Description	Target pollutant(s)/ benefit(s)	Operational considerations	Source[a]
Inorganic				
Wastewater Treatment Residuals	Byproducts from coagulation/flocculation treatment process in drinking water treatment plants. WTR can be Al, Fe, or Ca-based.	• Dissolved P (PO_4^{3-} and dissolved organic phosphorus)	Al and Fe WTR are suited for neutral to acidic pH. Fe WTR should be separated from anoxic zone to avoid reduction of Fe(III) to Fe(II) and subsequent release of dissolved P. Ca-based WTR can increase pH to alkaline conditions.	1
Zeolite	A naturally derived or synthetic aluminosilicate sorbent. Zeolite is effective for adsorption due to its high surface area, cation exchange capacity, and porous structure. Also, surface modifications can enhance bacteria removal.	• Heavy metals • NH_4^+ • Bacteria	The primary removal mechanism is ion exchange; therefore, basins with high salt loadings could potentially leach contaminants.	2
Iron-Based Amendments	Examples include zero valent iron or iron oxide coated sands.	• Heavy metals • Dissolved phosphorus • Bacteria (*E. coli*)	The presence of dissolved organic carbon can alter surface charge and reduce the efficacy of amendment.	2

Notes: Al = aluminum; Ca = calcium; Fe = iron; P = phosphorus; PO_4^{3-} = phosphate; NH_4^+ = ammonium; WTR = wastewater treatment residuals

[a] Information sources:

1 Marvin, Jeffrey T., Elodie Passeport, and Jennifer Drake. "State-of-the-Art Review of Phosphorus Sorption Amendments in Bioretention Media: A Systematic Literature Review." *Journal of Sustainable Water in the Built Environment* 6, no. 1 (February 2020): 03119001. https://doi.org/10.1061/JSWBAY.0000893.

2 Tirpak, R. Andrew, ARM Nabiul Afrooz, Ryan J. Winston, Renan Valenca, Ken Schiff, and Sanjay K. Mohanty. "Conventional and Amended Bioretention Soil Media for Targeted Pollutant Treatment: A Critical Review to Guide the State of the Practice." *Water Research* 189 (February 2021): 116648. https://doi.org/10.1016/j.watres.2020.116648.

8.3 Media Design Considerations for Hydrologic Performance

Media design will influence the storage capacity and hydrologic function of a bioretention facility. Drawdown time (infiltration) and storage capacity are described here. More details on hydrologic performance can be found in Chapter 10. Typically, it is recommended that ponded water draws down within 24–48 hours. The following equation can be used to calculate drawdown time (t, hours).

$$t = \frac{\left(\frac{V}{A_S}\right)}{i} * 12$$

Where:

- V represents the storage volume on the surface (in cubic feet),
- A_s represents the infiltration surface area (in square feet), and
- i represents the BSM infiltration rate (in inches/hour).

The BSM depth and infiltration rate are design parameters that can be modified to achieve drawdown requirements. Increasing BSM depth can also expand storage capacity. For bioretention facilities with an underdrain, adding IWS can increase storage and promote exfiltration. IWS is discussed more in Chapter 10.

When evaluating exfiltration, existing soils are a critical factor. Regions with fast-draining soils, especially gravel or sandy soils, may offer rapid exfiltration but require that the design prevents water seepage around built structures. When soils with moderate-to-high swell potential are present—where the presence or absence of water causes soil volume to expand or contract significantly—avoid exfiltration to minimize damage to adjacent structures. In these cases, an impermeable liner and underdrain system may be warranted. Additionally, consider the potential effects on local drinking water supplies if there is a risk of groundwater contamination from pollutants captured in the BSM. The presence of an impermeable media layer (e.g., clay) at a site does not necessarily rule out exfiltration. Gravel or stone wells can be included to create conduits to deeper permeable layers (PWD 2014). Depending on the design and application, these stone wells could be classified as Class V injection wells and subject to EPA underground injection control requirements.

A modified Philip-Dunne infiltrometer, which measures the soil's saturated hydraulic conductivity.

Photo: NC State Department of Biological and Agricultural Engineering

8.4 Media Design Considerations for Pollutant Removal

Water quantity and water quality aspects of stormwater management are often discussed separately, but the two are linked by the system's infiltration processes and hydrologic performance. Hydraulic residence time, or the average time a molecule of water resides in the system, is critical for removing many pollutants. Residence time is partly controlled by infiltration rates, but it can also be influenced by modifying the travel pathways by changing the BSM thickness or altering the bioretention surface by adding a check dam or vegetation. Longer residence times increase the effectiveness of the removal mechanisms illustrated in the bioretention facility schematic in Chapter 8.1 (i.e., filtration, sorption, and chemical and biological uptake).

Designing BSM for pollutant removal will vary depending on the targeted pollutant. Common pollutants of interest in stormwater include solids, nitrogen, phosphorus, bacteria, metals, and organic compounds, such as polyaromatic hydrocarbon (PAHs). Often, the pollutant of interest will be dictated by existing data or requirements related to total maximum daily loads, nutrient-sensitive watershed classifications, or pollutants associated with the watershed's dominant land use. For instance, BSM for industrial areas may include multiple layers specifically designed for pollutants not common to residential and ROW locations. Understanding the target pollutant and the primary removal mechanism will guide BSM design or optimization. The Water Research Foundation's *International Stormwater BMP Database: 2020 Summary Statistics* report provides consolidated information about types and removal mechanisms (WRF 2020).

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City of Santa Rosa

Soil media is visible during facility construction in Denver, CO (left) and Santa Rosa, CA (right).

Phosphorus is used as an example to illustrate how the pollutant type and mechanisms of removal impact BSM design. Total phosphorus includes dissolved and particulate forms. The dissolved forms of phosphorus include soluble reactive phosphorus (inorganic phosphate) and soluble unreactive phosphorus (polyphosphate and organic compounds). Soluble reactive phosphorus is a readily bioavailable form. Particulate phosphorus represents a combination of bacteria, inorganic particulate, algae, etc. The different forms of phosphorus are highlighted because dissolved and particulate components have different removal mechanisms. Particulate phosphorus is primarily removed via physical processes such as sedimentation and filtration within shallow depths of BSM. Soluble reactive phosphorus is removed via plant uptake (biological processes) and adsorption/precipitation (chemical processes). BSM cation exchange capacity is an important factor influencing phosphate sorption. Additionally, as noted in Table 8-2, other media amendments can be added, such as iron-coated sand, to increase phosphate specificity. Hunt et al. (2012) recommend BSM infiltration rates and media depths of 1–4 inches/hour and 2–3 feet, respectively.

Generally, less permeable soils increase residence time and enhance potential water quality benefits for nitrogen. For example, when an anoxic layer and carbon source is present, infiltration rates of 1–2 inches/hour are generally effective for denitrification (the microbial conversion of nitrate to nitrogen gas). Studies in natural and nonengineered soils have shown a negative correlation between microbial activity and sand percentage and a positive correlation between microbial respiration and soil organic carbon (Deeb et al. 2018). Retrofits can be implemented to increase residence times and are discussed more in Chapter 10.

Bioretention practices can export nutrients to groundwater or via an underdrain if present. If the bioretention practice is to be sited in a nutrient-sensitive watershed, evaluate both the existing soils and the BSM to determine the potential for nutrients leaching into groundwater or surface water. For example, if the existing soils are already rich in phosphorus, and phosphorus is a target pollutant, avoid using existing soils in the BSM. Promoting the growth of mycelium, a fungus with a rootlike structure, in BSM has been shown to help mitigate phosphorus export (Poor et al. 2018). Also, if the practice is situated in areas that apply road salts during winter months, ammonium and phosphorus leaching can occur (Donaghue et al. 2023; Erickson et al. 2022).

BSM can incorporate soil media amendments to enhance removal of dissolved pollutants such as heavy metals, nitrate (NO_3^-), phosphate (PO_4^{3-}), and organics (e.g., PAHs). Tables 8-1 and 8-2 summarize the most common media amendments and their operational considerations. Media amendments can be categorized into organic and inorganic amendments. Organic amendments biodegrade over time but tend to be low-cost. Alternatively, inorganic amendments are not biodegradable and can be implemented as a polishing step to target specific pollutants. Note that compost and biochar media are not all equal, and the properties of these media varies significantly based on the source material and preparation. Therefore, it is important to analyze and test amendments before implementation. Examples of amendments and their key considerations are noted below.

Compost is an example of an organic material that has historically been mixed with sand in bioretention facilities to support plant health. However, compost contains dissolved organic matter, nitrogen, and phosphorus, all of which can leach from BSM and compromise bioretention water quality benefits—especially when reapplied incorrectly during maintenance. As a result, compost should be applied with caution in nutrient-sensitive watersheds. Additionally, compost should be tested to ensure it has low metal concentrations and no pathogens. Erickson et al. (2022) tested various compost materials in outdoor mesocosm experiments that included leaf compost, sphagnum peat, reed sedge peat, and food compost. The media design with a layer of 10% leaf compost/90% sand (by volume), followed by a bottom layer of 5% iron fillings/95% sand, was effective in phosphorous capture in the presence and absence of road salts.

Biochar can serve as a soil amendment to enhance soil aggregation, water holding capacity, and organic carbon content. Researchers have been studying the effectiveness of biochar in BSM. Biochar can also be used for carbon sequestration, serve as a substrate binding site for microorganism, and be used in the remediation of contaminants. Contaminants adsorbed by biochar include heavy metals, pesticides, and organics. However, studies have not shown biochar to be effective in reducing the leaching of nutrients and dissolved organic matter (Iqbal et al. 2015). The *Minnesota Stormwater Manual* provides a comprehensive summary of biochar application in stormwater management (MPCA 2013). It is important to note that biochar is generated from a variety of source materials and temperatures. As a result, all biochar is not equal and specificity to certain pollutants will vary.

Inorganic additives can be used to target metal cations. The most common amendments include calcium and magnesium (Ca/Mg), which remove phosphorus via precipitation, and aluminum and iron (Al/Fe), which remove phosphorus via adsorption. The amendments may be naturally occurring (e.g., limestone, gypsum) or be derived from industrial and process waste materials such as water treatment residuals, fly ash, steel slag, acid mine drainage residuals, and zeolite.

8.5 Liners

Media liners are permeable or impermeable synthetic fabrics used to: (1) provide stabilization, (2) separate soil and aggregate media within a facility, or (3) prevent stormwater migration to groundwater or adjacent infrastructure.

Permeable liners (also called filter fabrics) are nonwoven geotextile fabrics that allow stormwater infiltration within a facility and provide separation between varying media and drainage layers. Used burlap coffee bags have worked in some regions as permeable liners (although these types of natural materials will degrade over time and become less effective). They prevent the sediment and clays in the top media layers from migrating into underlying coarser media, where they could cause clogging. Permeable liners placed below gravel, mow strips, or other landscaping materials help limit weed growth within the GSI surface area. Permeable liners can be installed along the side slopes of bioretention or horizontally between media layers.

Impermeable liners are impermeable membranes or geomembranes that prevent water migration to a particular area. They are used for scenarios such as hotspot areas of contaminated soils, high groundwater tables, or when a facility is next to structures (roadways/pavements and buildings). The four primary types are compacted till liners, clay liners, geomembrane liners, and concrete liners. When bioretention is next to pavements within the public ROW or a building, it is recommended that an impermeable liner be placed along the side of the facility.

Southern California Coastal Water Research Project (SCCWRP)

BSM installation for a bioretention planter implemented by the Riverside County Flood Control and Water Conservation District, Riverside, CA.

8.6 Aggregate Media

Using aggregate media in BSM design can serve several purposes, including separating distinct media layers, providing more stormwater storage, and maintaining drainage around underdrains. Note that all aggregate material should be clean, double-washed, and free of fines to prevent clogging of the media.

Choker layers are horizontal transition layers of aggregate media that prevent the migration of particulates from finer media layers into the coarser storage aggregate media layers without restricting flow. A choker layer is typically used between overlying soil or sand layers and the coarser storage aggregate media layers. The choker layer typically includes sand and aggregate numbers 7, 8, 9, or 89 (approximately 1/4-inch to 1-inch diameter stone). The depth of the layer varies as a function of material: sand depth typically ranges from 4–6 inches, and numbers 7, 8, 9, and 89 aggregate depths typically range from 2–6 inches. A choker layer of sand is a thin layer (2–4 inches) that acts as a transition layer between finer and coarser media, used primarily to prevent finer media from migrating to subsurface layers. Sand, which typically makes up 50%–80% of the total BSM design mix, encourages infiltration and storage.

Storage aggregate media is a coarser-graded stone placed in bioretention to provide more storage capacity within the cross-section of a cell. Some communities offer regulatory credit for retention storage. Storage aggregate materials include numbers 2, 3, 56, 57, and 67 aggregate (approximately 3/4-inch to 2.5-inch diameter stone). Storage aggregate media has a variety of applications in GSI. The Number 57 aggregate can be used as the primary storage aggregate layer of the facility and as the bedding

Cory Rayburn

Installing aggregate media in Atlanta, GA.

for the underdrain or distribution piping to mitigate clogging of the perforated pipe system. The numbers 2 and 3 aggregates are typically used below the primary storage aggregate layer. The depth of aggregate storage media depends on the BSM depth, CDA, the plan area of the facility, and the practice's designed storage volume. Aggregate bedding depths for underdrain systems will vary based on the diameters and configuration of the underdrain(s) within the bioretention facility. A minimum 4-inch offset from the outside diameter of the pipe is recommended.

City of Santa Rosa

Aggregate media in Santa Rosa, CA.

Chapter 9
VEGETATION

In this chapter

Plant selection, development of a planting plan, and establishment are important steps to a healthy and vibrant vegetated bioretention facility. Chapter 9 discusses important considerations during each of these steps.

Photo: Adrienne Donaghue

9.1 Why Is Vegetation Important?

Vegetation in bioretention design promotes evapotranspiration, reduces flow velocities, stabilizes soil, and improves water quality through nutrient uptake via plant roots and other biological processes. Root systems also encourage infiltration, and the vegetation helps capture trash and debris before it can enter the storm drain system. Plants offer more than just water quality benefits by creating urban wildlife habitat, mitigating the urban heat island effect, offering aesthetic appeal, and calming traffic. This chapter discusses how to select vegetation (typical plants, shrubs, and trees), choose planting plans and mechanisms, and establish vegetation.

