



# DESIGN GUIDEBOOK FOR GREEN STREET RETROFITS

US EPA Region 3 Water Protection Division  
Green Streets, Green Jobs, and Green Towns (G3) Program

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## EPA Region 3 Water Protection Division

Dominique Lueckenhoff, Deputy Director

Denise Rigney, Project Officer, Office of State and Watershed Partnerships

Ken Hendrickson, Office of State and Watershed Partnerships

Kaitlyn Bendik, NPDES Permits Branch

## Consultant Team

Lee-Ann Tracy, Project Officer, SRA

Emily Clifton, Project Manager, Low Impact Development Center, Inc.

Neil Weinstein, Low Impact Development Center, Inc.

Suzy Cho, Low Impact Development Center, Inc.

David Miller, Low Impact Development Center, Inc.

Megan Blakeslee, Low Impact Development Center, Inc.

# FOREWORD

In 2005, the U.S. Environmental Protection Agency (EPA) Region 3 initiated a green highways forum to bring together the EPA, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, the Transportation Research Board, trade organizations, and private transportation consultants to cooperatively establish a definition for and vision of a green highway. The effort led to the creation of the Green Highways Partnership. More than 40 members strong and nearing a decade in age, this partnership is a voluntary, public/private network focusing on effective green transportation partnering, innovation, and collaboration.

In 2011, EPA Region 3 and the Chesapeake Bay Trust joined forces to take what had been learned at the federal and state level and apply it to the local level via the Green Streets, Green Jobs, Green Towns (G3) program. The initiative was developed in response to the President's Chesapeake Bay Protection and Restoration Executive Order which called upon the federal government to lead a renewed effort to restore and protect the nation's largest estuary and its watershed. Its purpose is to support local greening efforts by towns and communities in urbanized watersheds that improve water quality, community livability, and economic vitality.

More than \$1.6 million has been awarded to 60 G3 grants since 2011. While the projects vary, the vast majority center upon the idea of reducing stormwater runoff and creating resilient, connected communities through the creation and promotion of urban "green streets."

This guidebook was developed to provide community leaders, community groups, the local design community, and other interested groups with practical, planning-level information on creating green streets on local roads and integrating low impact development design strategies and green infrastructure practices into the urban environment.

Dominique Lueckenhoff

Deputy Director, Water Protection Division  
EPA Region 3

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## CHAPTER 1

INTRODUCTION

## Intro to the Design Guidebook

Urban redevelopment projects hold great potential for improving watershed health by replacing or retrofitting a portion of the Chesapeake Bay watershed’s estimated 2 million acres of untreated or marginally treated impervious surfaces through the use of low impact development features. This guidebook was prepared to address one opportunity in particular: the existing road network. <sup>note 1</sup>

Roads and the public rights-of-way (the area between the property lines on either side of a road) account for a significant portion of total impervious surface in urbanized environments. These impervious surfaces are one of the largest sources of stormwater runoff and pollution. They also provide one of the greatest opportunities to retrofit existing impervious areas with improved stormwater management.

When stormwater flows onto the road, it is directed towards the curb or shoulder, presenting an ideal opportunity to install low impact development features to slow, capture, and treat stormwater runoff before it reaches the sewer. While not without their challenges, green streets provide an attractive option for local jurisdictions both for their ability to treat stormwater runoff from several acres of impervious surface in highly dense urban environments and for the multiple urban design benefits provided.

This guidebook is geared towards municipal and county planning officials, developers, and the local design community. Its purpose is to provide a greater understanding of the general design and implementation strategies for incorporating common green street elements into existing street networks.

More detailed, technically-oriented information for the green infrastructure practices described here can be found by visiting the jurisdiction-specific stormwater resources listed on page 51.

*The Design Guidebook for Green Street Retrofits* was written to help community leaders, members, and the design community to realize the potential for green street retrofit and reconstruction projects in the Chesapeake Bay watershed and throughout the rest of EPA Region 3, which consists of Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia.

Chapter 2 provides background information on stormwater runoff and traditional infrastructure and explains the regulatory benefits of green street retrofits in EPA Region 3 and the Chesapeake Bay watershed (which includes New York). In Chapter 3, the stormwater design “toolbox” is introduced, with suggestions for designing different green street retrofit elements. It also includes information on standard maintenance practices and pollution reduction performance credits related to state NPDES programs and the Chesapeake Bay Total Maximum Daily Load (TMDL).

EPA Region 3 and the Chesapeake Bay watershed are expansive, and no single road and right-of-way specification will apply to all green street retrofits. Chapter 4 illustrates how these different site strategies can be applied to a range of different street types and identifies opportunities and constraints to each. The final chapter walks the reader through the general approach for calculating stormwater performance using three Anacostia-based case studies. Chapter 5 also highlights the need to monitor, track, maintain, and report on green street retrofits over time in order to ensure that their benefits are real and verifiable.

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## CHAPTER 2

BACKGROUND

### What is Stormwater Runoff and Why Does it Matter?

In urban areas across the United States, a combination of too little natural vegetation (pervious surfaces) and too much pavement (impervious surfaces) impacts how water makes its way into our streams, wetlands, rivers, lakes, and coastline. The impervious surfaces created by urban features such as roads, sidewalks, highly compacted soils, and rooftops cause rainwater and snowmelt to flow quickly over the landscape — turning into stormwater runoff — instead of soaking naturally into the ground or being absorbed by plants and slowly released over time.

Stormwater runoff picks up speed as it flows over hard, non-porous surfaces. Along the way, it accumulates pollutants such as sediment, oil, grease, metals, and lawn fertilizers which harm fish and wildlife, foul drinking water, and make recreational areas unsafe and unpleasant.

Developed and urban land makes up only a small percentage (about 11 percent) of the Chesapeake Bay watershed's total land cover. However, this area contributes about 16 percent of the phosphorous, 16 percent of the nitrogen, and 25 percent of the total sediment loads entering the Chesapeake Bay on an annual basis. <sup>note 2</sup> In the highly built-up Anacostia watershed, where more than 70 percent of the land has been developed and impervious surfaces cover more than one quarter of the landscape, stormwater runoff contributes 75 to 90 percent of the pollution entering the Anacostia River. <sup>note 3</sup>

## Stormwater Management: Yesterday and Today

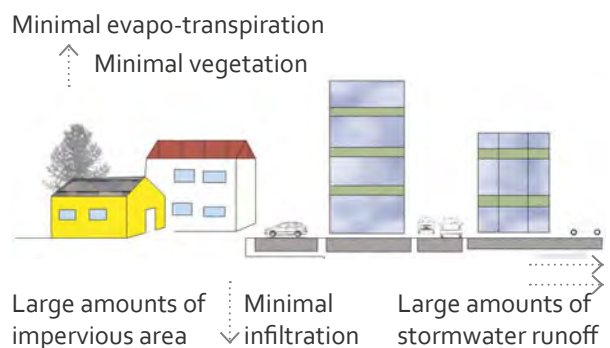
Water quality and watershed health are closely tied to population growth and development practices. As more people move into the watershed and develop new homes, roads, and businesses, more stormwater makes its way through swales, gutters, and sewer systems to the nearest waterbody.

Compounding this problem is that the vast majority of our urban areas were developed prior to the mid-1980s and lack stormwater quality controls. Before regulations governing stormwater quality, stormwater management was focused on minimizing the risk of flooding during large storm events by collecting and conveying stormwater runoff to the nearest sewer system or channel. Runoff would either enter the stream system without treatment or, in the case of older communities with combined sewer systems, be channeled into the same pipes as sewage and sent to a municipal wastewater treatment plant.

Our understanding of the causes and impacts of runoff have improved. So too have our stormwater management practices and regulatory requirements.

In 1972, the Clean Water Act was passed to restore the integrity of our polluted waterways. <sup>note 4</sup> Initial efforts focused on reducing “end-of-pipe” or “point source” pollution from wastewater treatment plants and industrial facilities, so named because the discharge came from a single location.

### Traditional Design



### Green Design

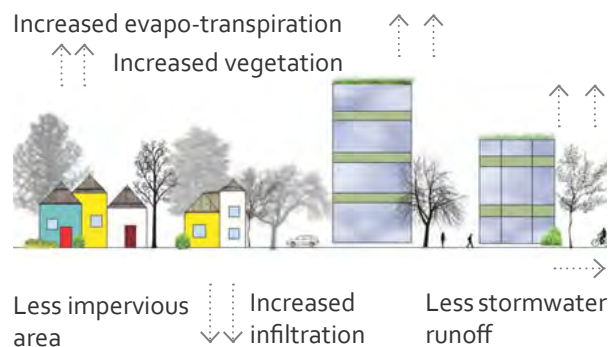


FIGURE 2.1. GREEN INFRASTRUCTURE IN URBAN ENVIRONMENTS

Traditional versus green design. Greener approaches treat a greater amount of polluted water on-site, providing multiple benefits along the way.

But by the mid-1980s, it became clear that regulating point sources were only part of the solution. The importance of treating “nonpoint” runoff was recognized, and the Clean Water Act was amended to place stricter regulations on nonpoint pollution like stormwater runoff. <sup>note 5</sup> States and many local governments began to require retention ponds at large developments to temporarily hold runoff before it flowed into a stream.

Regulations within the Bay states have tightened even more over the past decade — particularly for new development projects. Regulations now require on-site stormwater treatment via green street elements and low impact development Best Management Practices (BMPs). As a result, today’s stormwater management takes a more balanced and natural approach by placing greater emphasis on slowing down and treating rainwater where it falls.

## Green Infrastructure and Green Streets Defined

“Green infrastructure” is a flexible term that can have different meanings in different contexts. In the context of stormwater management, green infrastructure refers to practices that reduce and treat stormwater runoff by mimicking the natural hydrologic cycle or by reusing rainwater on-site.

Green infrastructure is often referred to as low impact development when discussed in the context of individual land development, redevelopment, or retrofit projects. In this document, the terms “low impact development features,” “green street elements,” and “BMPs” are used interchangeably.

### INCORPORATING GREEN INFRASTRUCTURE INTO STREETS

Traditional road building practices focus on methods to move stormwater away from the road as quickly as possible. These surfaces are most often made of impermeable materials

such as concrete, brick, or asphalt, causing any water flowing over the road to be directed towards curbs and gutters. These in turn help channel water down the street to sewers where the runoff is rapidly conveyed to nearby waterways or wastewater treatment plants.

Conventional “curb and gutter” designs are by nature litter and pollution conveyance systems. Litter and other pollutants that collect on roads and other impervious pavements are flushed into the sewer system and in the separate sewer system, eventually outfalling into nearby bodies of water.

By contrast, a green street retrofit is designed to slow down, clean, and reduce the volume of stormwater before it enters the sewer system or receiving waterbodies. This can be achieved by installing new landscape features or retrofitting streets using low impact development features such as installing permeable pavement to allow water to percolate into underlying soils; installing a network of streetscape bioretention areas to slow down and treat stormwater; or planting and preserving street trees to promote rainfall and snow interception and evapotranspiration.

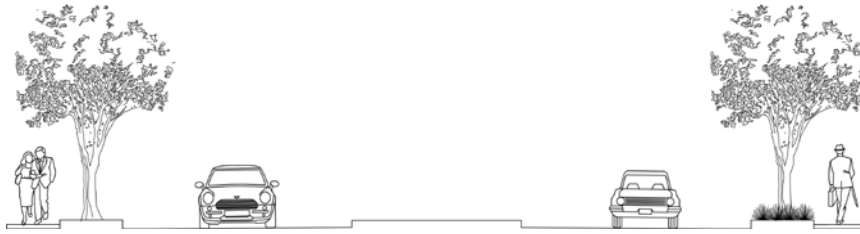
## Retrofitting for Green Streets

There is no universal design standard for green streets and green street retrofits. Each design must be tailored to specific locations, site constraints, and user needs based on drainage, traffic volume, material availability, surrounding land use, design standards, maintenance requirements, and available funding. Possible low impact development features include:

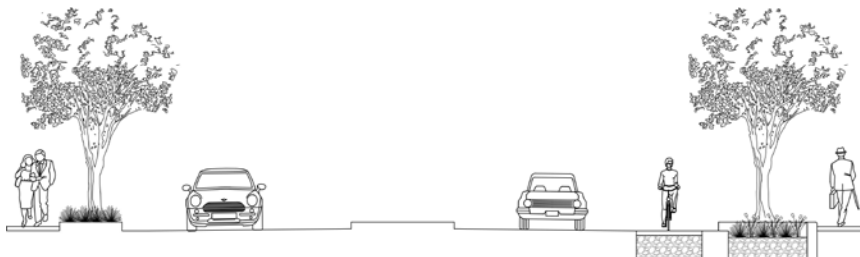
- » Street trees and sidewalk planter boxes to provide economical stormwater treatment in small spaces
- » Vegetated curb extensions to increase green space, treat stormwater, and calm traffic
- » Vegetated medians or refuge islands and highly visible crosswalks to provide safe, walkable streets
- » Lightly colored permeable pavement to reduce standing water, the urban heat island effect, and hydroplaning
- » Narrower roadways to allow for ADA-compliant sidewalks, bicycle lanes, and reduced impervious surfaces

Reconstruction and retrofit projects in particular face a number of challenges due to the built-up nature of their surroundings. In many cases, costs, timing, utility locations, and other restrictions may limit the number of low impact development features that can be incorporated into the green street, allowing only a portion of the stormwater runoff to be captured and managed. In some cases, the roadway can be modified adequately to allow stormwater runoff to be fully managed within the streetscape.

In its ideal form, a green street not only manages stormwater runoff within the streetscape but also encourages walking and biking by enabling safe access for all users. In doing so, green streets provide a tremendous opportunity to improve community livability by providing optimal stormwater management and a direct focus on alternative modes of transportation.



Street trees and landscaped areas are added to existing open areas to provide limited stormwater management. Existing street trees in good health are preserved and overall impervious areas are minimized.



Streetscape bioretention areas replace landscaped areas and/or permeable pavement replaces part of the existing paved surface, improving the overall pollutant removal and runoff detention capacities.



Stormwater is fully managed within the streetscape to provide minimum required levels of runoff treatment as specified by the locality — which typically targets the 1.0 inch rainfall event.



Green street elements are enhanced to boost success in meeting load reduction targets for impervious surfaces and TMDL pollutants of concern. Local stormwater requirements are exceeded.

FIGURE 2.2. GREEN TO GREENER

## The Regulatory Benefit of Green Street Retrofit Projects

Improvements to existing road systems can help local jurisdictions meet the various federal, state, and local regulations designed to control nonpoint source runoff into surface waters. The federal Clean Water Act requires municipalities within the Chesapeake Bay watershed and EPA Region 3 states to control stormwater runoff in order to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Several programs have been developed at multiple levels in order to meet these requirements.

### STORMWATER RUNOFF AND THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

Stormwater runoff is treated as a point source discharge to the waters of the United States under the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) program. In 1987, amendments were enacted that set the process of controlling stormwater pollution into motion. The changes were developed and instituted in two phases.

In the early 1990s, "Phase I" required medium and large municipalities with populations over 100,000 that owned and operated their own storm sewer system (known as municipal storm sewer systems, or MS<sub>4</sub>s); industrial facilities; and construction sites five acres or greater in size to obtain NPDES permits in order to discharge untreated stormwater runoff through a MS<sub>4</sub> to waters of the U.S. These regulations depended primarily on permittees developing stormwater management plans to direct stormwater management programs in Phase I communities.

Phase I MS<sub>4</sub>s are covered by individual permits, of which there are 24 in the Chesapeake Bay watershed and 26 in EPA Region 3. <sup>note 6</sup>

In 2003, a second wave of stormwater regulations took effect ("Phase II") to require smaller MS<sub>4</sub> communities within urbanized areas and certain small MS<sub>4</sub> communities outside urbanized areas to apply for NPDES stormwater permits. <sup>note 7</sup> Phase II requires permits for any construction activity that disturbs one acre or greater. Phase II MS<sub>4</sub> communities are often covered by a general permit, though some Phase II MS<sub>4</sub>s have individual permits. Primary NPDES responsibilities within EPA Region 3 and the Chesapeake Bay watershed have been delegated to state environmental agencies, with the exception of Washington, DC and federal facilities in Delaware.

NPDES permits require each regulated MS<sub>4</sub> to develop and implement a stormwater management program in order to meet water quality standards and to be consistent with the terms and conditions of applicable TMDL Wasteload Allocations (WLA). Both Phase I and II MS<sub>4</sub> permittees are required to address six minimum control measures. <sup>note 8</sup> Phase I MS<sub>4</sub>s must also have a program to account for industrial facilities within the MS<sub>4</sub>.

NPDES Permits are issued for no more than five years. If an MS<sub>4</sub> is contributing to a watershed for which one or more TMDLs for specific pollutants have been approved by the EPA, the next permit issued must include specific conditions for TMDL compliance. Some older communities contain combined sewer systems designed to collect stormwater runoff, domestic sewage, and industrial wastewater in the same pipe. Where these exist, NPDES permits are augmented to minimize discharges of raw sewage into nearby waterbodies during heavy rain events. There are 64 combined sewer communities in the Chesapeake Bay watershed. See [Table 2.1](#) for a summary of stormwater discharges and NPDES permit requirements.

### URBAN STORMWATER AND THE CHESAPEAKE BAY TMDL

The Clean Water Act’s section 303(d) focuses on ensuring that all waterbodies meet their designated uses (such as “fishable” or “swimmable”) or specific water quality criteria intended to protect those uses. Where water quality standards can’t be met, states are required by section 303(d) to list the waterbody as impaired. The list may include just a single segment of a waterbody, but in many cases extend to the entire waterbody or watershed. Over time, a TMDL is developed for every waterbody/pollutant combination in order to set limits on the amount of particular pollutant a waterbody can receive — called the loading capacity — and still safely meet its water quality standard, as well as establish a plan for reducing pollutants below the loading capacity.

TABLE 2.1. STORMWATER DISCHARGES AND THE NPDES PROGRAM: PERMIT REQUIREMENTS	
<b>Stormwater discharges from Municipal Separate Storm Sewer Systems (MS<sub>4</sub>s)</b>	
Phase I permits are required for medium and large cities or counties with populations of at least 100,000. There are 24 Phase I MS <sub>4</sub> s in the Chesapeake Bay watershed and 39 in EPA Region 3.	
Phase II permits are required for small MS <sub>4</sub> s in urbanized areas and small MS <sub>4</sub> s outside the urbanized areas that are designated to obtain a NPDES permit for their stormwater discharges. There are 400 Phase II MS <sub>4</sub> s in the Chesapeake Bay Watershed, and 947 in EPA Region 3.	
<b>Stormwater discharges from construction activities</b>	
Stormwater discharge permits are required for construction site operators engaged in clearing, grading, and excavating activities that disturb one or more acres.	
<b>Stormwater discharges from industrial activities</b>	
While not the focus of this document, stormwater discharges associated with specified categories of industrial activity require NPDES permits. These include industries that have their own treatment works and don’t send their wastes to a municipal treatment plant.	

In 2010, the EPA released a TMDL that covers the entire 64,000 square mile Chesapeake Bay watershed and is designed to achieve significant reductions in nitrogen, phosphorus, and sediment pollution. A combination of 92 smaller TMDLs for individual Chesapeake Bay tidal segments, this TMDL established watershed limits on the maximum amount of nitrogen, phosphorous, and sediment pollution the Chesapeake Bay can handle and still meet water quality standards. In response, the seven Chesapeake Bay jurisdictions created Phase I Watershed Implementation Plans (WIPs) that describe how each jurisdiction will implement 60 percent of their Chesapeake Bay cleanup practices by 2017 and 100 percent by 2025. Phase II WIPs soon followed. Phase II WIPs were prepared primarily by the state environmental authorities (or DC's environmental authority) with input from local governments and federal facilities. The Phase II WIPs describe the specific strategies local communities should take to achieve the required reductions, such as ordinances or the number of nutrient control practices that should be installed. Specific strategies at the local level include increasing the urban tree canopy and integration of other low impact development BMPs into the urban environment, such as green street retrofits.

In addition to the Chesapeake Bay TMDL, thousands of previously approved TMDLs have been established to protect local waters across EPA Region 3 and the Chesapeake Bay watershed that local jurisdictions are also required to meet. Some address nitrogen,

phosphorus, or sediment; many address other pollutants. For watersheds and waterbodies where both local TMDLs and the Chesapeake Bay TMDL have already been developed or established for nitrogen, phosphorus, or sediment, the more stringent TMDL applies. MS4 permittees are required by the permit to be consistent with the conditions and assumptions of any applicable TMDL WLA when TMDLs are present for other pollutants.

## STATE AND LOCAL STORMWATER REQUIREMENTS

State-issued NPDES permits for MS4s and stormwater discharges associated with construction and industrial activities must be at least as stringent as required by federal regulations. Many states and jurisdictions have more stringent requirements for new and redevelopment projects and industrial activities. For example, federal requirements dictate that all new and redevelopment projects that disturb one acre or more must have NPDES permit coverage. Washington, DC, requires all new and redevelopment activities that disturb 5,000 square feet or more to obtain a NPDES permit. Some states have state-wide retention standards, and all of the jurisdictions within the Chesapeake Bay watershed have published stormwater management guidebooks that include treatment design standards consistent with the jurisdiction's stormwater regulations.

Stormwater regulations in Chesapeake Bay jurisdictions have become stricter over the past ten years. They now require the use of low impact development practices and

on-site treatment of runoff. How runoff is computed and how baselines are established varies by jurisdiction. For example, Maryland uses a hybrid curve number (CN) and runoff coefficient (Rv). In Virginia, performance standards are based on phosphorous loads. Readers should refer to specific regulations and manuals for more detail. [note 9](#)

## ACCOUNTING FOR GREEN STREET RETROFIT PRACTICES

It is important for designers and local jurisdictions to have an understanding of the potential performance benefits that practices provide when planning for green street retrofits. Chapter 3 describes four green stormwater infrastructure practices typical of green street retrofit designs, with credit information provided based on current state regulations for stormwater discharges and the Chesapeake Bay TMDL process.

In practice, a green street's ability to improve the quality of urban streams and meet NPDES permit requirements for stormwater discharges from construction sites depends on multiple factors. These include precipitation patterns, the size of the drainage area, site condition requirements and limitations, and whether the implemented practices will convert enhance, or restore an existing stormwater management feature.

According to the Chesapeake Bay TMDL, performance credits are available for redevelopment or retrofit projects based on whether the site currently contains a BMP, and if present, whether it was previously reported. The Chesapeake Bay Program Office's Urban

Stormwater Workgroup released a report in 2012 for quantifying the composite benefits of retrofits that weighs pollutant removal fractions according to the runoff depth captured per impervious acre. [note 10](#)

The planner, designer, or engineer may also need to consider the potential standard credits available as they relate to individual Phase I or II MS<sub>4</sub> permit requirements and other local TMDLs, as well as other overlapping and related federal, state, and local regulations. These may include floodplain, wetland, natural stream, and dam safety regulations, among others. A discussion and examples on the use of green streets to meet MS<sub>4</sub> permit requirements is provided in Chapter 5.

[Table 2.2](#) summarizes the major requirements for stormwater management on new development and redevelopment sites in the Chesapeake Bay watershed and EPA Region 3. Redevelopment projects are subject to less stringent requirements, with the exception of Washington, DC, which requires new and redevelopment projects to meet the same standards. Regardless, redevelopment can lead to a net reduction of pollutants due to the large amount of untreated or marginally treated impervious surfaces in urban areas.

