Engineering Green Streets: 3 PDH

Three (3) Professional Development Hours
Course #CV1630

Approved Continuing Education for Licensed Professional Engineers

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Course Description:

The Engineering Green Streets course satisfies three (3) hours of professional development.

The course is designed as a distance learning course that provides a comprehensive overview of how to integrate green infrastructure practices into public rights-of-way—roads, alleys, sidewalks and parking areas—to better manage stormwater onsite. Course based on *Green Streets Handbook*, Publication EPA 841-B-18-001, 2021.

Objectives:

The primary objective of this course is to equip state and local transportation agencies, municipal officials, designers and stakeholders with the knowledge and tools to select, design and implement green infrastructure solutions that reduce impervious-surface runoff, improve water quality, and deliver environmental, social and economic co-benefits in “green and complete” streets projects.

Grading:

Students must achieve a minimum score of 70% on the online quiz to pass this course. The quiz may be taken as many times as necessary to successfully pass and complete the course.

A copy of the quiz questions is attached to the last pages of this document.

Contents

Preface

In large U.S. cities, 25 percent to more than 60 percent of the land area is covered by impervious roadways, alleys, driveways, sidewalks and surface parking lots. Stormwater runoff from these areas can produce significant runoff volumes and carry pollutant loads that negatively impact the water quality of surface waterbodies and reduce groundwater recharge because of the loss of soil infiltrative capacity. This course is intended to provide the reader with a systematic process to begin reducing the impervious surface footprint of the public right-of-ways and associated off-street surface parking areas.

Green streets can provide many environmental, social and economic benefits. In addition to the stormwater runoff reduction and water quality improvement benefits, green streets can be designed to calm traffic, provide safer pedestrian and bicycle paths, mitigate urban heat island effects, improve community aesthetics, promote a sense of place and stimulate community investments. These enhancements can help to make a “green and complete street” that is safe and accessible for all users while also being friendlier to the environment and beneficial for the community at large.

This course is intended to help state and local transportation agencies, municipal officials, designers, stakeholders and others to select, design and implement site design strategies and green infrastructure practices for roads, alleys and parking lots. Green infrastructure practices are designed to mimic natural systems by intercepting, infiltrating and evapotranspiring stormwater to reduce runoff and protect or restore site and watershed hydrology.

The course provides background information on street and road typologies and offers a programmatic framework to use when identifying areas that can be initially designed or later retrofitted with green infrastructure practices or systems. The course also contains information about green street design considerations, pretreatment and stormwater management practices, and external resources with additional detail for readers who wish to go deeper into a specific topic.

Don Waye, USEPA

Stormwater tree pits in a parking lot, Reston, VA.

1 Addressing Stormwater Runoff

In This Chapter

This chapter provides an overview of stormwater runoff from transportation infrastructure, including typical pollutant concentrations and common transportation-related sources of those pollutants. Green streets can be designed to incorporate a variety of green infrastructure practices to manage stormwater onsite, where precipitation falls. Green streets, which can also be part of "complete street" solutions, can provide many benefits including environmental, social and economic benefits. Many states and local governments across the country have also developed green street and green infrastructure design manuals that transportation designers can use.

Eric Vance, USEPA

Clean water is essential for protecting swimmers' health.

Eric Vance, USEPA

Runoff from urbanized areas contributes to pollution and flooding.

1.1 Road-Related Networks and Stormwater Runoff

Transportation Infrastructure Affects Stormwater Runoff Volume and Pollutant Load

Roads and parking lots are a highly visible part of the landscape. Counties, cities and towns control 76 percent of the more than 4 million U.S. roads. The remaining road miles are managed by state highway agencies (19 percent) and federal and other jurisdictions (4 percent) (FHWA 2016). Roadways are a critical component of the nation's infrastructure, but because of their imperviousness and associated pollutant loadings they can also significantly impact water resources.

Transportation-related land uses represent an especially high percentage of overall impervious surface area within urban and suburban areas. Within the urban environment, roads, driveways, sidewalks and parking lots can constitute up to 70 percent of the impervious surface area (Tilley 2006). When it rains or snows, the roadway networks can collect and convey large volumes of stormwater runoff, facilitating the transport of the pollutants deposited on the roadways from vehicles, the atmosphere, road construction or adjacent land uses. As shown in Table 1-1, the types of pollutant loadings depend on a variety of factors, including traffic volume, land use, total impervious surface area, storm events (intensity and duration), and accidental spills.

Table 1-1. Summary of the pollutant types found in road runoff (FHWA 1984)

Pollutant	Sources	
Particulates	Pavement wear Vehicles Atmospheric deposition	Rubber tire wear Winter sanding
Nitrogen and phosphorus	Atmospheric deposition Fertilizer Sediment	
Metals (e.g., zinc, iron, copper, cadmium, chromium, nickel, manganese)	Grease Tire wear Motor oil Brake linings	Vehicle rust Steel structures Engine components Diesel and gasoline
Sodium, calcium, chloride	Deicing salts	
Bacteria	Animal waste	

USEPA

Transportation network in Chicago, IL.

Eric Vance, USEPA

Land use patterns in a city.

Eric Vance, USEPA

Impervious expanse of a parking lot.

Two of the largest factors that determine pollutant loads are traffic volume and surrounding land uses. Greater traffic volume, measured in average daily traffic, results in increased amounts of vehicle-associated pollutants (Table 1-2). Likewise, areas that have rapid turnover of parked cars (e.g., retail parking areas) typically generate higher levels of contamination because of the vehicle-associated pollutant deposition and surface wear associated with frequent starting of vehicles (NRC 2008).

Surrounding land uses also affect the volume of runoff on roadways. Impervious surfaces, especially directly connected areas, convey runoff that picks up pollutants as it flows. Studies have shown that stream health (as measured by the concentration of pollutants, habitat quality, and aquatic species diversity and abundance) decreases as the amount of impervious area increases in a watershed (Arnold and Gibbons 1996). Large volumes of runoff entering streams can cause erosion that affects downstream water quality, destabilizes stream channels and damages habitat. Runoff can also lead to flooded and closed roadways, creating a nuisance for users.

Stormwater runoff flowing off impervious surfaces collects and transports pollutants such as metals, hydrocarbons, bacteria, excess nutrients and sediments. Under conventional drainage system designs, these pollutants typically are discharged untreated directly into receiving water bodies such as streams, lakes and bays.

Fortunately, communities can install practices to help mitigate stormwater-caused impacts. By replicating a site's original hydrology and encouraging the capture, infiltration and evapotranspiration of runoff, transportation network designers and planners can reduce excess stormwater flows while also managing pollutant loadings. Using these techniques represents a sound approach to protecting water quality while also meeting a community's transportation needs.

Table 1-2. Summary of pollutant concentrations found in road runoff from highways with small and large traffic volumes

Pollutant	Event mean concentration for highways with fewer than 30,000 vehicles/day (mg/L)	Event mean concentration for highways with more than 30,000 vehicles/day (mg/L)
Total suspended solids	41	142
Volatile suspended solids	12	39
Total organic carbon	8	25
Chemical oxygen demand	49	114
Nitrite and nitrate	0.46	0.76
Total Kjeldahl nitrogen	0.87	1.83
Phosphate phosphorus	0.16	0.40
Copper	0.02	0.05
Lead	0.08	0.40
Zinc	0.08	0.33

Source: Driscoll et al. 1990

Notes: mg/L = milligrams per liter

USEPA Copper-Free Brake Initiative

The U.S. Environmental Protection Agency (USEPA), states and the automotive industry are working together to reduce the use of copper and other materials in motor vehicle brake pads. The wearing of brake pads onto roadway surfaces contributes excessive levels of copper and other pollutants to waterways. The automotive industry has agreed to reduce copper in brake pads to less than 5 percent by weight in 2021 and 0.5 percent by 2025. For more information see USEPA's **Copper-Free Brake Initiative website**.

1.2 Stormwater Solutions: Green Streets

Using Natural Processes to Control Stormwater

Streets and parking lots can be designed using a variety of practices that mimic or preserve natural drainage processes to manage stormwater. These practices retain stormwater and snowmelt and promote infiltration into the ground to reduce runoff volumes that may contribute to flooding and water quality problems (Figure 1-1). This course uses the term green infrastructure to describe these practices. As defined under Section 502 of the Clean Water Act (CWA): "Green infrastructure means the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."

This course is focused on green infrastructure specifically for storm-water management practices in transportation infrastructure, such as roads and parking lots, but the term green infrastructure varies in its use in other contexts. Conservation ecologists use green infrastructure to describe the creation and networking of natural ecosystems and greenway corridors (e.g., forests, floodplains) that provide ecological services and benefits. In the context of stormwater, USEPA uses green infrastructure to refer to practices such as green roofs, porous pavement, swales and rain gardens that largely rely on using soil and vegetation to infiltrate, evapotranspirate, and/or harvest stormwater runoff and reduce flows entering drainage collection systems.

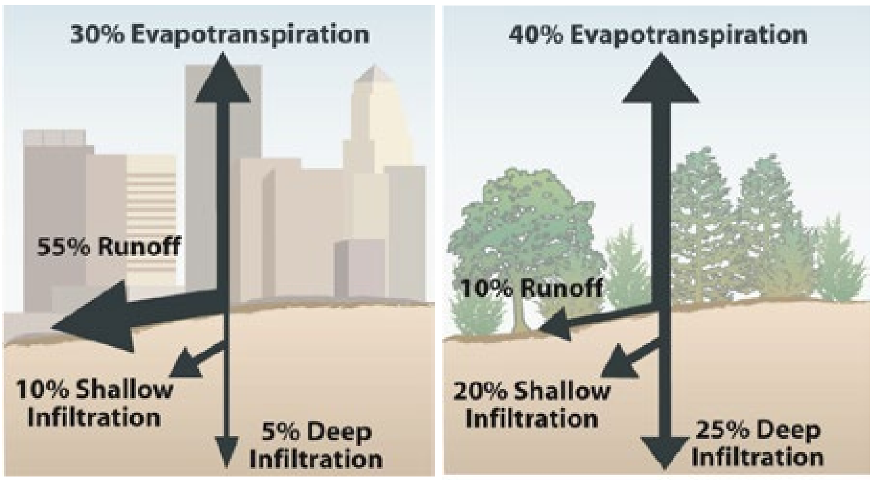


Figure 1-1. When impervious areas (roads, rooftops, parking lots) cover much of the land (left image), more than half the rainfall runs off and flows directly into surface waters, allowing only 15 percent of rain water to soak into the ground. In contrast, areas that are designed to mimic natural areas (right image) allow only 10 percent of rain to run off and nearly half to soak into the ground.

Some use other terms to reference the same practices as green infrastructure for stormwater management. For example, low impact development (LID) is a management approach and a set of practices that can reduce runoff and pollutant loadings by managing runoff as close to its source as possible. Other terms include low impact design, sustainable urban drainage systems, water-sensitive urban design and green stormwater infrastructure. The definitions of these terms may vary slightly among organizations and industry professionals; however, these concepts are generally captured in the CWA definition of green infrastructure. Therefore, this course will use the term green infrastructure from here forward.

Green Infrastructure in Transportation Networks

Traditional stormwater management systems along roads typically direct runoff into pipes or channels that often carry runoff great distances from where precipitation falls. In contrast, a *green street* incorporates a variety of green infrastructure practices that manage stormwater onsite, where (or very near to where) the precipitation falls. Because green infrastructure techniques are location-independent and can be applied across different regions and climatic zones, designers can adjust the basic forms and processes of practices to best suit local physical, social, and climatic conditions and goals. As discussed in Chapter 2, green infrastructure elements that re-create natural areas can be incorporated into almost all transportation projects.

Green Infrastructure Practices Rely on Natural Processes to Capture and Clean Stormwater

Strategies for green infrastructure design rely on naturally occurring hydrological and biophysical processes to manage the quantity of flow and improve water quality (Figures 1-2 and 1-3).

Hydrologic processes:

Infiltration. Water moves from the ground surface into the soil.

Detention. Water is stored temporarily, thus delaying conveyance downstream.

Retention. Instead of flowing downstream, water is captured and stored onsite for later evapotranspiration or infiltration.

Interception. Vegetation or buildings capture precipitation.

Evapotranspiration. The leaves of plants release water into the atmosphere.

Biophysical processes:

Filtration. Vegetation, soil and plant roots strain organic matter, phosphorus and suspended solids out of stormwater.

Sedimentation. Sediment drops out of suspension and accumulates as stormwater slows and pools in the practice.

Adsorption. Pollutants and excess nutrients carried in stormwater attach to clay particles in the soil and remain in place.

Microbial action. Bacteria in the soil and plant roots break down the pollutants and nutrients.

Uptake. Plants and soil organisms absorb metals and use nutrients such as nitrogen and phosphorus for their growth.

USEPA

Figure 1-2. Modifying or designing parking lot islands as bioretention areas can capture and temporarily store runoff, allowing the water time to infiltrate the soil or be evapotranspired.

Alisha Goldstein

Figure 1-3. Soil and plants absorb and filter out excess nutrients and other pollutants from runoff, while microbes in the soil help break down the chemical compounds.

Elements Support Complete Street Initiatives

Developing a green streets program complements the nationally recognized Complete Streets policy initiative supported by the Federal Highway Administration (FHWA) and USEPA. This initiative promotes street designs that promote neighborhood character, stimulate economic development, and serve the mobility and access needs of all users—motorists, transit riders, bicyclists and pedestrians. As seen in Figure 1-4, Complete Street objectives are primarily achieved by using measures to calm traffic and create well-defined barriers between transportation types (e.g., chicanes, islands, curb extensions, bike lanes).

Fortunately, many communities across the country recognize that a street is not necessarily "complete" without features that also serve environmental goals, and they strive to use traffic-calming measures that can double as stormwater-control features. For example, by placing a vegetated stormwater curb extension at an intersection or near a crosswalk, community transportation designers can encourage reduced traffic speeds and alert drivers to activity occurring adjacent to the road while also capturing street runoff. Adding a well-marked pervious pavement bicycle lane intercepts runoff and protects bicyclists from vehicular traffic. Similarly, planting street trees helps define road boundaries, protects pedestrians and motorists, and intercepts and absorbs rainfall.

Figure 1-4. A green and "complete street" in Seattle, Washington, includes specific streetcar, vehicle, bike and pedestrian zones and a rain garden and vegetated stormwater curb extensions to capture and treat runoff.

For More Information—Green Streets and Complete Streets

- Green Streets: A Conceptual Guide to Effective Green Streets Design Solutions. USEPA (2000)
- Managing Wet Weather with Green Infrastructure Municipal Handbook: Green Streets. USEPA (2015)
- G3 Partnership: Green Streets, Green Towns, Green Jobs. USEPA
- Urban Street Stormwater Guide (2017) and Urban Street Design Guide (2013). ($) National Association of City Transportation Officials
- Complete Streets. Smart Growth America/Complete Streets Coalition
- Boston Complete Streets. Boston Transportation Department, MA (2013)
- Complete Streets. U.S. Department of Transportation, FHWA
- Toronto Complete Streets Guidelines. City of Toronto, Canada

1.3 Benefits of Green Streets

Green Streets Provide Environmental, Social and Economic Benefits

Green streets are an investment in your community because good designs can provide many additional benefits beyond stormwater management. The design of streets and public rights-of-way can affect the public's perception of a community, influence the behavior of residents and visitors, and shape development decisions, while also helping to create a sense of place. The use of green streets can provide numerous benefits, such as:

- Improved water quality
- Enhanced community resilience
- Increased groundwater recharge
- Enhanced wildlife habitat
- Improved air quality
- Reduced urban heat island effects
- Increased pedestrian safety and traffic calming
- Enhanced well-being of individuals
- Increased sense of community
- Increased property values
- Reduced water treatment costs
- Reduced infrastructure costs
- Reduced property damage due to flooding

These benefits are grouped and described in further detail on the following pages.

Low Impact Development Center

Sketch of green street components such as a permeable pavement crosswalk, curb bump-outs and bioretention applied to a local road.

Environmental Benefits of Green Streets

Improves Water Quality

The green infrastructure elements incorporated into green streets help decrease the volume of stormwater runoff and pollutants entering water bodies by:

- Capturing the small, frequently occurring storm events.
- Filtering the first flush of runoff that can contain high concentrations of pollutants.
- Slowing down and temporarily storing runoff.
- Reducing erosion and sedimentation that can negatively impact aquatic habitat and destabilize stream channels.

Green streets can be designed to use the processes of filtration or infiltration to reduce the pollutant loadings that are discharged into waterways. The most cost-effective systems are typically soil-based vegetated designs, although permeable pavements, filtration and infiltration systems can also be used to mitigate the effects of stormwater runoff volumes and pollutant loadings from roads, rights-of-way and parking lots.

Enhances Community Resilience

The use of green streets can increase resilience to changing weather patterns and can help save energy. Incorporating street trees and green infrastructure practices that include vegetation (e.g., bioretention cells, bioswales) in the right-of-way can provide cooling and wind break effects that reduce energy use by nearby homes and businesses and, as a result, reduce emissions at nearby power plants. Green streets can also be designed to promote alternative modes of transportation such as walking and biking to reduce vehicle use and associated emissions (NCSC, n.d).

Increases Groundwater Recharge

Green street practices that infiltrate runoff, such as bioretention cells, bioswales, infiltration planters and permeable pavement, are designed to allow runoff to drain into subsurface soils and recharge groundwater supplies. Recharging aquifers can be particularly important in areas of the country that have limited groundwater supplies and are challenged to meet their water supply needs.

Stormwater runoff from impervious areas like streets can be directed to infiltration practices that help recharge groundwater resources. An April 2016 USEPA study of stormwater retention practices used to recharge groundwater found that the monetary value of this recharged water can be worth millions of dollars in some states.

Enhances Wildlife Habitat

Vegetated landscape areas can provide habitat for wildlife. Green infrastructure can be used to mitigate the effect of habitat loss that is typically a result of urbanization. Patches of vegetation and/or trees incorporated into a community's green infrastructure can serve as a nesting location for birds, temporary resting places for migrating wildlife, or sources of food for pollinators. In rural settings, larger areas of green infrastructure can serve both as habitat and wildlife corridors that enable animals to migrate.

Improves Air Quality

Trees and other vegetation on green streets can improve air quality by directly removing air pollution and slowing temperature-dependent reactions that form particulate matter that is hazardous to human health (MWCOG 2007; Vingarzan and Taylor 2003). The increased shade and evapotranspiration provided by trees lowers air and surface temperature of impervious areas, which can reduce the amount of electricity needed for cooling and thus reduce power plant emissions of pollutants. These benefits are of special importance to communities designated by the USEPA as nonattainment areas for the 8-hour ozone standard due to ground-level ozone and fine particulates in the ambient air.

The monetary and quantitative value of the air quality benefits that can accrue from trees can be calculated by using standard software models such as i-Tree, which is a suite of applications developed by the U.S. Department of Agriculture (USDA) Forest Service to design and evaluate urban forestry efforts. The i-Tree family of applications (USFS 2014) includes:

1. i-Tree Streets, which helps quantify the dollar value of environmental and aesthetic benefits.
2. i-Tree Hydro, which provides watershed scale analyses of vegetation and impervious cover effects on hydrology.
3. i-Tree Eco, which documents a range of ecosystem benefits, such as carbon storage and sequestration, oxygen production, avoided runoff and energy savings.
4. i-Tree Design, which can help designers determine the benefits of specific trees in a landscape design.

Reduces Urban Heat Island Effect

Green streets also can be used to reduce urban heat island impacts that result from solar radiation absorbed by pavement, buildings and other hard surfaces and reflected as heat (USEPA 2008). Temperatures in urban areas can average 5 to 10 degrees Fahrenheit higher than those in suburban areas. Using reflective surfaces (e.g., light-colored pavements, sidewalks) and incorporating vegetation can reduce these temperature impacts. Heat can be reflected back into the atmosphere by using reflective or light-colored surfaces, and vegetation can be planted that evapotranspires water and thereby cools the ambient air temperatures (USEPA 2008). Table 1-3 compares albedos (how reflective or bright an object is) of different materials. A higher albedo reflects more light and helps with cooling.

Table 1-3. Albedos for various reference materials

Material	Albedo
Concrete (new to aged)	0.2 – 0.35
Asphalt (new to aged)	0.05 – 0.2
Deciduous plants	0.20 – 0.30
Dry grass	0.30
Deciduous woodland	0.15 – 0.20
Coniferous woodland	0.10 – 0.15
Artificial turf	0.05 – 0.10
Grass and leaf mulch	0.05

Source: Santamouris 2001; Pomerantz 2003.

Social Benefits of Green Streets

Offers Pedestrian Safety and Traffic Calming

Green infrastructure features, such as stormwater curb extensions, bump-outs and porous/vegetated islands, can be incorporated into street designs (e.g., placed in intersections or in the middle of cul-desacs) to help slow traffic, reduce crossing distances and increase awareness of crosswalk locations. Adding or enhancing sidewalks, crosswalks and bike lanes can contribute to greater public safety for all users. Pedestrian deaths account for 12 percent of total traffic deaths in the United States; these typically result from inadequate or nonexistent pedestrian safeguards such as crosswalks, pedestrian refuge islands (i.e., safe locations, such as a section of pavement or sidewalk within the roadway, where pedestrians can stop), and school and public bus shelters (TFA 2011).

Enhances Well-Being of Individuals

Green street practices can be placed in or along roadways and sidewalks to create safe and aesthetically pleasing pathways that encourage active transportation such as walking or biking. Planting trees creates shade and cools the air temperature so people are more likely to walk or bike. Green spaces have been shown to enhance the strength of social ties between neighbors (Holtan 2014). Neighborhoods with social cohesion have lower rates of social disorder, anxiety and depression. Green spaces enhance well-being and help the mind recover from mental fatigue or stress (Kaplan 1995). In densely developed urban areas, adding green infrastructure provides some relief in areas otherwise devoid of green infrastructure such as parks.