Rhea Thompson

Stormwater curb extension bioretention in Philadelphia, PA.

9.2 Considerations for Vegetation Selection

Plant selection influences the performance and public acceptance of bioretention practices, especially within the public ROW. The following considerations can guide vegetation selection and optimize long-term success.

Use vegetation that is resilient across various site and microclimate conditions. Plant selection should be based on water and light availability, site conditions (land use, habitats, and aesthetics), and the species' tolerance for the site's soil characteristics. For example, drought-tolerant plants are suitable for drier climates. Choose vegetation that can adapt to local climate and microclimate conditions, such as an extended dry season or severe cold. In urban environments, growing conditions are often harsh, and the long-term viability of the practice could depend on incorporating hardy vegetation that can tolerate the accumulation of sediment and debris. Similarly, in snowy climates, select plants that can tolerate salt and magnesium chloride deicers. Choosing coastal vegetation that grows on roughly the same latitude may be appropriate. For example, when choosing salt-tolerant plants for Northern Ohio facilities, designers may favor plants that grow along Long Island Sound in Connecticut due to their salt tolerance (unless native plants are required or preferred). In residential settings, deer-resistant vegetation may be necessary (MC DEP 2019).

Use native, noninvasive vegetation whenever possible. Native plants are typically noninvasive, and they are acclimated to the local climate and need less maintenance. Also, the deep-rooted systems associated with native plants can filter pollutants and require less fertilizer and pesticides to remain healthy. For ideas, refer to local GSI design resources or tools for lists of suitable plants to fit your project needs (e.g., [Central California Coast LID Plant Guidance for Bioretention](), [Fresh Coast Guardians Plant Selection Tool]()). Although native vegetation is often encouraged, site conditions could favor a diverse plant mix that includes nonnative, noninvasive plants that are easy to manage. For example, in the northwestern United States, designers initially used many native wetland plants in bioretention practices. The wetland vegetation became too dense and overgrown in the practices placed in narrow ROWs. These conditions hindered pedestrian travel and increased maintenance demands.

Diversify the plant mix to include specialist and generalist species. Specialist species require habitats with a specific and often narrow range of temperatures, soil types, and precipitation to survive. In contrast, generalist species thrive in a broader range of habitats and environmental conditions. Some specialist species, such as those with high evapotranspiration rates or deep roots, can be incorporated into bioretention designs to increase infiltration. Other specialist species can target certain pollutants via phytoremediation (an active area of research). In general, bigger plants (both in size and density) with extensive root systems provide more evapotranspiration potential. Including generalist species, such as those that can tolerate occasional flooding and dry periods, will ensure your bioretention facility supports a healthy plant community long-term.

Mix plant types to enhance performance and co-benefits. Using a mixture of groundcovers, trees, sedges, shrubs, ornamental grasses, and/or other herbaceous plants is generally suggested to create a microclimate that can combat environmental stressors (e.g., drought, extreme temperatures, high winds, sun exposure), minimize susceptibility to insect and disease infestation, reduce


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A street-side planter with drought-tolerant plants in arid Pima County, AZ.

Rhea Thompson

Bioretention facility in Washington, DC.

Rhea Thompson

Naturalized vegetation with pollinator habitat in Omaha, NE.

Rhea Thompson

Bioretention with low-height plants in a parking lot in Montgomery County, MD.

Portland Bureau of Environmental Services

Aesthetically pleasing naturalized vegetation in a pedestrian area in Portland, OR.

weed growth, and reduce maintenance needs. For example, monocultures typically do not survive well and may supply fewer water quality benefits. Using turf grass, although generally not recommended, might be acceptable if the designer can show it meets all applicable requirements. Diversifying plant species' size, color, and texture also increases a site's aesthetic appeal. Trees and deep-rooted plant systems play a critical role in carbon sequestration and improve soil health, biodiversity, infiltration, and water retention.

Design for aesthetic appeal and performance year-round. Public acceptance is crucial to GSI success. When implementing bioretention in various climates, consider incorporating some plants that are green year-round to ensure the facilities do not appear dormant or unmaintained. For example, designs may include vegetation that has varying colors and textures through-out the seasons. Some species may perform strongest during the spring/summer, while others maintain functionality throughout the year. Ideally, plants should be native, become established quickly, offer long flowering periods (if applicable), be aesthetically pleasing in all seasons, and have lifespans of 5–10 years.

Predict plant growth and maturation. Vegetation will look different once established. When developing the planting palette, anticipate the future growth of the planted area to avoid problems such as trees interfering with overhead electric lines or plants needing intensive maintenance (a plant that grows and disperses seeds). Also, ensure the potential plant height does not exceed 42–48 inches above the sidewalk elevation near intersections to maintain required visibility (some resources recommend limiting heights to 2–3 feet or 24 inches near curbs).

Rhea Thompson

Vegetation can provide year-round seasonal interest and variation.

Montgomery County, MD, DEP

Select diverse plant types to create a healthy plant community. Include lower-growing plants to maintain sight lines for driver and pedestrian safety.

Consider community acceptance and preferences. Some communities may be open to naturalized types of planting like grasses and sedges. Other communities may prefer traditional turfgrass or ornamental plantings. Accommodating community preferences where possible and maintaining the practices will help to avoid complaints and increase acceptance. In general, planted bioretention areas are recommended for higher-profile settings where sufficient resources (financial and personnel) can be allocated to build community buy-in and ensure regular inspection and maintenance. Incorporating trees, shrubs, and ornamental grasses can also help reduce noise and pedestrian travel across bioretention facilities.

Incorporate vegetation that attracts pollinators. Planting bioretention areas with flowering vegetation that attracts butterflies and other pollinators can enhance the ecosystem services of the facility by increasing habitat diversity and community enjoyment.

Select vegetation that minimizes maintenance needs. Anticipate necessary vegetative maintenance to avoid the use of pesticides, intensive pruning, leaf litter removal, and high labor costs. Using aesthetically pleasing plants and maintaining manicured edges shows an intentional landscape design. Thus, select plants based on the intended level of facility care: (1) a low level of care (annual maintenance; no irrigation), (2) a medium level of care (quarterly maintenance; some water available), or (3) a high level of care (monthly maintenance; site may require irrigation). To ensure that areas do not become overgrown, select plants that grow slowly and require less mowing, pruning, and irrigation. Furthermore, choose plants that O&M staff can easily distinguish from weeds. Understand the resources needed to implement an effective maintenance plan, including equipment, personnel, training, educational and reference materials, tasks, and a schedule. Also, developing and implementing an integrated pest management (IPM) plan can help ecologically suppress pests and reduce or eliminate pesticide use. IPM plans integrate biological, operational, physical, and chemical controls with an integrative approach to control pests and reduce risks to the environment. For an excellent resource providing guidance, training materials, and other resources related to IPMs, refer to the Seattle Public Utilities' Integrated Pest Management web page.

Consider options for capturing runoff to irrigate plants during dry periods. Landscapes can be designed to encourage the collection, filtering, and storage of runoff for future use. In Washington, DC's Canal Park, linear bioretention facilities and tree pits implemented along the site's perimeter successfully capture, treat, and direct runoff to underground cisterns. The captured water is used to meet the site's irrigation and other water demands and saves more than 8,000,000 gallons of potable water annually (LAF, n.d.).

Integrate safety for pedestrian and roadside travel. Visibility is important around roadsides and other sensitive areas where vegetation may negatively impact lines of sight. Low-lying plants (turfgrasses, low-to-ground shrubs) are generally recommended for maintaining sight lines and maximizing visibility. Additionally, vegetation can be a visual barrier and deter pedestrians from traffic areas. Visibility is also an important factor near parks, schools, or other settings with children.


Rhea Thompson

A highly visible bioretention area that has clearly marked plant groupings for easy maintenance in Washington, DC.


City of Seattle and MIG/SvR

This low-maintenance swale ensures sight lines and fits the character of this neighborhood in Seattle, WA.

Trees

Trees provide stormwater volume and pollution control through rainfall interception and redistribution, enhanced infiltration, evapotranspiration, and nutrient uptake. Additionally, tree canopies offer shade and evaporative cooling, and they provide carbon sequestration benefits. However, unlike plants and grasses, trees require more space for growth above and below ground. The following resources highlighted below provide in-depth technical detail of tree benefits, tree crediting, design consideration for tree health, and more.

- U.S. Department of Agriculture's Urban Forest Systems and Green Infrastructure describes urban trees' stormwater benefits, tree crediting tools, and case studies (USDA 2020).
- EPA's *Stormwater Trees: Technical Memorandum* focuses on planting and maintaining trees in urban areas and includes soil amendment recommendations and an inspection checklist (USEPA 2016b).
- The Bioretention Design for Tree Health, developed for the Bay Area Stormwater Management Agencies Association, identifies and describes six critical requirements to improve tree health (BASMAA 2016).
- The Deep Root Blog by DeepRoot Green Infrastructure, LLC, covers recent research, projects, or design concepts (DeepRoot, n.d.).


Rhea Thompson

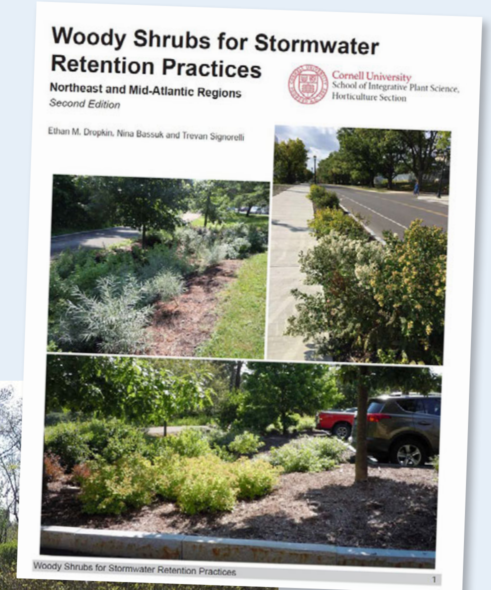
Bioretention facility with trees in Kansas City, MO.


Philadelphia Water Department

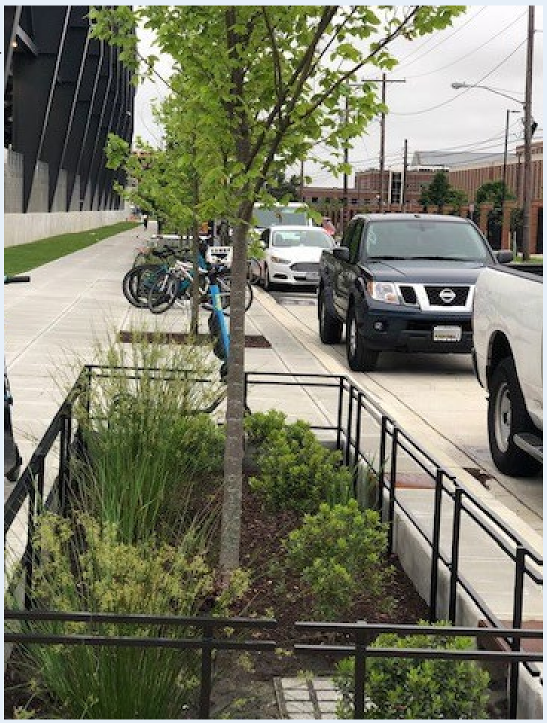
Bioretention facility with trees in Philadelphia, PA.

Shrubs

Including deep-rooted, woody shrubs in bioretention helps infiltrate and retain stormwater while creating wildlife habitat and adding visual interest (i.e., varying shrub heights, color, and growth patterns). The Cornell University Publication, *Woody Shrubs for Stormwater Retention Practices Northeast and Mid-Atlantic Regions Second Edition*, offers a comprehensive look at the use of woody vegetations/shrubs in GSI practices. Although the woody vegetation is specific to the Northeast and Mid-Atlantic, the highlighted approaches can be applied in other geographic areas (Cornell 2017). Consult with local horticulturists and plant specialists to select the woody vegetation most appropriate for your location.


Woody Shrubs for Stormwater Retention Practices
Northeast and Mid-Atlantic Regions
Second Edition
Cornell University
School of Integrative Plant Science, Horticulture Section
Ethan M. Dropkin, Nina Bassuk and Trevan Signorelli
Woody Shrubs for Stormwater Retention Practices 1

Rhea Thompson



Trees and shrubs are integrated into a series of bioretention facilities in Washington, DC.

Kary Phillips

Grasses and woody shrubs in this bioretention facility offer visual interest on the James Madison University campus in Harrisonburg, VA.

Rhea Thompson

Similar species are placed in dense, colorful groupings in Seattle, WA.

Cory Rayburn

Similar species are grouped in this bioretention practice in Atlanta, GA.

9.3 Planting Plan

Planting plans inform initial plant quantities, plant species, and planting frequency and impact the long-term viability and maintenance needs for a successful vegetated practice. The following components can guide the development of a planting plan.

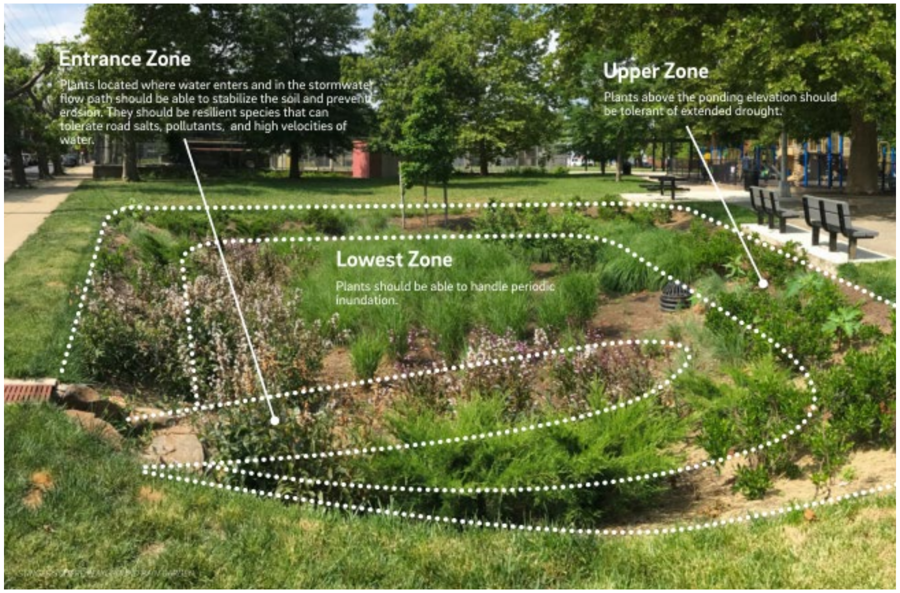
Plant diversity. Planting plans typically include vegetation of varying sizes, colors, and textures and consider compatibility among species. A diverse, dense plant cover reduces pollutants in stormwater, withstands urban stresses (e.g., insect and disease infestations, drought, temperature, wind, sun exposure) and adds aesthetic appeal to a site. Avoid choosing plants that will require excessive thinning, trimming, or removal due to site constraints. Planting plans may need to be adjusted if plants die off during the initial establishment period. In such cases, an alternative plant species might be better suited for the site conditions.