TABLE 2.2. CHESAPEAKE BAY AND EPA REGION 3 STATE STORMWATER STANDARDS FOR NEW AND REDEVELOPMENT

Stormwater discharges from Municipal Separate Storm Sewer Systems (MS4s)				
State	Performance Standard for New Development	Performance Standard for Redevelopment	Model	Applicability
DC	Retain runoff volume from the 1.2 inch (90th percentile) rainfall event on-site (or 0.8 inch for substantial improvement projects)		Runoff Coefficient	Disturbance > 5,000 sq.ft.
DE	Employ runoff reduction practices to achieve an equivalent of 0% effective imperviousness.	Reduce effective impervious area by 30% based on existing conditions	Curve Number	Disturbance > 5,000 sq.ft.
MD	Implement environmental site design (ESD) to the maximum extent practicable by integrating design, natural hydrology, and smaller controls to capture and treat runoff, replicating quality of runoff from "woods in good condition"	a) Reduce existing impervious areas by a minimum of 50%, or b) implement environmental site design to provide water quality treatment for a minimum of 50% of the existing impervious area, or c) a combination of both	Curve Number & Runoff Coefficient	Disturbance > 5,000 sq.ft.
NY	Provide runoff reduction for a minimum fraction of the water quality volume for the 90th percentile rain event	Reduce water quality volume by 25% through impervious surface reduction, BMPs, or alternative practices	Runoff Coefficient	Disturbance > 1 acre
PA	No increase in the post-development total runoff volume for all storms equal to or less than the 2-year 24-hour duration precipitation	Treat 20% of the existing impervious surface as if it were meadow condition, except for repair, reconstruction, or restoration of roads or rail lines, or construction, repair, reconstruction, or restoration of utility infrastructure when the site will be returned to existing condition	Curve Number	Disturbance > 1 acre
VA	Achieve a post-construction discharge of no more than 0.41 pounds per acre of phosphorous	For projects with no net increase in impervious surface: redevelopment > 1 acre, reduce phosphorous loads by 20% below predevelopment loading; for redevelopment < 1 acre, reduce the existing phosphorous load by 10%	Runoff Coefficient	Disturbance > 1 acre (or 2,500 sq.ft. in Chesapeake Bay Preservation Act areas)
WV	Reduce runoff from the first 1 inch of rainfall on-site	Reduce runoff from the first 0.25 to 1.0 inches of rainfall, depending on the type of redevelopment project	Runoff Coefficient	Disturbance ≥ 1 acre

Adapted from Schueler and Lane (2012)

**ENDNOTES: CHAPTER 1 & 2**

1. Chesapeake Stormwater Network, 2011. CSN Technical Bulletin No. 5: Stormwater Design for High Intensity Redevelopment Projects in the Chesapeake Bay Watershed, Version 3.0. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page.](#)
2. U.S. Environmental Protection Agency, 2010. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA 903S10002 - CBP/TRS-303-10. Chesapeake Bay Program Office, Annapolis MD. December 2010. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page.](#)
3. Natural Resources Defense Council, 2013. Cleaning Up the Anacostia River. [Return to page.](#)
4. 33 U.S.C. §1251 et seq. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page.](#)
5. Pub.L. 100-4, February 4, 1987. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page.](#)
6. US Environmental Protection Agency Region 3, NPDES Permitting Program. Click [here](#) for more information. [Return to page.](#)
7. Stormwater Phase II Final Rule: Small MS4 Stormwater Program Overview. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page.](#)
8. US Environmental Protection Agency Region 3, NPDES Permitting Program. Click [here](#) for more information. [Return to page.](#)
9. State links are provided at the end of this document in [Table 5.1](#). [Return to page.](#)
10. Schueler, T., Lane, C., 2012. Recommendations of the Expert Panel to Define Removal Rates for Urban Stormwater Retrofit Projects: Short Version. Chesapeake Stormwater Network, Ellicott City, MD. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page.](#)



## CHAPTER 3

# GREEN STREET STORMWATER MANAGEMENT TOOLBOX

## Green Street Stormwater Management Elements

Green streets can incorporate a wide variety of design elements. Retrofitting existing public rights-of-way to incorporate green infrastructure and low impact development practices generally involves reducing the amount of impervious area, utilizing existing or newly created green spaces for street tree plantings or stormwater bioretention features, or installing porous pavement in reconstruction projects.

This chapter provides details on four low impact development features that are commonly used in green street retrofit and reconstruction projects: impervious surface reduction, street trees, streetscape bioretention, and permeable pavement. Each can be implemented in isolation; however, storage and treatment capacity can be increased by incorporating enhanced designs, combining practices, and/or connecting green stormwater management facilities so that they operate as one system along the street. See [Table 3.1](#) for a full list of project types.

TABLE 3.1 GREEN STORMWATER INFRASTRUCTURE PRACTICES FOR RIGHT-OF-WAY RETROFIT APPLICATIONS

<b>Impervious Surface Removal</b>	
<b>Street Tree Planting or Preservation</b>	
<b>Streetscape Bioretention</b>	<ul style="list-style-type: none"> <li>» Rain garden</li> <li>» Stormwater curb extension</li> <li>» Tree box filter</li> <li>» Stormwater planter</li> <li>» Bioswale</li> </ul>
<b>Permeable Pavement</b>	<ul style="list-style-type: none"> <li>» Porous Asphalt</li> <li>» Pervious Concrete</li> <li>» Interlocking Permeable Pavers</li> </ul>

## INTEGRATING OTHER GREEN STREET ELEMENTS

There are other green street elements not covered in this guidebook that may be appropriate to particular settings. These include practices such as soil amendments, vegetated filter strips, inlet protection devices, and infiltration trenches. Street sweeping is also a common and cost-effective alternative practice that can be used to reduce stormwater pollution, and its value should not be overlooked. For further information about these and other green infrastructure practices and tools, it is recommended that the reader reference the appropriate state and local stormwater management guidebooks and other manuals for information about applicability, design, performance, and crediting.

It is also important when designing any green street to be aware of and adhere to local jurisdiction requirements and Americans with Disabilities requirements. Local jurisdictions generally follow a set of established standards for designing streets. Specific policies, standards, manuals, and guides vary by locality. The following are some of the more relevant guides and resources:

- » The American Association of State Highway and Transportation Officials' (AASHTO) A Policy on Geometric Design of Highways and Streets (the "Green Book")
- » The Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)
- » The National Association of City Transportation Officials (NACTO) Urban Street Design Guide, Transit Street Design Guide, and Urban Bikeway Design Guide
- » State-specific manuals on design, construction, and maintenance standards
- » Americans with Disabilities Act (ADA) regulations and standards
- » Local manuals or street design standards

## Tips for Selecting Green Street Retrofit Projects

Planning-level documents provide guidance for choosing green street retrofit locations. The Center for Watershed Protection's Urban Subwatershed Restoration Manual 3: Urban Stormwater Retrofit Practices (2007) was written to address urban retrofits in general but provides a good eight-step method for selecting potential retrofit locations. <sup>note 1</sup> Similarly, Chapter 4 of the City of Philadelphia Green Streets Design Manual (2014) includes information on siting green street elements within public rights-of-way. <sup>note 2</sup> A report published by the National Cooperative Highway Research Program provides guidelines for the selection and maintenance of highway-related green stormwater practices based on long-term performance and life-cycle costs. <sup>note 3</sup> <sup>note 4</sup> [Table 3.2](#) provides descriptions of two simple tools that can be used in the planning stage to estimate stormwater benefits.

TABLE 3.2. SIMPLE MODELS TO ADDRESS GREEN STREET RETROFIT OUTCOMES			
Name	Description		
EPA National Stormwater Calculator	A simple tool to compute small site hydrology for any U.S. location. Uses the well-established Storm Water Management Model (SWMM) to estimate stormwater runoff generated from a site. Once a baseline condition for a site is established, different scenarios can be developed and evaluated.		
	Low Impact Development Elements	User Inputs	Outputs
	Rain gardens, street planters, permeable pavement, infiltration basins, green roofs, downspout disconnects, rainwater harvesting	Site location, land cover, soil, topographic and climate data from national databases, low impact development elements and design features	Runoff volume and frequency analysis
Name	Description		
Center for Neighborhood Technology Green Values National Stormwater Management Calculator	A tool to compare the performance, costs, and benefits of low impact development elements to conventional practices. It helps the user determine the stormwater runoff volume reduction goal, define the impervious areas under a conventional development scheme, and then select low impact development practices to meet the runoff volume reduction goal.		
	Low Impact Development Elements	User Inputs	Outputs
	Reduced street width, permeable pavement, planter boxes, rain gardens, swales, trees, native vegetation, vegetation filter strips, amended soil, green roofs, cisterns	Annual or event precipitation, land cover, soil type, runoff reduction goal, low impact development elements, and design parameters	Runoff volume, cost, energy use, air pollution and carbon dioxide sequestration benefits, tree value, groundwater recharge, reduced treatment benefits

It is important to consider existing conditions when designing a green street retrofit project. Common elements include the amount of impervious surface, location of utilities, buildings, slopes, trees and landscaped areas, and the location of sewer system inlets into which stormwater flows. Understanding how water flows will allow green stormwater practices to target areas that maximize stormwater runoff capture and treatment.

## ESTIMATING PERFORMANCE

A number of models — ranging from simple to complex — are available to assess the water quantity benefits of implementing specific green street elements. <sup>note 5</sup> Some models also address costs and other environmental benefits. At the planning level, simpler, less resource-intensive models provide sufficient information for evaluating potential green street retrofit options. These often only provide runoff volume estimates. One caveat is that not all of the models easily translate from the standard lot type for which the calculators were primarily designed. It may be necessary to tweak the modeling approach to fit the linear nature of the public right-of-way when applying these models to a street. This can be done by breaking up the street into individual sections based on sewer system inlet locations.

More complex models are also available to evaluate the effectiveness of green street elements in reducing stormwater runoff volumes and improving water quality. Complex models require greater time, expertise, and input data from the user but have the advantage of providing a more detailed analysis. They often provide information on pollutant load estimates in addition to stormwater runoff volume reduction estimates when appropriate water quality parameters are included. The EPA’s Stormwater Management Model (SWMM) is the most well-known and widely used program available. A brief description is provided in [Table 3.3](#). <sup>note 6</sup>

Name	Description		
EPA Stormwater Management Model (SWMM) with Low Impact Development Controls	SWMM is an urban hydrology and conveyance system hydraulics software tool that models the hydrologic performance of specific types and combinations of low impact development practices to measure their effectiveness in managing stormwater and combined sewer overflows.		
	Low Impact Development Elements	User Inputs	Outputs
	Rain gardens, street planters, permeable pavement, infiltration trenches, vegetative swales, green roofs, rainwater harvesting	Soil, topographic, and climate data, land cover (e.g., impervious area and soil) and drainage characteristics, low impact development elements and features	Runoff volume, runoff rate, mean pollutant concentration, total pollutant load

## Green Street Retrofit Design Strategies

Retrofitting streets to better manage stormwater runoff may involve a combination of design elements. The following design strategies identify possible opportunities for redesigning the street in order to provide effective source control of stormwater, limit the flow of stormwater and pollutants to the collection system, restore hydrology to a predetermined baseline to the greatest extent possible, and provide environmentally enhanced streetscapes. Other considerations that factor into the decision are identified in Chapter 4.

### LOOK FOR WAYS TO REDUCE IMPERVIOUS AREAS

One of the first opportunities to explore when retrofitting or reconstructing a street is whether any impervious areas can be eliminated. Narrowing roadways that are wider than necessary for existing traffic patterns both reduces runoff by having less impervious pavement and greens the streetscape. Similar benefits can be achieved by taking advantage of wide sidewalk corridors or impervious medians to create green spaces.

### INCORPORATE STREET TREES AND BIORETENTION AREAS

Preserving and enhancing existing trees, incorporating new trees, and adding bioretention areas into existing and newly created open spaces helps green the street. Trees contribute significantly to the slowing, absorbing, and filtering of stormwater by intercepting water via the leaves, bark, and roots. Streetscape bioretention elements typically provide even greater water quality improvements. Stormwater is slowed by the interaction with plants and soil as it flows through the system, allowing sediments and associated pollutants to settle out.

### DESIGN PEDESTRIAN AREAS OR PARKING LANES WITH PERMEABLE PAVEMENT

Permeable pavement should be considered where medians do not exist or streetside areas are too narrow for bioretention. Permeable pavement is most appropriate for sidewalks or pedestrian areas and in parking lanes that are not used for bus traffic or peak traffic. They can also be used on very low-speed, low-traffic volume streets where load-bearing capacity is not a concern. The incorporation of permeable pavement is restricted to reconstruction projects — as opposed to resurfacing projects — where the option becomes more cost-effective. Similarly, streetscape bioretention practices involving curb replacements are typically more cost-effective when incorporated into reconstruction projects.



# Impervious Surface Removal

## OVERVIEW

Impervious surface removal refers to the replacement of impervious areas — such as asphalt and concrete — with vegetation or other permeable surfaces. Replacing hard, impermeable areas with healthy vegetated groundcover, bioretention areas, permeable pavement, or tree planting areas improves urban hydrology and water quality. It also adds green spaces back into the urban streetscape. Projects can range from simple to complex. Replacing small sections of pavement within a street’s sidewalk area or medians can be successfully incorporated into smaller retrofit projects to make way for vegetated medians, tree planting areas, or pocket parks. Projects that involve reducing the street width or replacing impervious street sections with permeable pavement are more applicable to street reconstruction projects.

## TYPES

Replacing existing concrete or asphalt with bioretention areas, pervious pavement, or street trees are three options for reducing the amount of directly connected impervious surface and total area of impervious surface in a green street project. Each of these three low impact development features are discussed later in this chapter. In other cases, the green infrastructure practice might be simpler, such as minimizing street widths, converting sections of expansive sidewalks to green areas, or incorporating vegetated medians and triangle parks into retrofit designs.



### IMPERVIOUS TO VEGETATED GROUNDCOVER

Impervious to vegetated groundcover conversion is also a green street technique. In some jurisdictions, a specific performance credit is provided for converting impervious areas to pervious areas, even when no additional treatment is provided. In other jurisdictions, the conversion is credited by reducing the total amount of impervious area that is required to be treated by other green infrastructure practices.



### IMPERVIOUS TO BIORETENTION, PERMEABLE PAVEMENT, OR TREE PLANTING AREA

Converting impervious surfaces to bioretention, permeable pavement, or tree planting areas reduces the total amount of impervious surface within a drainage area and provides space for stormwater to be treated and retained along the street. In the picture above, a street in Syracuse, NY, was retrofitted with stormwater planters that capture and treat stormwater runoff from the adjacent roadway. Stormwater enters the planter via four curb inlets, irrigating the native shade trees, ornamental shrubs, and colorful perennials, and then infiltrates through an aggregate trench into the ground below. The performance credit provided is determined by the runoff and pollution reduction credits associated with the green stormwater infrastructure practice.

## DESIGN CONSIDERATIONS

Target impervious areas that drain directly into the stormwater sewer system when selecting sites for impervious surface removal projects. Consideration should be given to the area's current or intended use to ensure that the pavement removal will not negatively impact the area's functionality. For example, if the targeted area is currently used as a shoulder, for parking, or for emergency vehicles, it is important to ensure that these considerations are addressed. Alternatively, if a portion of a sidewalk is to be removed, the reduced sidewalk width must still be in compliance with Americans with Disabilities Act (ADA) requirements.

Take care when removing pavement to avoid damaging concrete or asphalt areas that will remain in place. Demolition waste should be properly disposed of or recycled. If the impervious area is to be replaced with a specific green infrastructure practice such as streetscape bioretention or permeable pavement, the practice should be installed as per regulatory specifications.

## STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE CREDITS

For most jurisdictions within EPA Region 3 and the Chesapeake Bay watershed, converting existing impervious surfaces to a pervious area is considered "self-crediting" in that the land use conversion automatically provides a reduction in stormwater impacts. There is no assigned runoff reduction credit or pollution reduction credit. The "credit" or benefit comes from lessening the post-construction stormwater retention obligation by decreasing the amount of stormwater runoff that must otherwise be managed. However, credit can be received if the newly pervious area is used to install a stormwater control measure such as permeable pavement or streetscape bioretention area. The reader should refer to the potential volume reduction or water quality credits associated with the specific control measure.

Maryland and the Chesapeake Bay Program Office are slightly different. Both rely on the Chesapeake Bay Program Office's modeling tools to quantify the pollutant load reduction benefits associated with converting conventional pavement to a vegetated land use. The slight differences in expected load reduction rates noted in [Table 3.4](#) are due to the fact that Maryland's guidance on determining load rates is based on a prior CBP Watershed Model (Phase 5.3.0, versus Phase 5.3.2). <sup>note 7</sup>

## MAINTENANCE

Maintenance of pervious areas will depend on the specific groundcover or low impact development feature installed. Maintenance considerations for street trees, streetscape bioretention, and permeable pavement are addressed in the following sections of this chapter.

TABLE 3.4. IMPERVIOUS SURFACE REMOVAL PERFORMANCE CREDITS				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC	Deducted from total site area when computing water quality volume requirement	n/a	n/a	n/a
DE	Deducted from total site area when computing water quality volume requirement	n/a	n/a	n/a
MD <sup>a</sup>	n/a	84%	72%	13%
NY	Deducted from total site area when computing water quality volume requirement	n/a	n/a	n/a
PA	Results in reduced stormwater volume and rate calculations	n/a	n/a	n/a
VA	Deducted from total site area when computing water quality volume requirement	n/a	n/a	n/a
WV	Deducted from total site area when computing the target treatment volume	n/a	n/a	n/a
CBP <sup>b</sup>	n/a	85%	72%	23%

#### Notes for Table 3.4

- a. MD: Based on the pollutant load reduction expected when 1 acre of land cover is converted from impervious to pervious, providing an impervious acre equivalent of 0.62 acres. For pollution reduction efficiency credits associated with converting impervious areas to urban street tree planting areas, see the table related to street tree performance credits. Based on CBP Phase 5.3.0 Watershed Model. [Return to table.](#)
- b. Chesapeake Bay Program (CBP): Based on CBP Phase 5.3.2 Watershed Model. [Return to table.](#)



# Street Trees

## OVERVIEW

Trees are one of the most economical low impact development features that can be introduced into urban rights-of-way. When it rains, water is intercepted by the leaves, bark, and roots of trees, allowing some of the water to slowly evaporate back up into the air, be absorbed by the tree, or be released into the ground over time. Trees also help to reduce the urban heat island effect, improve urban habitats and aesthetics, and improve air quality.

Healthy trees should be protected and enhanced when implementing green street retrofit projects, and new trees should be incorporated wherever possible. In either situation, care should be taken to ensure adequate root space, improved soil conditions, and sufficient soil volumes and depths. Doing so will help street trees reach maturity and allow future generations to enjoy their benefits.

## TYPES

Street trees require space, proper soil, drainage, and irrigation in order to thrive. Soil properties and soil volumes are critical to a tree's longevity, while the soil's porosity, permeability, and infiltration rates affect not only tree health and maturity, but also the tree's ability to absorb stormwater. They can be placed in open soil planting areas, or, in cases where paved areas must be maximized, by utilizing a closed engineered system beneath the pavement. Trees may also be used in areas where open soil planting areas are combined with engineered systems. For systems that are designed to convey stormwater from streets, sidewalks, roofs, or other impervious areas into a tree planting area, the reader should refer to the section in this chapter on streetscape bioretention.

## OPEN SOIL PLANTING AREAS



Open soil planting areas are unpaved areas of soil surrounding a tree. They are designed to achieve adequate soil volumes for the size of tree that is being planted or preserved. Soil may be existing, new, or amended. For areas where more than one tree will be planted along the street, individual open soil planting areas may be separated by pavement, but it is important that each planting area contain the appropriate soil volume to hold the specified number of trees. [note 13](#)

## CLOSED ENGINEERED SYSTEMS

Closed engineered systems refer to systems such as suspended pavement, structural cells, and engineered soils. Paved surfaces require a certain level of soil compaction to remain stable, while root systems require looser soils that can cycle water, oxygen, and nutrients. Closed engineered systems are designed to work around this issue in tight spaces in order to provide sufficient support for foot or automobile use on paved surfaces above while providing a large area of uncompacted soils below ground for root growth, stormwater storage, and the breakdown of pollutants. [note 14](#)



## DESIGN CONSIDERATIONS

Street trees are most often planted in a linear fashion within a road's right-of-way between the curb and sidewalk. The streetscape setting can be hard on trees, particularly when planted in narrow areas that restrict root growth. Street trees must share limited space with underground and overhead utilities and are directly impacted by heat and pollution. Because of these challenges, street trees require more maintenance than other trees and often have shorter lifespans.

Incorporating street tree plantings or tree preservation in reconstructed streetscapes requires proper design. The greatest concern is ensuring the appropriate **soil volume** requirements are met. Other factors include the **soil depth** and **soil compaction**.

Sufficient **soil volume** is required for street trees to thrive and reach maturity, though the amount of soil required generally depends on the size of the tree. The standards used in Washington, DC's street designs require approximately two cubic feet of soil per one square foot of mature drip line area. <sup>note 8</sup> DC further defines minimum soil volumes for street trees based on whether a street

tree is categorized as a large, medium, or small street tree. <sup>note 9</sup> In New York State's Stormwater Management Design Manual, a minimum of 1,000 cubic feet soil media per tree is recommended, regardless of the size of tree at maturity. <sup>note 10</sup> See [Table 3.5](#) for details.

**Soil compaction** and **soil depth** are also considerations for street tree preservation and plantings. Soils in urban tree planting holes should be usable and uncompacted with adequate organic matter and nutrients to a depth of two to three feet. <sup>note 11</sup> In Washington, DC, it is recommended that soil extend three feet deep. <sup>note 12</sup>

Other design considerations include the soil's pH levels, poor infiltration, the location of overhead and underground utilities, pedestrian safety and foot traffic needs, and other uses of the public right-of-way.

In urban situations, the increased presence of concrete and limestone gravel can cause soil pH levels to be high (alkaline), whereas most trees grow best in neutral to somewhat acidic soils. Soil pH levels may need to be adjusted.

Depressed tree planting boxes may require fencing or setbacks from the curb to meet ADA requirements. Local jurisdictions often require that minimum distances from the curb, streetlights, stop signs, between trees, intersections, and utilities also be met to ensure safety and reduce potential conflicts.