Increases Sense of Community

Although this benefit is often qualitative in nature, it reflects the ability of a feature such as a green street to positively serve as a signature place or a destination for community residents or visitors and/or a model for development or redevelopment (DC OP 2011). In stressed or underserved communities, greening efforts can serve to help brand or rebrand a community to attract investments and provide residents and visitors a new perspective about their community. Green street projects can also serve to help educate the community about environmental issues such as protecting watershed health, building neighborhoods' weather resilience and caring for nature. Potential measures for evaluating this benefit include:

- Anticipated increase in sales by nearby merchants
- The number of events held in the project area
- Number of tourists and visitors anticipated to visit the project location
- Increases in community investments
- Improved environmental awareness in local schools

For More Information—Social Benefits of Green Streets

Cities Safer by Design: Guidance and Examples to Promote Traffic Safety through Urban and Street Design. World Resources Institute (2015)

Imaging Livability Design Collection: A visual portfolio of tools and transformations. AARP Livable Communities and the Walkable and Livable Communities Institute (2015)

Green Values Strategy Guide: Linking Green Infrastructure Benefits to Community Priorities. Center for Neighborhood Technology (2020)

Economic Benefits of Green Streets

Increases Property Values

Adding plants and trees to green streets creates attractive neighborhoods, which in turn can increase nearby property values by two to five percent (NRDC 2013). A research study evaluating street trees in Portland, Oregon, found that street trees added $8,870 to a house's sale price—equivalent to adding 129 finished square feet (sq ft). By extrapolating street tree benefits across the entire city, the study calculated that the increased property value translated into an increased annual property tax revenue of $13 million. Additionally, the benefits were found to outweigh the costs by almost 12 to 1. One study estimated the benefits created by green streets to be $54 million annually, compared to the annual cost of $4.61 million required to maintain the green street elements (Donovan and Butry 2010).

Reduces Water Treatment Costs

Green infrastructure practices that increase infiltration or use water on-site (e.g., bioretention systems, permeable surfaces) can reduce the amount of water being conveyed to wastewater treatment facilities and reduce combined sewer overflows (CSOs). Reducing the volume of water discharged to combined stormwater and sewer systems can reduce the need to treat significant volumes of runoff. Reducing intake volumes can also reduce the stormwater infrastructure needed to convey this volume of runoff. The avoided costs and resulting benefits of green infrastructure can be evaluated by determining the amount of stormwater that will be infiltrated or evapotranspired versus the costs of treatment and ongoing maintenance and management of the system. A study completed for the City of Lancaster, Pennsylvania, found that implementing their Green Infrastructure Plan could reduce wastewater pumping and treatment costs by approximately $661,000 per year using the Center for Neighborhood Technology's methods for evaluating benefits of green infrastructure (USEPA 2014; CNT 2010).

Reduces Infrastructure Costs

In addition to avoided treatment costs, green infrastructure practices can also reduce gray infrastructure costs by reducing the need for infrastructure expansion, extending infrastructure life expectancies and decreasing overall life-cycle costs.

For example, the City of Lancaster study found that their Green Infrastructure Plan could cut capital costs for gray infrastructure by $120 million—the estimated cost for reducing CSOs via gray infrastructure storage, such as a tunnel (USEPA 2014). In another study in West Union, Iowa, the life-cycle costs of a permeable paver system and a traditional concrete pavement in a parking lot were compared; the analysis showed that over the life of the project, savings could be close to $2.5 million by selecting the permeable pavement (NRDC 2013). Although green infrastructure could have greater capital costs, the potential extended life of the system and avoided costs can provide significant savings when analyzed over a long life cycle.

Reduces Property Damage Due to Flooding

Lastly, green infrastructure practices can lessen the level of damage from flooding. Among the types of flooding that could become more frequent are localized floods and riverine floods. Localized flooding happens when rainfall overwhelms the capacity of urban drainage systems, while riverine flooding happens when river flows exceed the capacity of the river channel.

In areas impacted by localized flooding, green infrastructure practices can be used to absorb rainfall and reduce the amount of water that is discharged in stormwater systems, pools in streets, or seeps into basements (Qin 2013). In areas impacted by riverine flooding, green infrastructure, open space preservation, and floodplain management can all complement gray infrastructure approaches and reduce the extent of flood damage.

1.4 Additional Resources: Green Infrastructure

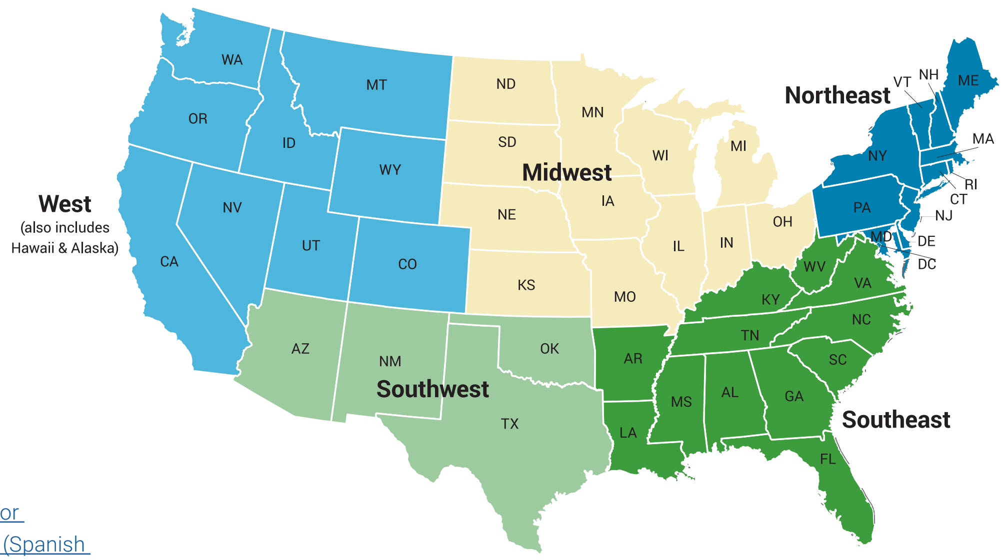
Numerous green infrastructure guidance and design manuals are available from online sources. As noted below, many have been tailored to represent the needs of particular regions of the country.*

West

- California (Los Angeles). Development Best Management Practices Handbook
- California (San Francisco). Green Stormwater Infrastructure Typical Details, Appendix B of Stormwater Management Requirements and Design Guidelines
- California (San Mateo County). Green Infrastructure Design Guide
- California. San Francisco Stormwater Management Requirements and Design Guidelines
- Colorado (Denver). Ultra-Urban Green Infrastructure Guidelines
- Oregon. Low Impact Development Approaches Handbook
- Oregon (Portland). Stormwater Management Manual includes Green Street Typical Details
- Washington (Puget Sound). Integrating LID into Local Codes: A Guidebook for Local Governments
- Washington (Seattle) Streets Illustrated: Right-of-Way Improvements Manual

Midwest

- Illinois (Chicago). Green Alley Handbook
- Michigan. Great Lakes Green Streets Guidebook
- Michigan. Low Impact Development Manual for Michigan
- Minnesota (North St. Paul). Living Streets Plan
- Minnesota Stormwater Manual
- Missouri (Kansas City). Green Stormwater Infrastructure Manual
- Nebraska (Omaha). Green Streets Plan for Omaha



Northeast

- District of Columbia. Greening DC Streets: A Guide to Green Infrastructure in DC
- Maryland Stormwater Design Manual
- Massachusetts (Holyoke). Green Streets Guidebook
- Pennsylvania. Philadelphia Green Streets Design Manual
- Rhode Island Low Impact Development Site Planning and Design Guidance Manual

Southwest

- Arizona. Green Infrastructure for Southwestern Neighborhoods (Spanish version)
- Arizona (Mesa). Low Impact Development Toolkit
- Arizona (Pima County). Low Impact Development and Green Infrastructure Guidance Manual
- Texas. San Antonio River Basin Low Impact Development Technical Guidance Manual

Southeast

- Kentucky (Louisville). MSD Design Manual, Ch. 18 Green Infrastructure.
- North Carolina. Stormwater Design Manual
- Tennessee (Nashville). Low Impact Development Stormwater Management Manual

* The map includes a sample of resources available; it does not represent all potential references that might be available from states and territories across the nation.

2 Transportation Typologies and Green Infrastructure Practices

In This Chapter

This chapter covers how green street concepts can be applied to different road classification systems, or transportation typologies, including arterial roads, collector roads, local roads, alleys and parking lots. Each typology is suitable for many different types of green infrastructure practices, from bioretention to bioswales to permeable pavements. Existing roadways also provide many opportunities for green infrastructure, including in verge zones along highways, in parking lanes, and in median spaces or planting areas of parking lots.

USEPA

Sidewalk planters capture runoff from a local road in Emeryville, CA.

2.1 Transportation Typologies

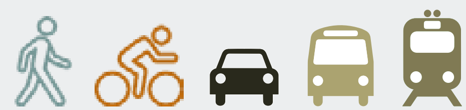
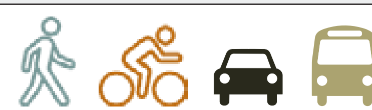
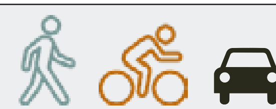
This course addresses typical low impact development and green infrastructure strategies that can be incorporated into public and private projects within rights-of-way that are part of a private development or are owned or maintained by a state, county, or municipal department of transportation (DOT).

The Federal Highway Administration's (FHWA's) road classification system, or transportation typology, defines roads based on specific function or purpose: **arterial**, **collector** and **local**. At the local level, additional sub-classes often include **alleys** and **parking lots** (Table 2-1).

Many cities further categorize streets according to land use context, neighborhood characteristics and other special considerations to recognize the scope of activities that occur along the street, such as:

- Parkway
- Main street
- Industrial thoroughfare
- Commercial (small, medium, large)
- Downtown historic corridor
- Shopping district
- Transitway
- Neighborhood/residential street

Table 2-1. Transportation category descriptions[1]

Transportation category	Description	Examples	Users
Arterial roads	Fast-moving, high-traffic roads for vehicular travel between and around urban areas. These roads typically have several travel lanes (two to four).	Interstates and highways	
Collector roads	Moderate-traffic roads that serve high-density areas, including residential, mixed use and neighborhood business districts. Speed limits and traffic volumes depend on adjacent land use. These roads offer some connections to individual parcels and driveways.	Avenues, boulevards and parkways	
Local roads	Low-traffic roads with slow speeds that serve residential areas. Many connections to individual parcels and driveways. These roads typically have one or two travel lanes, slower speed limits and low traffic volumes.	Road and streets	
Alleys	Low-traffic roads that provide access to areas adjacent to or behind buildings and residences.		
Parking lots	Areas that provide multiple parking spaces.		

[1] Modeled after FHWA functional classifications

Road Usage Influences Management Approach

To avoid compromising safety and disrupting access and mobility, a road's classifications and the context of the road project should be considered when determining where to site practices (Figure 2-1). The specific strategies and technologies implemented will vary depending on the following transportation system characteristics:

- Road usage types
- Traffic volumes
- Specific project conditions
- Adjacent land uses
- Contributing drainage area
- Available space
- Site characteristics (e.g., slope, soils, infiltration capacity)

Sections 2.2—2.6 discuss the type of practices that are typically appropriate for the various road classifications.

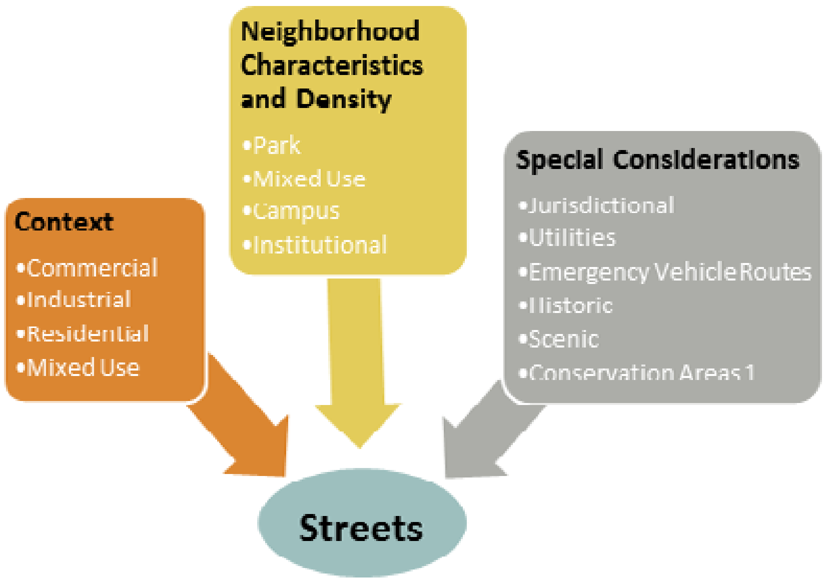


Figure 2-1. Numerous factors must be considered when choosing and siting green infrastructure practices as part of a green street design.

For More Information—Road Classification

[Highway Functional Classification Concepts, Criteria and Procedures, Section 3], U.S. Department of Transportation (2013)


Eric Vance, USEPA

Highway.


Eric Vance, USEPA

Downtown business area.


Eric Vance, USEPA

Neighborhood/residential street.

Road Usage Influences Choice of Projects

A variety of site design strategies and green infrastructure practices are appropriate for developing green streets. Table 2-2 provides a quick reference for screening practices that could be appropriate for the transportation typology or application being considered.

More detailed descriptions of practices appropriate for each of these road typologies are outlined in the following sections. Key design features for each of these practices are discussed in Chapter 4. Specific technical information for each practice type is provided in Chapter 6.

It should be noted that, in general, most of the green infrastructure practices in this course provide the same basic stormwater functions, but the shape of the practice (depth, width, geometry) will differ based on the site and geotechnical factors. For example, bioretention cells and stormwater curb extensions manage stormwater in a similar manner, but their construction and optimal site locations are different.

The practices in this course were chosen because they can be implemented in a variety of projects, ranging from narrow rights-of-way to urban sidewalks to highway shoulders. Additional practices not included in this course might also be appropriate in certain applications. Some of the resources listed within the chapters and in the reference section cover these practices.

For More Information—Roadway Rating Systems

Incorporating green infrastructure is just one element to consider when developing sustainable roadways. Other important factors include the types of materials and resources used, the operation and maintenance needs, and energy and atmosphere impacts. Several states and other third parties have developed scorecards to encourage transportation departments to address these topics. Some of these certification and rating systems include:

- Federal Highway Administration INVEST tool
- Illinois – Livable and Sustainable Transportation Rating System and Guide
- New York State Department of Transportation GreenLITES (Green Leadership in Transportation Environmental Sustainability)
- Greenroads Rating System ($)
- Institute for Sustainable Infrastructure (Envision rating system)
- EPA Guide to Sustainable Transportation Performance Measures (2011)

Table 2-2. Guide for screening green infrastructure practices for different transportation typologies

Green Infrastructure Practices for Roadways and Parking Lots ● Most appropriate ⊙ Depends on site context ○ Least appropriate	Bioretention	Bioswale	Stormwater curb extension	Stormwater planter	Street trees	Infiltration trench	Subsurface infiltration and detention	Permeable pavement
Arterial	⊙	●	○	○	●	⊙	○	⊙
Collector	●	⊙	●	●	●	⊙	⊙	⊙
Local roads	●	⊙	●	⊙	●	⊙	○	⊙
Alleys	○	○	○	○	○	⊙	⊙	⊙
Parking lots	●	●	⊙	●	●	⊙	●	⊙

2.2 Arterials

Arterials are roads that carry through-traffic between major urban areas or between the central business district and outlying residential areas. These roads generally have higher speeds and more traffic lanes than most other street types. Arterial roads are primarily designed for vehicular transit and are heavily used by trucks; however, some accommodations are made to improve accessibility when the road passes through urban areas.

Subcategories for arterials are called major and minor. Minor arterials serve smaller geographic areas, provide service for trips of moderate length and might have minimal connection to adjacent parcels as compared to a major arterial. In urban areas, minor arterials may carry local bus routes. These distinctions are helpful in identifying the types of users from which design decisions regarding lane widths can be determined. The minimum desired lane width determines the amount of right-of-way potentially available for other uses such as stormwater management or bicycle lanes.

The linear stretches of land alongside an arterial road provide opportunities for siting green infrastructure practices and treatment trains. The selection of practices is limited by the amount of available area, soil characteristics, existing topography and roadway safety requirements. A common challenge is the presence of compacted soils, which is typically the result of construction-related grading activities. Because of potential compaction issues, infiltration rates should be tested beforehand. If necessary, soil should be modified (i.e., by adding soil amendments) to meet design standards. Using pretreatment devices such as swales and buffer strips is highly recommended to reduce sediment loads and runoff volumes and

USEPA

A bioretention area is located adjacent to an arterial road along the Schuylkill River in Philadelphia, PA.

U.S. Geological Survey

A bioretention area located in the median of an arterial road captures runoff in the Great Lakes region.

maintain long-term infiltration rates. Green infrastructure practices are typically suitable in three main arterial road zones (Table 2-3):

- When present, **medians** are an ideal location for linear practices such as bioswales and infiltration trenches. Bioretention cells might be applicable depending on the amount of available area. Reforestation is an option if the median is large enough and the trees do not obstruct drivers' lines of sight or interfere with utilities.

- **Shoulders and breakdown lanes** of a road can be good locations for permeable pavement or open-graded friction course overlays (see Chapter 4.12) because traffic is slow and use is low. An open-graded friction course spreads flow, reduces splashing and maximizes infiltration. It also improves safety by reducing hydroplaning and light reflectivity off the road surface.

- The **verge**, the area adjacent to a roadway, can be ideal for linear practices such as bioswales, infiltration trenches and tree canopy enhancements. Trees require ample open space and should not obstruct drivers' lines of sight or be a collision safety hazard. Low-growing vegetation might be the best choice for curving roadways.

Table 2-3. Suitability of green infrastructure practices for arterial road zones

● Most appropriate ◉ Depends on site context ○ Least appropriate	Medians	Shoulder and/or breakdown lanes	Verge
Bioretention	●	○	●
Bioswale	●	○	●
Stormwater curb extension	○	○	○
Stormwater planter	○	○	○
Street trees	●	○	●
Infiltration trench	●	○	●
Subsurface infiltration and detention	○	○	○
Permeable pavement/open graded friction course	○	◉	○

Alisha Goldstein

Medians with rain gardens manage stormwater runoff from the street collected via stormwater inlets connected to subsurface pipes in Arlington, VA.

Low Impact Development Center

Road runoff will be treated by this bioswale in the median of Adelphi Road, an arterial road in Maryland.

2.3 Collector Roads

Collector roads serve to funnel traffic from local roads to other local roads or arterials. They have high traffic volumes and multiple travel lanes (two or three). These roads often serve as routes for public transit and must provide adequate pedestrian facilities to allow safe and comfortable access and waiting areas. They offer some connections to individual parcels and driveways, and they can include on-street parking and shared bike lanes.

Collectors in mixed-use or neighborhood business districts tend to have slower speed limits to accommodate pedestrians. The addition of green infrastructure practices can also enhance pedestrian safety. For example, placing stormwater curb extensions at intersections or near crosswalks can calm traffic and alert drivers to pedestrian activity. Additionally, extensions can decrease the crossing distance, enabling pedestrians to safely cross streets.

Figure 2-2 illustrates a collector road through a neighborhood business district. The placement and types of green infrastructure practices that are feasible along collectors are denoted in the legend. As shown on the next page, a street's configuration might also influence the selection of particular practices.