Placement and layout. Placing vegetation based on the species' tolerance to inundation increases survivability. Consider placing streambank-edge species or species tolerant of water flows at the facility's entrance, facultative wetland species at the facility's bottom, and decorative ornamental plants or uplands species and sod at the upgradient edges. The orientation of planting layout and spacing should correspond to site dimensions and conditions (i.e., the plants selected should be appropriate for the bioretention in terms of their mature size, growth characteristics, and maintenance requirements). Also consider grouping similar plants rather than intermixing species so O&M staff can more easily recognize and remove weeds.

Vegetative cover. Balance plant density to minimize weed growth, promote plant health, and prevent erosion. Placing a dense vegetative cover on the bottom and side slopes of a bioretention facility filters pollutants and reduces flow velocities, preventing erosion. Fine-leaved, close-growing grasses are often ideal because they increase the surface area of vegetation exposed to runoff and improve the system's effectiveness. Tightly spaced plantings promote efficient maintenance, ensure a neat appearance, and reduce areas available for weed growth. The initial planting density can be decreased for more cost-effective planting, especially when using plugs and/or plants that naturally self-seed or spread through rhizomes.

9.4 Planting Mechanisms

Various methods are used for establishing vegetation in bioretention facilities. These methods, also referred to as **planting mechanisms**, include placing seeds directly in the uncovered soil, installing sod over the soil, and planting already-established potted plants and plugs. Table 9-1 highlights the factors that can help determine the best planting mechanism for a bioretention site, given the site conditions, the availability of maintenance staff, and the project budget.



Philadelphia Water Department

An example planting plan by the Philadelphia Water Department.

Kary Phillips

This Harrisonburg, VA, facility features small trees, a dense layer of grasses and bushes, and colorful native flowers.

Table 9-1. Design considerations for various planting mechanisms.

Planting mechanism	Design considerations
Seeding	• A cost-effective method for large bioretention facilities. • Requires more maintenance early in the facility's lifespan to prevent weed establishment. • Requires careful seedbed preparation and pre-planting weed control to avoid excessive weed growth and confusion in differentiating bioretention plants from weed seedlings. • Vegetation establishment can occur slowly with seedlings, especially at the bottom of the basin. It typically takes native plants up to two years to fully establish their root structure before they expand foliage and bear flowers or fruit. • Seeds have a low survival rate if the facility receives heavy flows that scour soil and create bare areas. Consider using both the seeding and plugging mechanisms to increase success.
Sod	• Provides instant coverage of a bioretention facility and is easy to install. • Provides immediate visual appeal and soil protection, which limits the potential for erosion. • Can be difficult to establish if the facility receives flows immediately. If the practice receives flows upon installation, fully open any valves to limit stress on the sod until it is established and tolerant of longer inundation periods. • Becomes established more slowly than potted plants because sod must grow roots into the underlying BSM. • Plant choice is limited. Some nurseries are experimenting with bioretention plants to create a native plant sod, which might be a cost-effective, intermediate step between using the less-costly seeding option and the more-costly potted plant option (if native and adapted plants are desired over turfgrass).
Potted plants and plugs	• Available in various sizes, from deep cell plugs to more-established potted plants (gallon size). • Deep cell plugs (deep, narrow pots that drive root growth downward) are a cost-effective option for live plants that enhance early plant health and establishment. • Larger potted plants, although more expensive, offer instantaneous aesthetic appeal, are tall enough to limit stresses from initial inundation, and can be more tolerant of irregular irrigation during establishment. • When selecting a potted plant size, consider soil conditions, the growth rate and vigor of the plant, the time of year, irrigation requirements, and plant availability.

9.5 Vegetation Establishment

Successful vegetation establishment will be influenced by the BSM and frequency of watering or irrigation.

Bioretention Soil Media

The BSM (including existing soils) composition and application will influence plant selection and contribute to the long-term plant mix health and performance of the bioretention facility. The following considerations can help guide the selection and management of BSM to optimize success.

Ensure the soil composition and chemistry align with species-specific habitat preferences. Choosing the correct BSM will help establish and grow healthy plants. For example, in many cases, predominantly sandy soils will not support plant growth. If possible, use existing soil—when it represents natural conditions (i.e., is not historical fill)—or a similar BSM substitute, when native vegetation is planted.

Ensure sufficient soil volume is in place to support proper growth, especially for trees. The *Minnesota Stormwater Manual* provides a literature summary of soil volume requirements for tree trenches and tree boxes. A synthesis of studies indicates that 1–3 cubic feet of soil is needed per square foot of tree canopy (MPCA 2013). If the site does not provide ample root volume, use structural cells or suspended pavements to provide space for root growth and minimize soil compaction.

A good planting or seedbed improves the success of bioretention plants. Topsoil is often removed in development sites, resulting in compacted subsoil with a high clay content. Most plants do not thrive in these environments, which can promote weed growth.

City of Santa Rosa

A mesh mat was installed to suppress weed growth in a newly planted bioretention practice in Santa Rosa, CA.

Rhea Thompson

A newly planted bioretention practice in Fairfax, VA.

In areas where the receiving waters have nutrient impairments, consider the possible effect of fertilizer or compost before use. Native plants should thrive without fertilizer because they will obtain most of what they need from decomposing organic matter—adding fertilizer will only promote weed growth. Also, the BSM likely already contains compost or other amendments as determined during the design and installation phases. As a preliminary assessment, light brown or yellowish-brown soil suggests a low organic content. Compost is the most common amendment used to enhance soil carbon and nutrient content (see Chapter 8). A soil assessment can be used to determine if adding compost is necessary.

Mulch can be added over the BSM to reduce weed growth in planting beds. Mulch may be omitted if the plant density is sufficient to cover 75% or more of the bioretention media; otherwise, place 1–2 inches of wood mulch over the BSM to control weeds. Mulch application is less effective in areas of concentrated flow or slope surface because these site conditions contribute to washout into the stormwater system. EPA's 2021 fact sheet, *Stormwater Best Management Practice: Mulching*, offers guidance for using mulch as an erosion control practice. Many practitioners use wood chips, gravel, and other alternative ground cover materials that are less likely to wash away.

Avoid compacting the soil during planting and maintenance activities. To minimize compaction, plant in the middle of the garden, work toward the edges, and keep all equipment/foot traffic on planks, plywood, or other supports. When performing activities such as mulching, begin applying at the bioretention edges and then move inward by walking on the applied mulch.

Irrigation

To ensure survivability of new plants, irrigation is sometimes needed. The following considerations can help guide irrigation planning and implementation.

When planting, keep roots moist and provide adequate room. Dig the planting holes deep and wide enough to provide adequate backfill and allow full extension of root systems as they grow. Thoroughly water the plant after firming the backfill around the base. Watering helps create good soil-root contact.

Watering new plants is essential. Irrigation will be necessary to establish new plantings and sustain plant health, especially during periods of dry weather. Water regularly during the first and second growing season until 95% vegetative cover is in place. Water can be supplied by an automatic irrigation system or by a maintenance staff with an available water source and equipment such as a hose or sprinklers. Conducting weekly or biweekly inspections during the first growing season may be necessary.

Water the established plants on an as-needed basis. Monitoring the plants for water needs at least once every 10 days in the second season and once every 2 weeks thereafter. To support irrigation needs, consider the location of the facility's inlet(s) when placing plants (i.e., place more drought-tolerant plants further away from incoming water flows).

Other Considerations

The long-term health and survival of vegetation is also affected by other factors that can influence growth, including weather, sunlight, and damage. The following considerations can help inform your plans for vegetation establishment.

Weather conditions. When planting bioretention facilities, consider the time of year the vegetation is planted and determine any operational measures needed to ensure adequate establishment. For example, consider allowing the plants to become established before bringing the facility online.

Plant sizes and condition. Although small plants are initially more cost-effective, problems such as excessive weed growth can occur if proper maintenance is not provided during the establishment period. Plants should be durable, with well-developed roots that are not root-bound. Root-bound plants may be acceptable if not overgrown in the pot. If root-bound, soil balls should be scored or broken along the edges of the root mass to encourage new rooting during planting.

Kary Phillips

Lighter wood mulches can float and wash away into outlet drains, as is shown in this bioretention facility in Harrisonburg, VA. Using a heavier material such as gravel can reduce mulch loss.

Sunlight availability. Because bioretention relies on dense vegetation for pollutant removal and flow attenuation, proper sun exposure for selected plantings must be carefully considered. If grasses are used, the bioretention should receive a minimum of 6 hours of sunlight daily during the summer months throughout the length of the swale. Consider using alternative vegetation if sun exposure is limited due to shading by surrounding buildings or structures.

Perimeter protection. Install low fencing, edging, boulders, or other barriers to delineate and protect vegetation from unsolicited mowing, trampling, or animal incursion during establishment.

Plant location. Place plants at grade (preferably) or slightly above grade. For wetter bioretention practices, planting with a fraction of the rootball above grade ensures better vegetation survival.

CCD, Division of Green Infrastructure

Staff follow a plan as they prepare potted bushes and grasses for planting. Potted plants offer instantaneous aesthetic appeal and can better tolerate irregular watering during establishment.

CCD, Division of Green Infrastructure

Grass plugs were planted in a newly constructed bioretention facility in Denver, CO.

Chapter 10
UNDERDRAINS AND OUTFLOWS

In this chapter

Chapter 10 discusses considerations for outlet design when a bioretention facility does not rely on exfiltration alone. Information on underdrains, IWS, and outlet boxes is included.

Photo: Montgomery County, MD, DEP

10.1 Hydrologic Performance Goals and Outlet Types

Once runoff has been routed to a bioretention facility, water can exit the system via multiple pathways, including exfiltration, evapotranspiration, and outflow. Outflow from the bioretention facility is controlled by an outlet structure that can be located on the surface or subsurface. A facility's performance goals often necessitate balancing multiple hydrologic aspects, including:

- Drawdown time, which is the amount of time needed to infiltrate water ponded on the surface (or surface storage). Many jurisdictions require ponded water to drain from the surface within 24–48 hours.
- Peak discharge, which is the **detention** and controlled release of water from the outlet. In addition to water quantity, controlled release influences the residence time of runoff in the facility and can enhance water quality.
- Storage, which is associated with the **retention** of a specified water volume to promote exfiltration, evapotranspiration, or water quality improvement.
- Water budget, which is the balance of water flowing in and out of the facility, including changes in storage. To maintain plant health and vitality, the design should account for water budgets within the system, so the vegetation is not stressed with too much or too little water.
- Overflow or high flow conditions, which are runoff volumes beyond the design volume. Runoff can be managed via bypasses within the facility, such as curb openings connected to the gutter or emergency spillways.

Defer to Local Requirements and Site Conditions

Local requirements, adjacent land use, and design goals will determine whether a subset or all the hydrologic components listed here are relevant to outflow design.

An outlet's type, structure, and design are influenced by factors such as site location (e.g., in the public ROW versus a park) and performance goals such as design volume or peak discharge reductions. Surface outlets include curb cuts, orifices, weirs, and risers (summarized below). Subsurface outlets include underdrains, IWS, and outlet structures (described on pages 10-4 to 10-10).

Curb cuts are surface outlets that are commonly included in practices implemented in the ROW. Curb cuts used as outlets are positioned downstream of the inlet and direct water to the curb or storm sewer (CCD 2021).

Orifices on the surface are openings on an outlet box structure that manage the design ponding depth and bypass larger storms for online bioretention facilities. The elevation and size of the opening will vary based on the function (e.g., design ponded depth versus bypass for the 100-year, 24-hour storm event).

Weirs include a raised wall or check dam on the surface to pond water, reduce surface velocities, encourage infiltration, and increase residence time. Weirs are most common for bioretention cells used in series.

Risers include an outlet or orifice raised a certain height above the ground surface. Risers can help to control ponding and can be used alongside other outlet structures.

NYC Department of Environmental Protection

Curb cut

Adrienne Donaghue

Riser

City of Santa Rosa

Weir

Cory Rayburn

Underdrains being installed in Atlanta, GA.

10.2 Underdrains

Underdrains collect and release water that has infiltrated through the BSM, and they are used particularly when a site is characterized by poor exfiltration. Underdrains typically connect to an outlet control structure or convey water to another GSI practice. The section below outlines general applications and design considerations; consult local and municipal guidelines for specific requirements in your area.

Suitability

Underdrains are appropriate for site conditions when:

- The existing soil's infiltration rates below the facility are very low (for example, less than 0.2 inches/hour).
- An impermeable liner is needed under the practice to avoid risks of contaminant mobilization due to the presence of "hot spots" in the underlying soil.
- The design goals include detaining and slowly releasing water.
- A seasonal high water table exists.
- IWS is included in the design (discussed more in Chapter 11.2).

Design and Maintenance Considerations

When adding underdrains to your bioretention facility, consider the following:

- An underdrain is typically a 4- to 6-inch diameter PVC or a high-density polyethylene (HDPE) perforated pipe with equally spaced holes. Diameters greater than 4 inches are recommended to avoid clogging. The orifice equation for a single orifice relates the peak discharge rate (Q) and the underdrain or orifice opening (A) (in square feet).

$$Q = C_d A\sqrt{2gh}$$

Where C_d is the discharge coefficient (typically 0.6–0.65), g is gravity (32.2 feet per second squared), and h is the hydraulic head (in feet). For an underdrain, the hydraulic head represents the depth of water from the bottom elevation of the underdrain to the water surface elevation or the overflow orifice (if present).