TABLE 3.5. MINIMUM SOIL VOLUME REQUIREMENTS FOR STREET TREES IN DC

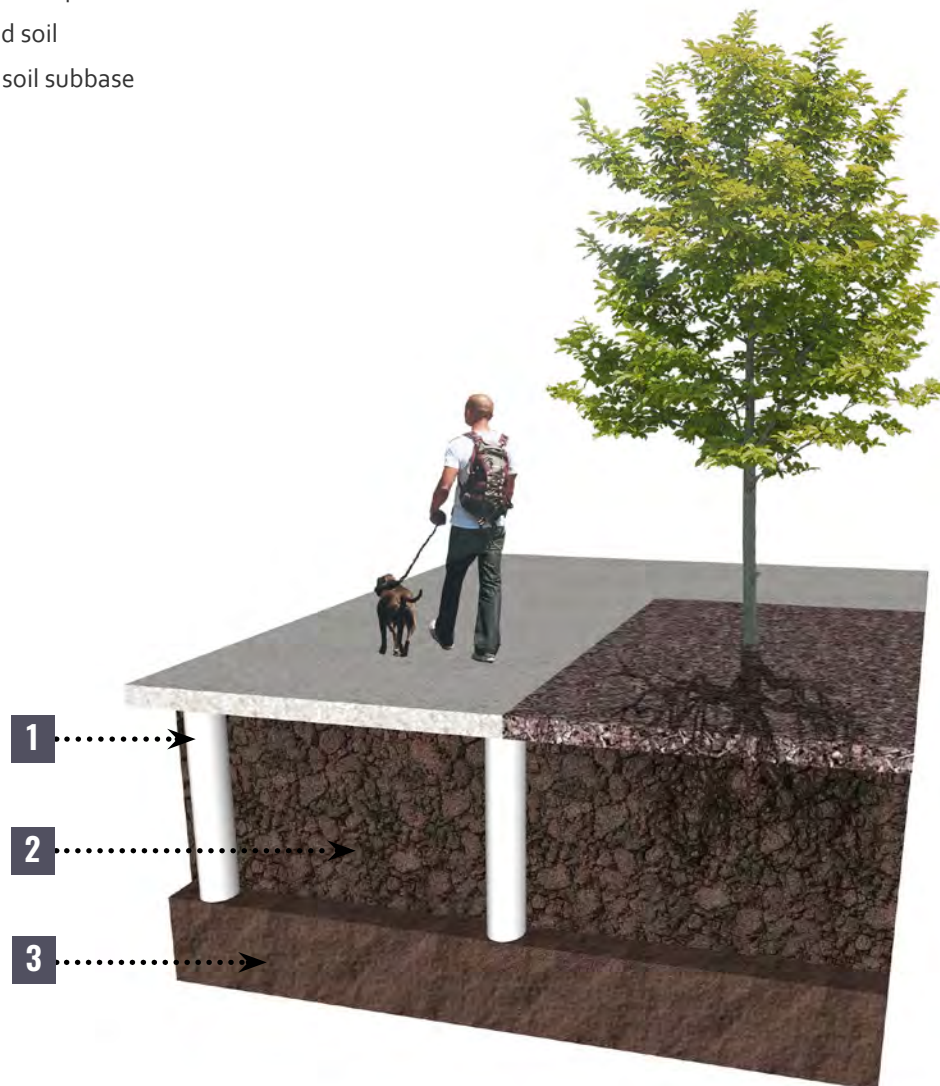
Tree Size	Minimum Soil Volume
Large Trees	1,500 ft <sup>3</sup>
Medium Trees	1,000 ft <sup>3</sup>
Small Trees	600 ft <sup>3</sup>

## SPECIAL DESIGN CONSIDERATIONS

**Suspended pavements** and **structural cells** utilize a network of pillars or piles to provide large subsurface areas of uncompacted soils for root growth, bioremediation, and storage of stormwater. Both systems are applicable to retrofit applications. Where existing trees are to be preserved, suspended pavement can be utilized to preserve the lateral roots. Both should be designed according to regulatory and manufacturer details.

FIGURE 3.1. SUSPENDED PAVEMENTS AND STRUCTURAL CELLS

1. Concrete pillars or prefabricated modules
2. Uncompacted soil
3. Undisturbed soil subbase



**Structural soils** utilize a specific soil-on-gravel mix that is designed to support the load-bearing requirement for pavement while also supporting tree growth by allowing roots to grow under and away from the pavement. Trees are planted as they would be in a normal soil, utilizing a 2 to 3 foot reservoir depth, or as specified by regulations, to optimize tree growth. Because the mix contains about 20 to 30 percent soil, larger volumes may be needed. Care must also be taken to ensure that the subgrade meets overall requirements for the desired traffic loading.

FIGURE 3.2. STRUCTURAL SOILS

- 1. Soil-on-gravel mix
- 2. Undisturbed soil subbase



## STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE CREDITS

The credit available for either preserving or planting a street tree in a street retrofit application varies by jurisdiction. Generally for those states with more recently updated stormwater management guidebooks or manuals, a higher performance credit is provided when an existing street tree is protected or enhanced and specific minimum requirements are met (such as tree type, minimum soil volumes, and minimum tree caliper and height requirements). For others, no credit may be available at this time. However, it is still important to identify where street trees are being planted or preserved, as well as the type, size, and planting details, so that future credits may potentially be obtained. <sup>note 15</sup> See [Table 3.6](#) for details about street tree preservation and planting credits by jurisdiction.

TABLE 3.6. STREET TREE PERFORMANCE CREDITS				
Tree Preservation				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <sup>note a</sup>	Retention value of 20 ft <sup>3</sup> per tree	n/a	n/a	n/a
DE <sup>note b</sup>	n/a	n/a	n/a	n/a
MD <sup>note c</sup>	n/a	n/a	n/a	n/a
NY <sup>note d</sup>	Deducted from total site area when computing water quality volume requirement <sup>note e</sup>	n/a	n/a	n/a
PA <sup>note g</sup>	Volume Reduction. = Existing Tree Canopy (ft <sup>2</sup> ) x 1/2 in. / 12	n/a	n/a	n/a
VA <sup>note h</sup>	n/a	n/a	n/a	n/a
WV <sup>note h</sup>	n/a	n/a	n/a	n/a
CBP <sup>note i</sup>	n/a	n/a	n/a	n/a
Tree Planting				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <sup>note a</sup>	Retention value of 10 ft <sup>3</sup> per tree	n/a	n/a	n/a
DE <sup>note b</sup>	n/a	n/a	n/a	n/a
MD <sup>note c</sup>	n/a	57% or 93% per 100 trees	77% or 94% per 100 trees	66% or 71% per 100 trees
NY <sup>note d</sup>	Deducted from total site area when computing water quality volume requirement <sup>note f</sup>	n/a	n/a	n/a
PA <sup>note g</sup>	Deciduous Trees: Volume Reduction = 6 ft <sup>3</sup> Evergreen Trees: Volume Reduction = 10 ft <sup>3</sup>	n/a	n/a	n/a
VA <sup>note h</sup>	n/a	n/a	n/a	n/a
WV <sup>note h</sup>	n/a	n/a	n/a	n/a
CBP <sup>note i</sup>	n/a	93% or 94%	94% or 95%	71% or 80%

See notes on page 32.

## Notes for Table 3.6

- a. DC: Preserved or planted with an average mature spread of greater than or equal to 35 feet and a minimum of 1,500 cubic feet of rootable soil volume per tree (or, for shared rooting space amongst multiple trees, a minimum of 1,000 cubic feet) are eligible to receive runoff reduction credit for the required 1.2 inch storm. Planted trees must be container grown, or ball and burlap, with a minimum caliper size of 1.5 inch. Trees planted with another BMP (e.g., a bioretention area) also receive the 10 cubic foot retention value. Additional criteria may include tree species, size, condition, and location. [Return to reference.](#)
- b. DE: Urban Tree Planting (Urban Tree Canopy) is included as a BMP in Delaware's Phase II WIP, with a goal of maintaining the existing 99 acres of urban tree planting. However, no site scale tree practice credit is available in the existing stormwater manual. [Return to reference.](#)
- c. MD: Based on the pollutant load reduction expected when less than or equal to 100 trees per acre are planted on pervious or impervious urban land cover. This practice provides an impervious acre equivalent of 0.38 acres for trees planted on pervious urban surfaces, or 1 acre for trees planted on previously impervious urban surfaces. To claim credits, a survival rate greater than or equal to 100 trees per acre (aggregated) is necessary with at least 50 percent of the trees less than or equal to 2 inches in diameter at 4 and a half feet above ground level. The lower percentage shown corresponds to the amount of pollutant reduction credited when a pervious area is converted to an urban tree planting area, and the higher percentage corresponds to when an impervious area is converted to an urban tree planting area. [Return to reference.](#)
- d. NY: The maximum reduction permitted for new and existing trees is 25 percent of directly connected ground level impervious area. The area considered for runoff reduction is limited to the pervious area in which trees are planted. In an urban setting, the area is calculated as follows: For up to a 16 foot diameter canopy of a mature tree, the area considered for reduction shall be half the area of the tree canopy. For larger trees, the area credited is 100 square feet per tree. [Return to reference.](#)
- e. NY: Applicable to existing trees with less than or equal to 4 inch caliper whose canopies are within 20 horizontal feet of directly connected ground level impervious areas can be used for runoff reduction. [Return to reference.](#)
- f. NY: New trees species must be chosen from the approved list. New deciduous trees must be less than or equal to 2 inch caliper and new evergreen trees must be greater than or equal to 6 feet tall to be eligible for the reduction. [Return to reference.](#)
- g. PA: No more than 25 percent of the runoff volume can be mitigated through the use of trees. For existing trees, the existing tree canopy must be within 100 ft of impervious surfaces to gain credit. Existing trees must be 4 inch caliper or larger; non-native species are not applicable. Planted trees must be native species, greater than or equal to 2 inch caliper, and greater than or equal to 6 feet tall. [Return to reference.](#)
- h. The VA and WV stormwater manuals do not currently include individual or street trees as separate green infrastructure or low impact development practices. However, some local communities like Montgomery County, MD, have incorporated a crediting system into design specifications. [Return to reference.](#)
- i. Chesapeake Bay Program (CBP) numbers are based on the CBP Phase 5.3.2 Watershed Model. The credit is based on the pollutant load reduction expected when land cover is converted from either pervious urban to forest (such as planting a tree in a grassy median) or impervious urban to forest. The lower percentage is applied to the former category. Currently, the model definition stipulates that, in order to get credit for tree planting, the planted area must be dedicated to being treed; that is, if it dies, one will be replanted. The "acreage" can be an aggregate of smaller sites Bay-wide or 100 trees equals 1 acre. An expert panel is currently reviewing CBP's urban tree planting/expanded tree canopy requirements that will be incorporated in future phases of the CBP watershed model. [Return to reference.](#)

## MAINTENANCE CONSIDERATIONS

Planting or preserving existing trees in the public right-of-way requires maintenance to keep them attractive and functioning, and long-term maintenance and irrigation needs should be part of the initial planning. Proper watering is critical for the first two to three growing seasons, in particular. Pruning, weeding, and mulching at specific times of the year are also common maintenance considerations. See [Table 3.7](#) for more detail.

TABLE 3.7. MAINTENANCE CONSIDERATIONS FOR STREET TREES	
Frequency	Maintenance Task
After installation	» Inspect tree for health and acclimation to new environment at least three times during establishment, and then every five years for the life of the tree.
After one year	» Remove stakes from tree.
First three years	» For the first year between April to October, give the tree 25 gallons of water weekly via a slow release device. For years two and three during April to October, give the tree 25 gallons of water bi-monthly via a slow release device.
Quarterly	» Remove weeds and trash.
Annually	» Mulch with 3 inch double ground shredded hardwood mulch, placing the mulch in a ring around the tree trunk, close enough to capture and infiltrate stormwater but far enough away from the trunk so that it is not mounded around or touching the trunk. Mulching should occur annually between Feb-April or as needed.
As-needed	» Prune the tree properly.



# Streetscape Bioretention

## OVERVIEW

Streetscape bioretention practices are versatile stormwater treatment systems that capture runoff from impervious surfaces during small storm events and allow it to infiltrate through the soil media. Streetscape bioretention practices also typically provide greater water quality improvements than other low impact development practices. As the water flows through the system, pollutants are removed from the stormwater runoff through a variety of mechanisms including adsorption, microbial activity, plant uptake, filtration, and sedimentation. The practices generally have an underdrain when designed as part of the streetscape, but may be open-bottomed when the in-situ soils have an acceptable infiltration rate.

## TYPES

Bioretention practices can generally be described as flat-bottomed cells that filter stormwater runoff through plants, an engineered soil mix, and often an underdrain. A range of shapes, sizes, and layouts can be used to adapt bioretention features to street configurations, grades, soil conditions, and space availability. Flexibility in terms of size and configuration allows streetscape bioretention practices to be adjusted for utility and other conflicts. Bioretention practices commonly associated with public right-of-way retrofits include rain gardens, stormwater curb extensions, stormwater planters, tree box filters, and bioswales.

## RAIN GARDENS

Rain gardens and micro-bioretenion areas are planted depressions with flat bottoms that are designed to slow down, collect, and clean stormwater runoff from small areas — such as an individual rooftop or another on-lot feature — giving water time to infiltrate into the ground or evapotranspirate into the air. Their small footprint allows rain gardens to easily fit into the urban landscape, but they are most applicable for residential yards and other small-scale applications. State requirements vary, but in general, rain gardens may be used to treat drainage areas of up to 2,500 square feet and 100 percent impervious surface areas.



## STORMWATER CURB EXTENSIONS

Stormwater curb extensions are designed to handle a larger amount of stormwater runoff. Stormwater flowing down the street is directed to the street bioretention facility through inlets or curb cuts. There, the runoff temporarily ponds above the surface and then filters through the bed. Where urban spaces permit, stormwater curb extensions can be designed to fully infiltrate down to the soils below. In most cases, the filtered runoff is collected in an underdrain and returned to the sewer system. Because public rights-of-way are primarily impervious and bioretention facilities work best with smaller drainage areas, the contributing drainage area for a single facility is generally limited to one-quarter to one-half acre, depending on state requirements.



## TREE BOX FILTERS

Tree box filters are installed in the sidewalk zone where urban street trees are common. They can be very effective at controlling runoff, especially when distributed and connected along the length of a street. Runoff is directed to the tree box, where it is cleaned by vegetation and soil before entering a catch basin. The runoff collected in the tree boxes helps irrigate the trees. Depending on the size and treatment requirements, the maximum drainage area for one tree box filter is around one-half to three-quarters acres.



## STORMWATER PLANTERS

Stormwater planters, commonly referred to as foundation planters, are an on-site retrofit option for treating rooftop runoff in ultra-urban areas. These flexible practices can be placed either above the ground or at grade between buildings and roadways, and can be designed to allow water to fully seep into the ground (i.e., infiltration planters) or as flow-through planters. Like stormwater curb extensions, the allowable drainage area may vary by state but is typically limited to one-quarter acre or less.



## BIOSWALES

Bioswales are bioretention facilities configured as linear channels that have a longitudinal slope of 1 to 5 percent to help convey stormwater. Check dams break the swale into sections to prevent erosive velocities and control flow depth. The longitudinal slope does not allow the system to provide as much retention storage as in other bioretention systems, so performance credits for bioswales differ from other bioretention devices. Bioswales also tend to have smaller surface area per drainage area as compared to bioretention. The maximum contributing drainage area that a bioswales can treat varies by state, but for highly impervious areas, is generally set at 2.5 acres.

## DESIGN CONSIDERATIONS

Streetscape bioretention facilities generally consist of inflow, vegetation, mulch layer, filter media, transition layer, gravel reservoir, and an underdrain. Streetscape bioretention facilities work best with smaller contributing drainage areas in order to ensure that they are not overwhelmed during large storm events by erosive runoff velocities. Except for bioswales, the surface area is generally 3 to 6 percent of the contributing drainage area, depending on the imperviousness and the desired bioretention ponding depth. <sup>note 16</sup> Bioswales should be approximately 3 to 10 percent of the size of the contributing drainage area, depending on the amount of impervious surface. <sup>note 17</sup>

Streetscape bioretention components will vary depending on the bioretention type; whether stormwater runoff in excess of what the facility can handle runs through or bypasses the system; the presence of hotspots or karst terrain; and whether or not it is designed for water to fully infiltrate into the ground. It is important to ensure that the selected practice or practices are correctly sized for the landscape.

An **inlet** or flow entrance conveys stormwater runoff to the streetscape bioretention area via sheet flow over a vegetated or gravel filter level spreader strip. Inlets must be properly sized and should be placed far enough away from any outlet structures to prevent water from leaving the system too quickly. There should be sufficient drop from the pavement edge to the entrance to the bioretention area

to ensure water can get into the bioretention area. When water enters via a roof leader or where an inlet cannot be used, stones or some other material must be employed to dissipate the energy and prevent erosion.

A **ponding area** provides temporary storage of stormwater runoff and allows larger debris and sediment to settle out of the water. Ponding depths for urban streetscape bioretention areas are usually shallower than non-urban applications (6 to 12 inches, versus 6 to 18 inches). State regulations may vary.

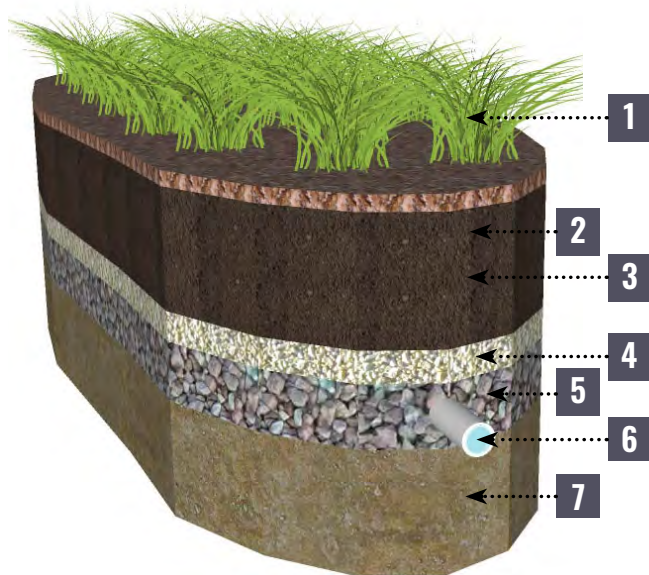
**Vegetation** can vary, but Bay-friendly native plants that promote aeration of soils and are adaptable to wet-dry soil conditions are preferred. Plants should be selected with long-term maintenance in mind. Simpler planting palates limit the number of plant types incorporated in the design and make for simpler maintenance over the long-term. For areas with greater visibility, a more varied planting palate may be preferred.

A proper **filter media** and a **mulch layer** are essential for bioretention facilities to be effective. The filter media typically contains 24 inches or more of pre-blended engineered soil mix designed as per regulatory specifications to maintain permeability over time while also providing nutrients to support plant growth. The mulch layer, or an appropriate alternative, provides a medium for biological growth and acts as the last line of defense for protecting the filter media. It is important that the mulch be replaced annually and that it is not laid on too thick.

An **underdrain** is required where underlying soils have low permeability in order to prevent water from saturating the soils for too long. Even with an underdrain, however, systems can be designed to boost stormwater runoff performance by slowing down the release of water to the sewer system. The underdrain layer should be separated from the filter media by a choker layer, or layer of choker stone.

FIGURE 3.3. TYPICAL DETAILS FOR A STREETScape BIORETENTION FACILITY

- |                            |                     |
|----------------------------|---------------------|
| 1. Native plantings        | 4. Transition layer |
| 2. Mulch layer             | 5. Gravel reservoir |
| 3. Bioretention soil media | 6. Underdrain       |
|                            | 7. Undisturbed soil |



### SPECIAL DESIGN CONSIDERATIONS

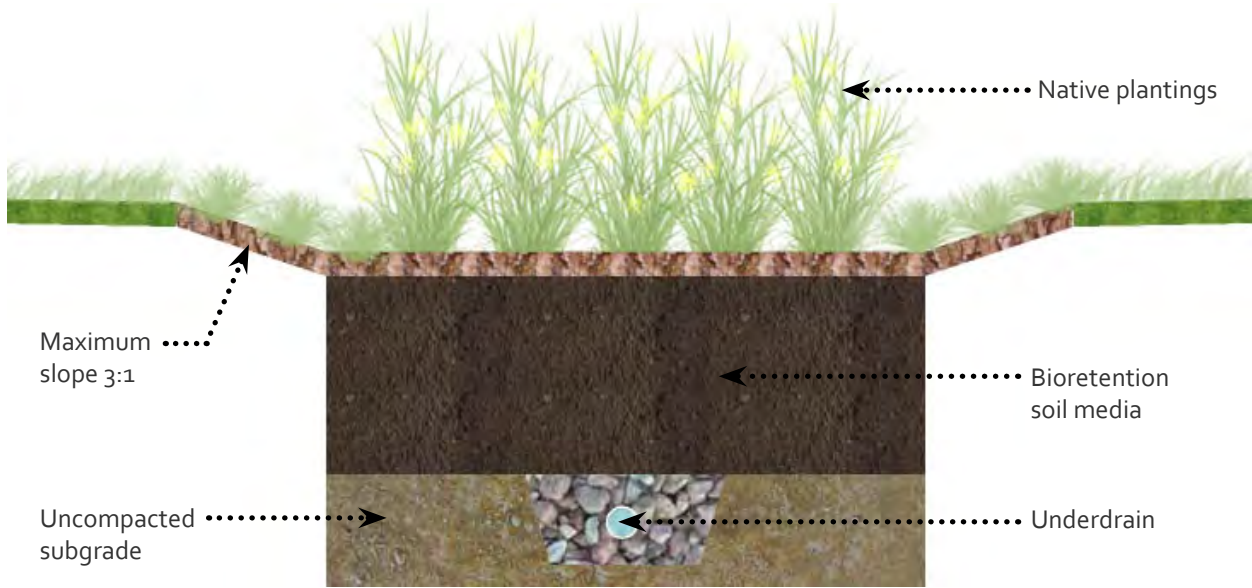
#### Rain gardens, stormwater curb extensions, stormwater planters, and tree box filters:

Care must be taken to protect existing site features such as utilities, structures, and mature trees when designing and installing urban stormwater retrofits. Public utilities are not always well-marked. In some cases, utilities

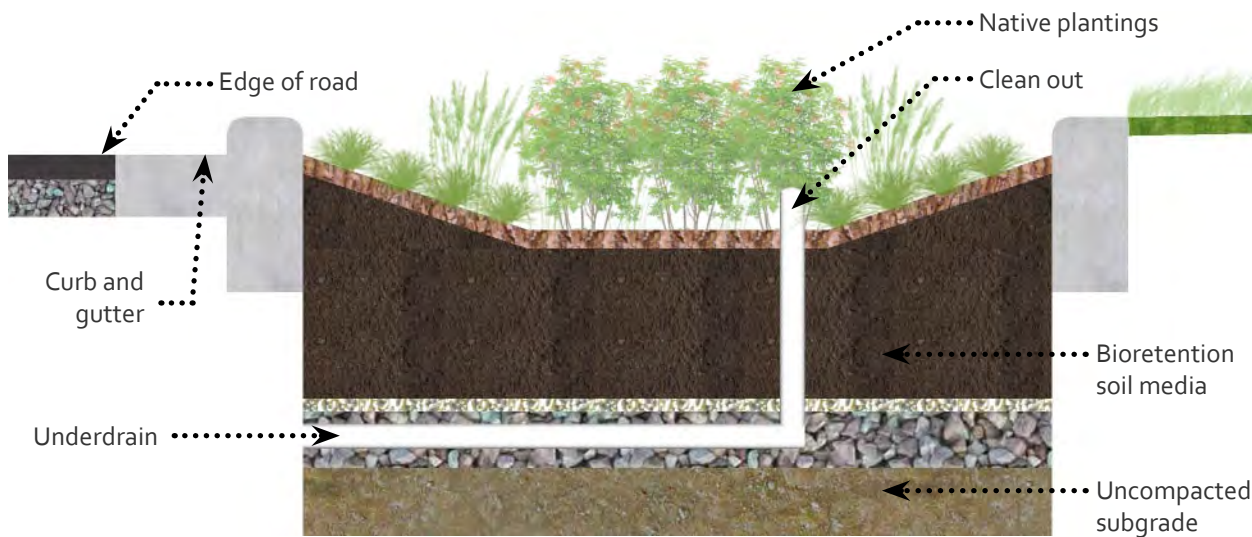
may be buried at shallow depths, limiting the horizontal and vertical clearance available for bioretention facilities. Concrete duct banks, in particular, are expensive to move and should be avoided. Protect any water and sewer laterals (e.g., smaller sewer pipe for house connections) when locating nearby stormwater retrofits.