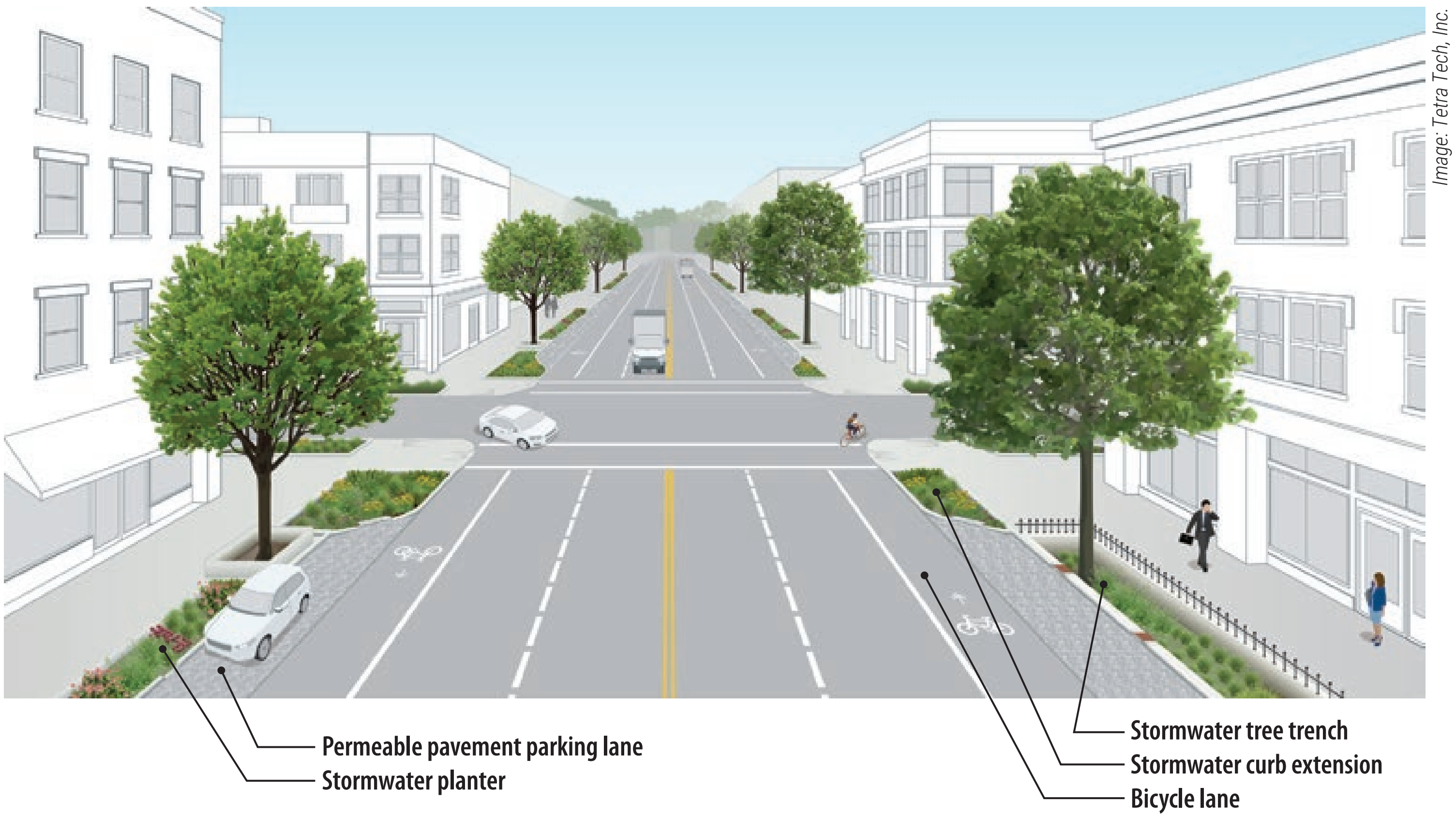


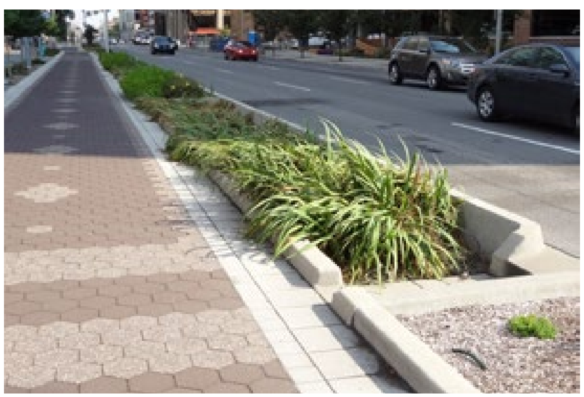
Figure 2-2. A collector road with green infrastructure features in a neighborhood business district.

Implementing green infrastructure practices in urban areas—especially in the right-of-ways on collector roads—is often challenging because less space is available and a utility conflict is more likely. In areas with high pedestrian traffic, practices with a smaller footprint or designs that preserve walkway width are more desirable. Green infrastructure practices are typically suitable in three main collector road zones (Table 2-4):

- **Medians and rights-of-way** are ideal for linear practices like bioswales and infiltration trenches. Collector roads without high pedestrian traffic might be better suited for bioswales, which often require more surface area and can handle large runoff volumes. Wide medians might also be appropriate for bioretention cells.
- **On-street parking areas, bike lanes or sidewalks** are best suited for permeable pavement, especially in dense urban areas where space for multimodal uses is at a premium. If space allows, stormwater planters can be used to separate a bike lane from a driving lane. Stormwater curb extensions can be placed mid-block or at the intersection of a parking lane. Maintenance needs should be planned and budgeted in advance.
- **Collectors with curbs and sidewalks are** appropriate locations for stormwater curb extensions, stormwater planters and street trees. These practices should only be installed where sidewalk width will support pedestrian traffic and horizontal and vertical space is available to accommodate tree growth. Suspended pavement designs that support the weight of paving and allow soil beneath to remain uncompacted can help provide sufficient soil volume for trees. Street trees help define the road boundary, protecting both pedestrians and motorists.

Table 2-4. Suitability of green infrastructure practices for collector road zones

● Most appropriate ◉ Depends on site context ○ Least appropriate	Medians	Bike or parking lanes	Verge
Bioretention	●	○	●
Bioswale	●	○	●
Stormwater curb extension	○	◉	●
Stormwater planter	○	◉	●
Street trees	●	○	●
Infiltration trench	●	○	◉
Subsurface infiltration and detention	○	◉	◉
Permeable pavement	○	◉	◉


Ann Rossi, USEPA

Bioswale separates sidewalks from bike lanes and vehicular traffic in Indianapolis, IN.


Alisha Goldstein

Permeable pavement parking lane in downtown Syracuse, NY.


Eric Vance, USEPA

Bioretention cell in sidewalk with seating along a commercial corridor in Washington, DC.

2.4 Local Roads

Local roads are low-traffic roads predominant in neighborhood areas. Because they serve residences, local roads could have a high pedestrian presence, sidewalks and shared bike lanes. There will be significant on-street parking for residents. Local roads account for the largest percentage of roadways in terms of total road miles (USDOT 2013).

Figure 2-3 illustrates the placement and types of green infrastructure practices that are appropriate along local roads. Other opportunities for siting practices are described in more detail on the following page.

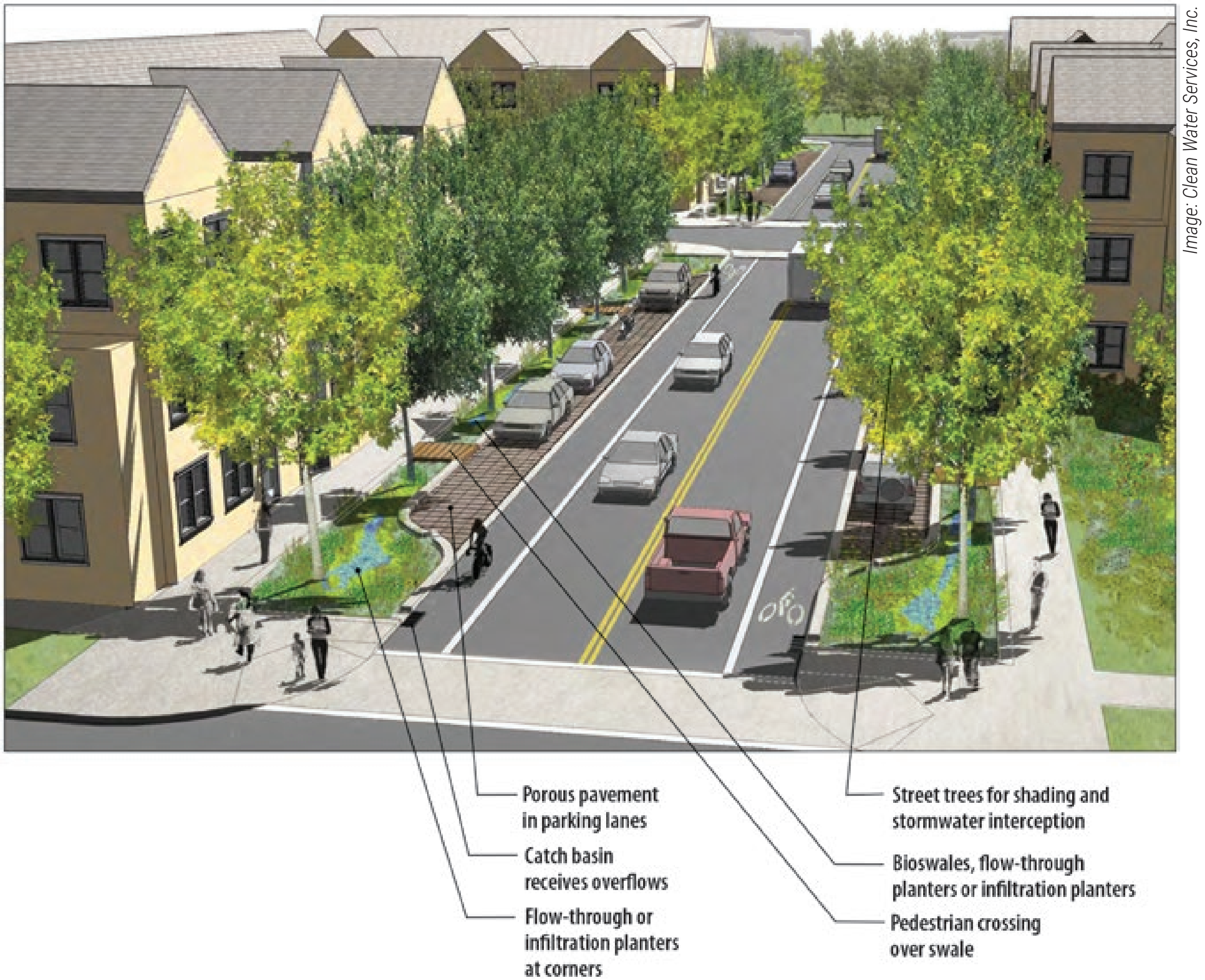


Figure 2-3. A local road with green infrastructure features in a neighborhood area.

Many of the green infrastructure practices recommended for collector roads also apply to local roads; however, local neighborhood characteristics should be considered as part of the decision-making process. Sufficient sidewalk widths and adequate separation from vehicular traffic should be maintained to preserve safety and comfort for pedestrians. Depending on the design, introducing green infrastructure can enhance pedestrian safety.

Green infrastructure practices are typically suitable in the rights-of-way or bike or parking lanes of local roads (Table 2-5). When choosing specific practices, consider the site's stormwater management characteristics:

- Practices applicable to **roads with curbs** include stormwater curb extensions, stormwater planters, tree pits and tree trenches, and bioswales. These practices require curb cuts or inlets to direct stormwater to the practice from the street.
- **Roads without curbs** are more commonly associated with bioretention and bioswales when sufficient area exists to locate these practices without infringing on vehicular or pedestrian traffic. These practices depend on sheet flow to convey runoff.

Table 2-5. Suitability of green infrastructure practices for local road zones

● Most appropriate ⦿ Depends on site context ○ Least appropriate	Bike or parking lanes	Right of way
Bioretention	○	●
Bioswale	○	●
Stormwater curb extension	⦿	●
Stormwater planter	○	○
Street trees	○	●
Infiltration trench	○	⦿
Subsurface infiltration and detention	⦿	○
Permeable pavement	⦿	⦿

USEPA

Pervious concrete pavement on a low-speed residential roadway in Shoreview, MN.

Alisha Goldstein

Stormwater curb extension installed with a sidewalk project in Maplewood, MN.

2.5 Alleys

Alleys have many connections to individual parcels and driveways, and they usually provide access for commercial deliveries, waste collection, access for emergency vehicles and parking. It is important to preserve right-of-way access for larger vehicles. Permeable pavement is an ideal practice for alleys because the drainage area is small and amount of sunlight reaching the ground is often limited (which can be a factor preventing the use of vegetated practices). Other appropriate practices include infiltration trenches and subsurface infiltration and detention (Table 2-6).

Table 2-6. Suitability of green infrastructure practices for alleys

● Most appropriate ◉ Depends on site context ○ Least appropriate	Alleys
Bioretention	○
Bioswale	○
Stormwater curb extension	○
Stormwater planter	○
Street trees	○
Infiltration trench	◉
Subsurface infiltration and detention	◉
Permeable pavement	◉

For More Information—Green Alleys

Chicago Green Alley Handbook. City of Chicago, IL (2010)

Green Streets and Green Alleys Design Guidelines Standards. City of Los Angeles, CA (2009)

Green Alley: Urban Street Design Guide. National Association of City Transportation Officials.

Abby Hall

Permeable asphalt alley in Chicago, IL.

Alisha Goldstein

Permeable paving in an alley in the Avalon neighborhood in Los Angeles, CA.

2.6 Parking Lots

Parking lots represent a good opportunity to incorporate green infrastructure into the layout, especially for new designs (Figure 2-4). Although retrofitting of parking lots might be expensive, it is often cost-effective to include green infrastructure practices when the parking lot is reconfigured or when the pavement is replaced or rehabilitated. Depending on the size of the parking lot and its use patterns, various surficial and subsurface practices can be incorporated into the design.

When designing new projects, site design principles aimed at minimizing effective impervious surface area should be evaluated before other practices are considered. Site design considerations include geometric layout, the number of parking spaces, the required dimensions of parking spaces and the direction of surface flow.

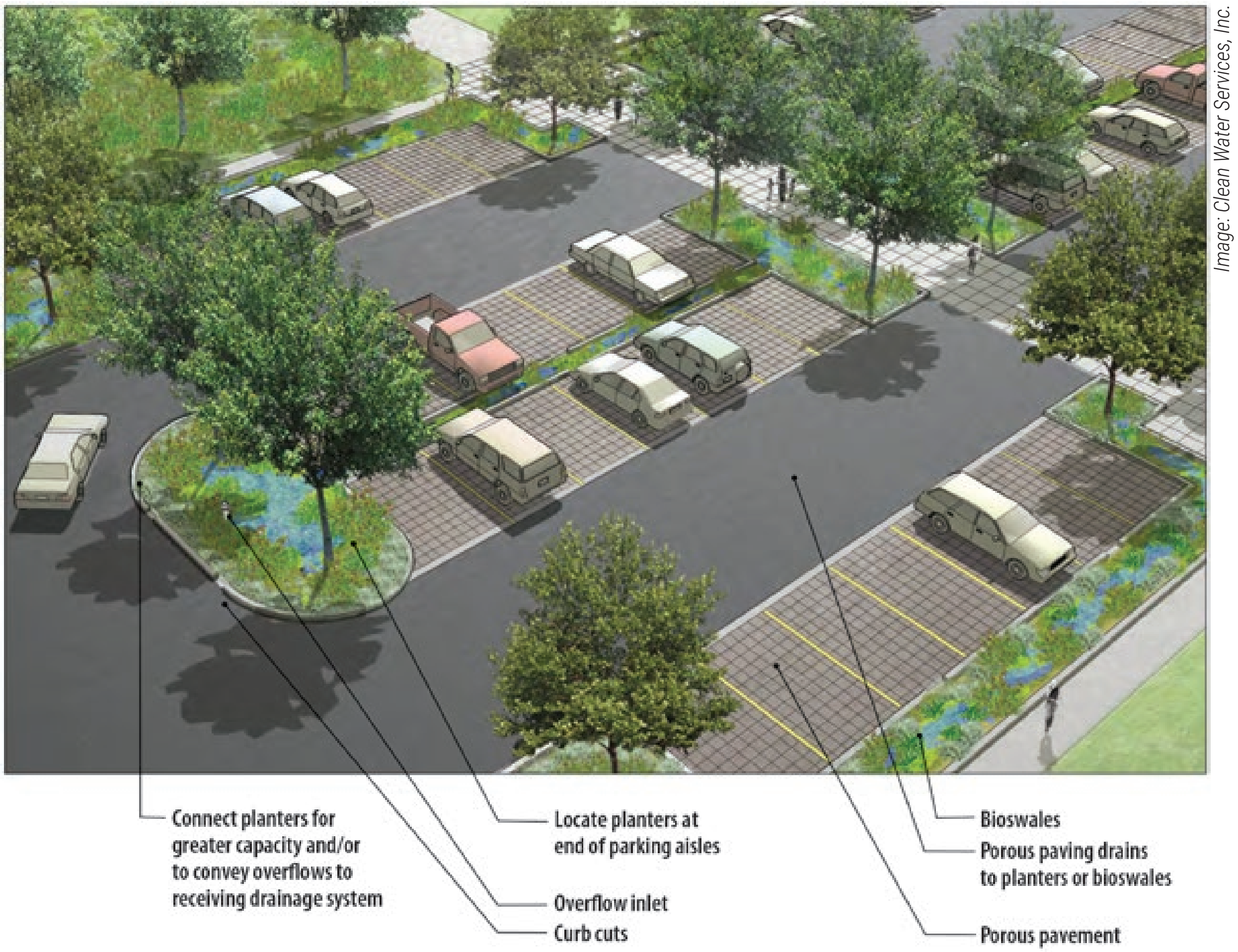


Figure 2-4. A parking lot with green infrastructure features (bioretention areas and street trees).

Green infrastructure practices should be designed with vehicle and pedestrian movement and safety in mind. Long linear practices should include pathways for pedestrians to cross without stepping on the practice. Practices must allow adequate room for motorists to safely exit their cars. Safety can be enhanced if practices are configured to serve as a buffer between vehicle travel lanes and pedestrians.

Stormwater management practices that include trees and large bushes can shade areas of impervious cover, providing heat mitigation benefits by reducing the effects of heat reflection and absorption. Shaded parking lots are also desirable for drivers who want to keep their vehicles cooler. Incorporating vegetation into practices can improve the visual aesthetic of a parking lot, making the establishment appear more welcoming.

Green infrastructure practices are typically suitable in parking bays, traffic islands and along the perimeter of parking lots (Table 2-7). Islands, parking bays and parking lot perimeters can be designed or retrofitted to include bioretention, bioswales, trees, infiltration trenches, street trees and subsurface infiltration/detention. Permeable pavement is most suitable for low-traffic, low-speed uses such as parking bays. Interlocking concrete pavers are more often used in high-load commercial and industrial settings. If cost or use patterns are a concern, consider using permeable pavement in the stalls and conventional pavement in the travel lanes. For an overflow parking lot with infrequent use, consider using grass pavers or concrete-grid gravel pavers instead of pavement.

For More Information—Parking Lot Design

[Design Guidelines for 'Greening' Surface Parking Lots]. City of Toronto, Canada (2013; email for copy)

[Green Parking Lot Resource Guide]. USEPA (2008)

[LID Parking Lots: Technical Assistance Memo]. California Water Quality Regional Control Board

[Sustainable Green Parking Lots Guidebook]. Montgomery County Planning Commission, PA (2015)

Table 2-7. Suitability of green infrastructure practices for parking lots

● Most appropriate ◉ Depends on site context ○ Least appropriate	Medians	Traffic islands	Perimeter or parking bays
Bioretention	●	●	●
Bioswale	●	○	●
Stormwater curb extension	○	○	○
Stormwater planter	●	○	◉
Street trees	●	●	●
Infiltration trench	●	○	●
Subsurface infiltration and detention	○	○	◉
Permeable pavement	○	○	○

Low Impact Development Center

Permeable pavers installed at the downgradient end of parking bays collect surface runoff and allow it to infiltrate.

2.7 Identifying Opportunities for Green Infrastructure Placement

Road Type Influences Rights-of-Way Zone Usage

Depending on their use categories, street and parking lot rights-of-way can be divided into zones such as travel lanes, parking lanes, curb zones/shoulders, throughway zones/pedestrian areas and store frontage zones. The width allotted to each zone is a critical aspect of street design; width influences traffic speeds, access for multiple users, and overall user comfort and safety. The road's use classification and location will influence whether the right-of-way zones are designed to emphasize benefits for pedestrians or vehicles (Figures 2-5 and 2-6).

Decisions for travel lane widths are based on transportation typology and context; however, traffic calming goals and desired use also should be considered. Travel lane width has been shown to impact traffic speeds: wider travel lanes are correlated with higher vehicle speeds (Fitzpatrick 2000). By reducing the street width, traffic speeds decline and space in the right-of-way becomes available for other purposes, such as the placement of green infrastructure practices.

Rights-of-way offer many opportunities for siting of green infrastructure practices, as depicted by the orange shaded areas on the photos on the next page. As shown in Figure 2-7, the rights-of-way between sidewalks, bicycle lanes and the vehicle travel lanes can be ideal sites for a storm-water planter. Similarly, green elements can be incorporated into long roadside zones (Figure 2-8) or parking areas (Figure 2-9), or in smaller spaces such as unused triangles at the intersection of diagonal streets (Figure 2-10).