- Underdrains are installed in a gravel layer or envelope below the BSM.
- Including a valve at the discharge point of the underdrain can provide flow control. The valve can be adjusted to increase or decrease the flow, change the hydraulic residence time, and enhance exfiltration.
- The upstream end of an underdrain is typically installed with a capped cleanout to allow inspections and maintenance. The cleanout location should avoid dense vegetation for easy access and provide adequate clearance from other site features, such as curbs or gabion baskets. The cleanout pipes on the surface can connect to the underdrain via a 45-degree elbow in the direction of flow. The cleanout opening is located above the design ponding depths (for example, 6–18 inches above the ground surface).
- Deep root systems, particularly trees, can encroach on underdrains and should be located in areas offset from the underdrain.

Rhea Thompson

A bioretention practice with an underdrain cleanout in Fairfax, VA.

Design Idea: Infiltration Cells

Municipalities often experiment with innovative designs to meet performance goals based on local conditions. The City of Omaha uses an infiltration cell (also termed "the bathtub drain") that provides capacity for 100% of the design volume to drain from the system into the underdrain within 24 hours. The infiltration cell is localized around the underdrain and occupies less than 5% of the bioretention media volume. The infiltration cell contains BSM that is often a mix of sand (80% by volume) and compost (10%–20% by volume). For more details, refer to *Bioretention Gardens: A Manual for Contractors in the Omaha Region to Design and Install Bioretention Gardens* (Hartsig and Rodie 2016).

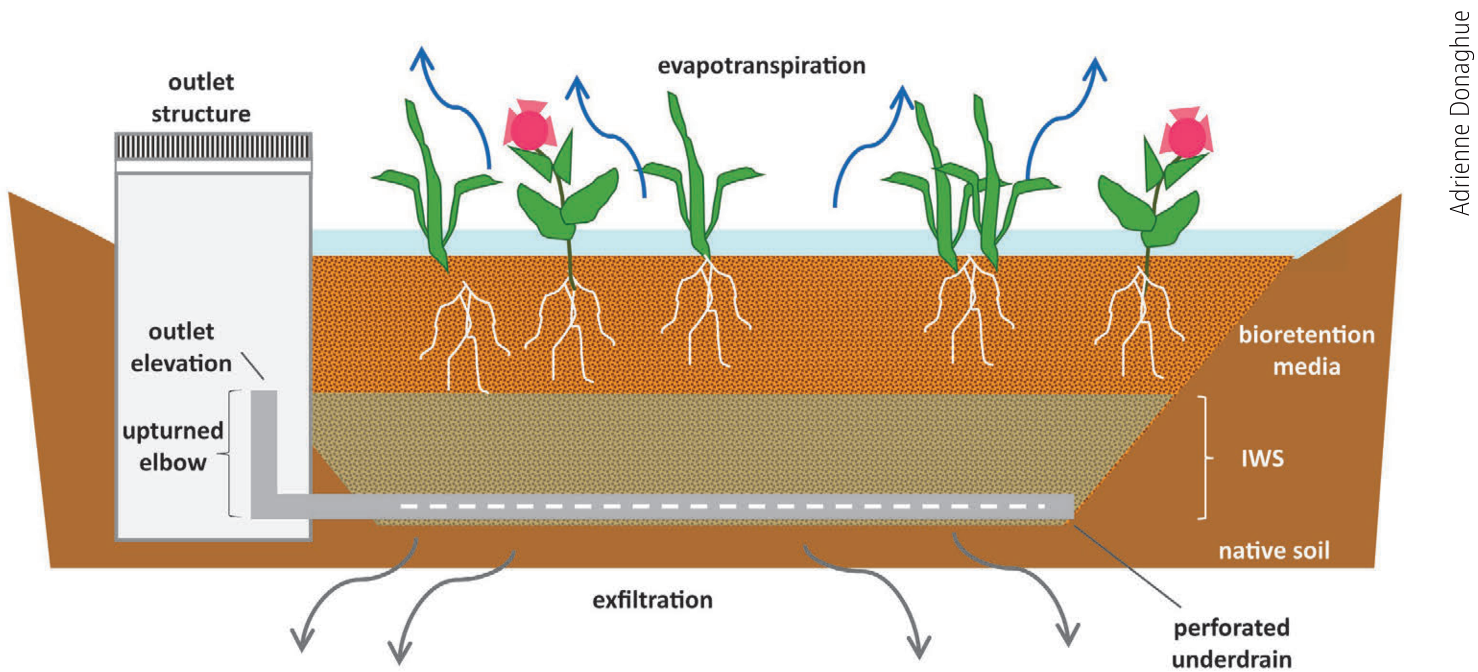
10.3 Internal Water Storage

IWS is an optional subsurface design element included to increase storage capacity or enhance water quality. IWS is created by raising the underdrain outlet elevation (see conceptual IWS schematic, next page). The runoff captured in IWS is released via exfiltration to the underlying soils and the underdrain once the IWS water level reaches the outlet elevation. IWS can also be created by including a weir or stop logs in the outlet structure.

Suitability

Consider the following factors when deciding if including IWS is appropriate for the site:

- IWS provides added storage capacity when water quantity is a primary design objective. The presence of permeable underlying soils enhances exfiltration and allows the IWS to empty before subsequent storms. Estimates of drawdown times for IWS can be determined based on the infiltration rate for the existing soil below the BSM using the drawdown time equation in Chapter 8.
- IWS also offers water quality improvements, such as nitrate removal and thermal pollution abatement. Nitrate removal in IWS occurs via denitrification, the microbial reduction of nitrate to nitrogen gas. IWS design for nitrate removal requires a saturated layer to promote anoxic conditions (low oxygen), the presence of a carbon source such as wood chips, and longer hydraulic residence times (more than 7 hours) to increase denitrification efficiency. Additionally, IWS buffers temperature by mixing warm runoff with the cooler water stored in the IWS and reducing discharge volumes.
- IWS sizing will depend on state or local post-development retention requirements and water quality performance goals. Generally, the saturated thickness ranges from 2 to 2.5 feet.
- Extension of IWS into unsaturated media, i.e., the BSM, can mobilize phosphorus or negatively affect plant growth and root health. Recommendations in published literature prescribe that the top 1.5–2 feet of media remain unsaturated (Hunt et al. 2012; Kim et al. 2003; Passeport et al. 2009).
- A separation between the bottom of the IWS and the seasonally high groundwater table (1–2 feet) allows for exfiltration and reduces the potential for mobilizing contaminants in groundwater (USEPA 2021b). Including IWS is unsuitable when the seasonal high water table interacts with bioretention media. Additionally, IWS should not be implemented near structures' foundations. Impermeable liners are recommended when the required separation distance cannot be achieved.



Conceptual IWS schematic

- The height of the underdrain with respect to the IWS depth can influence hydraulic efficiency (i.e., the effective use of the IWS volume). Hydraulic efficiency is most sensitive for narrow bioretention facilities, such as a bioretention swale (where the IWS width-to-depth ratio is less than 1). Under these scenarios, underdrains located near the top of the IWS create immobile zones, or stagnant water areas, which reduce IWS treatment volume (Donaghue et al. 2022).
- For bioretention facilities with a wider footprint (where the IWS width-to-depth ratio is greater than 1), hydraulic efficiency is less sensitive to underdrain height. Raised underdrains or underdrains located towards of the top of the IWS can provide O&M benefits. For example, a raised IWS underdrain can reduce sediment clogging and gas buildup from biological processes.
- IWS can be incorporated into existing bioretention facilities as a low-cost retrofit by raising the elevation of the underdrain outlet with PVC piping in the outlet structure or adding a weir to the outlet structure (Hirschman Water & Environment 2018). Other options could include raising the inlet to the storm sewer or adding IWS when it comes time for media replacement.

Design and Maintenance Considerations

IWS Design elements will vary depending on water quantity or water quality goals (Table 10-1).

Table 10-1. Considerations for IWS design elements and goals.

IWS design goal	Design elements
Water quantity and/ or sewer overflow reduction goals (e.g., reducing peak flow, managing runoff volumes to mimic the site's predevelopment hydrology)	• Underlying permeable soils are needed to promote exfiltration. • Thicker IWS zones (i.e., higher outlet elevations and larger volumes of retention media/void space) increase the storage capacity, enhance exfiltration, and reduce the volume and frequency of discharges from the underdrain. • Raking the bottom of the cell during construction minimizes soil compaction and increases exfiltration (Hunt et al. 2012).
Water quality goals (note: IWS-related water quality improvement is limited to mitigating nitrate or thermal pollution)	• Under this scenario, exfiltration is less of a design focus. The IWS is designed to maintain saturated conditions, create an anoxic zone, and increase residence time. If soil exfiltration rates are too fast, then including a liner may be necessary. • In cases where the design goal is nitrate removal, a carbon source (e.g., woodchips, sawdust) is necessary to promote denitrification (the microbial reduction of nitrate to nitrogen gas). • Having restrictive or less-permeable underlying soils reduces exfiltration and increases residence time, which enhances denitrification. • For narrow systems, such as a bioretention swale, the underdrain's location within the IWS layer can reduce hydraulic performance by underutilizing the IWS treatment volume. Underdrains at the bottom of the IWS optimize hydraulic performance (Donaghue et al. 2022). • Runoff can mobilize sodium from roadways in areas where deicers are applied during winter months. Runoff that contains elevated sodium concentrations can replace positively charged pollutants, such as ammonium, on bioretention media and cause them to be flushed from the bioretention cell (Donaghue et al. 2023). Capping the underdrain during colder months allows water to infiltrate and prevents pollutants from discharging via the underdrain.

William Hunt

An IWS system with an outlet box.

Adrienne Donaghue

Underdrain outlet in an outlet box.

10.4 Outlet Boxes

Outlet boxes tend to be the most engineered outlet structure, with both surface and subsurface components. The surface components may include orifices with different elevations to accommodate and safely pass various storms (e.g., 25-, 50-, and 100-year storm events). The subsurface component can connect to the underdrain and provide a tie-in to the storm sewer. Outlet boxes can be constructed on-site or prefabricated; they house operational features to control flow, such as orifice plates, valves, or stop logs.

Suitability

Consider the following when deciding if an outlet box is appropriate for the site:

- Outlet boxes can manage multiple hydrologic goals, including drawdown times, peak discharge, detention, storage, and overflow. Proper sizing and elevation of outlet types, such as orifices, is critical to ensuring the facility operates as intended.
- Outlet box overflow features are applicable for on-line systems (systems that receive runoff from storms greater than the design storm). Because these systems manage water quantity from larger storms, they help reduce flooding risks.

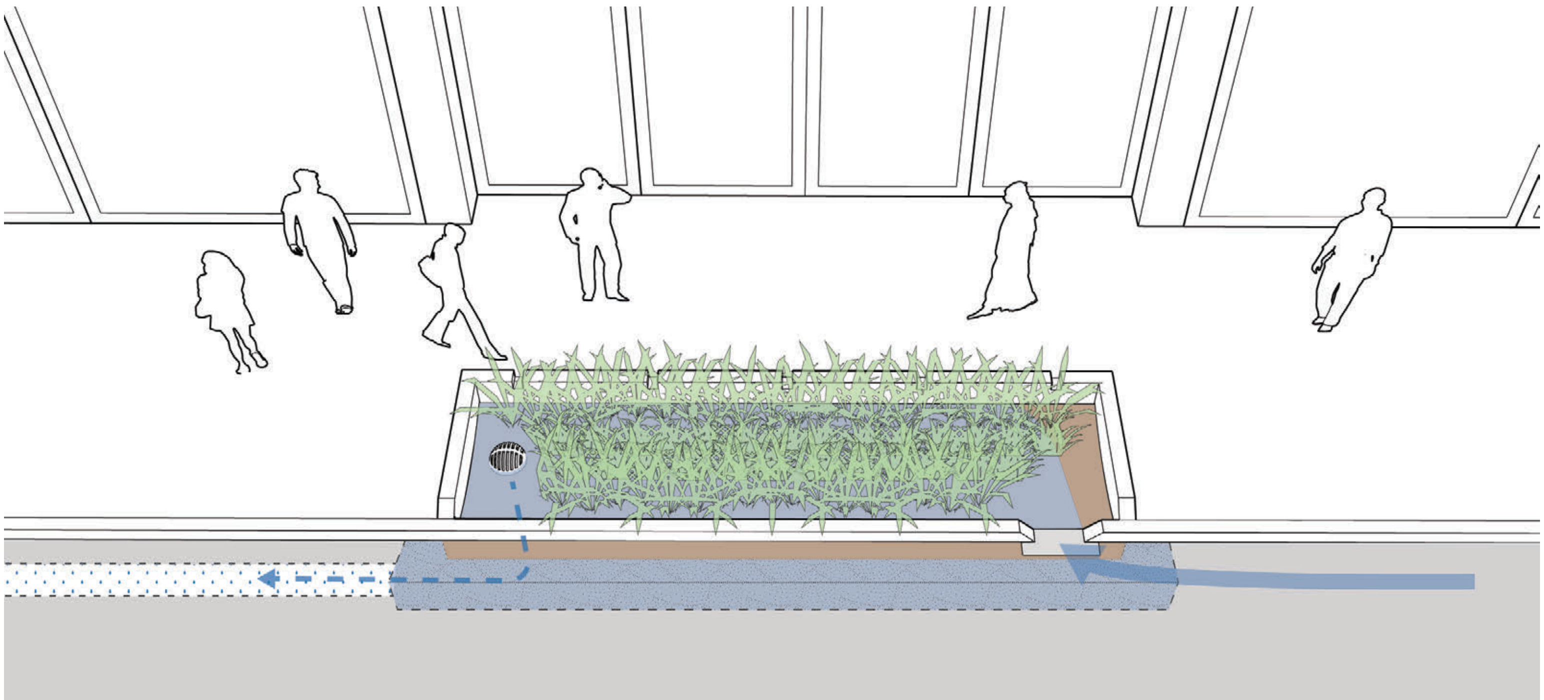
Kary Phillips

An outlet box in a bioretention facility in Winston-Salem, NC.