Roadway or structural stability may be a concern for practices installed in the public right-of-way or near buildings. In these cases, it may be necessary to provide structural support such as a retaining wall or an impermeable liner on the bioretention facility's road or building side. Such measures will reduce the possibility of nearby compacted soils migrating into the less compacted soils and will keep water from penetrating an existing foundation or underground utility. Bioretention areas should not be hydraulically connected to foundations. Some types (e.g., stormwater planters) may require no building setback so long as impermeable liners and underdrains are utilized. Other setbacks vary by the streetscape bioretention area's design and whether it is up- or down-gradient from the structure. In general, a minimum 10 foot setback is required.

While existing utilities and buildings pose obstacles, existing healthy trees — with their inherent stormwater benefits — represent an opportunity. Protecting healthy and mature trees along a right-of-way corridor will help determine the placement and type of bioretention practices available. When installing new tree boxes, the presence of overhead wires must be accounted for with tree placement and species selection. State requirements vary in terms of the amount of soil volume required, but in general, a minimum of 400 cubic feet is needed.



**1** FIGURE 3.4. RAIN GARDEN

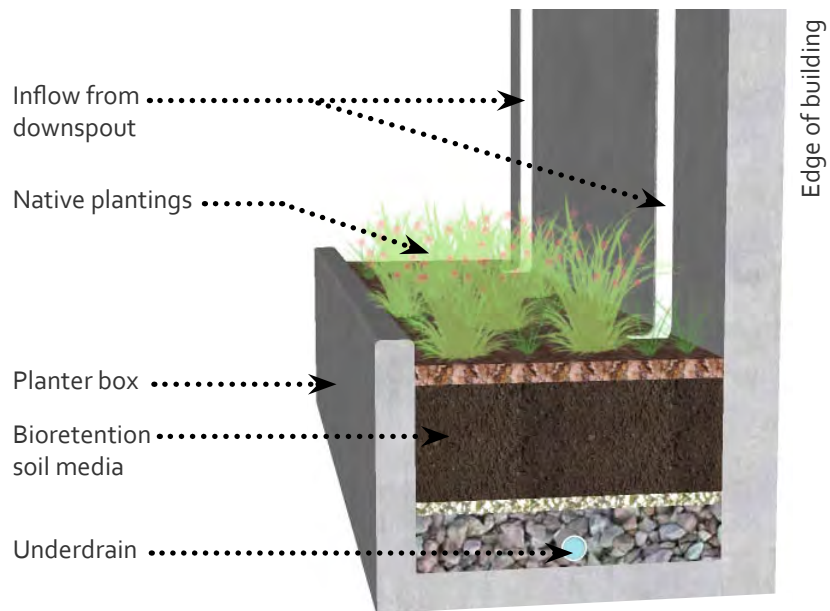


**2** FIGURE 3.5. STORMWATER CURB EXTENSION



3

FIGURE 3.6. TREE BOX FILTER



4

FIGURE 3.7. STORMWATER PLANTER

**Bioswales:**

The design specifications for bioswales differ slightly from other bioretention practices because they act primarily as conveyance systems. They are not designed to retain as much volume; instead, a longitudinal slope helps move water along. Check dams allow water to pool at different terraces and to reduce any erosive velocities in the channels.

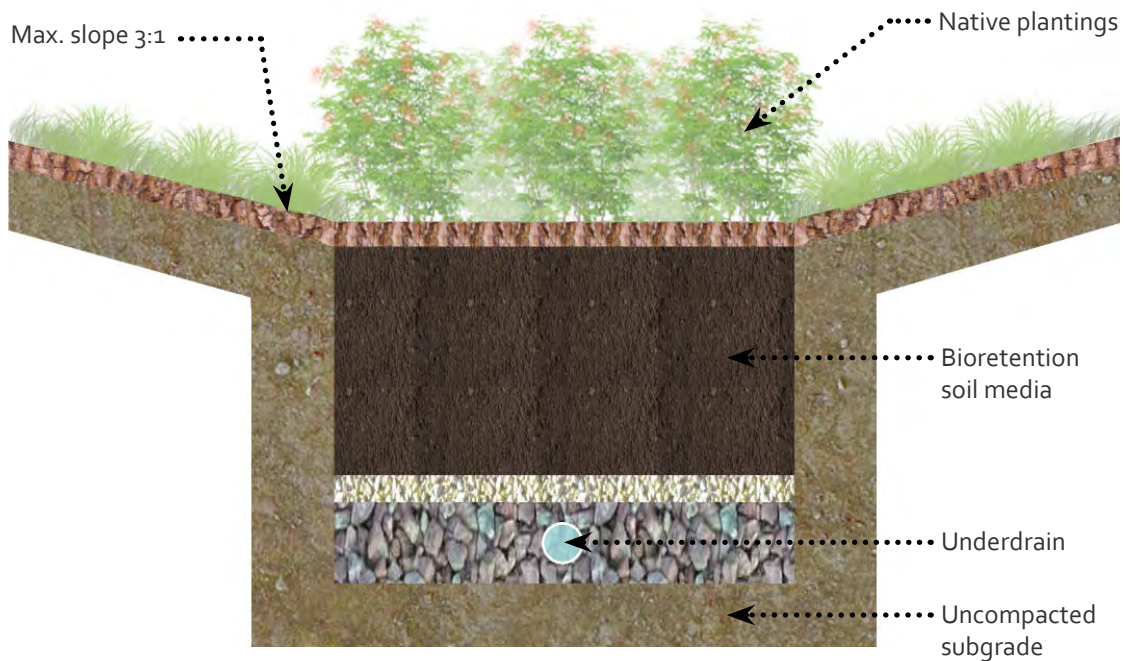
**5**

FIGURE 3.8. BIOSWALE

## IMPROVING STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE

Standard bioretention practices are often a preferred green stormwater practice because they function very well for removing pollutants and reducing runoff volumes. While more difficult to achieve in urban retrofit settings, standard bioretention facilities can sometimes be enhanced to capture greater volumes of stormwater runoff and boost pollution reduction performance.

Bioretention cells designed to fully infiltrate into the underlying soils can be installed to increase the storage and pollutant removal capacity when permeable soils exist underneath. This can be done by increasing the depth of the filter media and removing the underdrain. Where less permeable soils are present, retention times can be lengthened by combining a deeper filter medial layer above the underdrain with a storage area and infiltration sump below the underdrain. An underdrain with an upturned elbow can also be installed. Either option increases the ability for water to infiltrate for a longer period of time before the remaining runoff is directed to the sewer system.

The reality of urban retrofits is that numerous constraints often preclude the use of enhanced performance techniques. Streetscape bioretention facilities often have limited surface area and practice sizing; may require the use of impermeable lining; and must often deal with highly compacted urban soils. In most cases, runoff will be directed to an underdrain. As a result, for some states such as Virginia and West Virginia, rain gardens, stormwater curb extensions, stormwater planters, and tree filters are assumed to have only one design level.

Table 3.8 outlines the potential performance credits that rain gardens, stormwater curb extensions, stormwater planters, and tree filters provide, based on current state regulations and via the state's Chesapeake Bay TMDL reporting process. Actual credits will vary based on a variety of factors, such as the land cover type and hydrological soil conditions.

TABLE 3.8. BIORETENTION PERFORMANCE CREDITS FOR RAIN GARDENS, STORMWATER CURB EXTENSIONS, STORMWATER PLANTERS, AND TREE BOX FILTERS

Standard Level 1 Designs (With Underdrain)				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <sup>note.a</sup>	60% for Storage Volume (Sv) provided	100% for Sv provided	n/a	n/a
DE	50% of Retention Storage	100% of load reduction + 80% removal efficiency	100% of load reduction + 40% removal efficiency	100% of load reduction + 30% removal efficiency
MD <sup>note.b</sup>	Treat target rainfall to meet ESD standards	90%	60%	50%
NY <sup>note.c</sup>	40% of RR in C & D soils (rain gardens & bioretention); 45% of RR in C or 30% of RR in D soils (planters)	n/a	n/a	n/a
PA	Based on calculation	85%	85%	30% (NO <sub>3</sub> only)
VA <sup>note.d</sup>	40%	n/a	Change in EMC = 25%, Mass load removed = 55%	Change in EMC = 40%, Mass load removed = 64%
WV <sup>note.e</sup>	60% of Design Volume provided	70%	55%	64%
CBP	n/a	A, B soils: 80% C, D soils: 55%	A, B soils: 75% C, D soils: 45%	A, B soils: 70% C, D soils: 25%
Standard Level 2 Designs (No/Raised Underdrain)				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <sup>note.a</sup>	100% for Sv provided	None since 100% RR value given	n/a	n/a
DE	100% of Retention Storage	100% of Load Reduction	100% of Load Reduction	100% of Load Reduction
MD <sup>note.b</sup>	n/a	n/a	n/a	n/a
NY <sup>note.c</sup>	For A and B soils: 100% RR (rain gardens & planters), or 80% of RR (other bioretention)	n/a	n/a	n/a
PA	n/a	n/a	n/a	n/a
VA <sup>note.d</sup>	80%	n/a	Change in EMC = 50%, Mass load removed = 90%	Change in EMC = 50%, Mass load removed = 90%
WV <sup>note.e</sup>	100% of Design Volume provided (limited in urban situations)	95%	90%	92%
CBP	n/a	A, B soils: 90%	A, B soils: 85%	A, B soils: 80%

See notes on page 44.

### Notes for Table 3.8

- a. For DC, additional retention value can be achieved if trees are utilized as part of a bioretention area, pending minimum requirements are met. [Return to reference.](#)
- b. For MD, Maryland Department of the Environment’s recommendation is to follow its current guidance that uses water quality volume (WQv) as the standard for retrofitting (and not standard vs. enhanced designs). Also, streetscape bioretention, in many cases, will be considered a micro-bioretention practice designed to treat 20,000 sf or less. Micro-bioretention practices shall capture and store at least 75 percent of the ESDv. [Return to reference.](#)
- c. For NY, runoff reduction volumes for rain gardens and stormwater planters are separated out. [Return to reference.](#)
- d. Rain gardens, stormwater curb extensions, stormwater planters, and tree box filters are limited to Level 1 design credits in Virginia. The numbers shown in gray are those for bioretention practices in less constrained environments. EMC refers to the change in event mean concentration through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate. [Return to reference.](#)
- e. For West Virginia, rain gardens, stormwater curb extensions, stormwater planters, and tree filters are assumed to have only one design level. It is further assumed that the extended filtration function necessary for Level 2 designs is restricted due to limited surface area and practice sizing. Additional storage (and runoff reduction capacity) can be built into these bioretention facilities by increasing the soil media and/or underdrain layer depth, or, in rare cases, by designing an open-bottomed system that allows for infiltration. [Return to reference.](#)

## IMPROVING STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE FOR BIOSWALES

Some states provide credit when bioswale performance is enhanced by either removing the underdrain — where soil infiltration rates permit — or by adding 12 inches or more of underground storage layer below the invert level of the underdrain. [Table 3.9](#) outlines the potential performance credits available for bioswales.

FIGURE 3.5. BIOSWALE CROSS SECTIONS

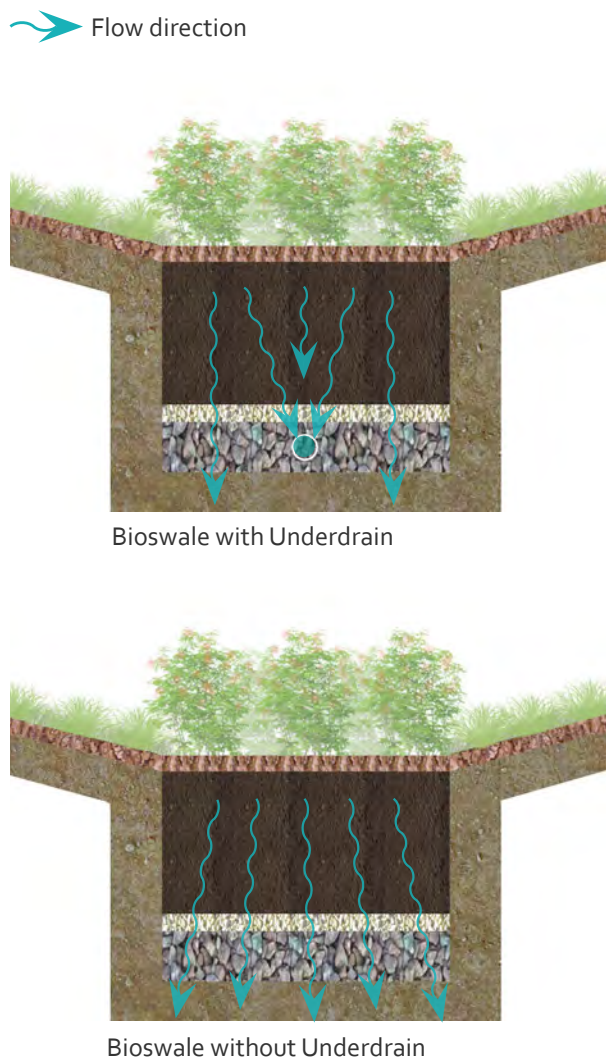


TABLE 3.9. BIOSWALE PERFORMANCE CREDITS				
Standard Level 1 Designs (With Underdrain)				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC	60% for Storage Volume (Sv) provided	100% of Sv provided	n/a	n/a
DE	50% of retention storage (A & B or compost- amended C soil) or 25% of retention storage (C & D soil)	n/a	n/a	n/a
MD <sup>note a</sup>	Treat target rainfall to meet ESD standards	90%	60%	50%
NY	40% (A & B soils) or 20% (C & D soils)	n/a	n/a	n/a
PA	Based on calculation	50%	50%	20% (NO <sub>3</sub> only)
VA <sup>note b</sup>	40%	n/a	Change in EMC = 20%; Mass load removed = 52%	Change in EMC = 25%; Mass load removed = 55%
WV	55% of Design Volume provided	65%	52%	55%
CBP	n/a	80%	75%	70%
Enhanced Level 2 Designs (No Underdrain)				
State	Runoff Reduction (RR)	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC	n/a	n/a	n/a	n/a
DE	n/a	n/a	n/a	n/a
MD <sup>note a</sup>	n/a	n/a	n/a	n/a
NY	n/a	n/a	n/a	n/a
PA	n/a	n/a	n/a	n/a
VA <sup>note b</sup>	60%		Change in EMC = 40%; Mass load removed = 76%	Change in EMC = 35%; Mass load removed = 74%
WV	100% of Design Volume provided	90%	76%	74%
CBP	n/a	n/a	n/a	n/a

#### Notes for Table 3.9

- Maryland Department of the Environment's recommendation is to use water quality volume (WQv) as the standard for retrofitting (and not standard vs. enhanced designs). [Return to reference.](#)
- For VA, EMC refers to the change in event mean concentration through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate. [Return to reference.](#)

## MAINTENANCE CONSIDERATIONS

Bioretention features require maintenance to ensure performance. Well-planned maintenance increase the long-term system performance. It can also extend the practice’s life cycle. Overall maintenance needs will vary by the design based on the size; the selection of pretreatment measures, planting palate, and ponding depth; and whether the treatment is an on-line or off-line system. Typical maintenance tasks are outlined in [Table 3.10](#).

Standing water is the most common non-routine maintenance problem. If water remains on the surface more than 24-72 hours after a storm (depending on state requirements for specific practices), adjustments to the grading may be required or underdrain repairs needed. The filter bed’s surface can also be problematic and should be checked after the first several storm events for accumulated sediment or a fine crust. If this happens, it will be necessary to verify that the underdrains are functioning. Other measures may also be required. <sup>note 18</sup>

TABLE 3.10. MAINTENANCE CONSIDERATIONS FOR STREETScape BIORETENTION	
Frequency	Maintenance Task
<b>After installation</b>	<ul style="list-style-type: none"> <li>» For the first 6 months following construction, the practice and contributing drainage area should be inspected at least twice after storm events that exceed ½ inch of rainfall. Conduct any needed repairs or stabilization.</li> <li>» Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover.</li> <li>» One-time spot fertilization may be needed for initial plantings.</li> <li>» Water a minimum of once a week during the first 2 months and then as needed during first growing season (April-October), depending on rainfall.</li> <li>» Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.</li> </ul>
<b>At least 4 times per year</b>	<ul style="list-style-type: none"> <li>» Mow grass filter strips and bioretention with turf cover.</li> <li>» Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow.</li> </ul>
<b>Twice during growing season</b>	<ul style="list-style-type: none"> <li>» Spot weed, remove trash, and rake the mulch.</li> </ul>
<b>Annually</b>	<ul style="list-style-type: none"> <li>» Conduct a maintenance inspection.</li> <li>» Supplement mulch in devoid areas to maintain a 3 inch layer.</li> <li>» Prune trees and shrubs.</li> <li>» Remove sediment in pretreatment cells and inflow points.</li> </ul>
<b>Once every 2-3 years</b>	<ul style="list-style-type: none"> <li>» Remove sediment in pretreatment cells and inflow points.</li> <li>» Remove and replace the mulch layer.</li> </ul>
<b>As-needed</b>	<ul style="list-style-type: none"> <li>» Add reinforcement planting to maintain desired vegetation density.</li> <li>» Remove invasive plants using recommended control methods.</li> <li>» Remove any dead or diseased plants.</li> <li>» Stabilize the contributing drainage area to prevent erosion.</li> </ul>

# Permeable Paving

## OVERVIEW

Permeable pavement provides a good alternative to conventional pavement systems for green street retrofit projects. Permeable pavement systems eliminate direct stormwater runoff by allowing water to penetrate a subsurface storage area through the pavement itself. From there, it either infiltrates the soils below or is released into the sewer system.

Permeable pavement can be used in a variety of settings, including low-traffic or low-speed streets, bike lanes, parking areas, pedestrian crossings, and sidewalks. However, state and local requirements and manufacturer specific recommendations should be consulted prior to designing and installing any permeable pavement system.

## TYPES

All permeable pavements employ a similar structure, consisting of a surface pavement layer, an optional bedding layer (as required by the manufacturer), an underlying crushed stone reservoir layer, and an optional water quality filter layer. Several types of permeable pavement surfaces are applicable to public right-of-way settings. These include porous asphalt and pervious concrete that, like conventional pavement, are poured-in-place applications; and interlocking permeable pavements that are delivered ready-to-install. While other surfaces may also be employed in the public right-of-way, these are most common.

## POROUS ASPHALT

Porous asphalt has been successfully used for right-of-way applications such as on-street parking, low-volume neighborhood streets, alleys, and trail surfacing. Porous asphalt is poured-in-place and, depending on the temperature and humidity levels, requires a thickness of 2 to 4 inches and between 2 to 7 days of curing time before being ready for use. While similar in color and appearance to conventional asphalt, its open structure allows water to drain through and is also a “cooler” pavement choice. With proper maintenance, porous asphalt can last up to 20 years.



## PERVIOUS CONCRETE

Pervious concrete is concrete mixed with an open grade sand aggregate that creates void spaces large enough to allow water to drain through. Pervious concrete is a poured-in-place application that has been successfully incorporated into a variety of public right-of-way projects. These include installations on residential streets, paths and walkways; light duty and commercial parking areas; and transit and pedestrian areas. Its surface thickness varies from 5 to 8 inches based on the intended use and anticipated traffic loads and requires a curing time of up to 10 days. Pervious concrete is not recommended in areas where large vehicles travel. Heavy loads can deform or crack the pavement. Properly maintained pervious concrete has a life span of up to 30 years.



## INTERLOCKING PERMEABLE PAVERS

Interlocking permeable pavers are available for even the smallest of applications, such as around urban street trees. They can help provide charm and character to both residential and urban streetscapes and have been successfully implemented in walkways, plazas, alleyways, and parking areas for larger projects. Pavers must be placed by hand or machine on an even surface. The surface is immediately available for use upon installation, and the typical life span for well-maintained interlocking pavers is 20 to 30 years.



## DESIGN CONSIDERATIONS

A permeable pavement retrofit is generally designed to treat two to four times the area of the impervious surface it is replacing <sup>note 19</sup>. All permeable pavements employ a similar structure, consisting of a surface pavement layer, an optional bedding layer (as required by the manufacturer), an underlying crushed stone reservoir layer, and an optional water quality filter layer. Other elements that may or may not be employed in a permeable pavement application include an underdrain, an observation well, and geotextile fabric.

The **bedding layer** is applied when required by the manufacturer or regulations, such as when installing interlocking permeable pavers in order to level out the surface materials. This layer generally consists of several inches of smaller stones that have been cleaned. For lighter-load porous asphalt and pervious concrete applications, the bedding layer is often optional.

The **reservoir layer** lies beneath the bedding layer and provides for the temporary storage of infiltrated water as well as structural support to the surface layer. The size of the reservoir layer depends on a variety of factors, such as the amount of precipitation, the capacity of the soil to soak up stormwater, and the structural requirements for the expected traffic load the pavement is intended to support. The clean and washed crushed stones within the reservoir layer are generally larger than those used in the bedding layer.

Beneath the reservoir layer, or between the bedding and the reservoir layer, additional water quality benefits can be achieved by adding an optional **water quality filter layer**. This layer generally consists of washed course sand to enhance filtration of pollutants and delay infiltration into the subgrade. The sand is placed over choker stone to prevent it from filtering down to the reservoir layer (when placed above the reservoir layer) or to prevent the sand from mixing with the underlying soils (when placed below the reservoir layer). When a water quality filter layer is used, care must be taken to ensure that no structural issues will arise.

In the past, **geotextiles** were used between layers to help keep layers in place. They are no longer recommended due to increased clogging potential. Instead, a drainage and separation fabric should be used on the sides to prevent migration of the soils into the stone layers. If infiltration down to the soils beneath must be completely limited, an impermeable liner should be placed beneath the system.

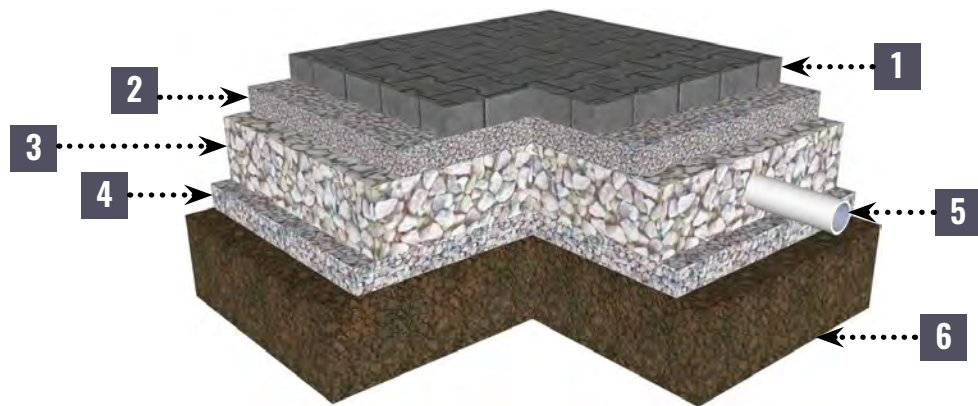
The use of an **underdrain** promotes drainage of the reservoir layer, particularly where low-infiltration soils are present. Even when not required, incorporating an underdrain that is capped at the downstream end of the structure provides an option in the future if the system becomes clogged. Measures to prevent clogging include limiting its use to areas where the drainage area is almost 100 percent impervious and avoiding high-trash or sediment areas.