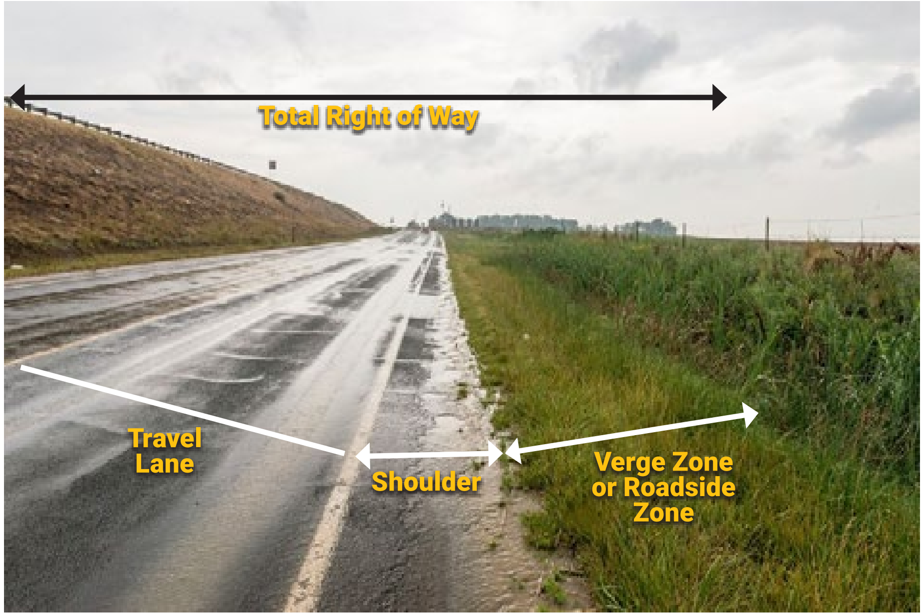
For More Information—Road Retrofits

Grey to Green Road Retrofits. Credit Valley Conservation, Canada (2014)

Municipal Handbook: Green Infrastructure Retrofit Policies. USEPA (2008)

Alisha Goldstein

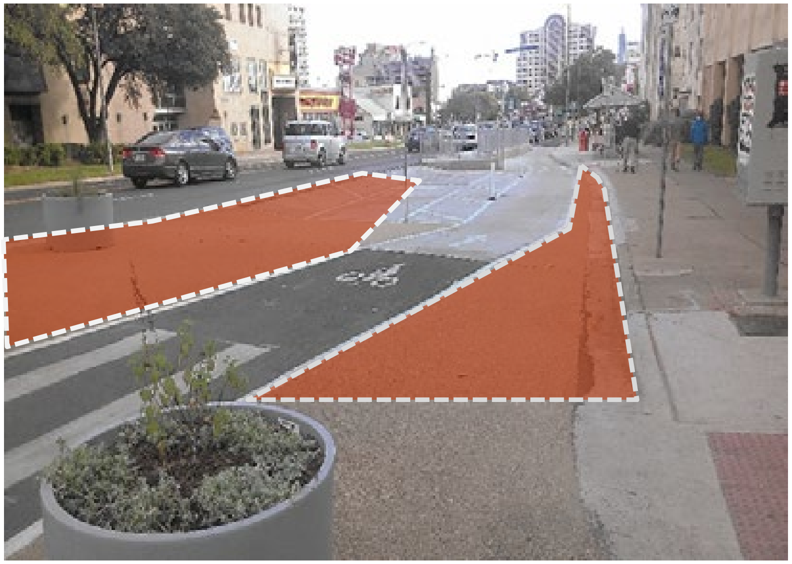
Figure 2-5. In this setting, pedestrian-friendly zones have a relatively high amount of space in the right-of-way relative to the size of the street.



Eric Vance, USEPA

Figure 2-6. In this setting, the right-of-way zones are geared toward vehicles.

Existing Roadway Rights-of-Way Offer Available Space for Green Infrastructure



Alisha Goldstein

Figure 2-7. Adding a buffer, such as a stormwater planter, between modes of transportation can control stormwater and improve safety.

Eric Vance, USEPA

Figure 2-8. Green elements such as a swale, permeable pavement or a permeable friction overlay can be added in the verge area (roadside zone).

Alisha Goldstein

Figure 2-9. Alternative surfaces such as permeable pavement can be used in on-street parking lanes.

Alisha Goldstein

Figure 2-10. Green infrastructure practices can be incorporated into unused space at the intersection of diagonal streets.

Existing Parking Lot Designs Can Accommodate Green Infrastructure

Parking stall dimensions are typically mandated by local zoning ordinances and are determined with respect to car size and frequency of vehicle turnover. Existing space in parking lots can often be filled with green infrastructure practices while preserving the same number of parking spaces.

For example, an existing parking lot island surrounded by a curb can be retrofitted to include a bioretention feature (Figures 2-11 and 2-12). Similarly, by adjusting the length or placement of the parking stall, space can be made available to add a swale either in a median between facing stalls or around the perimeter of the lot (Figures 2-13 and 2-14). Stall widths can also be varied in the same lot to accommodate green features. High-turnover stalls nearest to the establishment can be built wider than stalls farther away, creating room for green infrastructure without reducing the number of available parking spaces.

Alisha Goldstein

Figure 2-11. This conventional parking lot island could be retrofitted for green infrastructure features.

Alisha Goldstein

Figure 2-12. A parking lot island includes a bioretention feature in Maplewood, MN.

Alisha Goldstein

Figure 2-13. In this parking lot the impervious median space between facing parking stalls could be retrofitted to infiltrate runoff.

Tetra Tech, Inc.

Figure 2-14. In this parking lot the median space between facing parking stalls includes a bioretention area.

2.8 Reconfiguring Designs to Create Space for Green Infrastructure

Reconfiguring roadways offers opportunities to create new space for green infrastructure. FHWA uses the term "Road Diet" to describe this practice, which is a high-value, low-cost way to improve safety and enhance a street's overall functionality. Roadway reconfiguration projects typically include removing a lane and/or reducing lane width. A classic Road Diet involves converting an existing four-lane, undivided roadway segment to a three-lane segment consisting of two through lanes and a center, two-way left-turn lane (Figure 2-15).

A Road Diet can provide space that can be reclaimed for other uses such as bus lanes, bike lanes, bus shelters and green infrastructure features. These stormwater management features can be built in conjunction with pedestrian refuge islands or as safety/crossing barriers between motorists and pedestrians—achieving multiple benefits.

In 2014 the City of Lancaster, Pennsylvania, completed an award-winning retrofit of a dangerous intersection (Figure 2-16). The project removed a designated turn lane and added green elements, including permeable paver parking areas and patios, curb extensions and rain gardens, and a cistern that captures stormwater from the roof of a brewery adjacent to the intersection. The project calmed traffic and increased pedestrian safety by narrowing the traffic lane, while also offering aesthetic enhancement and patio space for the brewery. Research indicates that these types of roadway reconfigurations are likely to reduce accident rates (TRB 1990).

When a Road Diet is planned in conjunction with roadway reconstruction or simple overlay projects, safety and operational benefits often can be implemented at low cost (i.e., the cost of restriping the road). Incorporating green street elements should be considered when the overall design of the street is being changed or utilities are being installed or upgraded. Chapter 3 discusses how to select appropriate green infrastructure practices.

For More Information—Road Diets

Road Diet Informational Guide, Federal Highway Administration (2014)

Road Diets (Roadway Reconfiguration), Federal Highway Administration

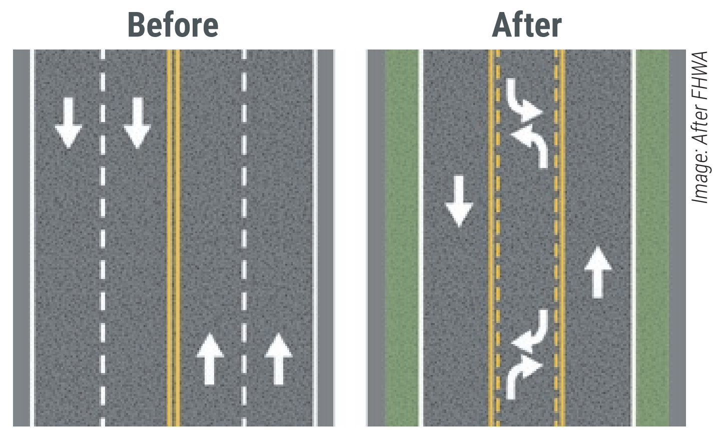


Figure 2-15. This simple road diet shows how two travel lanes are removed and replaced with one turn lane and two areas that could support green infrastructure practices.

Figure 2-16. A roadway was reconfigured to replace a turn lane with green infrastructure practices in Lancaster, PA.

3 Developing a Green Streets Program: A Process Overview

In This Chapter

This chapter covers the process to develop a green streets program, beginning with establishing objectives, identifying priority areas, characterizing the sites and developing a stormwater plan. A green street stormwater plan will help you identify site constraints and opportunities, calculate impervious areas and runoff volumes, select appropriate green infrastructure practices, and consider costs. An effective green street program will also engage community partners in the process.

Alisha Goldstein

Traffic calming and stormwater bioretention curb bump-out project, Cleveland, OH.

3.1 Programmatic Process Overview

Pursuing a green street program requires consideration of various tasks as noted in Figure 3-1. The programmatic process is presented in a linear fashion, but when retrofitting existing transportation networks, steps may be completed in a different order or concurrently. For example, if a street repaving project is under way, then the priority area has already been established and the objective(s) and a site characterization should be determined. A discussion of each task is provided in other areas of this course as denoted by the referenced section number.

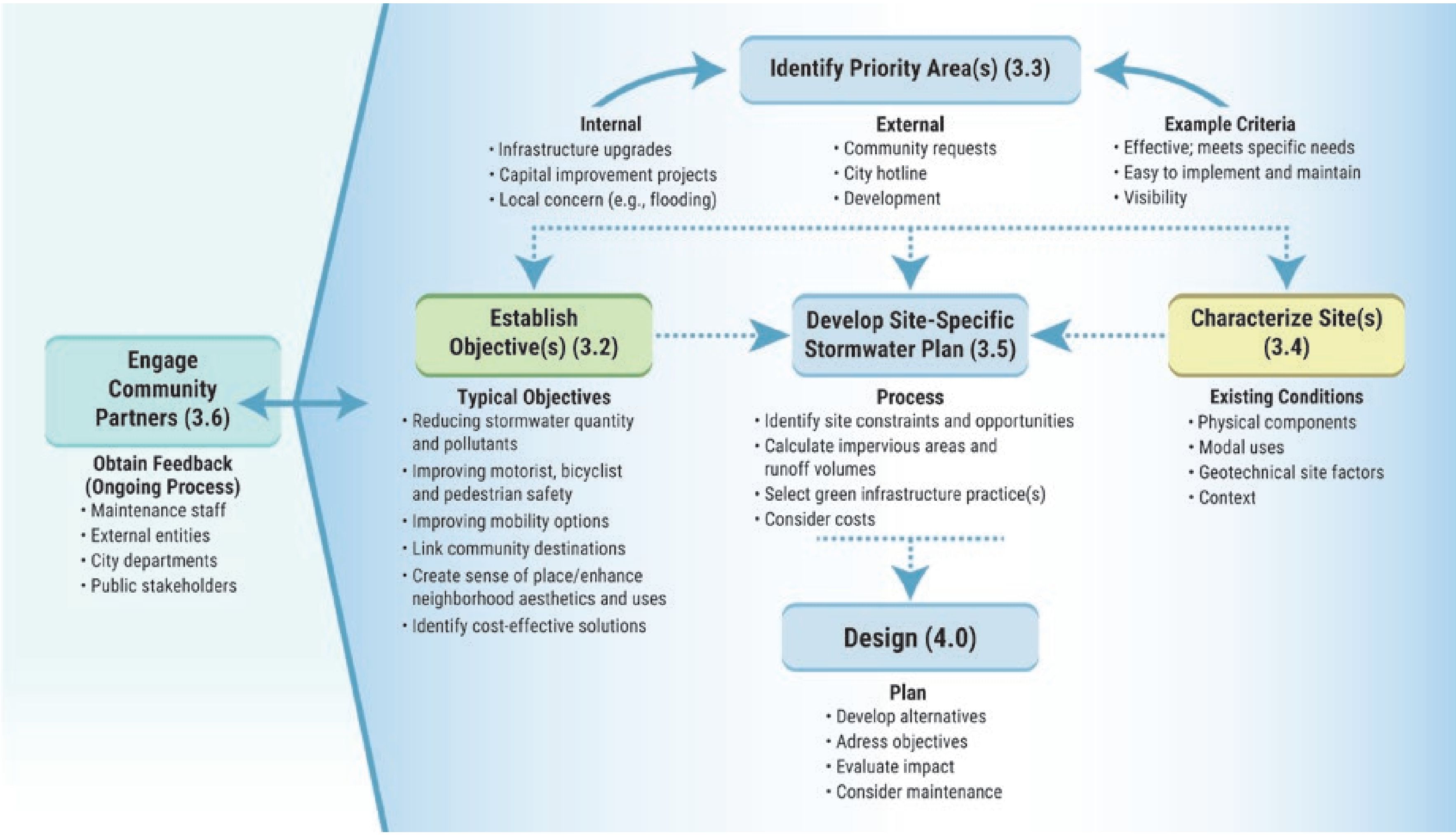


Figure 3-1. Recommended programmatic process for pursuing a green streets program.

3.2 Establish Objectives

Designing green streets requires a multifaceted approach to creating livable and aesthetically pleasing spaces. The following program objectives are commonly used to help justify a green streets program:

- **Stormwater control.** DOTs must often address regulatory requirements for stormwater runoff quantity and quality from streets (including MS4 permits, flooding, impaired waters, replacing aging infrastructure, etc.). Green streets can address multiple regulatory requirements in a single design.
- **Safety.** Green street designs can improve motorist, bicyclist and pedestrian safety by adding practices that slow traffic (curb bump-outs), adding separate bike lanes, and providing clear and separate areas for pedestrians and pedestrian crossings.
- **Access and mobility.** Green streets can be designed to offer multiple transit options or designed to improve access for bus, bikes and pedestrians. For example, dedicated bike and bus lanes can be integrated into a green street design to ensure dedicated access.
- **Context.** Context refers to the project's physical, economic and social setting. Green streets can help improve community cohesiveness, ecological function, aesthetics and transportation system efficiency.
- **Livability.** Green streets can improve community livability by increasing tree canopy cover and vegetated practices. Livability can also be improved by increasing walkability and access for bikes.
- **Cost-effectiveness.** Adding green infrastructure can reduce overall costs when compared to the construction and maintenance of traditional stormwater infrastructure.

Before embarking on a project, it is advisable to establish goals and objectives that can be easily communicated to the public and be used to measure success (examples are in Table 3-1). Early engagement of stake-holders (see section 3.6) is critical to securing participation and buy-in from the public and other agencies.

Table 3-1. Example objectives of a green streets program

Focus area	Objective
Stormwater control	– Identify priority watersheds and project opportunities
Safety	– Improve pedestrian safety at crosswalks
Access and mobility	– Balance multiple modes of transport
Context	– Create linkages between community destinations
Livability	– Explore opportunities to promote streets for additional uses (e.g., adding bike lanes)
Cost-effectiveness	– Reduce construction and maintenance costs

Jason Wright, Tetra Tech, Inc.

Stormwater control, safety and livability are among the objectives fulfilled by these green infrastructure practices in Greensboro, NC.

3.3 Identify Priority Area(s)

Priority areas can be selected on the basis of a site-specific need or by using established objectives (see section 3.2) to screen potential project sites. Priority area selection can be influenced by the municipality's internal priorities (e.g., needed infrastructure upgrades, upcoming capital improvement projects, existing localized problems such as flooding) or requests from external sources (request submitted by communities or through a hotline, planned development). For example, repeated traffic accident reports (internal) or a request from a community member (external) could influence a decision to retrofit an intersection for safety reasons. Similarly, redevelopment projects that impact rights-of-way could be routinely evaluated as part of the review process to determine opportunities to add green infrastructure practices.

Existing municipal stormwater management plans, capital improvement projects, weather resiliency plans, or citywide initiatives can be used to help identify potential green infrastructure sites. A stormwater plan can identify neighborhoods that have flooding issues that could benefit from widespread implementation of green infrastructure practices. The development of a new stadium, a commercial development, or a street expansion project represent opportunities to "green" public rights-of-way and more effectively manage runoff.

Once a list of projects has been compiled, the projects should be scheduled for implementation based on criteria selected for prioritizing projects, such as need, cost, public demand, etc. When a community is initiating the use of green infrastructure practices, selecting highly visible projects with a high probability of success often helps to garner public acceptance of green infrastructure because successful projects can create support or demand for similar projects within the jurisdiction.

Horsley Witten

To improve safety, curb bump-outs were added to the corners to decrease the crosswalk distance and make pedestrians more visible to motorists.

Melissa Kramer

Signs help raise the visibility of a project by communicating why the stormwater feature was built and the benefits it provides.

3.4 Characterize Sites

Once goals and priority areas have been identified, a designer must assess the site to determine which green infrastructure practices are appropriate for the site conditions. A base map can be a useful tool for determining site constraints and other factors that might influence the choice of certain green elements (Figure 3-2). The site assessment should include physical, modal, geotechnical and contextual analyses (Figure 3-3). Conducting site visits is recommended to ensure the accuracy of the existing data, especially if time has lapsed since the information was surveyed.

The results of the site characterization can help identify factors (e.g., the presence of underground utilities, high or low soil infiltration rates, or land use patterns and citizen behaviors) that might influence whether a given practice is appropriate for the site, given programmatic objectives, performance requirements, available funding or maintenance concerns.

For example, infiltrative capacity can determine whether a curb bump-out must have an underdrain or be designed as a flow-through planter. The size of the available area and its contributing drainage area also will determine what practices are appropriate. Foot traffic, sightlines, overhead utilities and maintenance requirements should also be considered. Design alternatives, however, can be used to compensate for some site factors as presented in Chapter 4.

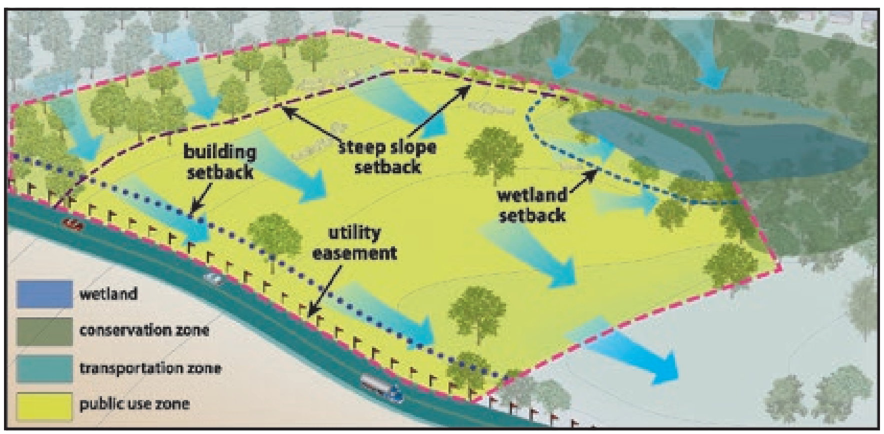


Image: Tetra Tech, Inc., after San Antonio River Authority

Figure 3-2. A base map indicates landscape and hydrologic features, necessary setbacks, existing easements and other components.

Physical Components

- Drainage area and flow paths
- Utility locations (e.g., water, sewer, gas, electric)
- Street grading and inlets
- Existing stormwater infrastructure
- Existing vegetation (especially mature trees)

Modal Use

- Types of users
- Circulation patterns
- Traffic volume
- Parking demands
- Rights-of-way and lane widths
- Pedestrian access points

Geotechnical

- Topography and flow patterns
- Soil borings logs
  - Description
  - Permeability
  - Depth to seasonal high groundwater table
  - Depth to bedrock
- Possible sources of contamination
- Floodplain

Context

- Neighborhood characteristics
- Location of buildings and other structures
- Loading and unloading zones
- ADA-designated parking space
- Land use
- Master plan and zoning
- Archaeological and cultural resources review

Figure 3-3. Types of analyses performed during a site assessment.

3.5 Develop Site-Specific Stormwater Plan

When developing a stormwater plan for a green street, several steps are necessary: (1) identify site constraints and opportunities, (2) calculate impervious areas and runoff volumes, (3) select green infrastructure practices, and (4) consider costs. (Note: a site-specific stormwater management plan is generally part of watershed plan, master plan or citywide stormwater plan that addresses larger management areas.)

Step 1. Identify site constraints and opportunities

First, identify opportunities in the rights-of-way, which might include medians, travel lanes, road shoulders, sidewalks and pathways, and slopes and drainage easements. Not all rights-of-way are appropriate for green infrastructure practices, however. Possible constraints should be assessed, which could include the width of the right-of-way, presence of utilities (above or below ground), roadway geometry and slope, proximity to storm drains, run-on stormwater flows, contributing drainage area, type of vehicular use, potential for pollution spills and high pollutant loads, ease of access for maintenance, reduced safety for pedestrians or vehicles, presence of bike and parking lanes, and cultural factors associated with the site.

Step 2. Calculate impervious areas and runoff volumes

Impervious areas associated with roads should be measured to calculate the volume of stormwater that runs off. Most state and local governments have specific requirements on how to calculate the stormwater design volume from impervious areas or the contributing drainage area(s).

Step 3. Select practices

Once the design volume is calculated, potential green infrastructure practices can be identified for specific locations. Chapter 2 includes examples of green streets for different street typologies. Chapter 6 provides information on the types of practices that are commonly used on green street projects.

Table 3-2. Relative costs for green infrastructure practices (per cubic foot of water)

● High ◉ Medium ○ Low	Capital	Operations and maintenance
Bioretention	○ ◉	○ ◉
Bioswale	○ ◉	○ ◉
Stormwater curb extension	◉	○ ◉
Stormwater planter	◉	○ ◉
Street trees	○ ◉ ●	○
Infiltration trench	○	○
Subsurface infiltration and detention	●	◉
Permeable pavement	○	◉

Sources: Clary et al., 2017; RTI and Geosyntec 2014

Step 4. Consider costs

Capital and operations and maintenance costs should be considered when selecting green infrastructure practices (Table 3-2). Costs will vary by location (i.e., site conditions or distance to material supplier), type of project (i.e., retrofit or new construction), and particular application and design specifications (i.e., required retention volume or depth of practice). Regional availability of expertise and supplies can also play a significant role in overall costs. Demand for green infrastructure can also create economies of scale that reduce material costs (e.g., in Chicago the cost of permeable pavement for alleys dropped significantly over the project period).

The costs for green infrastructure practices should be considered with respect to their ability to serve multiple functions, the benefits they provide and their anticipated life cycle. For example, practices such as permeable pavement, which serves both as a surface and a stormwater management practice, can save costs in a jurisdiction where stormwater management is required. By adding permeable pavement, the need for subsurface detention facilities, underdrains and related conveyance pipes can be reduced or avoided. Cost-benefit analyses and life-cycle assessments are useful methodologies for determining the costs of practices within a broader framework.

3.6 Engage Community Partners

Communication between all stakeholders should occur throughout the entire green street planning, design and implementation process. A dialog should be established with community residents, local business owners, and staff from public agencies or departments—especially agencies that need to maintain the green infrastructure or meet their own programmatic goals and objectives (e.g., landscaping or maintenance staff, fire and rescue services, planning and zoning departments).