Design and Maintenance Considerations

When adding outlet boxes to your bioretention facility, consider the following:

- Reference the local guidelines for overflow structure design requirements. For example, some municipalities require the handling of overflow up to and including the 100-year, 24-hour storm event. When applying the orifice equation (page 10-5) for an overflow opening on the surface of an outlet box, the hydraulic head represents the depth of water bottom of the orifice to the water surface elevation.
- A multistage outlet control may include several orifices for controlled flow and a positive overflow to quickly pass flow during extreme events.
- Ensure the outlet box provides enough space to allow for maintenance needs.



Schematic illustrating water flow entering through a curb-cut inlet, ponding in the facility, and overflowing into a raised outlet drain (also known as an overflow riser).
Source: NACTO (2017)

Chapter 11
MULTIMODAL TRANSPORTATION AND PUBLIC SAFETY

In this chapter

GSI installed in ROW settings requires balancing safety, mobility, connectivity, and traffic flow across various modes of transportation, including walking, cycling, and driving vehicles. This chapter highlights key considerations for successfully integrating bioretention that minimizes impacts on the public.

Photo: NYC Department of Environmental Protection

11.1 Why the ROW?

Green streets is a term used to describe the implementation of GSI to manage stormwater from transportation infrastructure, such as roads and parking lots. ROW settings include public lands that are adjacent to transportation infrastructure with a drainage network already in place. In addition to the environmental benefits of managing stormwater, integrating bioretention facilities into the ROW provides many social benefits, such as traffic calming, reduced crossing distances for pedestrians, and beautification. The *Green Streets Handbook* provides more detailed information on the benefits of green streets and considerations for developing a green streets program (USEPA 2021a).

USEPA

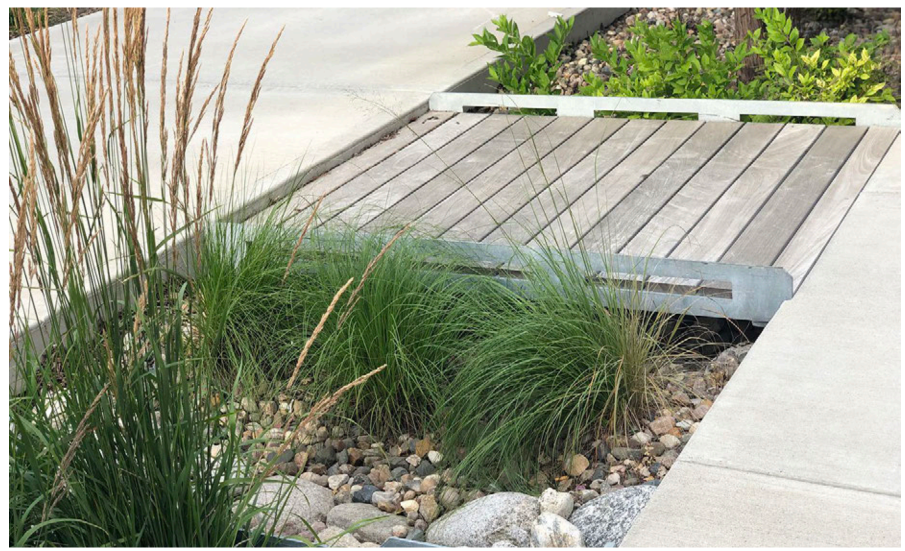
Stormwater curb extension facility that accommodates pedestrian crossing in Hoboken, NJ.

11.2 Pedestrian Mobility and Access

The following considerations can help designers integrate bioretention that supports pedestrian use.

Check permitting requirements. Implementing bioretention in ROW areas may require a sidewalk landscaping permit or a minor encroachment permit, depending on the scale and complexity of the project.

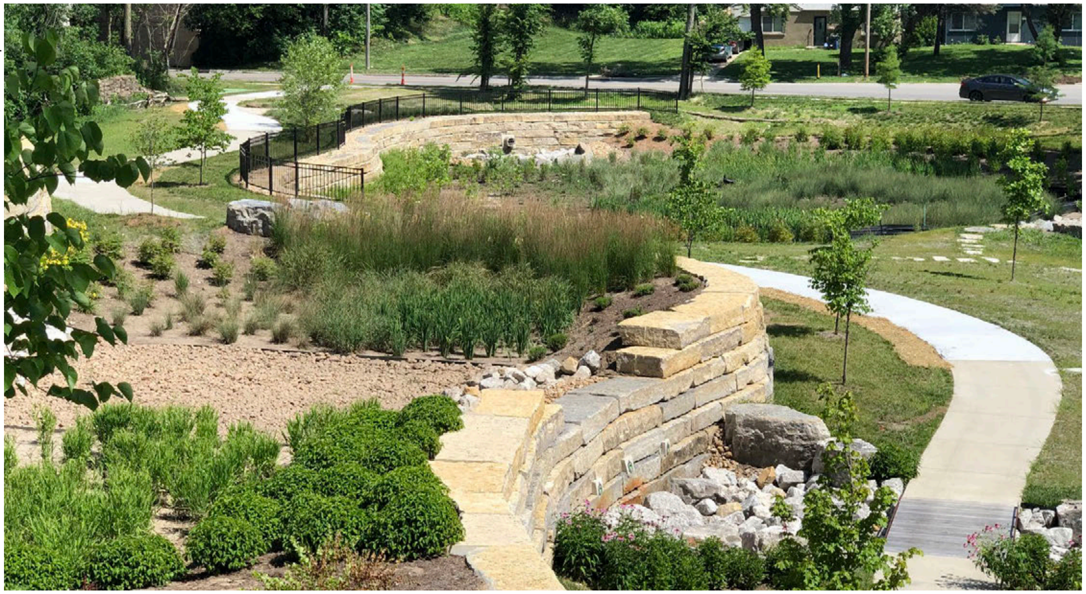
Maintain accessibility. Maintain access points across bioretention facilities for sidewalk crossings and direct connections between destinations, such as parking lots and building entrances. Provide access points using breaks between the planters, dedicated crossings, pedestrian bridges or walkways, or other techniques. Pedestrian bridges can be constructed of decking, grates, or other acceptable materials. When siting GSI adjacent to sidewalks, maintain a comfortable sidewalk width (typically 8–12 feet in dense contexts) based on the pedestrian level of use.



Rhea Thompson

A bioretention practice designed with a pedestrian bridge in Kansas City, MO.

Rhea Thompson



A pedestrian walkway was integrated into the design of this bioretention practice in Kansas City, MO.

Alisha Goldstein

Raised curbs and seating help delineate the edges of the GSI while providing a place for respite in Portland, OR.

Alternatively, when the GSI footprint competes for space with the pedestrian sidewalks, consider adding deeper bioretention facilities. Lastly, ensure pedestrian pathways are ADA-compliant and accessible to people who are blind by integrating extensive tactile warnings into the design.

Minimize compaction. Compaction is common in areas where pedestrians step off the sidewalk or curb into a facility. Avoid pathways through the facility's filter bed to avoid compaction and safety risks due to ponded water.

Prevent overflows. Maintaining bioretention facilities ensures both performance and functionality with adjacent pedestrian pathways. Stormwater ponding and overflows into pedestrian crossings and ramps limit mobility and can create barriers to transit stations and bus stops. Be aware that overflows into pedestrian pathways may result from debris-blocked curb cuts and basins, wear and tear of roadway pavement, or faulty stormwater drainage systems.

11.3 Traffic Mobility and Parking Access

The following considerations can help designers integrate bioretention that supports motorized vehicles and facilitates parking access.

Ensure bioretention in the ROW accommodates vehicle use and parking demands. To avoid affecting parking or curbside access, use stormwater curb extensions in areas where on-street parking is already prohibited, such as near fire hydrants. For on-street parking applications, place and design bioretention to maintain sidewalk access. Sidewalks must be wide enough to accommodate minimum widths of a step-out area, a bioretention area, and a sidewalk zone. A 12-inch to 48-inch step-out zone is common for on-street parking to allow access from vehicles to the sidewalk. In addition, account for regular spacing for crossings in the sidewalk about every 40 feet, or approximately the length of two parking stalls (ideally, access paths should align with private entrances and stairways). Provide sidewalk access along the curb. Bioretention cell crossings can be at the sidewalk level or may slope down to street level but should be elevated above the ponding depth of the cell.

Consider alternatives to bioretention when needed. Sometimes practices such as suspended or permeable pavement are more appropriate for ultra-urban streets that experience intensive demands for curb space. Curbside access is an especially high priority for urban streets, which typically support frequent stops by for-hire vehicles (e.g., taxis), commercial freight loading and deliveries, transit (including paratransit) and bicycle access, bike share stations, and on-street parking.

Rhea Thompson

A bioretention practice includes a pedestrian bridge for foot traffic access to a parking lot in Montgomery County, MD.

Rhea Thompson

A vehicle backed into a bioretention practice lacking adequate protection.

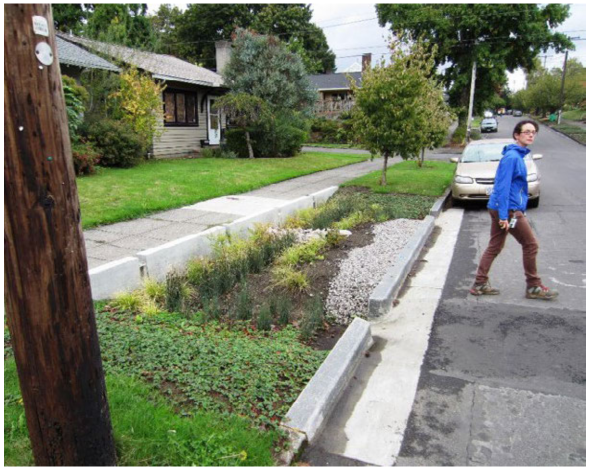
Portland Bureau of Environmental Services

Portland Bureau of Environmental Services

Examples of two step-out zone designs (left, right) in Portland, OR. Concrete is generally preferable over gravel due to weed growth.

Portland Bureau of Environmental Services

Portland Bureau of Environmental Services



City of Seattle and MIG/SvR

These three bioretention facilities lack proper step-out zones, creating a safety hazard for individuals entering and exiting vehicles. Providing easy access to step-out zones and pathways allow for pedestrian circulation and minimize trampling-related system damage.

Design bioretention elements for compatibility with frequent curbside traffic. Maintain clear paths and avoid placing vertical elements at accessible parking spaces and designated loading zones for freight or passenger pick-up. For local businesses that generate heavy freight and delivery activity, consider reducing parking duration, shifting deliveries or freight loading to off-peak hours, or siting designated freight loading zones on side streets to minimize conflicts. Provide separate pedestrian and bike-traffic zones to enhance mobility and safety. Features such as planter boxes or tree pits can function as stormwater retention and physical barriers.

Design to accommodate pedestrian movement entering/exiting vehicles. To limit bioswale damage along streets and parking lots, designers must ensure that the bioretention practice design leaves enough space between the parking stall edge and the bioretention facility for people to enter and exit their vehicles without stepping into the system. Smaller parking lots are often the most difficult to retrofit because of the high demand for available space. Larger parking lots require considerable investment to manage stormwater.

Avoid placing bioretention in historical snow storage areas. In colder climates, consider where salt has been stored or, historically, where snowplows have piled snow/salt mixtures for melting.


Rhea Thompson

Reflective bollards alert drivers about a stormwater curb extension bumpout in the road in Philadelphia, PA.

11.4 Public Safety

Assess the existing street design for opportunities to improve safety. Where possible, leverage bioretention projects with street design projects to realize complementary goals, including safe mobility. Addressing multiple objectives as part of a single retrofit project, such as combining a GSI retrofit with a mobility project, is efficient from a design and construction perspective and can unlock funding and resources.

As described below, key considerations for ensuring public safety around bioretention facilities include visually defining the facility and protecting pedestrians, bicyclists, and drivers from accidental incursions or other dangers.

Delineate the edge of facilities. Incorporating physical or visual protective barriers to delineate the edge of facilities prevents people from inadvertently entering into a system and potentially injuring themselves or trampling the filter bed. Establishing noticeable edges is especially important during construction and for facilities on a slope, in school yards or recreation spaces, or with curbless or in-ground planter designs. Protective barriers include raised curbs, walls, low fencing, railings, bollards, boulders, or dense edge plantings around the perimeter or the accessible side of the bioretention facility. Additionally, adding benches, streetlights, paving materials, trees, bicycle parking, and artistic elements can help further define the edges while enhancing aesthetics. Alternatively, placing high-visibility or retro-reflective safety measures at the leading edge of facilities can reduce the risk of motor vehicle incursion.

Philadelphia Water Department

A raised curb edge delineates a facility in Philadelphia, PA.

Bioretention facilities can provide traffic-calming benefits and improve safety conditions. Adding bioretention along streets or in parking lanes can reduce street widths and provide a visual and physical buffer between pedestrians and moving traffic. Generally, as vehicle speed decreases, the risk of vehicles entering GSI facilities decreases. Traffic-calming elements should reduce target speeds to safe and appropriate urban speeds (typically 20–25 miles per hour; rarely more than 30 miles per hour) by reassigning and narrowing motor vehicle traffic lanes.

Design inlets and outlets to resist incursions by vehicles and bicycles. For example, motor vehicle wheels may be prone to enter, especially during parking maneuvers in paved areas with no curb or wheel stop). Metal lids are an effective design strategy to block vehicle entry. Additionally, because bicycle wheels can get stuck or slip when wet, avoid installing grates near bike lanes. Chapter 6 discusses inlet design in more detail.

Maintain visibility requirements by highlighting bump-outs and preserving sight lines. For example, select low-growing plants and shrubs that do not block the view of oncoming vehicular or pedestrian traffic near intersections, medians, or pedestrian crossings. Additionally, maintain plant heights no more than 24 inches above the ground surface where pedestrians will gather or cross the intersection. Place larger trees along the back of the facility. Ensure trees do not obstruct street lighting or lines of sight for drivers, cyclists, or pedestrians. Moreover, select trees with branch heights or widths that will not cross into pathways or bikeways.