It is sometimes required and also recommended that a vandal-resistant **observation well** be installed in the farthest down-slope area so that the exfiltration rate can be monitored.

In the event that a storm event is larger than the system is intended to handle, the system should include methods to convey the storm directly to the sewer system.

FIGURE 3.10. TYPICAL LAYERS OF PERMEABLE PAVEMENT

- |  |  |
|--|--|
| 1. Permeable surface material                  | 4. Optional water quality filter layer |
| 2. Bedding layer (as directed by manufacturer) | 5. Underdrain (as required)            |
| 3. Reservoir layer                             | 6. Uncompacted subgrade soil           |



## IMPROVING STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE

Standard permeable pavement systems are built with an underdrain at the bottom of the reservoir layer to allow water to filter through the system — typically within a 24 hour period — giving time for a minimal amount of water to evaporate from the surface material or infiltrate down to the soils below, while the rest of the filtered water is directed back into the sewer system. The benefit of employing a standard system is a partial reduction in stormwater volumes, a reduction in stormwater pollutants, and some slowing down of larger storm velocities.

There are several design elements, however, that can be employed to enhance both the stormwater runoff reduction and water quality benefits of permeable pavement systems:

- » Installing capped underdrains (preferred) or not installing underdrains at all to allow the system to fully infiltrate within a given time frame; or
- » Employing other features to slow down the drainage time and to encourage the additional uptake of pollutants, such as elevating the underdrain and providing a water quality filter layer and infiltration sump underneath; modifying a standard underdrain with an upturned elbow to slow the drawdown of runoff and increase denitrification; and restricting the size of the orifice opening (where stormwater discharges) to encourage slower drawdown.

### STANDARD PERMEABLE PAVEMENT SYSTEMS PROVIDE:

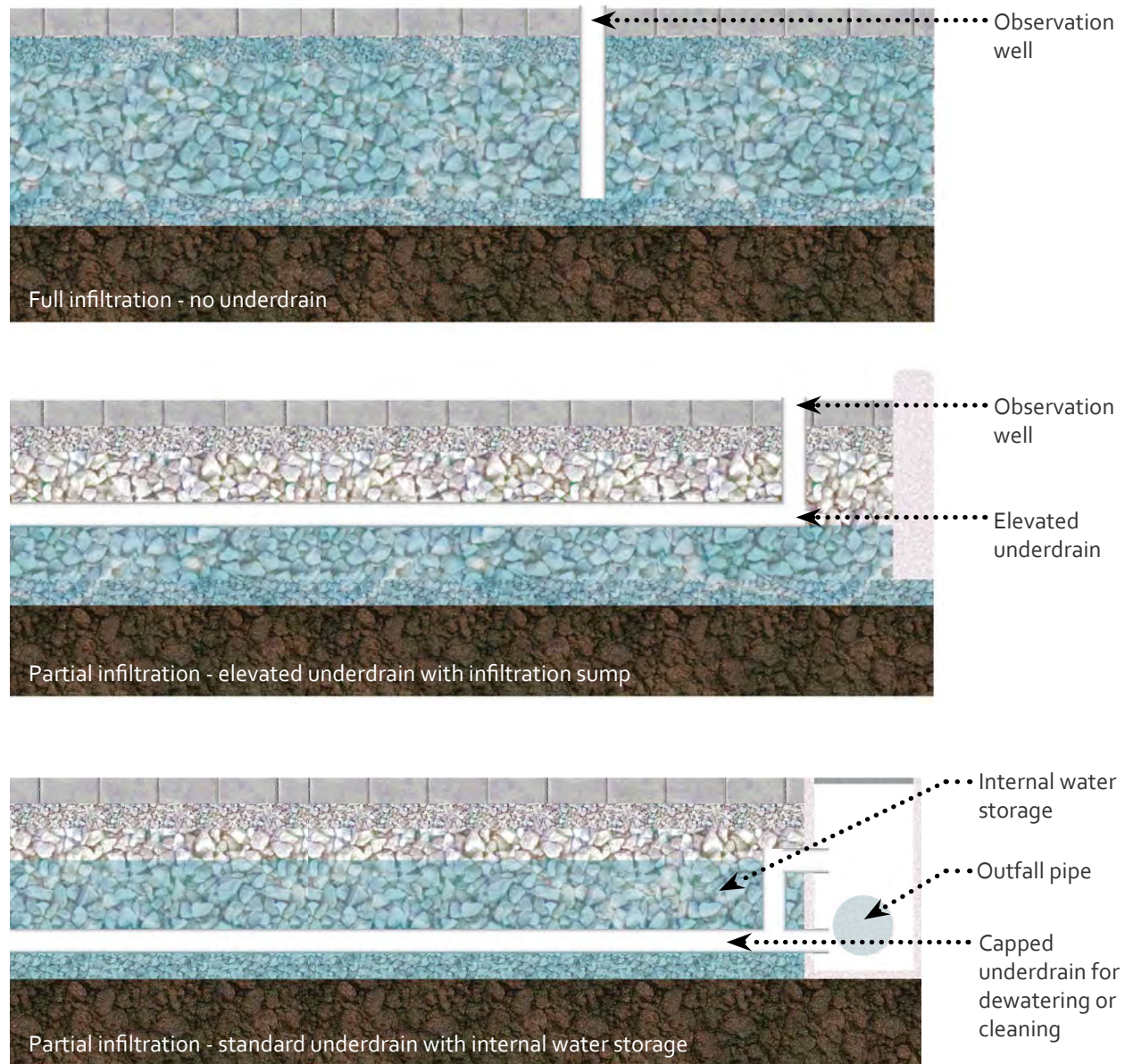
- » Partial reduction in stormwater volume due to evaporation and limited infiltration
- » Improved water quality
- » Prolonged flow time of stormwater runoff to reduce the peak discharge and runoff volume of large storms

### ENHANCED PERMEABLE PAVEMENT SYSTEMS PROVIDE:

Increased runoff reduction through full or partial infiltration

- » Additional water quality improvements
- » Additional attenuation of large storm events

FIGURE 3.11. TYPES OF ENHANCED PERMEABLE PAVEMENT SYSTEMS



### STORMWATER RUNOFF AND POLLUTION REDUCTION PERFORMANCE CREDITS

The amount of credit available for employing standard or enhanced designs can vary across Chesapeake Bay jurisdictions. A summary of the potential stormwater runoff and pollution reduction performance credits available for permeable pavement in the various Chesapeake Bay jurisdictions and by the Chesapeake Bay Program Office are provided in [Table 3.11](#).

TABLE 3.11. PERMEABLE PAVEMENT PERFORMANCE CREDITS				
Standard Level 1 Designs (With Underdrain)				
State	Runoff Reduction	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <small>note.b</small>	4.5 ft <sup>3</sup> per 100 ft <sup>2</sup> of practice area	65% for storage volume provided	n/a	n/a
DE	n/a	n/a	n/a	n/a
MD <small>note.c</small>	Curve number based on depth of sub-base and soil type (for A, B, & C soils). No credit for permeable pavement on D soil	90%	60%	50%
NY <small>note.d</small>	n/a	n/a	n/a	n/a
PA	n/a	n/a	n/a	n/a
VA	45%	n/a	59%	59%
WV	45%	n/a	n/a	n/a
CBP	n/a	Water quality filter layer + A, B soils: 70% Water quality filter layer + C, D soils: 55% A, B soils: 70% C, D soils: 55%	Water quality filter layer + A, B soils: 50% Water quality filter layer + C, D soils: 20% A, B soils: 50% C, D soils: 20%	Water quality filter layer + A, B soils: 50% Water quality filter layer + C, D soils: 20% A, B soils: 45% C, D soils: 10%
Enhanced Level 2 Designs (No Underdrain)				
State	Runoff Reduction	Pollutant Reduction, Total Suspended Solids	Pollutant Reduction, Total Phosphorus	Pollutant Reduction, Total Nitrogen
DC <small>note.b</small>	Infiltration systems: 100% Systems with UDa + sump: 4.5 ft <sup>3</sup> per 100 ft <sup>2</sup> for area below underdrain	No additional pollutant credit for area fully infiltrated; 65% for area with underdrain + sump	n/a	n/a
DE	Infiltration systems: 100% systems with underdrain + sump or OC: <small>note.a</small> 100% for area infiltrated	Infiltration systems: 100% Systems with underdrain + sump or OC: 100% for area infiltrated	Infiltration systems: 100% Systems with underdrain + sump or OC: 100% for area infiltrated	Infiltration systems: 100% Systems with underdrain + sump or OC: 100% for area infiltrated
MD <small>note.c</small>	n/a	n/a	n/a	n/a
NY <small>note.d</small>	Infiltration systems: 90% of WQv (for A, B, & C soils) Systems with underdrain: 90% of WQv for area below underdrain	n/a	n/a	n/a
PA	n/a	85%	85%	30% (NO <sub>3</sub> only)
VA	75%	n/a	81%	81%
WV	Infiltration systems: 100% Systems with underdrain + sump: 100% for area in sump; 45% for area at or above underdrain	n/a	n/a	n/a
CBP	n/a	All Infiltration systems (A, B soils): 85%	All Infiltration systems (A, B soils): 85%	Infiltration systems with water quality filter layer: 80% Without water quality filter layer: 75%

See notes on page 54.

### Notes for Table 3.11

- a. OC refers to underdrain outlets fitted with orifice control intended to reduce flow as a means of elongating the stormwater detention time. [Return to reference.](#)
  - b. For DC, peak flow credits may also be available. [Return to reference.](#)
  - c. Maryland Department of the Environment's recommendation is to follow its current guidance that uses water quality volume (WQV) as the standard for retrofitting (and not standard vs. enhanced designs). [Return to reference.](#)
  - d. In order to receive runoff reduction credit, the overflow device must be set at least 2 inches. [Return to reference.](#)
- .....

## MAINTENANCE CONSIDERATIONS

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on all permeable pavements:

- » Spreading sand
- » Re-sealing
- » Re-surfacing
- » Power washing (except for permeable pavement restoration projects)
- » Storage of snow piles containing sand
- » Storage of mulch or soil materials
- » Construction staging on unprotected pavement

The frequency of maintenance will depend largely on the pavement use, traffic loads, and surrounding land use. For large-scale applications, one preventative maintenance task involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the site. Many experts consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Typical maintenance tasks are outlined in [Table 3.12](#).

TABLE 3.12. MAINTENANCE CONSIDERATIONS FOR PERMEABLE PAVEMENT	
Frequency	Maintenance Task
After installation	For the first 6 months following construction, the practice and contributing drainage area should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1-2 months during growing season	Mow grass in grid paver applications.
As needed	Stabilize the contributing drainage area to prevent erosion. Remove any soil or sediment deposited on pavement. Replace or repair any pavement surfaces that are broken, flaked, or pitted.
2-4 times per year (depending on use)	Mechanically sweep pavement with a standard street sweeper to prevent clogging.

## ENDNOTES: CHAPTER 3

1. Schueler, T., Hirschman, D., Novotney, M., Zielinski, J. 2007. Manual 3: Urban Stormwater Retrofit Practices Manual: Urban Subwatershed Restoration Manual Series. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
2. Philadelphia Water Department, 2014. City of Philadelphia Green Streets Design Manual. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
3. Taylor, S., Barrett, M., Leisenring, M., Sahu, S., Pankani, D., Poresky, A., Questad, A., Strecker, S., Weinstein, N. and Venner, M. 2014. Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices. NCHRP Report 792. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
4. One planning-level document is the EPA's Green Streets Handbook from its Municipal Handbook series, last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
5. For a brief overview of the models identified here, as well as other models, visit the EPA Green Infrastructure Modeling Tools page [here](#). Last retrieved on 2/7/17. [Return to page](#).
6. For more information, click [here](#) to visit the EPA website. Last retrieved on 2/7/17. [Return to page](#).
7. Maryland Department of the Environment, 2014. Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated: Guidance for National Pollutant Discharge Elimination Systems Stormwater Permits. August 2014. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
8. District Department of Transportation, 2014. Greening DC Streets. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
9. District Department of Transportation, 2014. Green Infrastructure Standards. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
10. New York State Department of Environmental Conservation, 2010. New York State Stormwater Management Design Manual. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
11. Center for Watershed Protection, 2006. Urban Watershed Forestry Manual Part 3: Urban Tree Planting Guide. Prepared for and published by the United States Department of Agriculture Forest Service, Northeastern Area. NA-TP-01-06. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
12. District Department of Transportation, 2014. Greening DC Streets. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
13. Casey Trees, 2008. Tree Space Design: Growing the tree out of the box. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).

14. US Environmental Protection Agency, 2013. Stormwater to Street Trees. EPA 841-B-13-001. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
15. While street tree plantings and street tree preservation/enhancement are not included in the current versions of most state stormwater guidance manuals, the states generally recognize the benefits and acknowledge volume/pollutant reductions/credit plantings in accordance with guidelines developed by the Chesapeake Bay Program Office. An expert panel is currently reviewing the Chesapeake Bay Program Office's urban tree planting/expanded tree canopy requirements that will be incorporated in future phases of the CBP Watershed Model. [Return to page](#).
16. Requirements may vary by jurisdiction. See Sec. 3.6.1 of the District Department of the Environment's Stormwater Management Guidebook (2013) and errata. Last retrieved on 2/7/17. Click [here](#) to visit the website. Criteria are similar for other states. [Return to page](#).
17. Requirements may vary by jurisdiction. See Sec. 3.9.1 of the District Department of the Environment's Stormwater Management Guidebook (2013) and errata. Last retrieved on 2/7/17. Click [here](#) to visit the website. Criteria are similar for other states. [Return to page](#).
18. E.g., see Sec. 9.4 of Virginia DCR Stormwater Specification No. 9. Bioretention. Version 2.0. January 1, 2013. Last retrieved on 2/7/17. Click [here](#) to view the document. [Return to page](#).
19. The treated area should not exceed 5 times the surface area of permeable pavement; 2 times is recommended. [Return to page](#).



# DESIGNING GREEN STREET RETROFITS

## Incorporating Green Street Retrofits into an Existing Urban Street Network

Urban streets are generally classified into four different categories: [note 1](#)

- » Principal arterials
- » Minor arterials
- » Collector
- » Local streets

The green street retrofit designs provided in this guidebook are geared towards lower-speed urban streets — those classified as locally owned minor arterials, collectors, and local roadways. While principal arterial streets such as interstates, freeways, and other high-speed, limited access roadways also provide opportunities to incorporate green street elements, these roads are typically reserved for moving large volumes of auto traffic at a relatively fast speed, and have restricted access to adjacent land. Information about low impact development features available for these types of roads is available through the Green Highways Partnership. [note 2](#) Urban street standards vary by locality, so there is no one street and public right-of-way specification that is applicable to all green street retrofit or reconstruction projects. Rather, the templates included here are intended to depict a range of possible traffic, parking, and sidewalk conditions in urban areas within the Chesapeake Bay watershed and EPA Region 3 service area with varying amounts of low impact development features installed.

## Street Types

Table 4.1 provides descriptions of the five urban street examples included in this design guidebook. In addition, the guidebook provides design examples for how low impact development features can be integrated into highly visible street intersections. It is important to note that the street examples provided here are intended to be examples only. Street classifications and descriptions can vary somewhat by jurisdiction.

TABLE 4.1. URBAN STREET EXAMPLES		
Street Example	Classification	Description
Downtown Walkable Commercial	Minor arterial	Streets with 2-4 travel lanes plus bus zone or parking that provide connections between commercial areas of the city, such as neighborhood business districts.
Main Street Commercial	Minor arterial	Streets with 2-3 travel lanes plus parking and bike lanes located within pedestrian-oriented sections of neighborhood business districts.
High-Density Residential	Minor arterial or collector	Active pedestrian-friendly, high-density residential or mixed-use neighborhoods with 2-4 travel lanes plus parking and bike lanes. Streets are pedestrian-oriented, and most buildings are set at the street line.
Medium-Density City Neighborhood Street	Collector	Residential areas in older city areas where the building fronts typically meet the edge of the sidewalk.
Low-Density Residential	Local	Streets in residential areas with 1-2 travel lanes where dwellings are set back from the street line. Parking may be provided on at least one side; sidewalks are usually present.
Signature Intersections	Any	Not specific to one street type, this category represents the opportunity to place green street elements at highly-visible street intersections.

## Common Constraints






























Urban streets are often narrow, busy, and can pose numerous challenges for green street retrofit projects. These constraints may limit the number of green elements that can be incorporated into a streetscape retrofit or reconstruction project and the ability to implement enhanced designs to increase stormwater treatment and pollutant removal. However, there are a number of solutions that can be incorporated into green street designs to address these problems. Some of the most common constraints and potential solutions for green street reconstruction or retrofit projects along urban streets include:

- » **Utilities:** *Ensure that green stormwater management systems do not damage or block access to utility lines.* Underground utilities are typically located parallel to the road right-of-way, making total avoidance nearly impossible. Identifying the locations of utilities should take place early during planning and design. Conflicts may be minimized by coordinating with utilities to determine necessary responsibilities and horizontal/vertical setbacks and criteria. For permeable pavement designs, using permeable pavers decreases or eliminates the need to cut into the street surface to access utilities. An option for streetscape bioretention is to use an impermeable liner to protect utility lines from infiltrated water.
- » **Pedestrian Access:** *Allow pedestrians access to sidewalks, bus stops, and bike lanes while addressing safety concerns and ADA compliance.* On narrow walkable streets, such as main commercial streets, narrow planter boxes or street trees using structural soils or suspended sidewalks can be installed to allow pedestrian activity. Including a short fence around bioretention practices placed in sidewalk areas will help direct pedestrian traffic around them to prevent safety hazards and damage to the practice from pedestrians short-cutting across.
- » **Parking:** *Ensure that the number of available parking spaces meets demand.* Permeable pavement can be used to manage stormwater without reducing available parking. Streetscape bioretention can be installed in no-parking zones, such as those adjacent to street corners.
- » **Maintenance:** *Design to the level of future maintenance.* Streetscape bioretention designs that will not be regularly maintained should incorporate simpler planting palates with less upkeep.
- » **Sediment and Fertilizer Runoff:** *Deal with high volumes of sediment or fertilizer runoff.* Systems that receive a high volume of sediment runoff should include a pretreatment area in the design. This feature collects sediment and allows for easy removal during maintenance. Also, streetscape bioretention, which can manage and treat stormwater, may be the best option in lower density residential streets where large volumes of fertilizer are received from lawns.
- » **Directing Water:** *Guide water into and through a green stormwater management system.* Curb cuts, curbless streets, and conveyance systems with flow-through planters or check dams help direct water into bioretention systems. For locations where underlying soils have a low infiltration rate, designs may include removal of nearby impervious surfaces or an impermeable liner and an underdrain connection.

	Downtown Walkable Commercial				Main Street Commercial				High-Density Residential			
<b>Permeable Pavement</b>												
Porous Asphalt												
Pervious Concrete												
Interlocking Pavement												
<b>Streetscape Bioretention</b>												
Streetside Rain Garden												
Stormwater Curb Extension												
Planter Box												
Tree Box Filter												
Bioswale												
<b>Alternative Compliance</b>												
Street Tree												
Impervious Surface Removal												

TABLE 4.2. SUITABILITY MATRIX

Table 4.2 identifies which green street elements are most appropriate for retrofits occurring within the street types described here. With the exception of a few urban communities, a limited number of local green street standards exist in the Chesapeake Bay Watershed and EPA Region 3 service area at this time. It is expected that more localities will develop their own green street guidebooks that are better targeted to local street classification systems as their popularity increases.

	Medium-Density Residential Street				Low-Density Residential Street				Signature Intersections			
												
<b>Permeable Pavement</b>												
Porous Asphalt												
Pervious Concrete												
Interlocking Pavement												
<b>Streetscape Bioretention</b>												
Streetside Rain Garden												
Stormwater Curb Extension												
Planter Box												
Tree Box Filter												
Bioswale												
<b>Alternative Compliance</b>												
Street Tree												
Impervious Surface Removal												

Legend

	Travel lanes		Appropriate for most applications
	Bicycle/parking lanes		Appropriate for some applications
	Sidewalks		Not recommended
	Amenity zones/medians		

## IDENTIFYING OPPORTUNITIES:

### Downtown Walkable Commercial

Downtown commercial streets provide connections between commercial areas of a city (e.g., neighborhood business district). Major urban streets have high volumes of vehicular, transit, pedestrian, and bike traffic. Roadways vary in width but are typically 2 to 4 lanes divided by a median or a turning lane.

The rendered overlay of a downtown walkable commercial street illustrates how existing infrastructure can be retrofitted with tree box filters, bioswales, street trees, and bike lanes. Tree box filters should be placed and distributed along the length of a street to effectively intercept and treat stormwater runoff from the adjacent roadway. Placing tree box filters near existing infrastructure can provide an optimal opportunity to intercept stormwater and tie in overflows to existing infrastructure. Existing medians that are at least 5 feet wide can be converted into a functional bioswale with street trees.



FIGURE 4.1. EXAMPLE OF A TYPICAL DOWNTOWN COMMERCIAL STREET

#### OPPORTUNITIES

- » Add tree box filters or planter boxes along the existing curb line
- » Install permeable pavement in parking zones
- » Reduce lane widths and provide a designated bike lane
- » Convert medians into bioswales

#### CONSTRAINTS

- » Overhead and underground utilities
- » Pedestrian volume and circulation
- » High demand for parking in urban areas
- » Space availability for adequate soil volume
- » Designing to the level of future maintenance



FIGURE 4.2. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A DOWNTOWN COMMERCIAL STREET

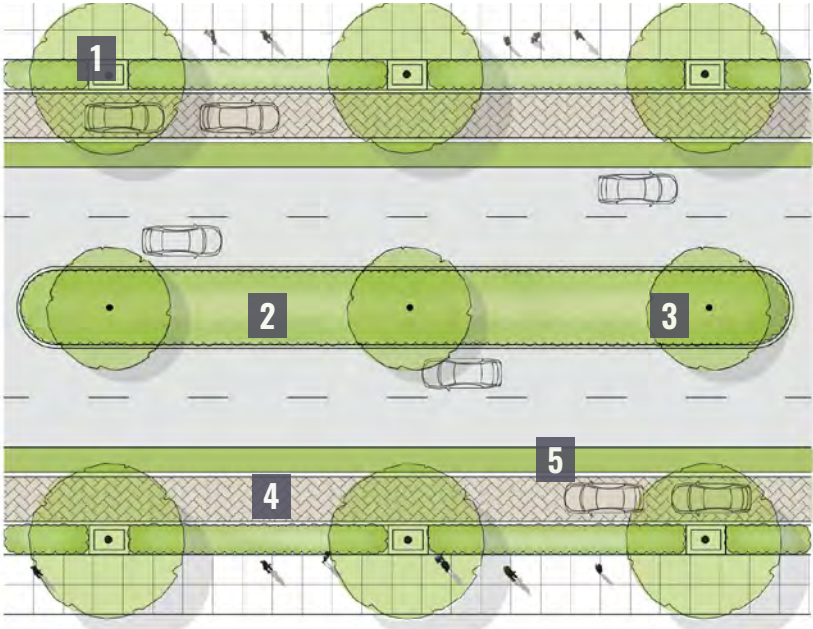


FIGURE 4.3. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A DOWNTOWN COMMERCIAL STREET

- Key Elements**
- 1. Tree box filter
  - 2. Bioswale
  - 3. Street tree
  - 4. Permeable pavement
  - 5. Bike lane

## IDENTIFYING OPPORTUNITIES:

### Main Street Commercial

A main street is a pedestrian-oriented corridor that stretches through a town's commercial, historic, or civic core. Main streets vary in width but are typically 2 to 3 lanes with on-street parking. Sidewalks are commonly laid with brick pavers and are narrower than major downtown commercial streets.