Implementing a diverse outreach plan can ensure that stakeholders are made aware of projects, educated about the objectives and empowered to influence the outcomes. With the advent of social media, stakeholders can be engaged online through participatory surveys, interactive design tools, websites and other platforms. These methods could also be coupled with neighborhood open houses, door-to-door outreach and direct-mail marketing. To encourage discussion, some municipalities have developed planning scenarios for stakeholders to help them understand the potential impacts of such decisions. Outreach strategies should be ongoing throughout the process to give ample opportunity for feedback and to keep stakeholders up-to-date.

Guidelines to consider for community engagement, as adopted from The Sustainable Communities Initiative (Bergstrom et al. 2013), include:

- Be proactive and targeted in engagement strategies.
- Build clear opportunities for decision making and partnerships among community organizations.
- Prioritize community knowledge and concerns.
- Develop cultural competency skills and cultivate humility.
- Support capacity building to engage meaningfully.
- Engagement processes should include space to be iterative and reflective.
- Target resources to support ongoing engagement.

Conferring and coordinating with other entities early in the process helps to secure buy-in, increasing support for the project and possibly helping to procure matching funds and other financial resources for ongoing maintenance and rehabilitation of the practices. Identifying and coordinating green street implementation with other community improvement projects (see box) can reduce costs, improve functionality, and increase overall benefits and acceptance of green infrastructure.

Example Community Improvement and Green Infrastructure Collaboration Opportunities

- Bicycle, pedestrian, transit or greenway planning
- Urban forestry stewardship initiatives
- Safe Routes to School initiatives
- Emergency vehicles and routes
- Stormwater master planning
- Open space planning
- Street repaving projects
- Utility infrastructure improvements
- Capital improvement projects
- Community/private connections
- Climate change resiliency or sustainability designs

For More Information—Programmatic Process Elements

Green Values National Stormwater Management Calculator (Costs). Center for Neighborhood Technology (2009)

Getting to Green: Paying for Green Infrastructure–Financing Options and Resources for Local Decision-Makers. USEPA (2014)

Community Solutions for Stormwater Management: A Guide for Voluntary Long-Term Planning. USEPA (2016)

Green Infrastructure in Parks: A Guide to Collaboration, Funding, and Community Engagement. USEPA (2017)

Nonpoint Source Outreach Toolbox. USEPA

Increasing Funding and Financing Options for Sustainable Stormwater Management. Center for Neighborhood Technology (2020)

4 Design Considerations

In This Chapter

This chapter covers design considerations for green infrastructure practices, including a planning checklist and how to select the most appropriate practice based on the pollutant of concern. Designs need to accommodate underground utilities, address stormwater runoff rate and volume, plan for eventual maintenance, and identify appropriate soil media and plants. Green infrastructure designs can include artistic elements to enhance aesthetics and better blend into the community, while also providing for pedestrian access and safety.

Note: The design details described in this course are meant to be conceptual and not final design specifications. Designers should refer to state or local requirements and recommendations to inform their designs.

Low Impact Development Center

Green street with streetcar, vehicle, pedestrian zones, rain gardens and trees.

Eric Vance, USEPA

Trench drain conveys street runoff into bioretention cells in Washington, DC.

4.1 Design Checklist

Designing Green Infrastructure

Design of the green infrastructure practice(s) should not proceed until after a field visit has confirmed that a site is suitable. This chapter provides information on design elements that should be considered when developing detailed design plans to achieve one or more objectives that pertain to the use of green infrastructure.

The design checklist shown in Table 4-1 summarizes key questions that designers should answer when developing the site design plan for a green infrastructure practice in a street or parking lot. As noted in the table, further discussion about each question is provided elsewhere in this course.

Designers should also consider applying the following practices when initiating a project:

- Conduct a geotechnical study for the site itself. Do not substitute a report from a nearby project.
- Be mindful of all uses on the site (e.g., carts in a shopping mall, informal pedestrian pathways) to protect soils and vegetation from encroachment.
- Design a stormwater control practice that you would want in front of your own house or business. The aesthetic appeal of the practice is important.
- Engage community participants early and throughout design process.

Table 4-1. Site design green infrastructure planning checklist (after site selection is complete)

Yes/No	Checklist for green infrastructure design
	Does your design include green infrastructure practices best suited to remove pollutants of concern? (See section 4.2)
	Has the design taken into account the presence of underground utilities on the site? (See section 4.3)
	Does the curb cut design (i.e., size and angle of opening, placement, grading) effectively capture the stormwater? (See section 4.4)
	If needed, is there an appropriate pretreatment device to capture sediment? (See section 4.5)
	Is there sufficient space available to treat and/or retain the runoff volume from the contributing drainage area? (See sections 4.4 and 4.11)
	Is there a structural feature at the inlet and along the flow path to dissipate energy, slow the velocity and prevent erosion? (See section 4.5)
	Is there ample volume for retention, correct placement and grade of outflow structures to control ponding and adequate structures to manage overflow? (See section 4.5)
	Is there access for maintenance equipment and space for cleanouts and observation wells? (See section 4.6)
	Does vegetation have sufficient soil volume of the appropriate composition type to thrive? (See section 4.7)
	Has the selection of vegetation accounted for local availability, water requirements, ponding and salt tolerance, maturity rate, sightlines, propensity for seed dispersal and maintenance needs? (See section 4.7)
	Does the layout of the green infrastructure practice allow movement through the site, especially by pedestrians (i.e., pathways to allow access between sidewalks and parking lanes across stormwater feature)? (See section 4.8)
	Are there visual or physical barriers around the green infrastructure practice to serve as a safety marker and protect the vegetation? (See section 4.9)
	Does the design support your community's livability objectives? (See section 4.10)

4.2 Selecting Appropriate Practices

The types of green infrastructure practices selected for your design will depend somewhat on the types of pollutants of concern in your stormwater and your water quality objectives. Table 4-2 provides an overview of the potential pollutant removal capability of common green infrastructure practices, which will help designers choose the practices best suited for their community's needs.

Various factors will influence the performance of green infrastructure practices, including site characteristics, design specifications, and operation and maintenance practices. The use of sequential practices (e.g., a treatment train approach) in a system also will affect overall performance. Refer to the additional resources listed (see box, next page) to understand how site and design factors influence performance.

Dan Christian, Tetra Tech, Inc.

Stormwater curb extensions, such as this one in Portland, OR, capture pollutants such as total suspended solids, total phosphorus, zinc and lead.

Table 4-2. Relative effectiveness of green infrastructure practices for various constituents based on pollutant-removal efficiencies when practices are properly maintained

	Total Suspended Solids	Total Nitrogen	Total Phosphorus	Fecal Coliform	Total Zinc	Total Copper	Total Lead
Bioretention	●	○	●	–	●	–	◉
Bioswale	◉	○	○	○	–	–	–
Stormwater curb extension	●	○	●	–	●		◉
Stormwater planter	●	○	●	–	●	–	◉
Street trees	●	◉	◉	●	◉	◉	◉
Infiltration trench	●	○	●	●	●	–	–
Subsurface infiltration and detention	●	◉	◉	●	●	●	●
Permeable pavement	●	–	◉	–	●	◉	◉
Permeable Friction Course	●	–	–	–	●	◉	●

Note: The values for subsurface infiltration and detention were considered equivalent to those for sand filters. Stormwater curb extension and stormwater planters were considered bioretention devices.

For all constituents, ○ = 0-30%, ◉ = 31-65%, ● = >65%, – = no data

For More Information—Green Infrastructure Practice Performance

Significant research data is available about the performance of green infrastructure for road and parking lot runoff. Monitoring guidance and information on the pollutant removal effectiveness of green infrastructure and conventional best management practices (BMPs) can be found in the **International BMP Database**, which is managed by the Water Environment Research Foundation WERF). It is important to note that performance and cost-effectiveness of practices depend on site conditions and design considerations.

The Transportation Research Board, through its National Cooperative Highway Research Program, provides funding to review the water quality benefits and construction and maintenance needs of stormwater BMPs used on roads. Their reports include:

- Volume Reduction of Highway Runoff in Urban Areas: Guidance Manual (2015)
- Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices (2014)
- Measuring and Removing Dissolved Metals from Stormwater in Highly Urbanized Areas (2014)
- Pollutant Load Reductions for Total Maximum Daily Loads for Highways (2013)
- Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas (2012)
- Evaluation of Best Management Practices for Highway Runoff Control (2006)

The Federal Highway Administration (FHWA) has developed several resources to assist communities in modeling, monitoring and managing water quality impairments from highway stormwater runoff, including:

- Stochastic Empirical Loading Dilution Model (SELDM) (2013) A joint project between U.S. Geological Survey and FHWA, this model helps develop planning-level estimates of event mean concentrations, flows, and loads from a highway site and an upstream or lake basin.
- Determining the State of the Practice in Data Collection and Performance Measurement of Stormwater Best Management Practices (2014) This report assesses data collection and performance measurement in stormwater programs at state departments of transportation.
- National Highway Runoff Water-Quality Data and Methodology Synthesis (2003)
  - Volume 1: Technical issues for monitoring highway runoff and urban stormwater, FHWA-EP-03-054
  - Volume 2: Project Documentation, FHWA-EP-03-055
  - Volume 3: Availability and documentation of published information for synthesis of regional or national highway runoff quality data, FHWA-EP-03-056
- Remotely Monitoring Water Quality Near Highways – A Sustainable Solution (2015) This document explores selecting and using a renewable and self-sustaining onsite monitoring system for highway runoff.

Trees planted in a bioswale between parking stalls.

Permeable concrete installed in a Washington, DC, alley.

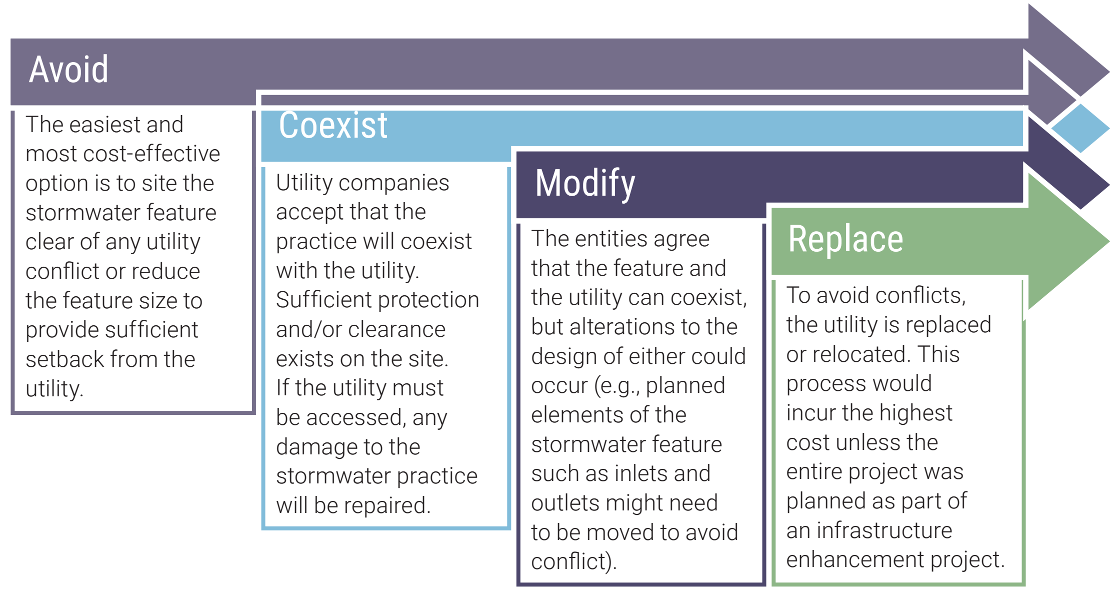
4.3 Accommodating Utilities

Although underground utilities are often cited as a challenge to green infrastructure implementation, their presence on a site does not need to prevent green project development. Depending on the site, planners have the option to avoid, coexist with, modify, or replace utilities when installing green elements (Figure 4-1). Obstacles arising during project design can include requirements for:

- Allowing access to utility lines or pipe galleries for repair or replacement.
- Providing adequate protection around utility lines and gravel envelopes.
- Eliminating potential for infiltrated stormwater to migrate into conduits and pipes.
- Leaving space available to accommodate vaults and valve boxes.

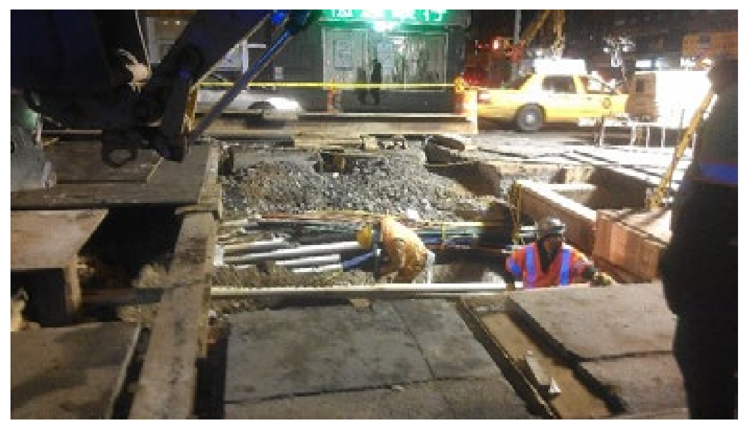
Depending on the site, these obstacles could be too costly or difficult to overcome. In other cases, workarounds are available to handle these utility challenges and enable construction of green infrastructure within the right-of-way. Key steps to eliminate problems include:

- Placing all utility vaults outside the "wet" zone of the stormwater feature when possible.
- Lining the practice along curbs or next to utility trenches with a thin, impermeable geotextile or liner to prevent migration of infiltrated stormwater.
- Constructing a deeper-than-conventional curb profile to physically separate roadbed subgrade or utility lines from the stormwater feature.
- Installing a clay or other impermeable plug within the utility trench to inhibit movement of stormwater within the trench line.



Source: Adapted from the San Mateo Green Infrastructure Design Guide (San Mateo 2020).

Figure 4-1. Options for accommodating utilities during design and planning of green infrastructure.



Alisha Goldstein

Underground utilities in New York City, NY.

4.4 Capturing Stormwater Runoff Types

An essential element of green infrastructure project design is ensuring the stormwater enters the system and is captured. In urban environments where curbs are prevalent, stormwater flow accumulates as it moves along the curbed edges of roadways. Adding curb cuts allows this concentrated flow to spill into green infrastructure practices. In contrast, stormwater drains off curbless roadways under sheetflow conditions to the lowest area.

For both concentrated flow entering a practice through curb cuts and sheet flow conditions, a minimum 2-inch elevation drop is recommended between the surface drainage and finish grade at the entrance to the stormwater feature to ensure that stormwater freely moves into the practice even with some sediment accumulation. To prevent erosion, an inlet should be designed with a dry sump, splash pad or other element that dissipates energy and spreads the flow. Riprap, stone and gravel are typically used, but some communities are moving away from these materials because they are difficult to maintain cost-effectively.

Capturing Concentrated Flow: Curb Cuts

To capture stormwater runoff from curbed roads, curb cuts are added at intervals along a raised curb, resulting in areas of concentrated flow. This practice is commonly used in urban bioretention cells, stormwater curb extensions, stormwater planters and urban tree trenches. Three key criteria should be considered when designing curb cuts:

- **Placement.** The curb cut should be placed in the pathway of stormwater flow alongside the gutter line. During the low levels of flow, water is directed into the feature; during high flow volumes when the feature is at capacity, the flow bypasses the curb cut and is directed downgradient along the curb.

- **Grading.** Slope the bottom of the concrete curb cut toward the practice (Figure 4-2). If the flow lines along the gutter are on a steep slope, developers can add a small, low-profile asphalt/concrete berm or other pavement modifications such as a runnel to direct stormwater flow into the practice (Figure 4-3).

- **Size and angle of opening.** The inlet opening can be sized for the storm event using standard FHWA software (Hydraulic Toolbox) or other design procedures that account for ponding, spreading of flow, slope and other conditions that affect the efficiency of the inlet. The curb cut opening should be as wide as possible to avoid restricting flow or becoming blocked by debris (Figure 4-4). The recommended minimum width is 18 inches or 3 feet in between wheelstops in a parking lot (Figure 4-5). The sides of the opening should have either vertical or chamfered (i.e., cut) sides with 45-degree angles (Figure 4-6). Side wings work well for practices that have steeper side slope conditions to retain the side-slope grade (See Figure 4-7).

Curb cuts can be modified based on site-specific conditions. Grated curb cuts prevent trash and other floatables from entering the practice (Figure 4-8). A trench drain (a shallow concrete trench with a grate or solid cover) can convey runoff to the practice where pedestrians or vehicles must cross the drain area (Figure 4-9). These drain systems help to provide egress space for on-street parking and to maintain grade and access for pedestrians.

Alisha Goldstein

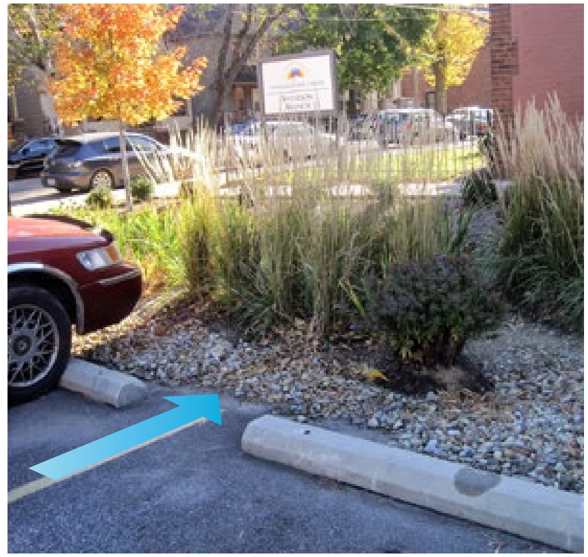
Figure 4-2. An angled curb cut with a graded gutter, Seattle, WA.

Alisha Goldstein

Figure 4-3. A runnel directs stormwater flow, San Juan Island, WA.

Low Impact Development Center

Figure 4-4. Metal extension inlet structure provides a wide opening for stormwater flow to enter the stormwater feature.



Alisha Goldstein

Figure 4-5. The space between adjacent wheel stops allows stormwater runoff to enter a vegetated swale in a parking lot in Cleveland, OH.

Alisha Goldstein

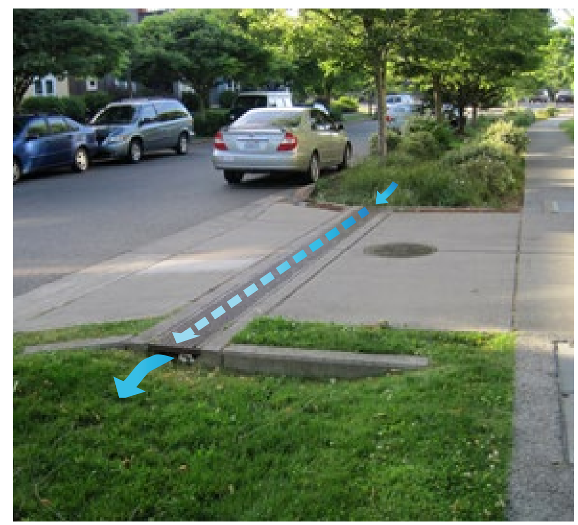
Figure 4-6. A curb cut with 45-degree chamfered edges conveys stormwater into a roadside rain garden in Friday Harbor, San Juan Island, WA.

Nancy Arazan, USEPA

Figure 4-7. A curb cut with wings retains the side slope grade and directs street runoff into a bioretention feature in Portland, OR.

Rebecca Dohn

Figure 4-8. A grated inlet prevents large floatable trash from entering practice along Deaderick Street in Nashville, TN.



Alisha Goldstein

Figure 4-9. Trench-grated drain conveys stormwater between swales while also capturing runoff in Seattle, WA.

Capturing Sheetflow

In areas without curbs and gutters, practices are designed to capture runoff via sheetflow across pavement and other surfaces. Establishing sheet flow conditions allows for an even distribution of runoff into the feature (Figures 4-10 and 4-11). Moreover, in conditions of low-velocity sheetflow, pretreatment such as a pea gravel apron installed between the impervious area and the practice can help capture suspended sediment.

Green infrastructure practices that capture sheet flow from curbless streets and parking lots often include a band of concrete edging that lies flush with the stormwater feature and the street/parking lot surface (Figure 4-12). Because of concrete's fine-grain composition, it is easier to use concrete than asphalt to achieve the necessary flat slope that will direct sheetflow into the stormwater feature.

Sidewalks can be designed with slight inslopes or outslopes to direct sheetflow into green infrastructure practices, but the sidewalks must also comply with local codes and ordinances and meet the slope requirements outlined in the Americans with Disabilities Act.

Alisha Goldstein

Figure 4-10. A curbless street allows sheetflow stormwater runoff to enter the vegetated swale in Lansing, MI.

Kary Phillips Tetra Tech, Inc.

Figure 4-11. A curbless grassed and gravel parking lot allows sheetflow stormwater runoff to enter a vegetated swale in Staunton, VA.

Nancy Arazan, USEPA

Figure 4-12. A sloped concrete band along a road evenly distributes stormwater to an adjacent vegetative swale in Seattle, WA.