Rhea Thompson

Dense low plantings discourage people from walking into this facility in San Diego, CA.

Account for tree growth during the plant selection phase. Ensure that trees planted next to sidewalks have sufficient subgrade root space to reduce the likelihood of broken or launched (elevated) sidewalks. Many urban soils can be compacted, especially in areas with sidewalks and high traffic, which can affect root growth. Suspended pavement systems or structural soils can be integrated to support tree growth for some species. Finally, designers should ensure that future tree canopy growth will not interfere with existing overhead utility lines. Chapter 9 offers more detail about incorporating trees into bioretention practices.

Minimize tripping hazards and prioritize vulnerable groups for safety. When space is available, facilities with graded side slopes are generally preferred because they allow for gentler transitions from the pedestrian path to the bioretention practice, which minimizes tripping hazards. Alternatively, bioretention facilities with steep side walls in tighter geometries can have shallower freeboard to reduce tripping and injury risk. Design the edges to be navigable by people who are blind or have poor vision, and integrate cues to distinguish zones traversed by vehicles.

Alisha Goldstein

Seating is used to delineate a facility in Washington, DC.

CCD, Division of Green Infrastructure

Aerial view of the installation of five bioretention facilities in the ROWs in conjunction with the reconstruction of a city-owned recreation center in Denver, CO. Barriers are being added around the perimeter of the construction staging area for public safety. Note the space reserved for pedestrian pathways to the right of the four bioretention units in the top left.

Chapter 12 PROMOTING COMMUNITY ACCEPTANCE

In this chapter

Bioretention may attract attention in visible public spaces by incorporating colorful plants, attractive seating, art installations, and open spaces. Bioretention can also receive negative attention when trash and debris accumulate, vandalism occurs, and parking spaces are removed to make way for the bioretention practices. This chapter highlights strategies to engage the local community, meet community needs, offer aesthetic and recreational benefits, and gain public acceptance.

Photo: Rhea Thompson

12.1 Importance of Community Involvement

Establishing community support for bioretention development can help attract local partners (faith-based institutions, schools, nonprofit organizations, etc.) willing to provide potential sites, funds, and volunteer labor. In contrast, community pushback can prevent a project from being implemented. Involving local groups early in the process allows the public to learn about the potential benefits of bioretention and contribute to the decision-making process—giving them a sense of ownership. Additionally, local residents can offer site-specific knowledge that builds awareness and improves the design to better fit into specific neighborhoods.

12.2 Building Community Engagement and Ownership

EPA offers several documents to help you engage with your communities, including *Storm Smart Schools: A Guide to Integrate Green Stormwater Infrastructure to Meet Regulatory Compliance and Promote Environmental Literacy*, *Enhancing Sustainable Communities with Green Infrastructure*, and *Saving the Rain: Green Stormwater Solutions for Congregations* (USEPA 2014, 2017b, 2021). The following key recommendations will help build community engagement and ownership in bioretention and GSI projects.

Design GSI to blend in seamlessly with the surrounding community and meet local needs. Community-centered GSI design incorporates social benefits to serve the surrounding community without compromising stormwater function. When planning GSI for a neighborhood, designers should ensure the practices and landscape materials reflect the image and character the

Camden County Municipal Utilities Authority

Community members working in a bioretention facility in Camden, NJ.

community desires while also creating lively, safe, pedestrian-oriented spaces. Community outreach and site assessments are critical to this process. Site assessments should include evaluating factors like recreational space, safety, visibility, art opportunities, parking, and access (sidewalks, step-out zones, etc.).

Provide opportunities for community ownership and co-design. Creating a public engagement strategy can maximize community involvement and ensure local stakeholders are consulted during all stages of the planning and design process (Greenprint Partners

2022b). Community meetings foster relationships across groups, inform designers about local needs, and allow community members to develop ownership. Stakeholder engagement may include local watershed groups, faith-based institutions, business districts, and other community groups. Degrees of involvement will vary across communities. Multiple strategies are available for engaging local groups, including electronic surveys, email, social media, printed media, community meetings, phone conversations, stoop surveys, and block parties. Community outreach should allow public input (when possible) on topics such as plant selection and design. For example, when promoting its green streets program, the Arlington County Department of Environmental Services developed four plant palettes (Sunny Meadow, Shrub and Wildflower Garden, Bright and Bold, and Shade Garden) and asked residents to vote for their favorite (City of Rockville 2017). This approach provided neighborhood residents the opportunity to choose the vegetation for the bioretention facility and fostered a deeper sense of ownership.

Advance the equitable implementation of bioretention to improve flood and climate resilience. Disadvantaged communities are often more vulnerable to flooding hazards, water pollution, and poor air quality. Identify environmental justice communities with the greatest need for bioretention projects by using state-developed mapping applications or EPA's Environmental Justice Screening and Mapping Tool (EJSCREEN). EJScreen provides a nationally consistent dataset and approach for combining environmental and demographic indicators (USEPA 2022b). Recognize that communities might be concerned about lower-income residents being displaced through the gentrification of their neighborhoods. The *Equity Guide for Green Stormwater Infrastructure Practitioners*, developed by the Green Infrastructure

Rhea Thompson

Bioretention was retrofitted with artistic signage in a mall parking lot near Minneapolis, MN.

Leadership Exchange and Greenprint Partners, provides best practices and approaches for advancing equity through GSI (Greenprint Partners 2022b).

Build constructive partnerships and work through a trusted community liaison. Community liaisons often know the area's historical context, especially with disenfranchised populations, and can educate team members on the proper techniques for engaging community members. As a result, these representatives can help champion a project through completion when there is community hesitation. In some cases, building constructive partnerships can lead to the liaisons taking ownership of a project post-construction. Recognizing private landowners' creative and innovative GSI projects is another way to showcase the value of GSI. For example, in 2014, the Philadelphia Water Department created the Stormwater Pioneers program to award and showcase the city's best stormwater management projects.

Educate and communicate co-benefits. When engaging community members, understand that many individuals may be unfamiliar with the purpose of GSI and the added environmental, social, and economic benefits—also known as co-benefits—it provides. Educating stakeholders on co-benefits, such as shade, beautification, and contact with nature in urban environments, can build community buy-in. When reaching out to the community, your messages should target the site-specific benefits delivered by the project. For example, in flood-prone communities, your educational message can emphasize flood mitigation benefits. From a social perspective, design plans may integrate high-quality public gathering spaces with natural


Adrienne Donaghue

A bioretention site integrated into a school playground in Philadelphia, PA.

features and create opportunities for community development and social cohesion. Demonstration projects are usually important for promoting understanding; therefore, consider placing GSI in building entryways, parking areas, or other visible locations to educate the public about their function and promote acceptance. Many places have integrated GSI facilities in schoolyards to teach the next generation about the importance of stormwater management. When communicating co-benefits, avoid overly technical terms. For example, some municipalities have found that using the term "rain garden" instead of "bioretention" increased comprehension and acceptance of a project. Ensuring public benefits (seating areas, pathways, art installations, flowers, etc.) are visible during the first phase of an ambitious project can help build community and political support and provide momentum for similar future projects.

Manage expectations and concerns. Educational materials, such as webpages and visual renderings, can help community members better conceptualize the project in their neighborhood. Show community members images of bioretention practices at all stages of construction and at different times of year to help manage community expectations and gain project support. Furthermore, address any parking and maintenance concerns early and ensure trash, debris, and overgrown vegetation are removed routinely to prevent bioretention from being perceived as an unsightly nuisance. Safety is also a concern. As previously emphasized, ensure that bioretention facilities drain within locally required timeframes (24–48 hours), maintain visibility, and have adequate barriers. Finally, consider the extensive community outreach and communication needed during construction, such as notifying local residents about street closures. Sharing information about funding sources and costs is also important.

12.3 Adding Design Elements to Build Community Acceptance

Previous chapters provided details on vegetation, multimodal design, safety, and other elements that are key to integrating a bioretention facility into a community. The most important community-focused design elements needed to help ensure community acceptance are summarized below.

Incorporate signage. Each bioretention facility should be stenciled or otherwise permanently marked to designate it as a stormwater management facility. The stencil or plaque could explain its water quality purpose, warn people that the facility may pond briefly after a storm, or explain that pedestrians should not walk on the basin floor. Educational signs are often necessary when implementing bioretention in a highly visible area.

Choose vegetation carefully. Plants should enhance the site and reflect the surrounding community. Vegetation can include a diverse palette of native plants and locally adapted plants varying in sizes, textures, and colors to offer aesthetic appeal and attract beneficial wildlife such as butterflies or other pollinators. In addition to being a visual amenity, trees and other tall greenery make the walking environment more inviting and pleasant by offering shade, reducing temperature, attenuating noise, and improving air quality. Community preference will vary depending on demographics and cultural factors.

Add multimodal elements. Including ample parking, bike lanes, pedestrian crossings, step-out zones, and other features to maintain pedestrian, bicycle, and vehicle movement is crucial to public acceptance. Where possible, align bioretention projects and funding with placemaking initiatives to incorporate improved walking and bicycling conditions including wider sidewalks, pedestrian-only paths, refuge islands (protected spaces in the center of the road for crossing pedestrians and cyclists), new bike lanes, bike parking, bike share stations, enhanced transit stops with high-quality shelters, and reduced motor vehicle speed and volume (using stormwater curb extensions).

Include safety elements. Low fencing, railings, benches, dense edge plantings, and bollards help delineate practices for drivers, cyclists, and pedestrians. Furthermore, ensure facilities drain effectively within 24-48 hours (depending on local requirements) so that they do not become a safety hazard. Finally, ensure visibility is maintained for all site users.

Cleanliness is crucial. Accumulated trash and unmanicured vegetation can lead to complaints from the surrounding community. For high-traffic sidewalks, expect more frequent trash removal needs. Consider enacting O&M agreements for debris removal and light weeding with specific businesses, business improvement districts, or merchant organizations to reduce costs and ensure longevity. Additionally, for settings with pedestrians and pets, incorporate signage and trashcans to promote proper disposal of pet waste.

Incorporate public features and amenities. Functional elements like pathways and seating can promote public use and acceptance. For example, a perimeter wall could be designed to function as a seat wall, or benches can be placed adjacent to the practice. Bioretention can also be integrated in a way to enhance the topography of a park, such as providing picnic and play areas, adding visual or physical barriers to designate spaces for meditation or wildlife viewing, and creating community gathering

Rhea Thompson

A bioretention practice with beautiful plantings and decorative seating in San Francisco, CA.

Darren Distefano

Bioretention with low fencing and walls for safety and benches for pedestrians in Washington, DC.

areas. These features offer a garden appearance and provide spaces for public enjoyment and recreation.

Add play/interactive areas. Engage and educate the public about stormwater management by including interactive design elements, such as features that allow users to see the water flowing through a garden.

Include art. Use design elements such as sculptures, murals, concrete imprints, memorials, or the layout of the stormwater feature itself. These elements create a sense of place, build community, and enhance the aesthetic appeal of the site.

Adrienne Donaghue

A sculptural installation provides a safe space to sit in Scissortail Park in Oklahoma City, OK.

Rhea Thompson

The City of Chicago installed a decorative trench drain with a walkway to allow users to see water flowing through this facility. In an area traditionally lacking investment, this allows community members to connect with nature and beautifies the surrounding areas as well.

Rhea Thompson

Permeable pavers were installed around this bioretention facility to create a stage and event space for the community in Chicago, IL.

Chapter 13 MANAGING THE CONSTRUCTION PROCESS

In this chapter

Construction inspection is critical to the long-term operation of bioretention. A system can be well designed, but construction brings the plan to life. Poor communication, a lack of oversight, and improper construction phasing can result in poor performance and unplanned maintenance, consequently increasing costs. Construction oversight and inspection should be performed by experienced staff.

Photo: Adrienne Donaghue

13.1 Importance of Construction and Inspection

Conduct routine inspections at important milestones during construction and post-construction to ensure the facility was built properly. System failures can often be attributed to errors during construction, such as the following, that can result in costly maintenance-related repairs.

Over-compaction of the subsoils and BSM. For example, placing heavy construction equipment on the practice compresses the soil.

Camden County Municipal Utilities Authority

Bioretention under construction in Camden, NJ.

Using incorrect materials. For instance, failures can occur if BSM has a high percentage of fines, the drainage stone is the incorrect size or is not washed free of fines, or the vegetation is dead or dying when planted.

Incorrect construction sequence. For example, excavating the bioretention cell before stabilizing the surrounding road can allow fines to clog the subgrade.

Improper grading or inlet construction. Improper grades can cause runoff to bypass inlets and observed LRs to be lower than designed. It is important that grades and direction of flow are clearly communicated on design plans and drawings. Contractors with less GSI experience might overlook these details.

13.2 Considerations for Construction Preparation and Implementation

Before construction can begin, assemble construction documents, conduct environmental assessments, and finalize needed agreements with partner agencies, adjacent property owners, or private partners so the project can be put out to bid and contractors selected. Moreover, consider any final approvals needed from agency administrators and elected officials for the project to enter construction or go out to bid. Other important factors to consider are described below.

Development approvals may be required. For example, a memorandum of understanding (MOU) may be needed for shared GSI. MOUs usually include agreements on funding of administrative costs, construction costs, and O&M costs by property owners for improvements along their property frontage.

Ensure that contractors are reputable (e.g., have certifications, provide a portfolio). Proper selection is important; once construction is complete, the contractor will likely be responsible for vegetation establishment. Where possible, ensure that contractors have experience designing and constructing GSI with trained and certified staff. It is not uncommon that the general contractor and the landscaping subcontractor are not as experienced with GSI construction. Consider providing training; for example, this handbook could serve as an educational tool.

Provide construction oversight with experienced personnel. During construction, communicate with contractors regularly to ensure they understand the goals, the materials are delivered, and they stay on schedule for proper construction phasing. Perform milestone check-ins and inspect systems during and after construction. In many municipalities, the jurisdiction's engineering staff reviews and approves the contractor's work. If available, a design and engineering consultant team will typically provide construction administration assistance to the jurisdiction's staff. Inspection is covered more in-depth in Chapter 15.3.