A main street is a great location to launch a green street pilot project because of its significance and proximity to the town's core. Most buildings are set at the street line, allowing raised planter boxes to be placed against the building to capture roof runoff. The rendered overlay illustrates how an existing commercial main street streetscape can be retrofitted with stormwater curb extensions, planter boxes, street trees, and bike lanes.



FIGURE 4.4. EXAMPLE OF A TYPICAL COMMERCIAL MAIN STREET

#### OPPORTUNITIES

- » Incorporate stormwater curb extensions and street trees along the existing curb line
- » Direct runoff from roofs into planter boxes via downspouts
- » Install permeable pavement for parking zones
- » Provide designated bike lane

#### CONSTRAINTS

- » Overhead and underground utilities
- » Pedestrian volume and circulation
- » High demand for parking in urban areas
- » Designing to the level of future maintenance

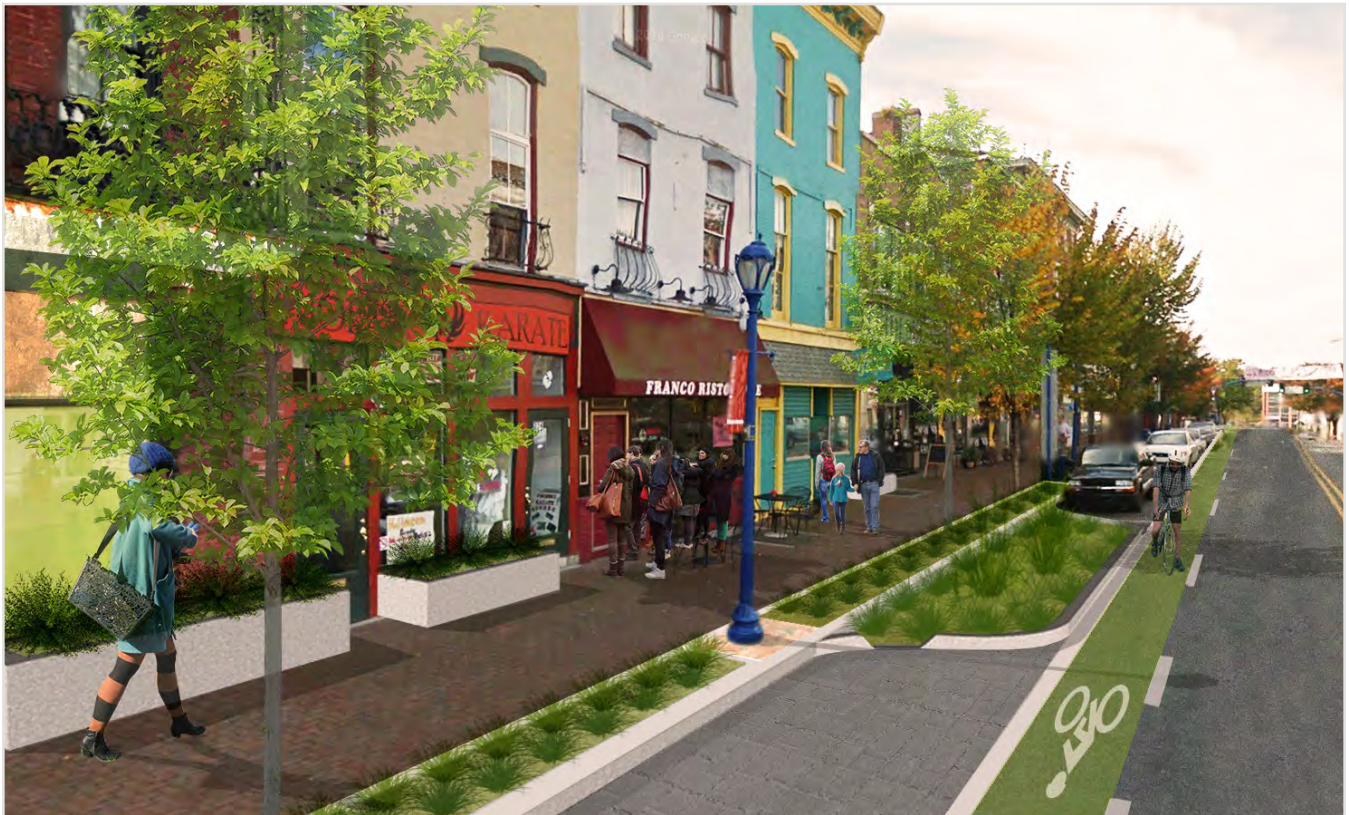


FIGURE 4.5. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A COMMERCIAL MAIN STREET

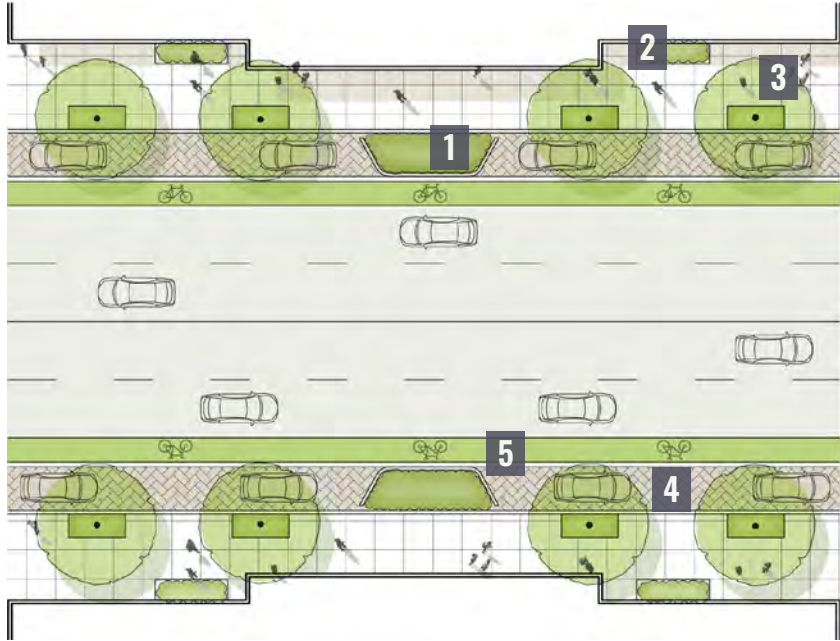


FIGURE 4.6. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A COMMERCIAL MAIN STREET

- Key Elements**
- 1. Stormwater curb extension
  - 2. Planter box - raised
  - 3. Street tree
  - 4. Permeable pavement
  - 5. Bike lane

## IDENTIFYING OPPORTUNITIES:

### High-Density Residential

High-density residential streets are pedestrian-oriented residential or mixed-use corridors with direct access to transit and downtown commercial areas. Roadways vary in width but are typically 2 to 4 lanes with on-street parking. Most buildings are set at the street line which makes it ideal to capture stormwater runoff from both the roadway and building roofs. Sidewalks are often wider than necessary, presenting a great opportunity to incorporate green street retrofits into the existing infrastructure without impacting pedestrian or vehicular circulation.

Nutrient and sediment runoff can be higher in these areas if high levels of trash or litter are present. <sup>note 3</sup> The rendered overlay illustrates how the sidewalk and parking lanes in a high-density residential area can be retrofitted to add planter boxes and permeable pavement. Planter boxes are often narrower than curb extensions and can fit into most high-density mixed-use streetscapes. Depressed planter boxes capture stormwater runoff from the roadway via curb cuts, whereas raised planter boxes capture runoff from building roofs via downspouts.

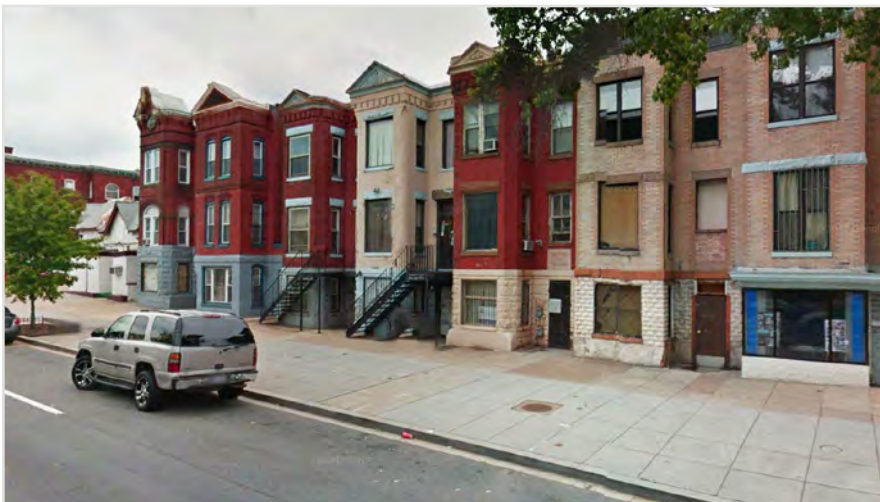


FIGURE 4.7. EXAMPLE OF A TYPICAL HIGH-DENSITY MIXED-USE STREETSCAPE

#### OPPORTUNITIES

- » Incorporate depressed planter boxes and street trees along the existing curb line
- » Direct roof runoff into raised planter boxes via downspouts
- » Install permeable pavement for parking zones if sidewalk does not have adequate space

#### CONSTRAINTS

- » Overhead and underground utilities
- » Pedestrian volume and circulation
- » High demand for parking in urban areas
- » Designing to the level of future maintenance



FIGURE 4.8. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A HIGH-DENSITY MIXED-USE STREETScape



FIGURE 4.9. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A HIGH-DENSITY MIXED-USE STREETScape

Key Elements

- 1. Planter box - depressed
- 2. Planter box - raised
- 3. Street tree
- 4. Permeable pavement

## IDENTIFYING OPPORTUNITIES:

### Medium-Density Residential

Medium-density residential streets provide connections between older residential areas in a city where the building fronts commonly meet the edge of the sidewalk. Medium-density residential streets are typically 1 to 2 lanes divided by a median or a turning lane.

Parking demand along medium-density residential streets can be high. This can be overcome by utilizing and transforming existing streetscape elements to maximize stormwater management with minimal parking loss. Gravel strips should be installed around permeable pavement in areas where organic materials could cause a clogging issue.

The rendered overlay illustrates how an existing median can be transformed into a streetside rain garden with curb cuts to treat runoff from the adjacent roadway. Tree box filters and permeable pavement allow for additional on-site stormwater management.



FIGURE 4.10. EXAMPLE OF A TYPICAL MEDIUM-DENSITY RESIDENTIAL STREET

#### OPPORTUNITIES

- » Incorporate tree box filters, stormwater curb extensions, or planter boxes along the curb line
- » Convert existing medians into rain gardens with street trees
- » Install permeable pavement for parking zones

#### CONSTRAINTS

- » High demand for on-street parking
- » High sediment and fertilizer runoff volumes
- » Directing stormwater runoff to BMPs
- » Designing to the level of future maintenance



FIGURE 4.11. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A MEDIUM-DENSITY RESIDENTIAL STREET

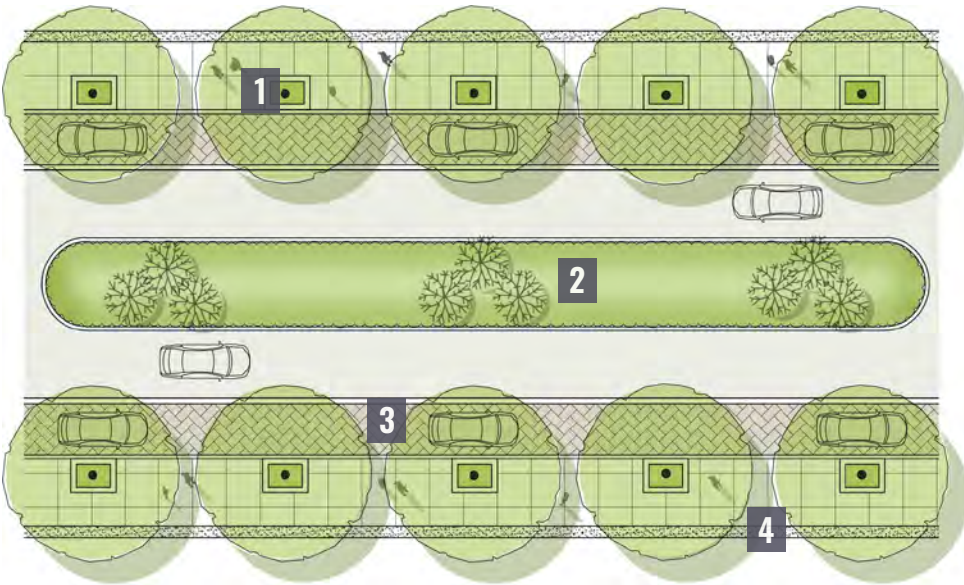


FIGURE 4.12. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A MEDIUM-DENSITY RESIDENTIAL STREET

- Key Elements**
- 1. Tree box filter
  - 2. Bioswale
  - 3. Permeable pavement
  - 4. Gravel strip

## IDENTIFYING OPPORTUNITIES:

### Low-Density Residential

Low-density residential streets provide access to residential neighborhoods where dwellings are set back from the street line and yards are larger. They are characterized by 1 to 2 travel lanes with low traffic volumes and speeds. On-street parking and sidewalks may or may not be present.

Residential lawns can be a major source of nutrient loads due to fertilization or over-fertilization. <sup>note 4</sup> There are many opportunities to capture and treat this runoff by placing green street retrofits in underused spaces. Stormwater curb extensions are ideal where available on-street parking meets or exceeds needs in a low-density residential street. The rendered overlay provides an example of how larger-than-necessary parking lanes can be retrofitted to accommodate stormwater curb extensions to treat stormwater runoff from the lawn areas prior to it making its way into the sewer system. A low-maintenance bioswale is added to treat stormwater runoff from the street.



FIGURE 4.13. EXAMPLE OF A TYPICAL LOW-DENSITY RESIDENTIAL STREET

#### OPPORTUNITIES

- » Install bioswales or streetside rain gardens in appropriate spaces
- » Incorporate stormwater curb extensions into parking zones
- » Plant street trees along the roadway

#### CONSTRAINTS

- » High demand for street parking
- » High volumes of sediment and fertilizer runoff
- » Directing stormwater runoff
- » Designing to the level of future maintenance



FIGURE 4.14. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A LOW-DENSITY RESIDENTIAL STREET

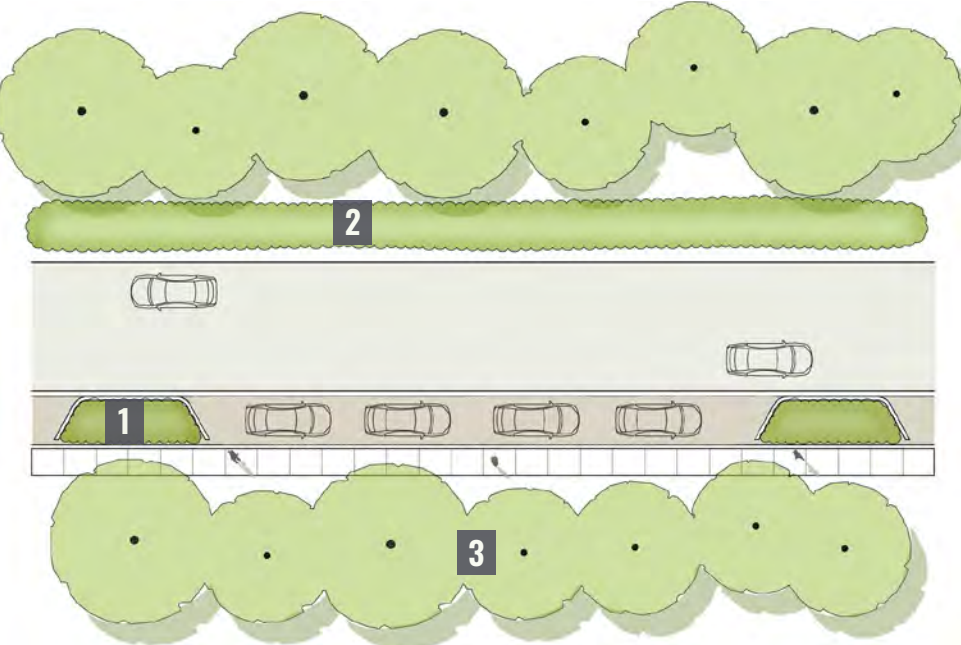


FIGURE 4.15. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A LOW-DENSITY RESIDENTIAL STREET

- Key Elements
- 1. Stormwater curb extension
  - 2. Bioswale
  - 3. Street tree

## IDENTIFYING OPPORTUNITIES:

### Signature Intersection

Not specific to one street type, signature intersections represent an opportunity to place green street elements in highly-visible areas. In urban areas, intersections can be retrofitted with green street elements to promote safety and comfort for pedestrians and bicyclists.

Many intersections have large curb radii that can be reduced to slow down traffic and increase pedestrian safety. Parking adjacent to corners should be restricted to ensure visibility for pedestrians and vehicular traffic. Stormwater curb extensions can be placed at intersections to reduce pedestrian walking distance. A planted median can further shelter pedestrians from traffic. The rendered overlay illustrates how an intersection that accommodates pedestrians, cars, and trains can be transformed into a greener space by adding stormwater curb extensions, street trees, and vegetated areas.



FIGURE 4.16. EXAMPLE OF A SIGNATURE INTERSECTION

#### OPPORTUNITIES

- » Minimize curb radii for turning vehicles
- » Install stormwater curb extensions
- » Plant street trees along the roadway
- » Install permeable pavement for parking zones
- » Provide space for refuge if medians are present

#### CONSTRAINTS

- » Plant materials should meet the line of sight requirements
- » Overhead and underground utilities
- » Pedestrian volume and circulation
- » Designing to the level of future maintenance



FIGURE 4.17. RENDERED OVERLAY OF GREEN STREET RETROFITS IN A SIGNATURE INTERSECTION



FIGURE 4.18. PLAN VIEW OF TYPICAL GREEN STREET RETROFITS IN A SIGNATURE INTERSECTION

- Key Elements
- 1. Stormwater curb extension
  - 2. Street tree
  - 3. Permeable pavement
  - 4. Narrowed crosswalk

## ENDNOTES: CHAPTER 4

1. FHWA, 2013. Highway Functional Classification Concepts, Criteria and Procedures. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
2. Additional information can also be found on the National Cooperative Highway Research Program's website, such as NCHRP Report 565: Evaluation of Best Management Practices for Highway Runoff Control. Click [here](#) to view the document. Last retrieved on 2/7/17. [Return to page](#).
3. Chesapeake Stormwater Network, 2011. Technical Bulletin No 9: Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed. Version 1.0. August 15, 2011. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).
4. Chesapeake Stormwater Network, 2011. Technical Bulletin No 9: Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed. Version 1.0. August 15, 2011. Last retrieved on 2/7/17. Click [here](#) to visit the website. [Return to page](#).

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# ACCOUNTING FOR GREEN STREET RETROFITS

## Green Streets for the Long Haul

Green street retrofit and reconstruction projects can play an important role in enabling urban communities to treat stormwater runoff. To be effective, it is important to ensure that the performance and functionality of low impact development features last throughout their expected life span.

## Site-Specific Performance Calculations

Chapter 3 provided general design guidance and performance information for determining whether an individual green street retrofit project is meeting state-specific stormwater standards. Each state has established stormwater sizing methods, design criteria, and compliance tools to ensure design professionals meet the required performance standards for new development or redevelopment projects. Green street retrofit projects which fall within the existing right-of-way are typically required to incorporate green stormwater infrastructure to the maximum extent practicable (MEP).

Site designers can use local and state-specific methods to evaluate what BMPs are appropriate for each application. [Table 5.1](#) provides links to state-specific stormwater resources; however, some localities may impose additional requirements. It is important to check with local approval authorities for any additional regulatory requirements.

TABLE 5.1. STATE STORMWATER RESOURCE LINKS - RULES, MANUALS, AND WORKSHEETS

State	Environmental Authority	Link
DC	District Department of Energy and the Environment Stormwater Management Division	<a href="https://doee.dc.gov/service/stormwater-management">https://doee.dc.gov/service/stormwater-management</a>
DE	Delaware Department of Natural Resources and Environmental Control – Division of Watershed Stewardship’s Drainage and Stormwater Section	<a href="http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx">http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx</a>
MD	Maryland Department of the Environment Stormwater Management Program	<a href="https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/">https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/</a>
NY	New York Department of Environmental Conservation Stormwater Program	<a href="http://www.dec.ny.gov/chemical/8468.html">http://www.dec.ny.gov/chemical/8468.html</a>
PA	Pennsylvania Bureau of Clean Water	<a href="http://www.dep.pa.gov/Business/Water/CleanWater/StormwaterMgmt/Pages/default.aspx">http://www.dep.pa.gov/Business/Water/CleanWater/StormwaterMgmt/Pages/default.aspx</a>
VA	Virginia Department of Environmental Quality Statewide Nonpoint Source Pollution Control Program	<a href="http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx">http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx</a>
WV	West Virginia Department of Environmental Protection -Stormwater Program	<a href="http://www.dep.wv.gov/WWE/PROGRAMS/STORMWATER/Pages/sw_home.aspx">http://www.dep.wv.gov/WWE/PROGRAMS/STORMWATER/Pages/sw_home.aspx</a>

Website addresses accurate as of 2/7/17. This document is not responsible for any outdated web addresses.

Each state has different requirements and performance evaluation methods, but the general approach remains the same across all jurisdictions. For a given drainage area, a storm event is used to determine the depth of rainfall over a given area. Combined with land use data, the rational method or the Soil Conservation Service (SCS) method can be used to determine the volume and flow rates of the stormwater runoff. <sup>note 1</sup> <sup>note 2</sup> This information is used to determine the size of the BMP. Once the size, land use, and treatment depth is known, the pollutant removal can be calculated. Each jurisdiction has removal efficiency values that depend on the BMP type, local pollutant conditions, and other jurisdiction specific factors. To extend these calculations to an entire green street, the BMPs are simply added to find the total treatment value.