4.5 Managing Stormwater Flow

After a site-appropriate practice is selected to capture the stormwater flow, several techniques should be considered to manage the flow as it enters and exits the practice. Correct design elements can prevent erosion, enhance treatment capabilities and maintain the stormwater feature's function:

- **Pretreatment** practices can trap sediment or debris suspended in the runoff before it enters the practice.
- **Energy dissipation** elements help prevent scouring and erosion of the media around the inlet.
- **Overflow structures** allow excess flows to exit the system to prevent scouring or other damage.
- **Bypass structures** permit excess flow to bypass the practice completely.
- **Back-up infiltration** practices catch flows that exceed the design capacity of the practice.
- **Underdrains** remove excess volume to protect the system and also to reduce ponding or improve infiltration in low-permeability areas.

Pretreatment Practices

Pretreatment is often recommended to trap sediment or debris before it moves through the stormwater management practice because the sediment could clog the practice, reducing infiltration. Commonly used sediment pretreatment devices include forebays, swales/channels, catch basin sumps, grit chambers and filter strips (Figure 4-13). For details about specific pretreatment practices, refer to Chapter 5.

Depending on the volume of flow and available space, pretreatment measures are often designed at the entrance to the practice using a forebay with a overflow structure such as a weir (Figure 4-14). Pretreatment measures should be sized according to the expectant loads and type of debris (e.g., floatables, leaves, sediment). The area downstream of the forebay commonly has high-density planting of vegetation that acts as a containment dam. To ensure the functionality of any pretreatment measure, accumulated sediment should be periodically removed.

Alisha Goldstein

Figure 4-13. A sediment forebay slows the concentrated flow to allow sediment to drop out of suspension in Tucson, AZ.

Jason Wright, Tetra Tech, Inc.

Figure 4-14. A sediment forebay with weir helps trap sediment and control flow volume in an alleyway bioswale in Los Angeles, CA.

Energy Dissipation

Adding energy-dissipating elements at both the inlet and along the length of the green infrastructure practice will help manage fast-moving stormwater flows. A concrete splash pad (Figure 4-15), riprap or landscape stone should be installed just inside the inlet to dissipate the flow as it enters, which will help prevent scouring and erosion of the soil media around the inlet.

Throughout a linear practice, especially those with a steep grade, check dams and weirs should be built at intervals to reduce the velocity, thereby avoiding wash-out and increasing storage (Figures 4-16, 4-17 and 4-18). Check dams are stone, concrete, wood or soil berms that are perpendicular to the flow and span the width of the treatment cell. Check dams help pond water, which increases infiltration by slowing water flow velocity in high slope conditions (BES 2008) and reducing erosion. Scour protection, which can be provided by placing a strip of gravel at the downstream side of the check dam, can also control erosion. Check dam height should be less than the top elevation of the curb. The placement of check dams is dictated by flow rates and velocities.

Weirs can be designed with adjustable heights to provide flexibility on sites that have variable soil conditions. These practices also help control the ponding of water, which influences the hydraulic residence time and effective treatment. A longer retention time helps to settle sediment out of suspension and filter pollutants. As a result, check dams are also applied on sites with minimal longitudinal slopes to promote infiltration where the soils are suitable, or to promote filtering to an underdrain in areas with poorly draining soils.

Eric Vance, USEPA

Figure 4-15. Concrete paver splashpad dissipates energy from stormwater entering from a trench in Washington, DC.

Alisha Goldstein

Figure 4-16. A piled stone weir/gravel filter combination slows the water flowing through this bioretention feature in Gainesville, FL.

Abby Hall, USEPA

Figure 4-17. Concrete check dams slow flow in a stormwater curb extension with a 4.2% slope in Portland, OR.

Alisha Goldstein

Figure 4-18. Concrete check dams with splashpads slow flow velocities along a steep slope in Seattle, WA.

Overflow Structures

Overflow structures are designed to discharge excess stormwater flow from the feature to prevent flooding or damage to it. Practices can be designed as off-line or on-line practices. An off-line practice is sited outside of the normal runoff flowpath and is designed to receive and treat a specified water quality volume. Off-line practices must infiltrate the required design storm amount and will have an emergency overflow path or a bypass/flow-splitter device (see next page) to convey excess flows to an alternative practice or storm drain system. On-line systems are placed within the normal runoff flow path and always require an outlet to allow excess flow to move through or around the practice.

A system should be designed to dewater within 24 to 72 hours after saturation (refer to your local jurisdiction for specific time requirements for dewatering). This design feature will help prevent long-term saturation and ensure the system has storage available for the next storm event. Dewatering also reduces the likelihood that mosquito breeding can occur within the practice.

Key design considerations for overflow systems include:

- The **overflow inlet** should be sized to pass flows that exceed the design storm event. The inlet structure should be wide enough to allow access for cleaning the outflow pipe or the underdrain. The top of the inlet should be set at the ponding depth, approximately 6 to 12 inches (depending on local regulations and site conditions) above the top of the mulch layer (Figures 4-19, 4-20 and 4-21). Using a domed grate on the top will prevent debris from entering the overflow structure and will be less likely to become clogged than a flat grate (Figure 4-22).
- An **overflow weir** should be included in on-line facilities. The weir should safely convey overflow from a larger-scale storm event to an adequate outfall. For small-sized practices receiving low flows, a stabilized reinforced grass outfall might be sufficient.
- The **overflow outlet** should drain to a stabilized outfall and be connected to a manhole, inlet or other structure. Carefully consider maintenance requirements because of the potential for clogging of the inlets and the consequence of the underdrain becoming blocked. Calculate hydraulic grade lines to ensure the outfall pipes are adequately sized.


Nancy Arazan, USEPA

Figure 4-19. Raised overflow structure in a bioretention feature in Houston, TX.


Rebecca Dohn

Figure 4-20. Concrete band constructed around the outflow allows ponding in Nashville, TN.


Alisha Goldstein

Figure 4-21. Raised overflow drain allows a design volume of stormwater to collect in a bioretention area in Portland, OR.


Alisha Goldstein

Figure 4-22. Beehive overflow grate prevents debris from entering the overflow structure in a roadside bioswale in Arlington, VA.

Bypass Devices

Bypass devices such as diverters and splitters can be used to prevent high water flows from causing damage to a stormwater feature. Bypass devices are typically incorporated into off-line green infrastructure practices (i.e., outside of the normal runoff flow path). Off-line practices are designed to receive and treat a specified water quality volume (e.g., the runoff generated from a 1-inch, 24-hour storm). In the case of roadside practices, the size of the opening and depth of the feature controls the amount of runoff allowed to enter the practice (e.g., planter, bioretention cell)—allowing flow to be bypassed in two ways:

1. A practice is designed with an entrance that restricts the amount of water able to enter the practice (e.g., curb cuts, weirs); therefore, high-volume flows are split so only a controlled amount of runoff enters the practice while the rest continues on its normal flow path.

2. A practice is designed to collect a controlled amount of runoff until reaching its water quality treatment design. At that time, the system will redirect all excess stormwater back into the normal runoff flow path, which is often a conventional curb-and-gutter stormwater conveyance system (Figure 4-23).

Back-up Infiltration Practices

Backup infiltration approaches can be used when adjacent surface areas are available to provide additional infiltration capacity. For example, overflows from permeable pavements can be managed by placing a strip of exposed gravel downslope of the pavement that will direct excess runoff to a nearby grassed area, or by incorporating vegetated swales that can collect and infiltrate excess volume (Figure 4-24).

USEPA

Figure 4-23. In this tree pit bypass system in Washington, DC, curb cuts allow stormwater to enter until the practice is filled, at which point additional flow bypasses the system and continues down the street to the storm drain.

USEPA

Figure 4-24. Vegetated swales were installed adjacent to a permeable parking lot in Chicago, IL, to provide overflow control and back-up infiltration as needed.

Underdrains

Underdrains can also be used to manage excess volumes of stormwater flow, depending on the suitability of the underlying soil structure, soil condition, depth to seasonal mean high water table and the capacity of the system relative to volume. Overflow systems are generally preferred over underdrains because they are easier to maintain and not as likely to clog. Overflow devices also allow the feature to be used to retain and infiltrate the desired water quality volume. In contrast, systems with underdrains often serve primarily as filtration systems. Underdrains are also used to reduce excessive ponding or improve infiltration in areas of lower permeability (i.e., where native soils have infiltration rates of less than 0.5 inches per hour). If an underdrain is included, it should be designed appropriately to convey flows to existing inlets or manholes.

An underdrain consists of a perforated pipe set in a drainage gravel bed (Figure 4-25). The underdrain pipe is typically a 4- to 6-inch polyvinyl chloride (PVC) or high-density polyethylene (HDPE) perforated pipe with equally spaced holes. The upstream end of the underdrain is fitted with a cleanout to allow the underdrain to be inspected and cleaned if necessary. A cleanout consists of a pipe that is accessible from the surface of the practice. The pipe is connected to the underdrain at a 45-degree angle in the direction of flow via an elbow or wye (y-shaped plumbing fitting). A cleanout typically extends vertically 6 to 12 inches beyond the top of the mulch layer, set flush with the designed ponding depth.

The top end of the cleanout is fitted with a locking cap. The exact size of the underdrain opening should be selected based on the drainage area of runoff entering the practice and the time needed to dewater the system. The system should be dewatered within 24 to 72 hours after saturation (refer to local jurisdiction for specific time requirements for dewatering).

The upstream end of the underdrain is also capped. The downstream end of the underdrain is connected to an overflow inlet or curb cut. The under-drain may be level, but it is recommended to have a minimal slope, such as 0.5 percent, so that any accumulated debris or sediment can be flushed through the system as it drains.

If water retention is a performance requirement, underdrains can be installed above the bottom extent of the practice or designed with a 90-degree upturned pipe so that the system begins to drain only after the required water volume is retained. The water percolates down through the soil into the internal water storage (IWS) layer and is slowly released into the soil underneath the practice.

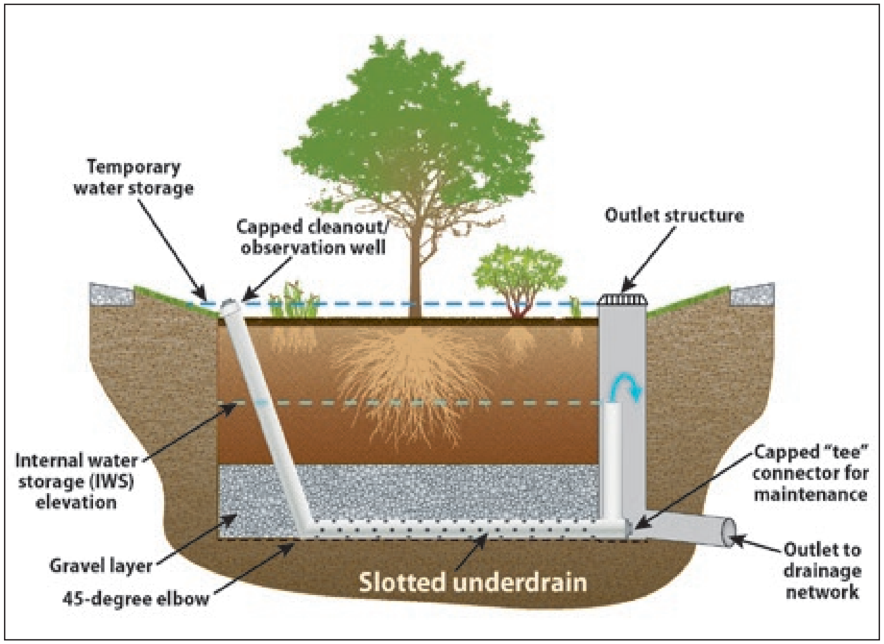


Image: Tetra Tech, Inc.

Figure 4-25. In this underdrain design cross-section image, an upturned pipe connected to a slotted underdrain ensures that a permanent internal water storage layer is maintained within the practice before the excess infiltrated water spills into a secondary drainage network. In this design, a surface overflow drain is included to provide added protection against high volume flows.

4.6 Planning for Maintenance

Structural Practices

Maintenance should be considered as part of any green infrastructure design. To perform recommended tasks, the design plan must allow for access into the practice by personnel and maintenance equipment and must provide space for pipe drain cleanouts and possibly observation wells (Figures 4-26 and 4-27).

Certain design practices can influence the type of maintenance needed. For example, the size of openings on a grated trench drain could limit the type of trash that enters the practice, reducing the amount of clean-out needed. In some cases, however, small grate openings can clog easily, needing more frequent maintenance in areas with abundant trash (Figure 4-28).

Site conditions can also influence selection of the practice and requisite maintenance. For example, a curbless neighborhood might not be suitable for permeable pavement without the construction of sediment traps because pavers can easily become clogged.

Specific maintenance for each stormwater management practice is discussed in Chapter 6. At a minimum, practices should be inspected annually to remove trash, clean inlets/outlets, remove invasive species, prune vegetation and replace mulch. Maintenance should be conducted after large storms and more frequently while vegetation becomes established.

Nonstructural Practices

In addition to the specific maintenance practices required for each green infrastructure practice, communities can identify and implement nonstructural practices that help prevent pollution from entering the watershed drainage system (see box at right). These practices in turn reduce the maintenance needed on structural practices.

Nonstructural practices require programmatic management to develop implementation plans, select appropriate technology and budget the resources for these ongoing tasks. Quantification of performance for nonstructural practices varies widely because it depends on the frequency and type of application, site-specific characteristics and climate.

Key Nonstructural Practices

- Street sweeping
- Catch basin and storm drain cleaning
- Irrigation runoff reduction practices
- Slope and channel stabilization
- Trash management
- Anti-icing management
- Water-smart landscaping
- Erosion control on construction sites
- Spill prevention and response plans
- Education/awareness for the public and employees

Figure 4-26. A wide-angled curb cut with an energy-dissipating splashpad also serves as access steps for maintenance in Maplewood, MN.

Figure 4-27. To facilitate maintenance, an observation well is installed next to a bioretention area in Houston, TX.

Alisha Goldstein

Figure 4-28. The small spaces in this grate are clogged with cigarette butts, which block drainage and are difficult to remove.

4.7 Selecting Soil Media and Vegetation

Soil Media Selection

The specifications for filter media mixes will vary by availability of local materials, local climatic conditions and stormwater requirements for the specific placement of the green infrastructure practice within the transportation corridor. A typical filter media mix will include a well-blended, homogenous combination of the following soil types:

- **Sand.** Must be cleaned and washed to be free of deleterious materials. A medium "concrete" sand such as ASTM C33 or an equivalent is often used (average particle diameter <2.0 millimeters is recommended).
- **Silt and clay.** Includes fines with a texture of sandy loam, loamy sand or loam mixture to encourage nitrogen, phosphorus, metal and other pollutant removal. (Note: a low-clay content, less than 2 percent, is necessary to avoid clogging.)
- **Organic matter.** Commonly includes a compost or mulch amendment.

To support plant growth while removing phosphorus from runoff, the filter media mix must have a low phosphorus index (P Index). The P Index is a management tool that estimates the relative risk of phosphorus leaching. Recommended levels are between 10 and 30 milligrams per kilogram when using the Mehlich-3 test (MPCA 2013). Organic matter can be a source of phosphorus loading and must be carefully managed where elevated phosphorus concentration is a concern.

Geotextile fabrics are often used in green infrastructure infiltration practices to protect the filter media from becoming clogged by the sediments and clays contained within in-situ soils. The liners typically extend along the side slopes. The liner should have sufficient openings that are properly sized for the existing soil conditions to prevent clogging. Impermeable liners can be used to prevent infiltration into sensitive sites. The material should be durable and flexible. Composite systems of nonwoven geotextiles are used to prevent puncture during construction.

Tetra Tech, Inc.

In preparation for planting local native vegetation, a soil media mix was chosen and backfilled into this roadside bioretention area in San Diego, CA.

Vegetation Selection

Planting schemes will vary depending on the site location and design specifications; however, soil type and moisture conditions will usually determine the types of species selected. For example, facultative wetland plants are typically used on the bottom of a bioretention cell, while facultative upland species are frequently chosen for areas around the perimeter of a bioretention cell or in mounded areas. Numerous factors should be considered when selecting plants:

- **Soil moisture conditions.** Choose plants that can tolerate summer drought, ponding fluctuations and saturated soil conditions for the design drawdown period.
- **Sunlight.** Assess existing and anticipated exposure (e.g., when vegetation is mature).
- **Expected pollutant loadings.** Select plants that tolerate pollutants from contributing land uses (e.g., choose salt-tolerant plants in cold climates where road salt use is common).
- **Adjacent plant communities and habitats.** Select native plants and hardy cultivars; this is particularly important in areas with significant invasive species.
- **Location aesthetics.** Consider the type of neighborhood, adjacent land uses, and expected pedestrian and roadway traffic (providing pathways and maintaining sight distances).
- **Maintenance needs.** Assess a plant's growth rate and its propensity for seed dispersal.

Native plants are usually adapted to the local climate and provide habitat for wildlife. Selected vegetation should grow tall enough to exceed the desired design flow depth. Additionally, the vegetation should be moderately stiff and non-clumping to provide sufficient surface contact for water quality treatment and to avoid formation of concentrated flow conditions. A mix of fibrous and deeply rooted small trees, shrubs, and perennials will help maintain soil permeability.

Eric Vance, USEPA

Native plants are adapted to local climate conditions and provide valuable wildlife habitat.

Alisha Goldstein

Street trees provide water storage, interception and evapotranspiration.

Anticipate plants' mature conditions to avoid choosing a species that could interfere with overhead electric lines or with roadway sightlines and or that would require intensive maintenance because it has a propensity to grow and disperse seeds. Properly selecting plants and supporting them during establishment should eliminate the need for fertilizers and pesticides. Initially after planting, frequent maintenance will be necessary to ensure the vegetation becomes established.

Sufficient soil volumes should be made available to the plant (especially trees) to ensure proper growth. If the site doesn't provide ample space, construct root paths to an adjacent open space or structural cells that can support sidewalks or pavement while providing space for unimpacted soil below the ground surface.

Urban Street Trees

Including urban trees in green infrastructure designs could pose challenges that must be considered. These include space requirements for the tree pit, soil quality and texture, overhead and underground utilities, pavement, and proximity to structures. A detailed site evaluation can identify these challenges and options to mitigate any problems. EPA's *Stormwater Trees: Technical Memorandum* (2016) includes information on site evaluation and site constraints, choosing the right tree, inspection and maintenance.

4.8 Providing Pedestrian Access

Adding Walkways and Bridges Across or Around Practices

When incorporating green infrastructure into a street or parking lot design, pedestrian movement should be carefully considered. Providing clear paths for pedestrians is crucial to the design and is a good practice for protecting green elements from damage.

For on-street parking, adequate space should be provided to allow people to exit their cars and access the sidewalk. A minimum 3-foot-wide egress zone adjacent to the street curb is suggested.

Walkways (Figures 4-29 and 4-30) or bridges (Figure 4-31) can be provided for people to safely cross the green infrastructure practice and access the sidewalk. The use of bridges preserves space, provides continuity of stormwater flow and prevents soil compaction, erosion and trampling of vegetation.

For areas with pedestrian traffic and little room for stormwater planters or tree boxes, porous surface materials (Figure 4-32) are an option to consider. Using these materials allows water to infiltrate and preserves sidewalk width for pedestrian use.


Alisha Goldstein

Figure 4-29. Permeable pavement walkways provide access to on-street parking in Seattle, WA.


Nancy Arazan, USEPA

Figure 4-30. Walkway built across vegetated swale to allow users to access their cars in Portland, OR.


Alisha Goldstein

Figure 4-31. A grated walkway bridge allows pedestrians to access parked cars on Bagby Street in Houston, TX.


USEPA

Figure 4-32. Tumbled green glass fills the spaces between permeable pavers in a sidewalk area in Chicago, IL.

4.9 Ensuring Pedestrian Safety

Providing Visual and Physical Barriers Around Practices

An important aspect with regard to pedestrian safety is assuring that people can detect and are guarded against a sudden drop in grade. Check your city's guidance to determine (1) the maximum allowable depth for a stormwater management practice that is installed adjacent to a pedestrian area and (2) the appropriate or required barrier needed to enclose the practice. A suggested guideline is to install a barrier when the vertical drop is at minimum 6 inches immediately adjacent to a sidewalk. Common techniques to either visually or physically denote a vertical drop include a raised curb edge (Figure 4-33), railing (Figure 4-34), fence (Figure 4-35), detectable warning/paving strips, bollards and/or seating (Figure 4-36).

These design features help ensure that streets or parking lots are safe and accessible for all users. Many green infrastructure practices can be used to enhance the pedestrian experience and provide a buffer against vehicular traffic, reduce pedestrian crossing distances and/or improve sight angles at intersections.

Alisha Goldstein

Figure 4-33. A raised curb with inlets defines the edges of a sidewalk stormwater planter in Washington, DC.

Alisha Goldstein

Figure 4-34. Fence protects pedestrians from the drop in grade in the adjacent bioretention feature in Minneapolis, MN.

USEPA

Figure 4-35. Short fencing protects pedestrians from stepping into this stormwater tree box in Washington, DC.

Melissa Kramer, USEPA

Figure 4-36. Seating adjacent to a bioretention unit provides an amenity for passersby and also serves as a barrier in Washington, DC.

4.10 Enhancing Street Design

Adding Artistic Elements

Green street design can incorporate artistic features such as sculptures, murals and concrete imprints. In many cases, the stormwater management practice itself is designed as an artistic feature. These elements can enhance community aesthetics and attract visitors.

Alisha Goldstein

The Beckoning Cistern serves as an artistic feature and a stormwater management practice. Designed to resemble a large upturned hand, the 15-foot-tall structure adds visual interest while collecting roof runoff, some of which is directed into a series of cascading stormwater planters along Vine Street in Seattle, WA.

Alisha Goldstein

Concrete art can highlight the presence of green infrastructure. The raindrop ripple effect sidewalk etching allowed the Watershed District's Public Art Initiative to call attention to the function and benefit of rain gardens in managing stormwater in the Bartelmy-Meyer neighborhood in Maplewood, MN.