Coordinate projects to avoid impacts from other local or municipal development projects. If other projects such as road re-grading or road widening are planned, bioretention should be constructed last when possible so that grading does not change after implementation. The fines from the asphalt can clog the subgrade or BSM if not properly stabilized before the bioretention is constructed.

Build more time into the project schedule for first installations. To clarify expectations, consider conducting an initial review of the cell grading and mock-ups of key elements before proceeding with constructing all systems. Although adding this review step

Cory Rayburn

Bioretention under construction in Atlanta, GA.

requires extra time at the beginning, construction is more likely to run smoothly and quickly once the approach is reviewed and approved.

Strive to implement simple shapes and minimize excavation needs. Systems should generally be arranged in simple shapes. Complex configurations are difficult to construct. When planning the grades for surface systems, the designer should minimize the excavation where possible and work with existing contours to reduce the overall system depth.

Be flexible with design if conflicts arise. Consider reorienting or reducing the size of facilities (rather than relocating them)

CCD, Division of Green Infrastructure

Bioretention under construction in Denver, CO.

to provide sufficient setback from the conflicting element(s). Proactive accommodation of a subsurface space can generally save reconstruction or retrofit costs as streets evolve over time. Consider installing design elements such as empty sleeves that provide conduits and protection for future utility connections and power needs (such as transit shelters and curbside kiosks) that may run through GSI installations in the ROW. Additionally, incorporate access points such as utility access holes for maintenance needs. ROW systems are typically placed adjacent to sidewalks and roadways and may extend under these features when more storage is needed. Storage included under paved sidewalks or roads should typically not take up more than half of the cartway to allow room for other utilities in the ROW, and storage designs should factor in the thickness of the overlying material (e.g., an asphalt roadbed is thicker than a concrete sidewalk).

Eliminate impacts to nearby structures and foundations. If bioretention facilities are in close proximity to buildings with basements or subsurface structures, line the practices along curbs or next to utility trenches with a thin, impermeable plastic liner to prevent migration of infiltrated stormwater to sensitive areas. Under these conditions, water can be directed downward to avoid lateral flow or to prevent vertical flow. Bioretention may require deeper walls to prevent lateral water seepage into nearby basements.

Avoid compacting BSM and the subgrade so the design infiltration capacity is not compromised. Over-compaction often results from heavy equipment being placed on infiltration beds during fill and grading activities. It is generally recommended to first rototill any imported soil media with the existing soil in 6-inch layers, then use foot compaction in 6-inch layers or a landscape roller to finish

Cory Rayburn

Bioretention under construction in Atlanta, GA.

the grade of gardens. Be aware of other construction or utility work in the ROW, which can damage the bioretention facility during construction (e.g., vehicles driving over BSM).

Communicate with other relevant municipal departments and the public. Scaffolding, construction fences, and other equipment associated with private property development adjacent to ROW GSI may limit accessibility to the site. To combat this issue, the New York City (NYC) Department of Environmental Protection (DEP) provides all proposed ROW GSI locations to the NYC Department of Buildings to ensure GSI construction is coordinated with private property development. Additionally, ensure the public knows about upcoming construction-related street closures and other impacts to their daily activities. Prior to closure, contractors should proactively contact affected homeowners and identify any special needs. The public should also be made aware of maintenance schedules and who is responsible for the work. Chapter 12 provides strategies for communication.

Consult local construction resources when possible. Many municipalities have guidance manuals listing implementation guidelines, material specifications, and applicable requirements.

13.3 Construction-Related Inspection

Inspect bioretention facilities during construction milestones. For example, to ensure proper installation and function according to plans, inspect the site: (1) after excavation, (2) after subgrade preparation is complete, (3) after BSM installation, (4) before and after planting, and (5) after construction is complete. Ongoing inspection throughout the life span of systems is necessary to ensure maintenance tasks are being conducted and identify adaptive changes to the maintenance plan.

During Construction

Inspect bioretention facilities before and after the BSM and vegetation are installed, as follows:

- ✓ Perform a walk-through before installing the BSM and preparing the subgrade. Inspect the soil mix and subgrade materials to ensure the proper type is used, such as washed number 57 stone (correct) instead of ABC stone or crusher-run gravel (incorrect). All stones used in the bioretention should be washed and free of fines.
- ✓ Ensure BSM and the subgrade are not compacted after installation. Test the infiltration rate of the subgrade before

installing the drainage layer or BSM; then, test the infiltration rate of the surface of the soil media after installation is complete.

- ✓ Conduct walk-throughs before and after planting. Before planting begins, check that the plants are the types specified in your planting plan and are healthy.

After Construction

Once the bioretention facility is complete, regular inspections are essential, as described below:

- ✓ Confirm that water is not bypassing the bioretention facility due to improper grading and/or inlet construction (e.g., proper angle and slope are essential). If possible, examine how water flows during a storm through the system and ensure that runoff has a residence time before entering overflow structures. Alternatively, a synthetic runoff test can be performed using a hydrant or water truck to fill the bioretention facility to observe water flow.
- ✓ Ensure adequate infiltration is occurring. No ponded water should be visible 24–48 hours after rainfall (depending on local requirements). Be aware that poor infiltration can be related to improper BSM mix, compaction, sediment buildup due to inadequate pretreatment, and clogging of the underdrain. Look for sediment buildup, which can cause clogging over time. Synthetic runoff tests or double ring infiltrometer tests can be used to determine soil infiltration.

Double ring infiltrometer

The double-ring infiltrometer is an instrument used to measure the rate of infiltration. Two rings are secured into the area to be tested; water is poured into each ring, and the drawdown time is measured. The double ring is preferred because it minimizes the errors associated with lateral flow.

- ✓ During each inspection, identify and immediately repair eroded areas inside and downstream of the facility. Identify and immediately repair any damage to the structural elements of bioretention (pipes, concrete drainage structures, retaining walls, etc.). To prevent more structural damage, patch or fill cracks, voids, and undermined areas.

Chapter 14 LONG-TERM O&M AND ASSET MANAGEMENT

This chapter outlines O&M considerations across design elements and notes considerations for continued performance across the lifecycle of GSI. Conducting routine O&M is as important as quality design and construction for maintaining bioretention aesthetics and functionality over the facility's life cycle. A lack of maintenance can lead to a higher risk of failure and increase operating costs. Chapter 14 also describes how asset management—applying a business approach to managing GSI—can be implemented to strategically target maintenance efforts as the GSI inventory increases. Finally, this handbook concludes with holistic design concepts such as accommodating a changing climate and monitoring the practice over time.

Photo: MSC WMO

14.1 Planning for O&M

Previous chapters noted examples of designing with maintenance in mind for specific bioretention elements such as inlets and vegetation. This chapter highlights O&M considerations for designating responsibilities, conducting training, and managing staff turnover. The EPA webpage [Operation and Maintenance Considerations for Green Infrastructure] provides helpful information on O&M planning (USEPA 2023).

Establish an O&M plan and designate roles and responsibilities to reliable entities. Written O&M plans and standard operation procedures (SOPs) provide detailed direction for maintenance needs and activities and play a key role during periods of staff turnover by ensuring consistency in efforts. They can also serve as a record of what entities are responsible for specific O&M tasks. In addition to O&M plans and SOPs, records of design, as-builts, completed maintenance, and staff activities should be properly filed. While municipalities are usually responsible for maintaining publicly installed GSI, O&M can be performed by landscaping contractors, residents, businesses, local parks staff, school staff, workforce development crews, summer youth, or community stewards. Long-term maintenance will likely involve sustained public education, deed restrictions, and maintenance covenants or ongoing maintenance contracts with the owner for bioretention facilities on private property. Ideally, maintenance should be taken on by entities that can commit to responsibilities long-term using interagency agreements or MOUs. An interagency agreement may involve routine maintenance by landscape crews with experience or O&M training for GSI facilities. They can also remove trash and water the site during dry periods. An MOU can be enacted with specific businesses, business improvement districts, or merchant organizations for debris removal and light weeding to reduce

Rhea Thompson

A facility experiencing erosion, unhealthy vegetation, and unwanted bike parking.

costs and improve performance. The municipality can perform nonroutine maintenance activities requiring technical expertise and specialized equipment.

Ensure sufficient funding sources are available for ongoing O&M costs. Local tax and utility fees can provide a funding stream for GSI maintenance. For example, Tucson implemented a green stormwater fee (approximately $1 on each water bill) to finance maintenance. Other funding strategies could include splitting costs via cost-sharing or interagency agreements.

Provide O&M training where necessary. Although hiring knowledgeable contractors and personnel who understand GSI maintenance requirements is ideal, maintenance personnel may sometimes be working with GSI for the first time. Training is crucial for new staff or when assets are transferred from contractors. Provide site training, pictorial training materials, and interpretive signs to explain the hydrologic and horticultural systems so they are maintained properly. Consider having maintenance programs be developed by jurisdictions (e.g., municipalities, states) where qualified instructors provide "hands-on" mentoring; landscaping contractors can also be trained or managed by the municipality. Partnerships with local universities, community colleges, or cooperative extension offices can also be an avenue to develop and deliver training materials. Local and national GSI training programs and published maintenance guides and inspection checklists are available. Novice municipalities can also learn from more GSI-savvy municipalities nearby.

Balance O&M demands across staff and other resources. Maintenance personnel often provide O&M for hundreds to sometimes thousands of constructed GSI facilities, often in the

Montgomery County, MD, DEP

A site with high maintenance demands due to weed growth and no routine maintenance in Maryland.

ROW. Hiring and training should be paced with new construction—the maintenance team should grow as the number of new practices increases if needed to keep up with demand. To keep pace with new construction, some municipalities use drones for O&M. Drones have the potential to offset staffing limitations and assist in GSI inspection and asset management. Alternatively, drive-by inspections could be used to identify O&M tasks and then send out O&M crews as needed. In dire circumstances, highly visible systems can be maintained more frequently than less-visible systems to make maintenance more efficient and cost-effective.

Incorporate community priorities into O&M plans. The aesthetics and cleanliness of GSI facilities are often more important to adjacent businesses and street users than functionality. O&M plans that incorporate engagement strategies can provide a feedback loop to ensure community needs are being met.

14.2 Maintaining Specific Design Elements

O&M plans will vary based on GSI design, location, season, and land use. Long-term inspection and maintenance activities specific to each design element of the bioretention facility are noted here for consideration. When applicable, recommended frequencies of activities are noted but local design guides should also be consulted. In general, facilities should be inspected once every six months. Additionally, facilities should be inspected, at least annually, during or immediately following a significant rainfall event to evaluate facility operation (e.g., 0.5 inches or greater rainfall event). Some municipalities require a minimum of one annual inspection completed by a third-party inspector.

EPA's technical memorandum, *Operation and Maintenance of Green Infrastructure Receiving Runoff from Roads and Parking Lots*, answers common O&M questions and offers guidance for evaluating the O&M needs for GSI facilities that service roadways and parking lots (USEPA 2016a).

Rhea Thompson

Even with pretreatment, this example shows a facility clogged with sediment and experiencing severe erosion due to lack of maintenance.

Inlets

Routine cleaning of inlets and pretreatment is required to prevent occlusion, bypass, clogging, and channelization of flow into a facility. Curbless systems should also be cleared regularly to maintain clean edges.

Inspection and Maintenance Activities

- Visually inspect all inlet components. Ensure the water is not bypassing the system due to changes in grading and or inlet damage. If possible, examine the system during/after a storm or perform a low-flow hydrology test on inlets.
- Look for erosion and sediment buildup at the pretreatment area and throughout the bioretention facility on an annual basis. Repair and reinforce as needed.
- Check inlets and pretreatment areas for accumulated grit, leaves, and debris that could block inflow, and regularly clear any substances that could lead to occlusion and prevent the free flow of stormwater into basins (3–4 times/year).
- Remove sediment from the inlet structure and sedimentation chamber when buildup reaches a depth of 6 inches, is more than 50% full, or when proper functioning of inlet and outlet structures is impaired.
- Street sweeping can be an effective tool in preventing trash, grit, leaves, debris, or any other substances from entering GSI facilities. Municipalities' street sweeping programs generally guarantee routine maintenance for the municipality.
- In colder climates, snowplows may not work well with bumpout designs and cause damage. Additionally, ice and snow may block inlets. Mitigate this issue if necessary.

Adrienne Donaghue

Example of erosion and sediment build up in pretreatment area. Erosion near inlet has exposed geotextile fabric.

Bioretention Soil Media

Unless damaged by unusual sediment loads, high flows, or vandalism, BSM can be left undisturbed and allowed to age naturally.

Inspection and Maintenance Activities

- During quarterly inspections, check for signs of erosion of the filter bed, settlement (depression in media), or compaction.
- BSM can become clogged when runoff carries high quantities of sediment and collect debris and trash on the surface. One approach to check for clogging may include digging a hole to identify signs of a clogging layer. Maintenance of the BSM, including media replacement, might be necessary

if drawdown time exceeds local requirements (provided all other components of the system are functioning correctly).

- If clogging occurs, excavate the BSM to a depth that would remove the clogging layer (the top 3- to 6-inch layer of media is common).
- Remove the previous mulch layer and apply a new layer by hand in the spring (once every two to three years). Be mindful of not overapplying mulch, as it will float into the stormwater system and/or cause the storage volume of the bowl to decrease. Shredded wood chips, native wildflowers, and ground covers may be used as an alternative.
- If dewatering of the system is necessary due to prolong drawdown times, ensure dewatering is properly conducted.

Rhea Thompson

Pretreatment maintenance often requires removing the grate and scooping out sediment and debris for disposal off-site.

Vegetation

Treat vegetation as assets. They protect filtration media from surface crusting and sediment clogging. Plant roots also provide a pathway for water to permeate into the media, further enhancing a system's hydraulic performance. Because bioretention is often placed in highly visible areas, maintenance demands may be high—similar to any well-manicured landscaped area—to maintain aesthetics year-round (O&M depends on design factors like the selected plant palette). Many state and local municipalities have published vegetation maintenance schedules for reference. Providing training for less-experienced maintenance staff may be necessary. For example, personnel can quickly identify flowering plants, while intermixed plant designs can be more confusing and make weeding difficult. Offering plant-identification training and reference pictures might be necessary.