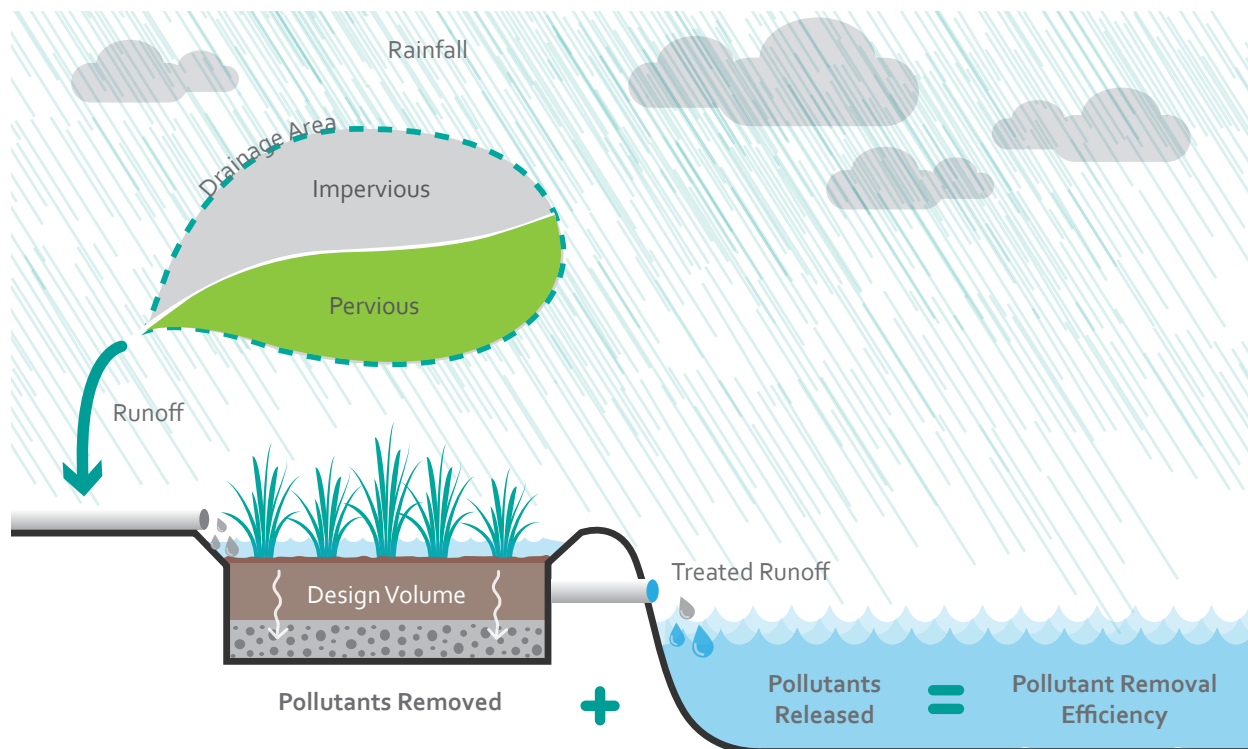


FIGURE 5.1. GENERAL APPROACH FOR STORMWATER CALCULATIONS

## Understanding Differences in Calculations

The methods for determining runoff volume are similar regardless of location, but there are certain factors that influence performance credit calculations. Pollutant loads can vary based on state- or watershed-specific factors, region-specific studies, and jurisdictional design guidelines. Rainfall patterns, the amount of runoff required to be treated, individual BMP efficiency values, and the model used to compute runoff can also differ significantly across states, counties, and watersheds. The differences in the models used to compute runoff were touched upon in Chapter 2. A brief description of the other factors follows.

### RAINFALL PATTERNS

Different areas have different rainfall patterns - i.e., the intensity, duration, frequency of storms, and annual rainfall totals. For example, the average annual rainfall in Maryland is 42 inches. Approximately 90 percent of rainfall occurs during events that cause a measurable runoff, resulting in a potential annual maximum runoff depth of 37.8 inches. <sup>note 3</sup> In the District of Columbia, the average annual rainfall is 40 inches, and approximately 95 percent of the rainfall occurs during events that cause a measurable runoff. <sup>note 4</sup> This results in a potential annual maximum runoff depth of 38.0 inches. Even though there is more annual rainfall in Maryland, due to the rainfall patterns, the District of Columbia actually has a greater potential annual runoff depth.

## DESIGN STORM

The design storm is the storm event that a BMP is required to treat. Sometimes this is referred to in inches (for example, the 1 inch storm event) and sometimes in years (such as the 2-year storm event). From this storm event and the land use information, a treatment volume is found and used to size the BMP. State performance standards are generally higher for new development projects than they are for redevelopment projects. Local approval authorities (certain counties and municipalities) can require stronger performance standards for either. Depending on the jurisdiction, retrofit projects within the right-of-way may be required to treat a minimum runoff depth or treat to the maximum extent practicable.

## BMP EFFICIENCY VALUES

BMP removal efficiency refers to the percentage of pollutants that a BMP removes from any runoff that is retained or filters through it, up to the rainfall depth of the design storm. These BMP efficiencies are calculated for the full life expectancy of the BMP. In the Chesapeake Bay watershed, the Chesapeake Bay Program has formed a peer-review panel to establish standard removal rates for a wide range of urban BMPs.<sup>note 5</sup> Some jurisdictions defer to these standards, while others have developed their own standards. Washington, DC is an example of a jurisdiction that used information from the Bay panel, the International Stormwater BMP database, and their own data to develop DC-specific pollutant removal rate curves.<sup>note 6</sup>

## Anacostia Green Street Examples: Putting it into Practice

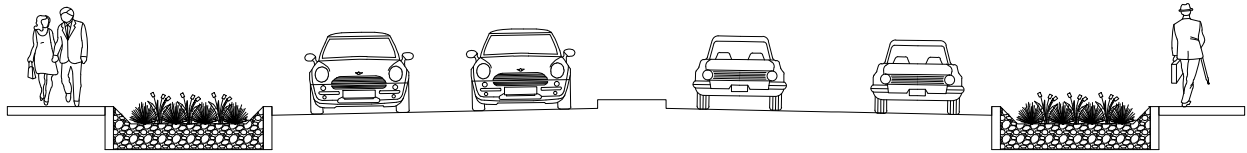
The following case studies show how local and jurisdiction-specific methodologies were used to measure the annual pollutant load reductions from three existing green streets. All three retrofit projects are located within the Anacostia watershed. The Anacostia watershed lies within the Chesapeake Bay Watershed and covers portions of Maryland and Washington, DC. Decatur Street and Dennis Avenue are in the State of Maryland, and Nannie Helen Burroughs Avenue is in Washington, DC.

The three examples provide a range of green street scenarios: one in a highly urbanized environment with limited treatment options; one in a moderately urbanized area with more opportunities to treat roadway runoff; and one where the entire drainage area can be treated within the right-of-way. Each demonstrates the ability green streets provide for local jurisdictions to reduce pollutant loads. This is true even for the most constrained sites.

How much credit can be attained for implementing low impact development BMPs – and by extension, how much is available per an individual green street project – differs based on which calculation method is utilized. For the Anacostia case studies, design plans, computations, and as-builts (the set of drawing and stormwater computations submitted by a professional engineer upon completion of a project) were

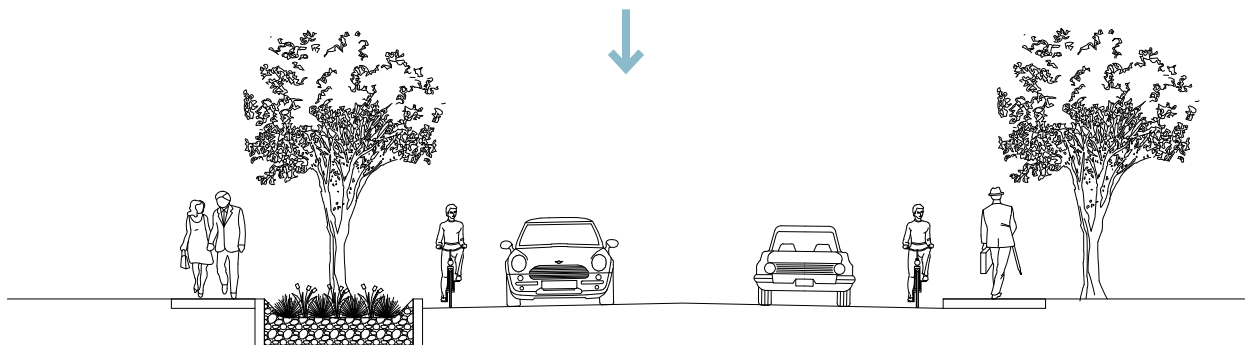
used to evaluate each BMP. When information was not available, assumptions were made to enable comparisons between different projects designed under different regulations, in different jurisdictions. Pollutant loads, weighted pollutant removal efficiencies, and the amount of pollutants removed varied.

FIGURE 5.2. ANACOSTIA GREEN STREET SCENARIOS



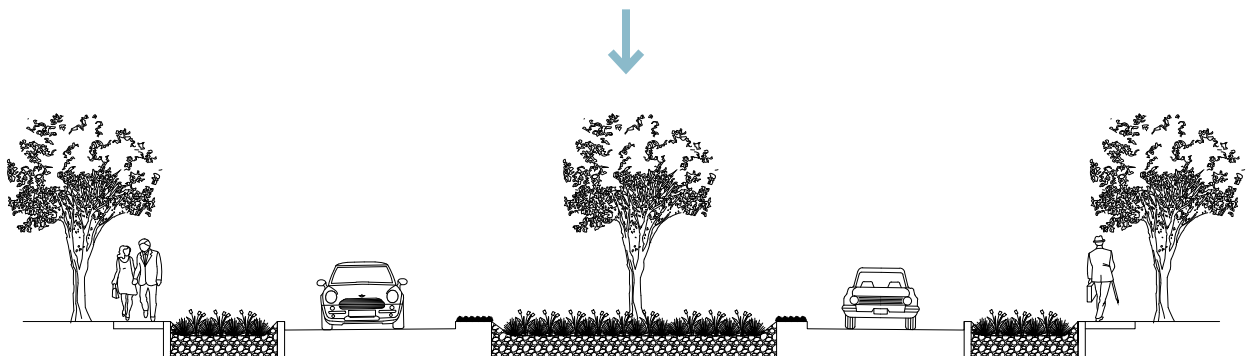
**Nannie Helen Burroughs Avenue**

Highly urbanized area with greatest site constraints; stormwater treated wherever possible



**Decatur Street**

Many right-of-way constraints; street trees and landscaped areas provide limited stormwater management



**Dennis Avenue**

Multiple opportunities to provide full treatment of street and surrounding residential areas

## IDENTIFYING OPPORTUNITIES:

# Nannie Helen Burroughs Avenue

## WASHINGTON, DC

Nannie Helen Burroughs Avenue is situated in an older, highly urbanized section of Washington, DC's Ward 7 that suffers from disinvestment. Between 2009 and 2012, the community, the DC Office of Planning, and the Department of Transportation worked together to redesign and reconstruct the 1.45-mile road into DC's first model green street. The project was part of the District's Great Streets program. <sup>note 7</sup> <sup>note 8</sup>

Prior to the retrofit, the roadway had three eastbound lanes (one occupied by parking) and two westbound travel lanes with wide, poorly maintained sidewalks on both sides. City officials and community residents sought to turn the urban street into a thriving, inviting neighborhood center. The plan included enhancing the appearance and improving pedestrian accessibility and overall safety for all roadway users. <sup>note 9</sup> Landscaped medians, street trees, stormwater curb extensions, and other stormwater infrastructure upgrades were added to increase the treatment of pollutants from the street runoff.



FIGURE 5.3. A SECTION OF NANNIE HELEN BURROUGHS AVENUE IN 2005

### OPPORTUNITIES

- » Install bioswales or streetside rain gardens in appropriate spaces
- » Add stormwater curb extensions into parking zones
- » Plant street trees along the roadway

### CONSTRAINTS

- » Underground and overhead utilities
- » Narrow 50' right-of-way
- » Flat topography
- » High groundwater
- » Street used by trucks
- » Driveway access



FIGURE 5.4. RENDERED OVERLAY OF GREEN STREET RETROFITS ALONG NANNIE HELEN BURROUGHS AVENUE

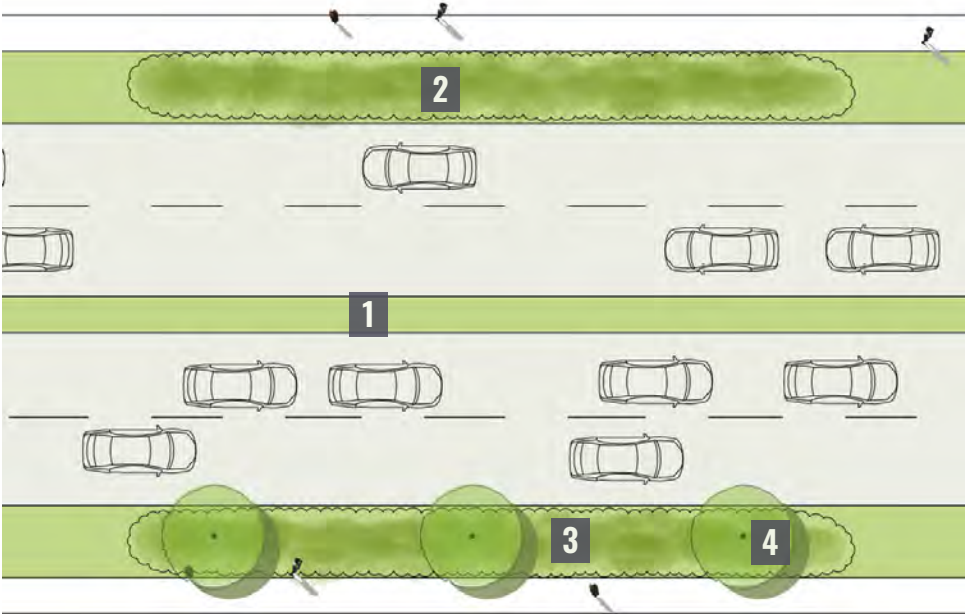


FIGURE 5.5. PLAN VIEW OF GREEN STREET RETROFITS ALONG NANNIE HELEN BURROUGHS AVENUE

- Key Elements**
- 1. Landscaped medians
  - 2. Stormwater curb extension
  - 3. Bioswale
  - 4. Street tree

## STORMWATER ENHANCEMENTS

The Nannie Helen Burroughs Avenue retrofit project incorporates seven different engineered low impact development practices. These include bioretention cells and planters, bioswales, grassed swales, porous concrete over structural soils, permeable pavers over structural soils, and a soil amended median. In total, 30 engineered low impact development practices were installed within the 1.45-mile long right-of-way. In addition, some existing impervious surfaces were removed along portions of the roadway to make room for other street amenities. Trees were added along the roadway in newly landscaped areas. The stormwater infrastructure were funded in part through a coordinated grant from the EPA and FHWA under the former Targeted Watershed Grant Program, and coordinated through the Green Highway Partnership.

## STORMWATER PERFORMANCE CALCULATIONS

The Nannie Helen Burroughs Avenue retrofit project was designed and installed several years before Washington, DC's runoff reduction practice guidance was revised. The project served as a pilot for the District's 2013 Stormwater Management Guidebook. <sup>note 10</sup> The project's design standards and specification drew from the District's 2003 standards. <sup>note 11</sup> As such, some of the BMP treatment volumes are smaller than what would be required under current standards. For comparison purposes, it was determined that the BMPs should be credited as if they met the standards under which they were designed.



A bioswale is added along the street.

## Drainage Areas

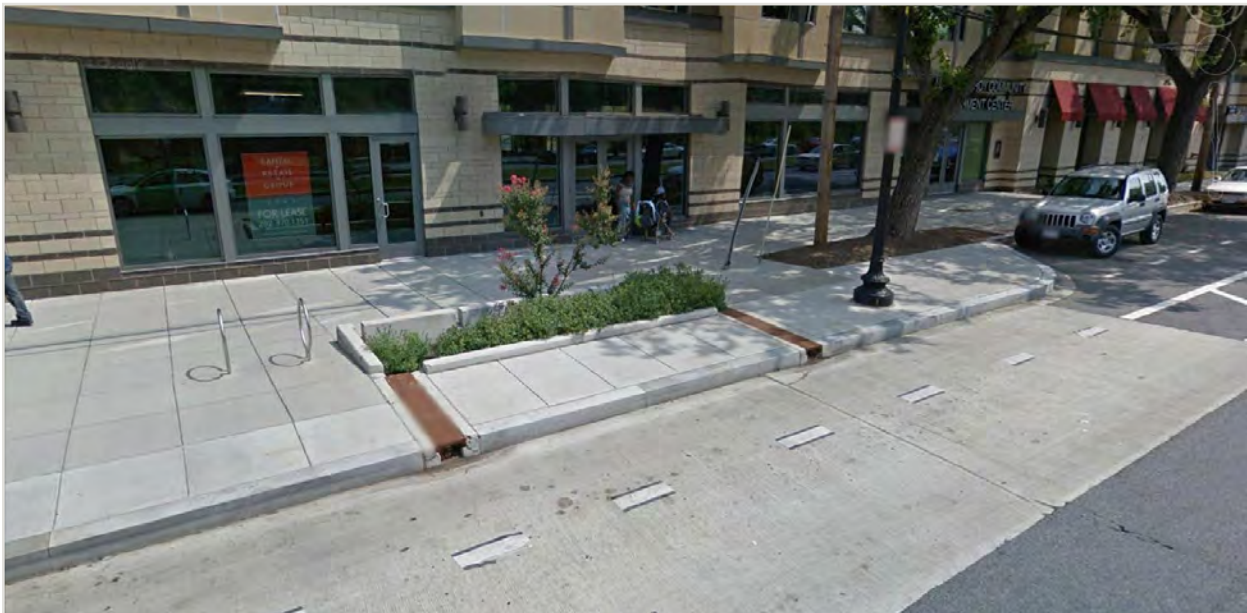
Limited space meant that it was not possible to treat stormwater runoff from the surface of the entire right-of-way. The retrofit project covered an area of the roadway and sidewalk that was approximately 12.5 acres, yet the 30 BMPs were only designed to fully treat approximately 4 acres. The overall drainage area for the portions of the right-of-way draining to the BMPs was determined to be more than 82 percent impervious (see [Table 5.3](#)). Looking at the street as a whole, the retrofits were able to treat 26 percent of the impervious area and 33 percent of the non-impervious area.

## Annual Rainfall

Washington, DC bases its average annual rainfall estimates (40 inches) on the “long term record (1948-2013) annual average rainfall depth at Ronald Reagan Washington National Airport”. [note 12](#)

## Annual Runoff

Rain that does not immediately soak into the ground can turn into runoff. In highly impervious urban environments, this can be significant. Turf and forest areas tend to generate a smaller volume of runoff than impervious areas. To account for this, impervious, turf, and forest are assigned a runoff coefficient (Rvc) that relates to the land type and the underlying soils.



A bioretention planter and permeable pavement are added along the street.

The annual runoff was determined by taking the known average annual rainfall of 40 inches and applying a composite runoff coefficient to represent the combination of impervious and pervious land found in the BMP drainage area. Not all precipitation events drop enough rain to cause runoff; about 5 percent are considered short, non-intense storms (a light misting that only lasts a few minutes) which do not result in runoff. To account for this, the annual runoff amount is multiplied by a factor of 0.95. Annual runoff can be found using the following equation:

$$R = 0.95 \times P \times [(Rv_i \times \%I) + (Rv_c \times \%C) + (Rv_N \times \%N)]$$

Where: R = annual runoff; P = precipitation;  $Rv_i = 0.95$  (runoff coefficient for impervious cover); %I = percent of site in impervious cover;  $Rv_c = 0.25$  (runoff coefficient for compacted cover); %C = percent of site in compacted cover;  $Rv_N = 0.00$  (runoff coefficient for natural cover); and %N = percent of site in natural cover.

The land cover was predominantly impervious in the sections of Nannie Helen Burroughs Avenue that were treated by the 30 BMPs, with a small portion covered by compacted soils. No natural cover was present.

### **Design Storm**

Each BMP was sized to treat as much rainfall as practicable. In the Nannie Helen Burroughs Avenue case study, the average rainfall treatment depth across all 30 BMPs was determined to be 1.15 inches.

### **BMP Efficiency Values**

The Department of Energy and the Environment utilized District MS<sub>4</sub> outfall monitoring data to develop event mean concentrations (EMCs) for Total Nitrogen, Total Phosphorous, and Total Suspended Solids. <sup>note 13</sup> Annual pollutant loads and load reductions are calculated by evaluating the drainage area, runoff coefficient (a function of land cover and soil type), and precipitation to determine runoff from a particular area. Runoff is then used in conjunction with a pollutant EMC to calculate the pollutant load.

TABLE 5.2. NANNIE HELEN BURROUGHS AVENUE – POLLUTANT REMOVAL CALCULATIONS			
Pollutant	Pollutant Load (pounds/year)	Weighted Removal Efficiency (percent)	Pollutant Removed (pounds/year)
Total Nitrogen	98.9	55.4	54.8
Total Phosphorous	11.3	55.4	6.3
Total Suspended Solids	2,175.0	55.4	1,204.5

The Washington, DC government commissioned a study to develop removal efficiency curves for each BMP. Similarly, each watershed was studied to provide flow-weighted mean pollutant concentrations, or the average pollutant load, for each pollutant of concern during storm events. Combined with average annual rainfall data, the annual pollutant load and removal can be calculated (see [Table 5.2](#)). This rainfall depth, pollutant concentration, and a conversion factor can yield the annual pollutant load in pounds per year:

$$L = A \times R \times C \times 0.226$$

The amount of pollutants removed annually in pounds per year can be found by multiplying the annual pollutant load by the removal efficiency:

$$L_R = L \times R_E$$

Where: L = annual pollutant load, expressed in pounds/year; A = drainage area, in acres; R = annual runoff, in inches; C = flow-weighted mean pollutant concentration, expressed in milligrams per liter;  $L_R$  = amount of pollutants removed, in pounds per year;  $L_R$  = annual pollutant removal rate, expressed as a percentage; and  $R_E$  = removal efficiency, expressed as percentage.

The unit conversion factor of 0.226 is used to convert the units to pounds per year for pollutant concentration.

TABLE 5.3. NANNIE HELEN BURROUGHS AVENUE – FACILITIES SUMMARY

Facility	Facility Description	Drainage Area Treated (acres)	Impervious Area Treated (acres)	Design Storm (inches)	Annual Runoff (inches)
BP1	Bioretention planter <a href="#">note a</a>	0.08	0.08	0.5	38.00
BP2	Bioretention planter <a href="#">note a</a>	0.07	0.07	0.5	38.00
BP3	Bioretention planter <a href="#">note a</a>	0.03	0.03	1.25	38.00
BP4	Bioretention planter <a href="#">note a</a>	0.03	0.03	1.25	38.00
BP5	Bioretention planter <a href="#">note a</a>	0.10	0.10	0.5	38.00
BP6	Bioretention planter <a href="#">note a</a>	0.07	0.07	0.75	38.00
BP7	Bioretention planter <a href="#">note a</a>	0.03	0.03	1.25	38.00
BP8	Bioretention planter <a href="#">note a</a>	0.05	0.05	0.75	38.00
BP9	Bioretention planter <a href="#">note a</a>	0.20	0.19	0.25	36.38
BP10	Bioretention planter <a href="#">note a</a>	0.04	0.04	1.0	38.00
BP11	Bioretention planter <a href="#">note a</a>	0.05	0.05	1.0	38.00
BP12	Bioretention planter <a href="#">note a</a>	0.13	0.13	0.25	38.00
BC1	Bioretention cell <a href="#">note a</a>	0.39	0.24	1.0	27.46
BC2	Bioretention cell <a href="#">note a</a>	0.44	0.30	1.0	29.04
BS1	Bioswale <a href="#">note b</a>	0.42	0.17	0.25	21.35
S1	Grassed swale <a href="#">note c</a>	0.25	0.20	0.50	31.99
S2	Grassed swale <a href="#">note c</a>	0.32	0.20	0.75	27.57
PC1	Porous concrete over structural soil	0.21	0.21	2.25	38.00
PC2	Porous concrete over structural soil	0.20	0.20	2.25	38.00
PP1	Permeable pavers over structural soil <a href="#">note a</a> <a href="#">note d</a>	0.01	0.01	2.25	38.00

TABLE 5.3. (CONTINUED) NANNIE HELEN BURROUGHS AVENUE – FACILITIES SUMMARY					
Facility	Facility Description	Drainage Area Treated (acres)	Impervious Area Treated (acres)	Design Storm (inches)	Annual Runoff (inches)
PP2	Permeable pavers over structural soil <small>note a note d</small>	0.01	0.01	2.25	38.00
PP3	Permeable pavers over structural soil <small>note a note d</small>	0.01	0.01	2.25	38.00
PP4	Permeable pavers over structural soil <small>note a note d</small>	0.01	0.01	2.25	38.00
PP5	Permeable pavers over structural soil <small>note a note d</small>	0.01	0.01	2.25	38.00
SA1	Soil amended median	0.17	0.17	2.25	38.00
SA2	Soil amended median	0.09	0.09	2.25	38.00
SA3	Soil amended median	0.03	0.03	2.25	38.00
SA4	Soil amended median	0.03	0.03	2.25	38.00
SA5	Soil amended median	0.12	0.12	2.25	38.00
SA6	Soil amended median	0.40	0.40	2.25	38.00
	Total:	4.0	3.28	1.14	n/a

### Notes for Table 5.3

- Bioretention: The 2013 Stormwater Management Guidebook only provides 60 percent credit when computing treatment depths and volumes where underdrains are present. In this example, the bioretention planters, bioretention cells, and permeable pavers were given full credit even when underdrains were present to make them comparable to Maryland standards (which provide full credit for underdrain designs).
- The treatment depth and volume for the bioswale was calculated based on 90 percent details.
- Grassed Swales: Grassed Swales are considered to have no treatment value under the 2013 standards. For this case study, the grass swales were treated as if their design included a media/gravel section to enhance their water quality benefit. This was to make the calculations comparable to the two Maryland examples.
- Permeable Pavers: For the permeable pavers, the drainage area was assumed to be equal to two times the area of pavers and 100 percent impervious as recommended in the 2013 standards.