USEPA

A bioretention area artfully designed to resemble a rocky river wraps around the Oregon Convention Center in Portland, OR.

Alisha Goldstein

Artists collaborated on this curving bioretention design for the Waterloo Parking Lot in a Cleveland, OH, art district.

Adding Community Amenities

Incorporating user amenities such as benches, bicycle racks and streetlights into green streets planning and design helps encourage use of the area by pedestrians and cyclists. By creating an attractive and welcoming streetscape, community livability improves, which potentially benefits neighborhoods and businesses.

Alisha Goldstein

Incorporating bicycle lanes and bicycle racks into green street design encourages non-motor vehicle access along city streets in Austin, TX.

Alisha Goldstein

Decorative stone benches installed at the edge of a bioretention area offers a resting spot for pedestrians along Sandy Boulevard in Portland, OR.

USEPA

Benches installed next to stormwater curb bumpouts provide an area to rest in the New Columbia neighborhood in Portland, OR.

4.11 Accounting for Extreme Weather

Arid Climates

Designing practices for arid regions requires different considerations. The low amount of annual precipitation in these areas reduces the storage area needed to treat water quality. Because of high evaporation rates, any harvested rainwater should be stored in a closed container instead of stored with a large surface area exposed to the sun. The low frequency of storm events can lead to a build-up of pollutant concentrations. Therefore, the capture volume designated for first-flush treatment should be greater than those designated for humid regions.

The soil and topography in arid regions are conducive to soil erosion and increased sediment transport due to flashy storm events and wind action. Particular care should be given to the selection of vegetation according to these principles:

- The type of plant species and the number of plantings should be chosen with respect to the available water supply. Native and drought-tolerant plants are suggested.
- If irrigation is deemed necessary, group plants according to their water needs and adjust irrigation schedules according to the season and weather.
- Plants should be able to tolerate inundation.

A resource for determining water needs for specific plants is presented in Brad Lancaster's *Rainwater Harvesting for Drylands and Beyond, Volume 1* and the Arizona Municipal Water Users Association's *Landscape Plants for the Arizona Desert*.

Note: Before harvesting rainwater or designing and installing any green infrastructure, check the regulations pertaining to water rights in your locale.

Cold Climates

For a cold-climate environment, the predominant design consideration are snow and deicing agents. Areas adjacent to roadways or parking surfaces are commonly used to stockpile snow that has been plowed from surfaces. These areas accumulate large water volumes and high pollutant loadings (e.g., sand and gravel, deicing chemicals, hydrocarbons). Infiltration practices should not be placed in areas that are dedicated as snow storage areas. Deicing agents and debris from the roadway will negatively impact vegetative growth and can clog media and permeable surfaces.

Two suggested management strategies can help overcome the challenge of co-managing snow and stormwater:

- If possible, collect snow on an impervious pad and divert the meltwater for treatment (e.g., detention and routing to a wastewater treatment facility).
- Minimize the pollutants associated with meltwater runoff by using improved application technology with trucks and reducing the use of deicing chemicals.
- Design pretreatment facilities to remove particulate material before any snowmelt enters a stormwater infiltration practice.

Research has shown that green infrastructure, such as permeable pavement, groundwater recharge by local infiltration, and road drainage infiltration systems, can be effective under cold-climate conditions as long as they are adequately maintained to assure their effective performance (MCPA 2013).

4.12 Avoiding Design Flaws

Improper design and a failure to consider the surrounding site characteristics can lead to diminished function of green infrastructure. The following images present and explain some design problems that prevent a practice from functioning at full capacity or cause other problems.

Alisha Goldstein

These permeable pavers received runoff from a gravel driveway and became clogged with sediment.

Alisha Goldstein

The large-spaced grate on this overflow drain will not prevent floatables and debris from entering.

Alisha Goldstein

These unsecured blocks installed next to a bioretention area pose a safety risk.

Alisha Goldstein

These trash cans, installed in front of stormwater inlets, block flow.

Alisha Goldstein

This undersized curb cut is easily clogged by mulch and other debris.

Alisha Goldstein

The overflow drain is placed in the flow path of water entering the practice.

Alex Foraste, USEPA

This stormwater planter does not provide space for passenger exit.

5 Pretreatment Practice Options

In This Chapter

A sediment forebay provides pretreatment for parking lot runoff entering a bioretention cell at Villanova University, PA.

This chapter covers information on pretreatment methods that should be considered when designing green infrastructure systems. Pretreatment practices help protect the main treatment systems by dissipating energy and reducing flow velocity, removing coarse sediments and large particles from the flow, capturing trash and other debris, and reducing overall stormwater flow volume by encouraging infiltration. Successful, functioning pretreatment practices will help improve performance, reduce maintenance and increase lifespan of the overall stormwater management system.

Note: The design details described in this course are meant to be conceptual and not final design specifications. Designers should refer to state or local requirements and recommendations to inform their designs.

5.1 Pretreatment: Sediment Forebays

Description

A sediment forebay is an excavated pit or basin with a berm or weir designed to slow and detain incoming runoff. Sediment forebays are placed before practices such as bioretention systems or bioswales to dissipate energy from runoff and allow for sedimentation to occur. Sediment forebays serve to minimize, but do not eliminate, the amount of sediment being transported into downstream practices.

Horsley Witten

A sediment forebay provides pretreatment for a bioretention cell in Barnstable, MA.

Site Considerations

Sediment forebays provide pretreatment that enhances the performance and longevity of downstream practices. With proper maintenance, sediment forebays can have a long life cycle. As a surface practice, they should be easily accessible for sediment removal and other maintenance. Sediment forebays provide a greater detention time than proprietary separators. Although sediment forebays allow sedimentation of some particulate matter, they primarily remove only coarse pollutants and no soluble pollutants (MADEP 2008). Frequent maintenance is essential to ensure proper performance.

Design Considerations

Slopes should be designed for safety and erosion control (maximum 3:1 [horizontal run: vertical rise (H:V)] slope). The forebay volume should be 10 percent of the water quality volume at minimum. The depth should be a minimum of 2 feet and a maximum of 6 feet.

Energy dissipation methods, such as splash blocks or riprap, should be included at both the inlet and outlet locations. Exposed earth slopes and bottom of basins should be stabilized using seed mixes that are appropriate for the soils, suitable for expected mowing practices, and drought-tolerant or resilient to inundation periods, depending on the volume of stormwater expected. To facilitate maintenance, the bottom of the pretreatment practice may be "hardened" with concrete to allow for easier collection and removal of sediments. Always design your system to allow access to the pretreatment practice for maintenance.

Sediment Forebays

Advantages:
- Relatively inexpensive
- Long-lasting if properly maintained

Most suitable for:
- Bioretention
- Bioswales
- Curb extensions

Maintenance Requirements

Because sediment forebays help reduce the sediment load entering green infrastructure practices, it is imperative to remove accumulated sediment to ensure the system continues to function as designed. The frequency of cleaning required depends on the contributing sediment loading rate and the occurrence of storm events. The contributing sediment loading rate is based on the size and type of drainage area. One suggested practice is to install a staff gage or other measuring device to indicate the level of sediment accumulation and to establish a level at which clean-out is required. Typical maintenance needs required for sediment forebays are outlined in Table 5-1.

Table 5-1. Recommended maintenance activities for sediment forebays

	Activity	Frequency	Additional advice
Soil	Remove sediment	As needed, but annually at minimum	If excessive sedimentation is observed, the site might need to be regraded and reseeded to avoid excessive upland erosion.
Soil	Remove any trash on the surface	Twice per year	
Soil	Inspect for rutting caused by concentrated flow	Annually	Eroded areas should be filled in with soil and the bare areas should be reseeded.
Vegetation	Mow embankments to control growth of woody vegetation	Annually (in spring)	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
Vegetation	Remove and replace vegetation as necessary	As needed	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
Vegetation	Weed invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing	Annually	

Alisha Goldstein

A sediment forebay provides pretreatment for a rain garden in Maplewood, MN.

Sediment Forebays

Key design features and maintenance needs:

- Periodically remove sediment
- Provide a mechanism to dissipate energy from incoming flow
- Avoid compaction during construction and maintenance or by service vehicles

5.2 Pretreatment: Vegetated Filter Strips

Description

Vegetated filter strips are gradually sloped, densely vegetated areas designed to receive and treat sheet flow. They are designed as flow-through devices to slow down and infiltrate runoff and to remove sediment before it reaches a downstream stormwater management practice. Vegetated filter strips can be distinguished from grassed swales because the filter strips typically have more surface roughness, energy dissipation capacity and denser vegetation, while grassed swales serve more as grassed conveyance systems. Performance is limited by grading, because little to no treatment is achieved if the filter strips are short-circuited by concentrated flow paths (MADEP 2008).

Installing a level spreader might be necessary to ensure runoff becomes sheet flow before it enters the vegetated filter strip.

Filter strips can be amended with compost and subsurface gravel to increase removal of dissolved metals and increase moisture capacity, which can improve infiltration rates and reduce flow velocities. An example of this is the compost-amended vegetated filter strip (CAVFS), currently in use in Washington State (WSDOT 2016). Designs can also be modified to provide significant pollutant reduction by incorporating a media filter drain in areas with minimal slopes.

Site Considerations

Filter strips are best suited to smaller drainage areas, low-velocity roadways or small parking lots because they do not have the capacity to reduce peak discharges or handle large velocities (WSDOT 2011). The maximum impervious contributing length should be 75 feet to 100 feet, and the maximum pervious contributing length can be up to 150 feet (SEMCOG 2008; MPCA 2013). Vegetative filters are not suited for areas with traditional curbs and gutters, for sites with excessive longitudinal slope (greater than 5 percent), side slopes (greater than 25 percent), or in areas with unstable slopes or erosive soils (MPCA 2013).

Vegetated Filter Strips

Advantages:

- Perform better than swales because the non-concentrated flow allows for greater sedimentation and infiltration
- Reduces pollutants associated with sediments such as phosphorus, pesticides and insoluble metallic salts

Most suitable for:

- Bioretention
- Bioswales
- Subsurface infiltration and detention

Design Considerations

- **Slope.** To prevent erosion or channelization from developing, design filter strips with slopes between 2 and 6 percent to ensure sufficient velocities and level surface with no pits, gullies, or ruts.
- **Size.** The flow length should be at least 25 feet for sufficient treatment, but should remain less than 75 feet long for impervious drainage areas and 150 feet for pervious drainage areas to prevent channelization from occurring. It is recommended that the filter strip width be equivalent to the width of the area draining to the strip.
- **Border.** To ensure even flow, it is often necessary to border the perimeter of the parking lot or road with a level spreader. Examples of spreader devices include a strip of pea gravel, slotted sections in the highway shoulder that are perpendicular to the road direction, concrete sills or a strip of porous pavement (Young et al. 1996). Level spreaders help to evenly distribute flows and trap sediments.
- **Vegetation.** Dense, soil-binding deep-rooted grasses that are water tolerant should be used in the construction of vegetated filter (Young, et al. 1996). If the filter will receive runoff from highways that require heavy application of deicing salts, salt-resistant plants should be specified.

Maintenance Requirements

It is important to periodically evaluate the condition of the filter strip during the first two years of construction, particularly after major storm events. Typical maintenance needs required for vegetated filter strips are outlined in Table 5-2. The frequencies provided are minimum suggestions; the activities should occur as needed.

Table 5-2. Recommended maintenance activities for vegetated filter strips

	Activity	Frequency	Additional advice
Soil	Remove sediment to ensure sheet flow into the filter area and to avoid concentrated flow	Annually	If excessive sedimentation is observed, the site might need to be regraded and reseeded to ensure sheet flow can be maintained.
Soil	Remove any trash on the surface	Twice per year	
Soil	Inspect for rutting caused by concentrated flow	Annually	Eroded areas should be filled in with soil and the bare areas should be replanted.
Soil	Turn or till soil, especially if compaction occurs	As needed	If maintenance efforts are unsuccessful, the soil media and underdrain might need to be removed and replaced.
Vegetation	Mow turf or grass	At least annually	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
Vegetation	Remove and replace vegetation as necessary	As needed	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
Vegetation	Weed invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing	Annually	

Nancy Arazan

Vegetated filter strip at the edge of a parking lot intercepts and filters stormwater runoff before the water reaches the infiltration bed at the center of the practice.

Vegetated Filter Strips

Key design features and maintenance needs:

- Ensure site is graded accurately to maintain sheet flow along entire flow length
- Use level spreaders to slow incoming flow velocities
- Avoid compaction during construction and maintenance or by service vehicles
- Periodically remove sediment
- Maintain a dense vegetative cover

5.3 Pretreatment: Swales

Description

Pretreatment swales are shallow, vegetated channels that capture runoff and slowly convey it along the swale while infiltrating and filtering coarse sediment. They are similar to bioswales, except that they are designed primarily for conveyance without enhanced infiltration/filtration components; therefore, they provide limited water quality enhancement and reduction of runoff volume and peak discharge. Pollutant removal rates will vary greatly with the species of vegetation chosen for the swale. Types of swales include drainage channels, grass channels and dry swales.

Site Considerations

These practices provide coarse sediment removal and limited infiltration and detention. They also convey stormwater to downstream practices. **They are applicable in parking lots and roadways as a pretreatment practice.** Swales can be used in treatment trains to provide initial treatment for practices such as bioretention, surface and subsurface infiltration practices, and stormwater basins.

Design Considerations

Swales should be designed for capacity and stability so the design depth can convey the maximum specified design flow but the channel will not erode under maximum design flow velocities. To maximize treatment performance, runoff should flow through the entire swale. Therefore, runoff should be directed to an inlet and should not enter as sheet flow along the entire length of the swale (CEI and NHDES 2008). Depending on the longitudinal slope, check dams might be necessary to slow down flow and encourage surface contact.

Channel cross-section design should be trapezoidal or parabolic. A study conducted in Texas and California by the University of Texas Center for Research in Water Resources in Texas determined that the optimum cross-section for swales in highway medians is a V-shape, rather than the trapezoidal shape commonly listed in manuals, because most of the treatment occurs along the slopes (Barrett 2004). The bottom of the swale should not be within the seasonal high water table.

Pretreatment Swales

Advantages:

- Provide stormwater conveyance
- The open-drainage systems provide easy access for maintenance
- Are a less-costly alternative to curb-and-gutter stormwater conveyance systems

Most suitable for:

- Bioretention
- Bioswales
- Subsurface infiltration and detention

Alisha Goldstein

Grass swale serves as pretreatment for a bioretention area in the High Point neighborhood in Seattle, WA.

The design should include vegetation types that will maximize treatment. Vegetation species should reflect the site specific soil, topography, flow velocities and maintenance needs. If using trees or shrubs in the vegetated swale design, plants that are resilient to both drought and flooding should be selected. Trees should not be planted in areas that require enhanced structural stability (BES 2006). Swales' effectiveness for stormwater treatment is greater where more surface contact occurs. For this reason, a fine, close-growing, flood-resistant grass should be selected.

Maintenance Requirements

It is important to periodically evaluate the condition of the swales during the first year after construction, particularly following major storm events. Mow vegetation to maintain heights of 4 to 6 inches. After 5 years, scrape the channel bottom to remove sediment buildup and restore the original cross-sectional geometry. Typical maintenance needs required for pretreatment swales are outlined in Table 5-3.

USEPA

A pretreatment bioswale conveys and treats runoff from a parking lot and road in Stafford, VA.

Table 5-3. Recommended maintenance activities for pretreatment swales

	Activity	Frequency	Additional advice
Soil	Remove sediment, especially if 3 inches accumulate in any spot or it covers vegetation	Annually	If excessive sedimentation is observed, the site might need to be regraded and reseeded to ensure sheet flow can be maintained.
	Remove any trash on the surface	Twice per year	
	Inspect for erosion	Annually	Eroded areas should be filled in with soil and the bare areas should be reseeded.
	Turn or till soil, especially if compaction occurs	As needed	If maintenance efforts are unsuccessful, the soil media and underdrain might need to be removed and replaced.
Vegetation	Mow turf or grass	Dependent on grass type	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
	Remove and replace vegetation as necessary	As needed	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
	Weed invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing	Annually	

Pretreatment Swales

Key design features and maintenance needs:

- Ensure accurate grading to maintain sheet flow
- Use level spreaders to slow incoming flow velocities
- Avoid compaction during construction and maintenance or by service vehicles
- Periodically remove sediment
- Maintain a dense vegetative cover

5.4 Pretreatment: Modified Catch Basins

Description

A catch basin is an inlet device designed to capture sediment, debris and associated pollutants. Catch basins can be modified with a deep sump to provide extra storage for the accumulation of sediment (Figure 5-1). They can include a hood or inverted elbow to minimize the amount of floatables, oil and grit that can exit the catch basin and enter the downstream treatment practice (Figure 5-2). Finally, they are considered part of a green infrastructure approach if they are modified as leaching catch basins that have perforated sections to allow water to infiltrate surrounding soil.

Modified Catch Basins

Advantages:

- Minimal space requirement
- Compatible with subsurface storm drain systems
- Is long-lasting if properly maintained
- Design allows easy access for maintenance

Most suitable for:

- Bioretention
- Bioswale
- Curb extension
- Stormwater planter
- Trees trenches
- Infiltration trench
- Subsurface infiltration and detention

Site Considerations

Catch basin modifications such as deep sumps and hoods can be used for water quality improvement, but are not designed to reduce runoff volume or peak discharge. Leaching catch basins should not be used where infiltration is not desired (e.g., because of potential groundwater or soil contamination or presence of high groundwater or bedrock). Modified catch basins provide pretreatment for downstream practices by removing coarse sediment, debris, floatables, oil and grit. Modified catchbasins might be the only applicable practice for sites with constrained spaces, poor infiltrating soils, or existing subsurface contamination.

Image: University of NH Stormwater Center

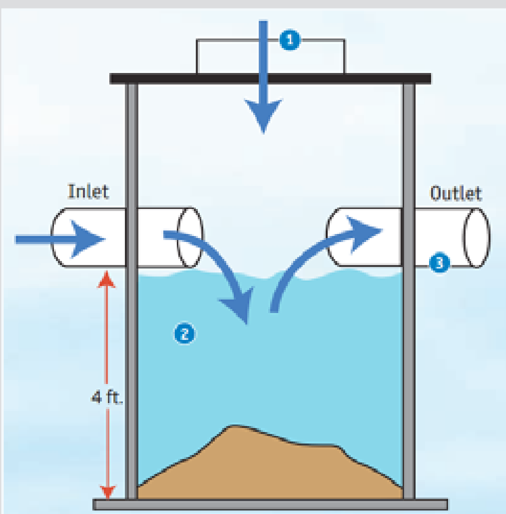


Figure 5-1. Simple modified catch basin

Deep Sump Catch Basin Operation Steps:

- **Runoff flows into the deep sump catch basin typically through an inlet or surface grate on the street (1) and drops into the sump (2).**
- **The sump provides a deep collection area (2) between the incoming flow (1) and outgoing flow (3), which allows coarse sediments and trash to drop out of suspension. Trash grates, hoods (4), or filter skirts can enhance performance by preventing floatables from entering outflow pipes.**
- **Outgoing flows (3) continue to a centralized drainage network or can be designed to discharge to a surface or subsurface green infrastructure practice.**

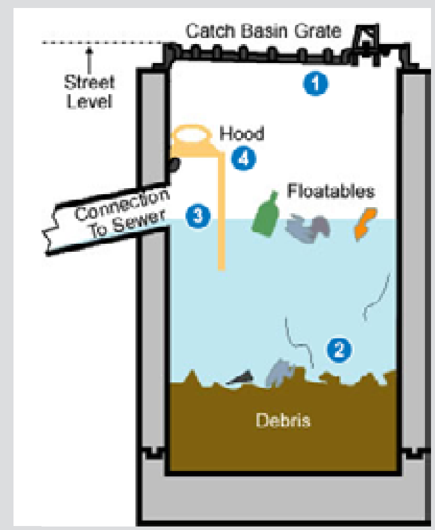


Image: USEPA

Figure 5-2. Hooded catch basin

Modified catch basins are highly applicable in urban and retrofit situations because they are compatible with subsurface storm drain systems and require limited space. Constraints include the presence of underground utilities, shallow bedrock, or a high groundwater table. Catch basins should be easy to access, and they should not be used unless adequate funding for regular inspections and maintenance is ensured.

Design Considerations

Inlets must be sized appropriately to capture the design volume. Inlet sizing is particularly important on steep slopes to ensure that runoff is adequately captured (RIDEM and CRMC 2010). Grates should be sufficient to keep out larger debris, typically with holes of 1 inch or less (MADEP 2008). Recommended maximum drainage area is less than 0.25 acre of impervious areas (NHDES 2008).

Sump depths should be 4 feet or deeper to allow accumulation of sediment and to limit resuspension of accumulated sediment. Except for leaching catch basins that are designed for infiltration, all flow will exit the catch basin through an outflow pipe. These outflow pipes should include a hood or elbow to limit the amounts of floatables, oil and grit that are transported downstream.

To enhance pollutant removal, these systems may be designed off-line to divert large flows to another practice designed for water quantity (MPCA 2013).

Maintenance Requirements

Maintenance is relatively easy and, if properly maintained, these systems can be long-lasting (MADEP 2008). Typical maintenance of catch basins includes trash removal (if a screen or other debris capturing device is used) and removal of sediment using a vacuum truck or wet-vac. As a rule of thumb, once the sump is half full of sediment, it cannot provide additional sedimentation. Depending on location, several cleanings of the sump might be required per year. At minimum, inspection should occur twice annually, once after snow melt and once after leaf drop.