Inspection and Maintenance Activities

- Once established, regular maintenance may include mowing, watering, pruning, and weed and pest control. Ideally, maintain systems with minimal fertilizers, pesticides, and organic herbicides where possible to prevent leaching of contaminants.
- Check vegetation for invasive and indicator species. For example, the presence of cattail species typically indicate that the system is too wet and not draining effectively.
- Water plants during the crucial establishment period. Remove weeds by hand. Manage the vegetation to preserve a dense, healthy plant cover while performing regular maintenance to prevent plant overgrowth or weed establishment, protect the garden-like curb appeal, and preserve sight lines to keep pedestrians and vehicles safe.

- As previously mentioned, an IPM approach is encouraged to control pests and diseases in the landscape before turning to pesticide use. When pesticides are required, apply the least-toxic and least-persistent pesticide that can provide adequate pest control.
- Conserve water use where possible. As previously discussed, re-use collected water (e.g., rain barrels, cisterns) and consider native and low-water-use vegetation when designing the system and developing the planting plan.
- Mow the grassed facilities at least once yearly or when grass heights exceed 6 inches. Avoid cutting the grass shorter than 3–4 inches; otherwise, the effectiveness of the vegetation in reducing flow velocity and removing pollutants may be reduced.
- Vegetation may need to be thinned and/or replanted over time. Ensure overgrown vegetation does not block outlets or overflow structures.
- Check vegetation health. If necessary, remove and replace dead or diseased vegetation that is considered beyond treatment (semi-annually). Treat all diseased trees and shrubs mechanically or by hand, depending on the type of insect or disease infestation.
- More frequent maintenance in the fall is recommended due to the presence of trees, especially collecting leaves before anticipated storms if they could clog the facility's primary inflow. Leaves can be vacuumed and ground to be used as compost.
- In the late winter, trim bunch grasses, mow turf grasses, and harvest other types of vegetation according to recommendations in the planting specifications. Remember that vegetation may appear dormant in the dry season—train personnel so that they do not mistakenly remove the dormant vegetation.

Portland Bureau of Environmental Services

Vegetation overgrowth is blocking an overflow structure.

- It is recommended to install salt-tolerant vegetation in bioretention sites where chlorides may be an issue. Deicing chemicals, salt, and sand can impact plants that are not salt-tolerant, especially if salts are over-applied. If salt appears to be detrimental to plant growth, consider replacing vegetation with salt-tolerant species. For example, consider using coastal vegetation found on the same latitude.

Underdrains and Outflow

Outflow structures should be maintained to meet hydrologic performance goals and drawdown requirements.

Inspection and Maintenance Activities

- If drainage is poor, check the BSM and outlet structures (weirs, riser, underdrains, etc.) for clogs.
- At least once annually, complete a drawdown report in conjunction with a rainfall event equal to or greater than the design capture depth of the facility, or perform a test of the facility after filling with a secondary water source (at minimum a hose and double-ring infiltrometer). Note the date and time the facility was observed as full and the date and time it was observed as empty, verifying that drawdown occurred in the required time frames.
- Inspect the cleanouts to ensure they are capped and properly connected to the underdrain. Damaged clean outs can cause the runoff to bypass the soil media. Adding concrete donuts can protect cleanouts from mower damage.
- Clean the underdrain piping network to remove any sediment buildup as needed to maintain the designed drawdown time.

Rhea Thompson

Ponded water remained for days after a storm, indicating poor drainage due to soils or outflow design.

William Hunt

A broken cleanout.

14.3 Asset Management

As bioretention assets build over time, incorporating green assets into an existing asset management plan or implementing an asset management plan is an effective tool for agencies or municipalities to cost-effectively operate, maintain, and protect GSI over its life cycle. When resources are limited, asset management provides a decision tool to determine the effective allocation of staff, money, and equipment for maintenance, repairs, or replacement. The Green Infrastructure Leadership Exchange's 2021 Greenstormwater Infrastructure Asset Management Resources Toolkit provides lessons learned and examples for each of the different components of asset management for GSI assets. The components and additional information on asset management are discussed in the EPA webcast Stormwater Asset Management: Letting Your Green Infrastructure Work for You.

The components include:

- Level of service
- The current state of the asset
- Criticality
- Life-cycle costing
- Long-term funding

Asset management plans should promote flexibility and an adaptive management approach to enable lessons learned to be incorporated into future assets or maintenance routines. EPA offers an online training resource, Asset Management 101 – Basics for Small Water and Wastewater Systems, to provide introductory information for identifying and managing assets. Additionally, the Asset Management Switchboard, developed by the Southwest Environmental Finance Center in partnership with EPA, offers a


City of Omaha

In colder regions, bioretention areas are often used for snow storage.

repository of documentation and tools covering a range of asset management topics.

Another critical asset management element is coordinating with utility and construction entities to take precautions and safeguard practices, preventing damage that requires expensive maintenance and repairs. Meet with public works and utility entities early in the process to avoid conflicts during and after construction. More specifically, a higher level of GSI implementation coordination will be needed for dense utility infrastructure, duct banks, subterranean basements, and underground transit infrastructure. NYC DEP is a good example of how to coordinate efforts. In the past, construction by other utilities in the ROW caused damage to constructed (or under construction) GSI facilities. NYC DEP now provides a list of all ROW GSI facilities to the Department of Transportation (DOT) Street Permitting group. The NYC DOT Street Opening Permit protects streets or blocks where reconstruction or resurfacing occurred within the last five years.

Consider digital tools to keep track of nearby work. Kansas City, for example, uses geospatial data to track all ROW projects near GSI. They use excavation notifications provided by Missouri One Call (the state’s 811 “call before you dig” provider), where polygons for GSI projects are added to the Missouri One Call map. When companies call to report planned digging, a polygon is created for their proposed dig site. If the polygons overlap, they receive a notification with contact information, and they reach out if there are conflicts that could impact GSI. This enables them to quickly engage with personnel to avoid conflicts before beginning construction or utility work, which proactively protects assets and prevents damage.

14.4 Longevity and Continued Performance

Using a holistic design approach increases the likelihood of bioretention longevity and resilience. Anecdotal evidence from the City of Portland, Oregon, where the first documented bioretention facilities were implemented, indicates that good design and careful management can lead to practice life spans of over two decades (see the photo of the Reed College facility installed in 1996, next page). This handbook concludes with the following considerations to ensure longevity and continued performance.

Use trained installers. Engaging trained and certified personnel to perform construction oversight and inspections helps ensure facilities are correctly implemented as designed. Conducting routine site inspections after the facility is first brought on-line helps to identify and correct performance errors quickly. Proper construction and inspection are especially important for

City of San Mateo

An artist’s rendition of a street median that could be transformed into a low-maintenance bioswale to capture runoff and serve as a high-profile community asset.

demonstration or high-profile GSI projects. If done correctly, these initial projects will likely spur future GSI investment and influence approaches to subsequent projects.

Minimize watershed disturbance. Land-disturbing activities in the watershed (clearing, re-grading, changing vegetative cover, etc.) can alter water flow volumes and pollutant transport; minimizing these types of watershed changes will help protect bioretention longevity.

Maintain the practice. Inconsistent and improper maintenance impacts a bioretention facility's ability to perform as intended, increases the likelihood of failure, poses risks to adjacent properties and the public, and negatively influences the public's perception of bioretention. Designate routine maintenance responsibilities early on, and identify a schedule and needed labor, costs, and equipment. Maintenance tasks may include monitoring plant health, ensuring curb inlets are clear, removing weeds and debris, and monitoring drainage. Establishing partnerships with other local entities or developing a funding mechanism to support maintenance ensures success. For example, in 2020, the City of Tucson added a GSI fee based on water usage to finance O&M needs.

Monitor the facility. If resources permit, monitoring is a tool for understanding a system's water balance, the impact of a new design element, and improving maintenance efforts over time. Monitoring can also help to assess system response to changes in climate patterns. Long-term continuous monitoring (20 years) of a bioinfiltration traffic island at Villanova University showed the practice managed 86% of all rainfall and discharged 14% of the rainfall (Wadzuk et al. 2023). The cumulative analysis demonstrated that three years of continuous monitoring would produce the same water balance with a 5% uncertainty (Wadzuk et al. 2023).

Rhea Thompson

A facility completed in 1996 is still functioning properly at Reed College in Portland, OR.

Monitoring methods vary from deploying continuous sensors to collecting discrete samples, and the lessons learned can be applied to future sites. Establishing partnerships with other local groups, state agencies, community volunteers, or universities can provide additional funding and technical resources to support monitoring.

Retrofit as needed. A retrofit is defined here as a new installation or an upgrade to an existing GSI practice in a developed area lacking stormwater management. Bioretention facilities are dynamic systems; thus, adapting to potential shifts in performance helps maintain functionality long-term. For example, a retrofit may include amending BSM to improve pollutant removal or raising the outlet's elevation to promote denitrification.

Account for climate resiliency. Climate change is expected to exacerbate the increased runoff quantities that result from altered landscapes and impervious surfaces. For example, precipitation in the northeastern United States is expected to intensify, with annual amounts predicted to increase by 10%–15% by 2100 (Frumhoff et al. 2007; Guilbert et al. 2015). Sizing bioretention facilities to account for future design storms can improve practice resiliency and avoid failures. For example, the Chesapeake Bay Program and partners developed projected intensity-duration frequency (IDF) curves to reflect two future climate change scenarios (2020–2069 and 2050–2099) (MARISA 2021). This effort was motivated by the need to provide consistent design standards within the watershed that account for future climate conditions.

Consider future land use. When identifying prospective sites for bioretention, designers should ensure that the systems can accommodate future development and societal demands without overwhelming the facility's storage and treatment capacity. For instance, Canal Park in Washington, DC, was revitalized as part of the Anacostia Waterfront Initiative. Redevelopment of the site involved installing bioretention and other GSI practices to capture, treat, and reuse stormwater to meet up to 95% of the park’s water demands, including irrigation and fountains. Designers planned for the development of adjacent parcels that treats runoff while adding aesthetic value to an outdoor space can be tied into the existing Canal Park stormwater system to meet up to 99% of the water needs (LAF, n.d.).

Adrienne Donaghue

Holistic design incorporates stormwater management and community use in Oklahoma City, OK.

LID Center

An infiltration planter treats runoff while adding aesthetic value to an outdoor space at the Navy Yard in Washington, DC.

GLOSSARY

Photo: Oklahoma City, OK

Adaptive management – The process of observing and learning how a system performs over time and using that knowledge to adapt O&M strategies, retrofits, or future designs to improve overall functionality and performance.

Bioretention facility – Within the context of this handbook, bioretention facilities encompasses the following GSI practices: bioretention, rain gardens, bioswales, bioretention planters/boxes, and tree pits.

Bioretention soil media – See Chapter 2.

Choker layer – See Chapter 2.

Contributing drainage area (CDA) – Refers to the total area (both pervious and impervious) draining to a bioretention facility.

Energy dissipator – See Chapter 2.

Existing soil – See Chapter 2.

Freeboard – Is defined as the distance between the top of the facility's overflow elevation and the maximum ponding depth. Freeboard provides a margin of safety for larger storm events.

Gray infrastructure – Includes piped networks and man-made engineered components in the built environment, such as drains, storage tanks, and gutters, that collect and convey stormwater.

Green stormwater infrastructure (GSI) – GSI used in this handbook is synonymous with the term green infrastructure defined in the CWA[1] as the range of measures that use plant or soil systems; permeable pavement or other permeable surfaces or substrates; stormwater harvest and reuse; or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters. Some use other terms to reference the same practices as green infrastructure for stormwater management. Similar terms may include low impact development, natural infrastructure, and nature-based solutions. The definitions of these terms may vary slightly among organizations and industry professionals. However, these concepts are generally captured in the CWA definition of green infrastructure. GSI and green infrastructure are both terms used in planning and research to achieve various ecosystem services.

Green streets – A term used to describe the implementation of GSI to manage stormwater from transportation infrastructure such as roads and parking lots.

Loading ratio (LR) – LR is a design parameter equal to the impervious CDA divided by the bioretention infiltration surface area. LR is an important design consideration because LRs that are too high (i.e., greater than 25:1) can lead to maintenance problems (e.g., excessive sediment accumulation); LRs that are too small can hinder plant growth and result in nonuniform infiltration (O'Connor 2023).

[1] See Water Infrastructure Improvement Act, 2019. https://www.congress.gov/115/plaws/publ436/PLAW-115publ436.pdf

Heavy metals – Include metals with a high density such as arsenic, cadmium, chromium, copper, lead, and zinc. Some heavy metals are essential to living organisms (copper and zinc) while others are toxic at trace levels (cadmium and lead).

Hydraulic efficiency – Describes the effective use of the BSM or IWS volume under saturated conditions. Hydraulic efficiency is the ratio of the observed hydraulic residence time (for example, measured during a tracer study) to the theoretical residence time. A hydraulic efficiency of 1 indicates that stormwater infiltrating into BSM and/or IWS flows through 100% of the provided media volume.

Hydraulic residence time – Describes the average length of time stormwater resides within the bioretention facility.

Inflow – See Chapter 2.

Internal water storage (IWS) – See Chapter 2.

Liner – See Chapter 2.

Memorandum of understanding (MOU) – Describes an agreement between two or more parties (for example a municipality and landowner) that states each party's commitments and responsibilities. When used in the context of GSI, MOUs may define agreements on funding of education and outreach signage, construction, or O&M and define responsibilities for long-term O&M and facility access.

Mulch layer – See Chapter 2.

Operation and Maintenance (O&M) – Encompasses the routine or restorative activities taken over the lifespan of a bioretention facility to maintain long-term performance. O&M activities vary based on factors such as the design components implemented, surrounding land use, and climate. Inadequate or lack of O&M can lead to system failure.

Outlet – See Chapter 2.

Overflow – See Chapter 2.

Pretreatment components – See Chapter 2.

Right-of-way (ROW) – ROW settings here are defined as public land adjacent to transportation networks and infrastructure such as sidewalks, bike lanes, and pedestrian pathways. Typically, ROWs already have a drainage network in place.

Stone storage/drainage layer – See Chapter 2.

Underdrain – See Chapter 2.

Vegetation – See Chapter 2.

City of Omaha, NE

Educational signs explain the benefits of rain gardens and native plants in Omaha, NE.

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