## IDENTIFYING OPPORTUNITIES:

# Decatur Street

## EDMONSTON, MD

Decatur Street is a main residential street in Edmonston, Maryland. The street acts as a commuter link between two major transportation corridors and experiences some heavy truck traffic. In 2008, The town sought assistance to turn Decatur Street into a green street. The purpose was to treat stormwater runoff, reduce localized flooding, provide traffic calming, and create a safe, pleasant environment for pedestrians and bicyclists. <sup>note 14</sup>

The Town evaluated several green street designs for the 50-foot right-of-way. <sup>note 15</sup> The final design included narrowing the traffic lanes to accommodate stormwater curb extensions, alternating sides on each block, with street trees planted on the opposite sides. Permeable asphalt pavement was installed into the newly added bike lanes. A narrower street width and the addition of green features also helped meet the community's objectives to calm and slow traffic and shorten pedestrian crossing distance.



FIGURE 5.6. A SECTION OF DECATUR STREET IN 2007

### OPPORTUNITIES

- » Stormwater curb extensions
- » Street trees
- » Shared, permeable bike lanes
- » Reduced pedestrian crossing distances and slower traffic

### CONSTRAINTS

- » Underground and overhead utilities
- » Narrow right-of-way
- » Flat topography
- » High groundwater
- » Street used by trucks
- » Driveway access



FIGURE 5.7. RENDERED OVERLAY OF GREEN STREET RETROFITS ON DECATUR STREET

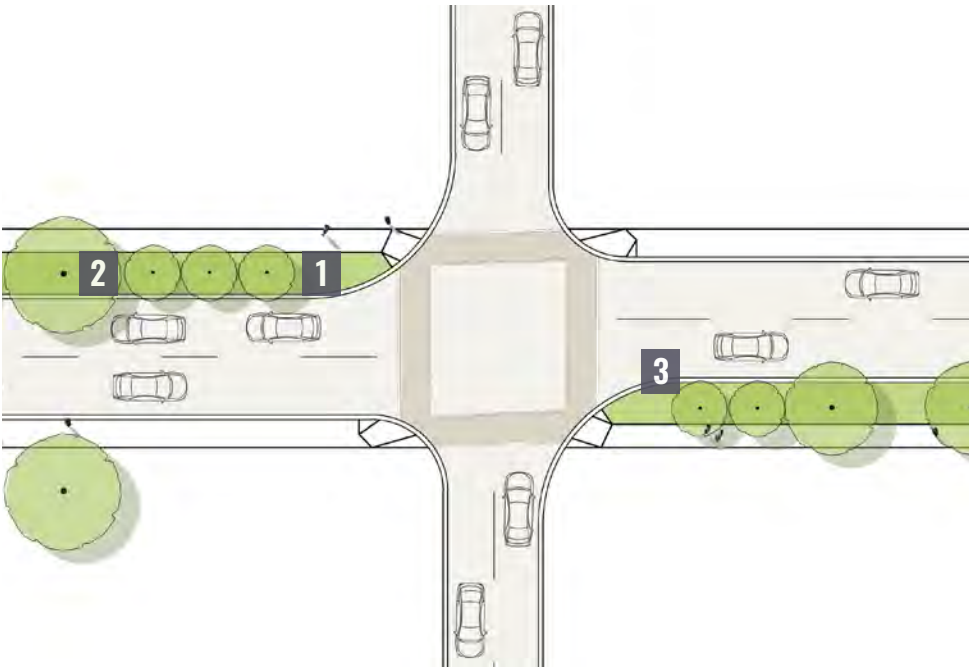


FIGURE 5.8. PLAN VIEW OF GREEN STREET RETROFITS ALONG DECATUR STREET

- Key Elements**
- 1. Stormwater curb extension
  - 2. Street tree
  - 3. Permeable bike lane

## STORMWATER ENHANCEMENTS

Decatur Street provided just enough space to incorporate low impact development BMPs to treat runoff from portions of the street and right-of-way. However, the BMPs could not be sized large enough to treat runoff flowing into the street from adjacent properties or other roads. Existing impervious surfaces were removed and 8 stormwater curb extensions were added into new planting strips between the road and sidewalk. Seven stretches of 3-foot permeable asphalt bicycle lanes were also incorporated. Stormwater runoff from the roadway was directed into the stormwater curb extensions and permeable asphalt.

## STORMWATER PERFORMANCE CALCULATIONS

The Decatur Street green street project was designed and installed between 2008 and 2010. The design was based on previous stormwater management standards for Prince George's County, MD. While tree plantings and impervious area removal were also part of this project, calculations were not included in this example because it was determined that the treatment credit for those practices was too minor to have a significant impact.



Stormwater curb extensions installed along Decatur Street (top and middle). A close-up of a stormwater outlet (bottom).

## Drainage Areas

Drainage areas for the 6 stormwater curb extensions and the 6 permeable asphalt sections were primarily confined to the road's right-of-way. The cumulative drainage area for the low impact development BMPs was determined to be 1.99 acres, or 100 percent of the street's area. (See [Table 5.5](#))

## Annual Rainfall

Precipitation, quantified through rainfall, drives the generation of runoff and pollutant loads. In Maryland, the annual rainfall is 42 inches per year. [note 16](#)

## Annual Runoff

Not all events are large enough to cause measurable runoff. In Maryland, 90 percent of precipitation falls in rainfall events that are large enough to cause stormwater runoff. This number differs from Washington, DC, where 95 percent of rainfall is considered to fall in events that are large enough to cause stormwater runoff (note that differences from state to state are common and are determined based on local weather patterns).

To determine the amount of runoff produced during the design storm in Maryland, 90 percent of the average rainfall is multiplied by a volumetric runoff coefficient for the drainage area. Annual runoff is derived using the following equation:

$$R = 0.90 \times P \times R_v$$

Where R = annual runoff; P = precipitation;  $R_v = [0.05 + (0.9 \times I)]$ ; and I = Percent impervious cover in the drainage area.

## Design Storm

The stormwater curb extensions were determined to treat the 1 inch storm, and permeable pavement facilities were determined to have treated the 0.75-inch storm. The areas were treated to an average depth of 0.9 inches.

## BMP Efficiency Values

In Maryland, BMP removal rates and pollutant reduction rates for Nitrogen, Phosphorous, and Total Suspended Solids are determined using Chesapeake Bay Program expert panel recommendations. Each BMP is classified as a runoff reduction (RR) practice, a stormwater treatment (ST) practices, or other practice. Based on the BMP classification, a specific pollutant removal curve is used to determine nutrient and sediment load reductions. [note 17](#)

TABLE 5.4. DECATUR STREET – POLLUTANT REMOVAL CALCULATIONS			
Pollutant	Pollutant Load (pounds/year)	Weighted Removal Efficiency (percent)	Pollutant Removed (pounds/year)
Total Nitrogen	29.0	55.0	16.0
Total Phosphorous	4.4	63.6	2.8
Total Suspended Solids	1,159.8	67.6	784.0

Table 5.4 provides the combined pollutant load reduction credits for the Decatur Street green street retrofit project. The rainfall treatment depth, pollutant concentration, and a conversion factor (based on the BMP classification) are utilized to yield the annual pollutant load in pounds per year. The calculation, which is standard for determining the annual pollutant load, is the same that is used for Washington, DC:

$$L = A \times R \times C \times 0.226$$

The amount of pollutants removed annually in pounds per year can be found by multiplying the annual pollutant load by the removal efficiency:

$$L_R = L \times R_E$$

Where: L = annual pollutant load, expressed in pounds/year; A = drainage area, in acres; R = annual runoff, in inches; C = flow-weighted mean pollutant concentration, expressed in milligrams per liter;  $L_R$  = amount of pollutants removed, in pounds per year;  $L_R$  = annual pollutant removal rate, expressed as a percentage; and  $R_E$  = removal efficiency, expressed as percentage. The unit conversion factor of 0.226 is used to convert the units to pounds per year for pollutant concentration.

TABLE 5.5. DECATUR STREET – FACILITIES SUMMARY					
Facility	Facility Description	Drainage Area Treated (ac.)	Impervious Area Treated (ac.)	Design Storm (in.) <small>note a</small>	Annual Runoff (in.)
BIO1	Stormwater curb extension	0.19	0.17	1.0	32.33
BIO2	Stormwater curb extension	0.04	0.035	1.0	31.66
BIO3	Stormwater curb extension	0.21	0.18	1.0	31.05
BIO4	Stormwater curb extension	0.17	0.16	1.0	33.91
BIO5	Stormwater curb extension	0.14	0.13	1.0	33.48
BIO6	Stormwater curb extension	0.11	0.1	1.0	32.82
BIO7	Stormwater curb extension	0.15	0.14	1.0	33.64
BIO8	Stormwater curb extension	0.16	0.15	1.0	33.78
PP1	Permeable pavement	0.14	0.12	0.75	31.05
PP2	Permeable pavement	0.14	0.12	0.75	31.05
PP3	Permeable pavement	0.06	0.05	0.75	30.24
PP4	Permeable pavement	0.13	0.11	0.75	30.68
PP5	Permeable pavement	0.14	0.13	0.75	33.48
PP6	Permeable pavement	0.12	0.1	0.75	30.24
PP7	Permeable pavement	0.09	0.08	0.75	32.13
	Total:	1.99	1.78	0.90	n/a

### Notes for Table 5-5

- a. The size and capacity of the BMPs was determined using a preliminary site plan, aerial photography, and on-site hand-measuring of facilities. [Return to table.](#)

## IDENTIFYING OPPORTUNITIES:

### Dennis Avenue

#### SILVER SPRING, MD

Dennis Avenue is a primary residential roadway that runs through several suburban neighborhoods in lower Montgomery County, Maryland. Just under a mile of the 2.5-mile-long roadway was retrofitted as a green street from 2012 to 2014 by Montgomery County's Department of Environmental Protection and Department of Transportation. <sup>note 18</sup>

Dennis Avenue's wide right-of-way provided many opportunities to integrate green infrastructure practices into the medians and grassy areas between the road and sidewalk. While the project involved three phases, the modest scale of the individual low impact development BMPs enabled the county to "fast-track" the installation process and significantly reduce construction time.



FIGURE 5.9. A SEGMENT OF DENNIS AVENUE IN 2008

#### OPPORTUNITIES

- » Install bioswales and streetside bioretention in existing green spaces
- » Add stormwater curb extensions to parking zones
- » Plant street trees along the roadway

#### CONSTRAINTS

- » Limited construction time frame
- » Large amounts of stormwater flowing into right-of-way
- » Steep slopes
- » Managing closures on residential roads



FIGURE 5.10. RENDERED OVERLAY OF GREEN STREET RETROFITS ALONG DENNIS AVENUE

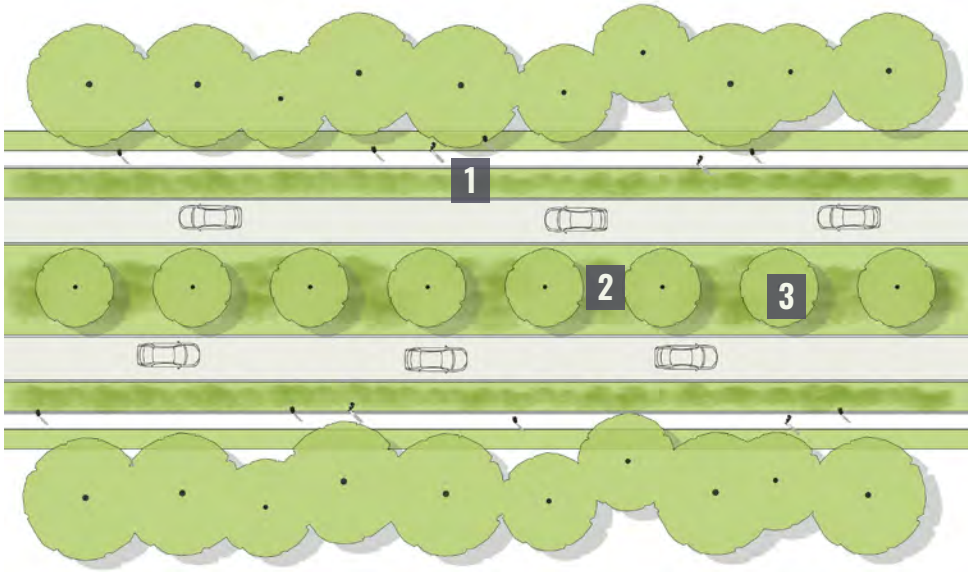


FIGURE 5.11. PLAN VIEW OF GREEN STREET RETROFITS ALONG DENNIS AVENUE

- Key Elements**
- 1. Stormwater curb extension
  - 2. Bioswale
  - 3. Street tree



Dennis Avenue's wide right-of-way and existing grassy areas provided many opportunities to add low impact development BMPs.

### STORMWATER ENHANCEMENTS

Stormwater runoff from Dennis Avenue flows to Sligo Creek – a tributary to the Anacostia watershed. A total of 24 engineered low impact development BMPs were installed within a 0.91 mile stretch of the Dennis Avenue right-of-way. These included infiltration devices, tree box filters, and various forms of streetscape bioretention. The 24 BMPs were designed to manage runoff from 25 acres of land, with 8 acres being impervious surfaces. An additional 24 low impact development BMPs were installed along three adjacent residential streets during the same period. However, those practices were not considered in this analysis.

### STORMWATER PERFORMANCE CALCULATIONS

The Dennis Avenue green street retrofit project design followed current stormwater management standards for Montgomery County and the State of Maryland. As-built drawings and tables were used to determine the size and capacity of each BMP.



Workers excavate part of the Dennis Avenue right-of-way to make way for a bioswale.



A bioswale after construction



Close-up of a stormwater inlet along Dennis Avenue



An overflow riser installed along Dennis Avenue

### Drainage Areas

Drainage areas were calculated for the 24 BMPs utilized in the Dennis Avenue green street retrofit project (see [Table 5.6](#)). Unlike Nannie Helen Burroughs Avenue and Decatur Street, the BMPs installed along Dennis Avenue treat stormwater runoff flowing into the roadway from portions of the adjacent lots and streets for up to the 1 inch storm. The overall drainage area for the newly treated portions was determined to be approximately 25 acres – 58 percent of which is impervious.

### Annual Rainfall

An average annual rainfall amount was used to determine the runoff and pollutant loads for various BMP types. In Maryland, the average annual rainfall depth is 42 inches.



A step pool storm conveyance system (SPSC) during the installation process (left), and post-construction (right). While not detailed in this guidebook, SPSCs can provide slope and outfall stabilization.

TABLE 5.6. DENNIS AVENUE – FACILITIES SUMMARY

Facility	Facility Description	Drainage Area Treated (ac.)	Impervious Area Treated (ac.)	Design Storm (in.) <sup>note a</sup>	Annual Runoff (in.)
BIO1	Bioretention	1.18	0.42	1.75	5.06
BIO2	Bioretention	0.83	0.24	1.5	5.58
BIO3	Bioretention	3.78	1.19	0.5	2.77
BIO4	Bioretention	5.13	1.48	0.5	3.10
BS1	Bioswale	0.31	0.08	4.0	64.44
BS2	Bioswale	0.04	0.04	6.0	177.09
BS3	Bioswale	0.55	0.32	0.5	9.56
BS4	Bioswale	0.18	0.06	2.0	18.90
BIO/S1	Bioswale / Bioretention Hybrid	0.63	0.18	1.25	9.45
BIO/S2	Bioswale / Bioretention Hybrid	2.54	0.57	0.75	7.45
BIO/S3	Bioswale / Bioretention Hybrid	0.93	0.21	0.5	10.49
BIO/S4	Bioswale / Bioretention Hybrid	2.54	0.76	2.0	21.71
BIO/S5	Bioswale / Bioretention Hybrid	2.18	0.75	1.5	3.61
TBF1	Filtterra 12'x6'	0.39	0.11	1.0	13.23
TBF2	Filtterra 6'x4'	0.1	0.09	1.0	22.30
TBF3	Filtterra 6'x4'	0.17	0.11	1.0	17.90
TBF4	Filtterra 6'x4'	0.09	0.06	1.0	258.93
TBF5	Filtterra 6'x4'	0.08	0.06	1.0	27.41
TBF6	Filtterra 6'x4'	0.1	0.09	1.0	22.30
TBF7	Filtterra 8'x4'	0.19	0.17	1.0	56.32
SPSC1	Step Pool Storm Conveyance	0.04	0.035	1.0	14.88
SW1	Swale	0.21	0.18	1.0	74.79
SW2	Swale	0.17	0.16	1.0	11.67
<b>Total:</b>					
		<b>24.85</b>	<b>7.92</b>	<b>1.01</b>	<b>n/a</b>

See notes on page 103.

### Notes for Table 5.6

- a. Stormwater treatment depths were capped at 2.5 inches when calculating the pollutant removal benefits. This is because the pollutant removal efficiencies dramatically diminish beyond this point. The maximum treatment depth allowed for credit under the Maryland Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated is 2.5 inches. [Return to table](#).

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### Annual Runoff

Some rainfall events are too small to cause any measurable runoff. During other storm events, more stormwater runs off impervious surfaces than non-impervious surfaces. The same equation used to find the annual runoff in each drainage area for Decatur Street was also used for Dennis Avenue.

### Design Storm

The stormwater volumes and drainage areas for the 24 low impact development BMPs were taken from as-builts of the site and reflect the in-field conditions. Each BMP was sized to treat as much rainfall as practicable. The design storm determination, or average rainfall treatment depth, was rounded to the closest increment found on the Maryland wasteload allocation manual chart.

The average rainfall treatment depth across all 24 BMPs was 1.01 inches. Eight of the newly installed BMPs treat runoff depths ranging from 1.5 to 6 inches and were able to offset those where full treatment of the 1-inch storm was not feasible. The installed BMPs treated a portion of the runoff from adjacent properties. While not always possible in urban settings, this extra treatment was possible because of the large width of the original right-of-way and the ability to easily convert existing green areas in the right-of-way into stormwater treatment areas.

The large medians and grassed strips along the periphery of the right-of-way allowed for a comprehensive approach to stormwater treatment. Use of standard low impact development BMPs such as bioretention, swales, and Step Pool Storm Conveyance systems was combined with tree box filters for areas with more space limitations. The project also used BMP chains, where one BMP flows into another, to increase treatment volume and pollution reduction benefits in areas where site conditions allowed.

TABLE 5.7. DENNIS AVENUE - POLLUTANT REMOVAL CALCULATIONS			
Pollutant	Pollutant Load (pounds/year)	Weighted Removal Efficiency (percent)	Pollutant Removed (pounds/year)
Total Nitrogen	143.0	53.4	76.4
Total Phosphorous	21.5	62.4	13.4
Total Suspended Solids	5,720.6	67.8	3,880.4

### BMP Efficiency Values

The process for calculating the pounds of Total Nitrogen, Total Phosphorous, and Total Suspended Solids removed annually for the low impact development BMPs installed along Dennis Avenue is the same as that for Decatur Street. Based on the BMP classification, a specific pollutant removal curve is used to determine nutrient and sediment load reductions. The rainfall treatment depth, pollutant concentration, and a conversion factor (based on the BMP classification) are utilized to yield the annual pollutant load in pounds per year. The combined pollutant removal benefits for the green street retrofit as a whole is provided in [Table 5.7](#).

## Reporting and Verifying Retrofits

Once a green street retrofit has been installed, it must be reported in order to be credited. Each year, MS4 communities are required to prepare and submit annual reports to their NPDES permitting authority about stormwater-related programs and projects targeted to reduce stormwater runoff and improve water quality. Information on individual projects is collected and aggregate data is reported to the state. This information could be used to evaluate whether NPDES permit requirements are being met and to determine how well localities are doing at achieving aggregate load reductions required under the Chesapeake Bay TMDL.

It is important to ensure that the correct information is collected and tracked as part of the process of installing green street retrofit projects. The type of information collected and the required format can vary by state. The following information is typically required in order for MS4 permit reporting to be consistent with Chesapeake Bay Program standards: <sup>note 19</sup>

- » BMP class (e.g., new retrofit)
- » BMP type (e.g., bioswales)
- » GPS coordinates

- » 12 digit watershed location
- » Total drainage area
- » Total impervious area treated
- » Runoff storage volume
- » Date installed

Some practices — such as street sweeping — will not adhere to this type of reporting system. When unsure of what to report, planners or designers should check with the appropriate permitting authority.

### VERIFICATION OVER TIME

Proper inspection of low impact development BMPs during the construction process and through post-construction verification is a way of ensuring that designs are installed as intended. Implementation, tracking, and reporting needs do not stop when a green street retrofit project is installed but continue throughout the lifetime of the individual green street elements. Conducting regular maintenance inspections is important to verify the green street element is still working and to identify any maintenance needs over the practice's life.

Phase I and Phase II MS4s are required to have an inspection program and must perform maintenance inspections of installed BMPs pursuant to permit requirements. Quality assurance programs become more important as the use of small-scale green stormwater infrastructure practices increases.

Taken on its own, the stormwater benefits of just one green street retrofit may seem small. The real contribution, however, comes from a collective approach of aggregating green street retrofits in a watershed. All three retrofit projects discussed in this chapter are located within the Anacostia watershed. Although each were faced with different opportunities, challenges, and solutions, they shared common goals of improving water quality and providing health and aesthetic values to the urban environment. This approach of clustering green infrastructure and low impact development is the ideal path to creating a meaningful and catalytic impact in Chesapeake Bay communities.

## ENDNOTES: CHAPTER 5

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