Operators need to be properly trained in catch basin maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of geographic information systems to track sediment collection and to optimize future catch basin cleaning efforts. The disposal of trapped sediment, debris, oil and grit removed during maintenance activities should be considered during design. Avoid damaging the hood during cleaning activities.

Modified Catch Basins

Key design features and maintenance needs:

- Ensure adequate size for both the inlet and the catchbasin to capture and detain the flow
- Requires access for maintenance
- Inspect and maintain practice at least twice annually (frequency is site-dependent)

Martina Frey, Tetra Tech, Inc.

A curb inlet cover allow runoff to enter a catch basin but prevents inflow of trash.

5.5 Pretreatment: Flow-Through Structures

Description

Flow-through structures are subsurface structures that include a settling or separation unit that improve water quality by removing coarse sediments, floatables, oil and grit from runoff. These types of structures include vortex separator systems, oil and grit separators, and proprietary devices.

The vortex separator systems, also known as swirl separators, hydrodynamic separators and swirl concentrators, use vortex action to separate coarse sediment and floatables from stormwater. Although these practices are not designed to reduce runoff volume or peak discharge, they do provide water quality pretreatment by removing coarse sediment, floatables, oil and grit. Like catch basins, pretreatment flow structures are not considered green infrastructure practices, but they are useful tools that can reduce the negative environmental impacts of transportation infrastructure on water resources. In highly urbanized areas with large percentages of impervious surfaces, these practices can be essential elements of hybrid gray and green infrastructure stormwater management systems.

Flow-Through Structures

Advantages:

- Effectively captures coarse sediments and floating debris
- Minimal space requirement
- Can be implemented in any soil or terrain

Most suitable for:

- Bioretention
- Bioswale
- Curb extension
- Stormwater planter
- Trees trenches
- Infiltration trench
- Subsurface infiltration and detention

Horsley Witten

Vortex separator being installed.

Site Considerations

These practices are commonly used near the source of runoff and serve as pretreatment to a number of downstream stormwater management practices. These structures can be constructed in locations with potentially high pollutant loads where other practices might not be applicable. Some states and municipalities require oil and grit separators on sites with higher expected pollutant loads or risk of petroleum spills (i.e., high-turnover parking lots, gas stations, fleet storage areas, and vehicle and equipment maintenance areas).

Because they are subsurface systems that require a relatively small footprint, these systems are useful in situations where land availability is limited. The drainage area for such systems is limited by both the capacity of the chosen system and the available land area.

For More Information—Pretreatment

Underground Hydrodynamic Separators. Fact sheet. Montgomery County, MD (2018)

Pretreatment. Philadelphia Water Stormwater Management Guidance Manual (Chapter 4, Section 10). City of Philadelphia, PA (2018)

Pretreatment Practices. New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design, Chapter 4-4. New Hampshire Department of Environmental Services (2008)

Structural Pretreatment BMPs. Massachusetts Stormwater Handbook (Volume 2, Chapter 2). Commonwealth of Massachusetts (2008)

Design Considerations

These practices should be designed off-line to handle the first flush (initial runoff from precipitation event) for water quality improvement; a bypass line should be provided to handle larger flows. Design options include multichamber systems and devices that include vortex-induced circulating flow paths to promote sedimentation and removal of trash, oil and grease.

By attaching the inflow at a tangential angle to the cylindrical system, a swirling action is induced. Coarse sediment is removed by sliding down a cone in the center of the system to a settling chamber or by directing runoff through a screened area that traps and drops sediment into a chamber. Depending on the manufacturer, these systems can treat flows from 0.75 to 300 cubic feet per second.

In multichamber systems, typically the first chamber provides sedimentation, the subsequent chamber provides additional sedimentation and oil and grease removal (with a hood or inverted elbow), and the final chamber contains the outlet to the downstream practice (Figure 5-3). Devices should be able to safely pass the desired design storm and should include an overflow for large storms to limit resuspension of captured particles. Similar to a deep sump catch basin, the sump in the initial chamber should be at least 4 feet deep (CEI and NHDES 2008).

Maintenance Requirements

These systems require proper maintenance to limit the potential for resuspension of captured sediment. Units should be inspected after major storms and at least one per month (MADEP 2008). Units should be cleaned of captured sediment and debris twice per year. More frequent cleaning will provide more available volume for future storms and less resuspension and associated pollutant transport. The rate of sediment accumulation will depend on the site characteristics; the maintenance plans should reflect these characteristics. Because these practices could be expensive to construct and maintain, costs should be a key consideration when evaluating and selecting them.

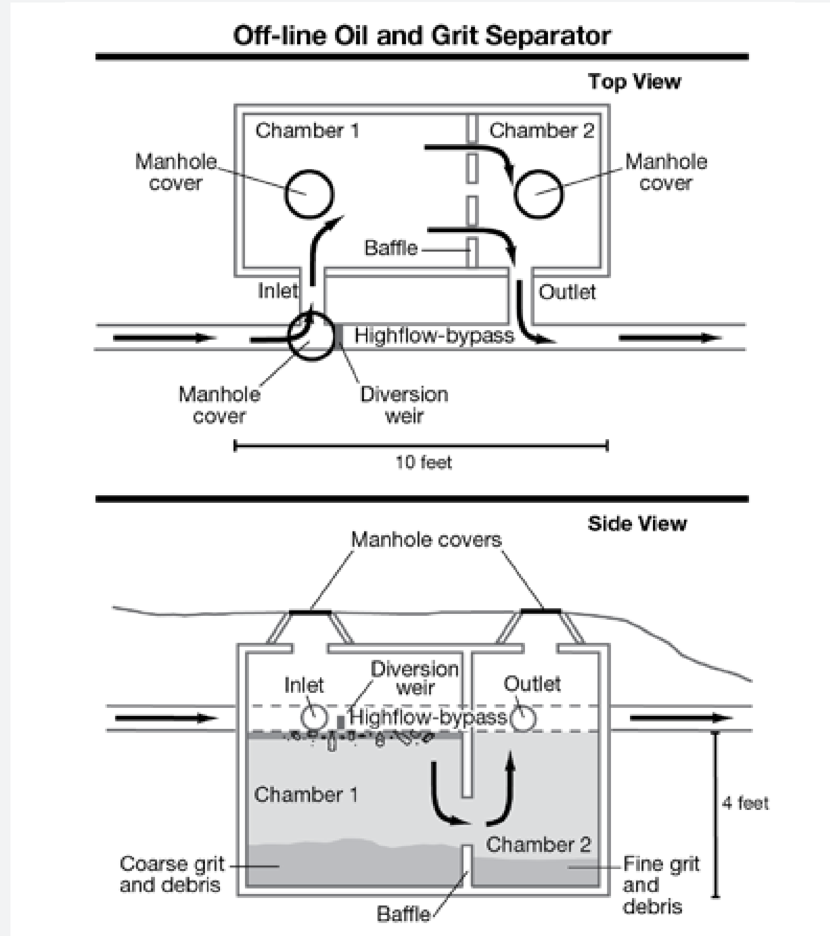


Image: After U.S. Geological Survey

Figure 5-3. An off-line oil and grit separator diverts incoming stormwater into two chambers that slow flow and allow oil and grit to separate from the water stream.

Flow-Through Structures

Key design features and maintenance needs:

- Install as an off-line device to limit potential for resuspension of captured material
- Inspect units monthly and after major storms
- Clean as needed, but at least twice per year

6 Green Street Stormwater Practices

In This Chapter

This chapter covers site design strategies and stormwater management practices that can be incorporated into street and parking lot designs for the retention and treatment of runoff. Information on pretreatment methods that should be considered and incorporated as necessary in the design of the practices and systems is included in Chapter 5. For each practice, information on siting opportunities, design details, performance and supplemental resources is provided.

Note: The design details described in this course are meant to be conceptual and not final design specifications. Designers should refer to state or local requirements and recommendations to inform their designs.

Kary Phillips, Tetra Tech, Inc.

Sand-filled permeable pavers allow rainfall to infiltrate instead of generating erosive runoff in a sensitive coastal area in Virginia Beach, VA.

6.1 Bioretention (Rain Gardens)

Description

A bioretention area is a shallow surface depression usually planted with native vegetation to retain, infiltrate and filter both runoff and pollutants. The volume of runoff is reduced by infiltration and retention in the soils and through interception, uptake and evapotranspiration by the plants. Peak discharges are also reduced. Physical, chemical and biological processes in plants and soils help to absorb and treat pollutants.

The form of bioretention is flexible and can be designed for collection with (1) filtration and infiltration or (2) filtration and conveyance. Once established, bioretention typically requires minimal maintenance. In-ground bioretention is typically in the form of cells, rain gardens or swales. Stormwater curb extensions, stormwater planters and bioswales use the principles of bioretention but include unique design features and are described as different green street practices in this guidebook.

Site Considerations

Bioretention has a significant advantage over other practices because it can vary in size, shape and placement. Bioretention practices can be designed to accommodate large volumes of stormwater runoff or designed to treat small drainage areas. Depending on the source of runoff, they are placed either directly adjacent to the area generating runoff or offset in sidewalks, public plazas or street medians. Bioretention can be designed as a series of multiple cells along the roadways or parking lots.

Bioretention systems can be either infiltration or flow-through systems, but should be designed with pretreatment to address potential sediment loads and debris that can be common in roadways. In ultra-urban areas or retrofit projects, bioretention might be more difficult to site due to the presence of existing infrastructure such as buildings or utilities. Design alternatives that can help overcome site constraints are discussed on the next page.

Bioretention

Advantages:

- Can be sized for large and small drainage areas.
- Good for highly impervious areas
- Good retrofit capability
- Modest maintenance requirements
- Provides aesthetic enhancement
- Reduces runoff
- Reduces pollutant load, thus reducing treatment costs
- Provides wildlife habitat

Most suitable for:

- Parking lot perimeters
- Parking lot islands
- Sidewalks
- Street frontage
- Intersections
- Road medians
- Road shoulders

Road runoff drains through a curb cut and into this bioretention feature on a residential front yard in Maplewood, MN.

Overcoming Site Challenges

Site constraints such as land use and environmental conditions can create perceived obstacles for implementing bioretention, however, many design alternatives are available to help overcome these challenges (Table 6-1).

Table 6-1. Bioretention: site constraints and design alternatives

Challenge	Design alternatives and recommendations
High pedestrian activity	Provide pedestrian bridges or walkways across the practice to allow for uninterrupted movement.
Sites requiring depths between 6 to 12 inches	Install barriers or additional protection around the practice as a safety provision for pedestrians.
Site slopes that are greater than 10%	Incorporate diversion berms, check dams, or terracing with weirs to allow for the bottom to be flat-sloped.
Sites near heavy traffic or high pollutant areas (i.e., potential hotspot)	Avoid placing infiltrating systems due to concerns of groundwater contamination. Recommended practices include pretreatment and/or impervious liner.
Proximity to water table	Recommended 4-foot separation to water table, with a minimum separation of 2 feet with impermeable liner and underdrain or very low-volume roadways.
Sites near sensitive areas such as building foundations or road gravel base materials or above karst topography or brownfields	Incorporate impermeable liners to direct water downward to avoid lateral flow or to prevent vertical flow to underlying sensitive areas depending on what the site requires. Provide a minimum setback of 10 feet from any foundation.
Areas that have significant salt usage or storage during winter months	Avoid using infiltrating bioretention cells in snow storage areas (especially in areas where salt is applied) due to the potential for impacting downstream environmentally sensitive areas.
Poor draining native soils (i.e., hydrologic soil groups C and D)	Amend soils or design practice with an underdrain to convey excess runoff to a downstream practice or stormwater conveyance system.
Compacted soils	Either rototill or mix compacted soil with soil amendments or entirely replace compacted soil with structural soils or modular structural cells.

Horsley Witten

Bioretention in sidewalk with protective stone wall that doubles as a bench in Washington, DC.

Horsley Witten

Roadside bioretention area includes a sidewalk bridge over the inlet to avoid obstructing pedestrian flow.

Components: Bioretention

A bioretention practice typically includes (Figure 6-1):

- Inlet (or sheet flow)
- Native vegetation, or vegetation that is resilient to both wet and dry conditions
- Bioretention soil media that includes a mixture of sand, soil and organic matter

Practices can be designed with optional features to convey inflow, manage overflow and provide pretreatment:

- Inflow structure(s) (e.g., flume, inlets, runnels)
- Highly permeable mulch layer
- Vegetated filter strip
- Forebay or ponding areas
- Outflow/overflow inlet
- Underdrain

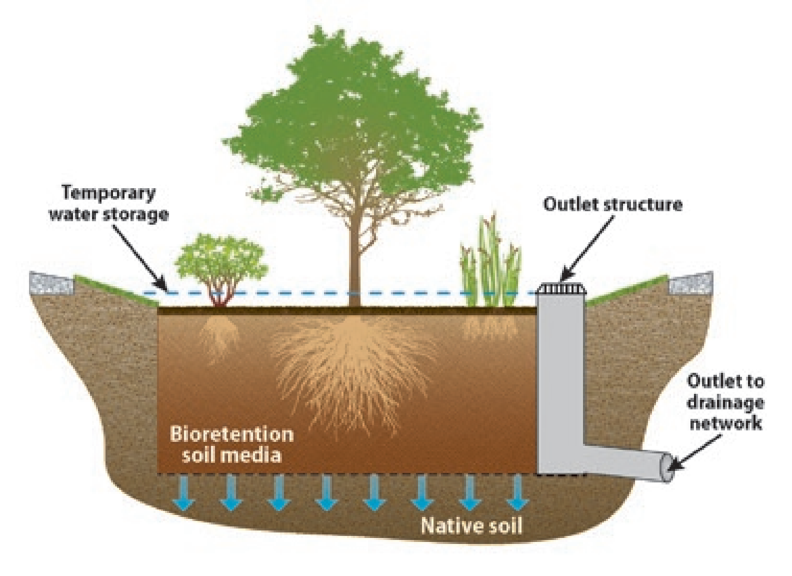


Image: Tetra Tech, Inc.

Figure 6-1. Cross-section of a common bioretention practice design.

Design Considerations

Sizing

Design considerations for bioretention cells are largely influenced by the design objective (e.g., improve water quality or provide channel protection, increase groundwater recharge, reduce peak flow) and the geographic/climatic region of the United States in which it is being applied. Bioretention cells can have many different configurations that are dependent on the land use, climate and pollutant loads. The bioretention feature should have a 2 percent or less longitudinal slope and recommended side slopes of 4:1. The cross section design can be parabolic, trapezoidal, or flat with a minimum 2-inch freeboard.

Inlet Design

For uncurbed areas, a maximum side slope of 3:1 is recommended to reduce the velocity of runoff from the paved areas and to filter out some of the sediment and finer particulates that can clog the bioretention surface. The slope vegetation should include some ground cover plants. For curbed parking lots and roads, designated inflow points must be provided where the majority of the flow will enter. Inflows should be designed to be nonerosive; energy dissipaters or diversions may be necessary to direct erosive flows away from the inlet.

Bioretention

Key Design Features:

- Flexible in size and configuration
- Maximum drainage area: 5:1, not more than 1 acre to one rain garden
- Ponding depths between 6 and 12 inches, which will allow for drawdown within 48 hours
- Plant selections that tolerate hydrologic variability, salts and environmental stress
- Amend soil as needed
- Provide overflow for extreme storm events
- Stable inflow/outflow conditions

Maintenance Requirements

Yearly inspections at a minimum are recommended to monitor infiltration and drainage. For the first 1 to 2 months of vegetation establishment, watering is recommended once every 2 to 3 days. If infiltration rates are lower than expected, it might be necessary to cultivate or replace media (top 2 to 3 inches) to improve the infiltration rate. The following activities and minimum frequencies should be determined with regards to the specific site and as warranted by environmental conditions (Table 6-2). The maintenance cost is similar to traditional landscaping but initial training for workers may be necessary.

Table 6-2. Recommended maintenance activities for bioretention practices

	Activity	Frequency	Additional advice
Debris	Remove sediment or trash that has accumulated.	Semi-annually	If sediment loads are excessive, observe and add upstream sediment controls to lessen load.
	Inspect underdrains for obstructions.	Yearly	Remove any obstructions.
Vegetation	Cut back grasses and herbaceous vegetation. Weed invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing. Prune trees and shrubs.	Bimonthly during establishment; yearly afterwards (preferably in early spring)	If at least 50% of vegetation coverage is not established after 2 years, provide additional plantings. When replacing vegetation, place the new plant in the same location as the old plant, or as close as possible to the old location. The exception to this recommendation is if plant mortality is due to: – Initial improper placement of the plant (i.e., in an area that is too wet or too dry). – If diseased/infected plant material was used and there is risk of persistence of the disease or fungus in the soil.
	Separate herbaceous vegetation rootstock when over-crowding is observed.	Every 3 years	
	Remove and replace vegetation as necessary.	Yearly (preferably in spring)	
Soil	Turn or till soil, especially if compaction occurs.	Yearly	If maintenance efforts are unsuccessful, the soil media and underdrain might need to be removed and replaced.
	Evaluate check dams for undercutting and soil substrate for channel formation.	Every 2 to 3 years (preferably in spring)	
	Remove and properly dispose of the previous mulch layer, or rototill it into the soil surface and add a new layer of mulch.	Yearly	Do not exceed 3 inches in depth for mulch layers. Avoid blocking inflow entrance points with mounded mulch or raised plantings. Once a full groundcover is established, mulching might not be necessary.
	Stabilize any areas where erosion is evident.	As needed	Determine the cause for erosion; this could require adding new features to dissipate energy or to allow the flow to bypass the practice.

Performance

Bioretention pollutant removal performance data is limited but growing in availability. Bioretention appears to be one of the most effective water quality practices given that this practice can remove many pollutants of concern; however, actual mass loading reductions will vary based on flow attenuation and influent water quality. Overall, removal of pollutants has been positively linked to the length of time the stormwater remains in contact with the herbaceous materials and soils (Colwell et al. 2000).

Data indicate that the ability of bioretention to remove total suspended solids, metals (dissolved and particulate-bound), and oil and grease is very strong, while its ability to reduce nitrogen and phosphorus has been mixed (Davis et al. 2009). Because consistent removal of excess nutrients from the pollutant stream is important when considering bioretention, more recent studies have evaluated how amendments to the media can improve adsorption rates.

For More Information—Bioretention

Fact Sheet: Bioretention (Rain Gardens). City of Lancaster, PA (2011)

Minnesota Stormwater Manual: Bioretention; Phosphorus Sorption. Minnesota Pollution Control Agency (2015)

New Jersey Stormwater Best Management Practices Manual: Bioretention Systems. New Jersey Department of Environmental Protection (2016)

Stormwater BMP Manual: Bioretention. North Carolina Department of Environment and Natural Resources (2018)

Technical Guidance Manual for Puget Sound: Chapter 6.1 Bioretention. Washington State University Extension and Puget Sound Partnership (2012)

Bioretention for Infiltration Conservation Practice Standard 1004. Wisconsin Department of Natural Resources (2004)

State-of-the-Art Review of Phosphorus Sorption Amendments in Bioretention Media: A Systematic Literature Review. Marvin, J.T., E. Passeport, and J. Drake (2020) ($)

Abby Hall, USEPA

Bioretention in a residential neighborhood in Portland, OR.

Alisha Goldstein

Bioretention area outside the recreation center at the University of Florida, Gainesville, FL.

6.2 Bioswales

Description

Bioretention swales, also referred to as bioswales or vegetated swales, are typically parabolic or trapezoidal depressions that use bioretention soil media and vegetation to promote infiltration, water retention, sedimentation and pollutant removal. Bioswales differ from bioretention cells because they are designed to be conveyance treatment devices. Bioswales are typically dug to a depth of 12 to 24 inches and compost-amended; in contrast, installing a bioretention cell entails replacing the full volume of soil with an engineered planting media. Similar to traditional grassed swales that convey flows, bioswales provide additional water quality benefits because the stormwater interacts with the plants and bioretention soil. Bioswales are typically located in rights-of-way or parking lots and receive flow from adjacent impervious areas. Bioswales can be used in conjunction with pretreatment BMPs such as sediment forebays, vegetated filter strips, or other sediment-capturing devices that prevent sediments from accumulating in the swale and negatively affecting treatment and retention performance.

Bioswales

Advantages:

- Combine stormwater treatment with conveyance
- Can replace curb and gutter systems at lower cost
- Mitigate peak runoff velocities
- Can be sized for various layouts and topography
- Reduce total suspended solids and metal concentrations

Most suitable for:

- Parking lots
- Sidewalks
- Road medians
- Road shoulders

Site Considerations

Rights-of-way are ideal for bioswales, particularly for roads with wide shoulders or rights-of-way that have long, uninterrupted stretches of land to convey the necessary design flows (e.g., medians, the planting strip between a sidewalk and a roadway). **Because they are easy to implement and relatively low cost to construct, bioswales are applicable for both retrofits and new residential and commercial development.**

Horsley Witten

Grassed bioswale in New Hampshire.

Overcoming Site Challenges

Bioswales can be designed to overcome site constraints (Table 6-3).

Table 6-3. Bioswales: site constraints and design alternatives

Challenge	Design alternatives
High pedestrian activity	Provide pedestrian bridges or walkways across bioswales to allow for uninterrupted movement.
Unsafe site depths for pedestrians	Provide barriers or additional protection around bioswale (in pedestrian areas, depths should not exceed 6 to 12 inches)
Site slopes that are greater than 5%	Incorporate terracing, diversion berms or check dams to accommodate steeper-sloping sites.

Components: Bioswale

A bioswale typically consists of (Figure 6-2):

- A trapezoidal or parabolic channel
- Vegetation (dependent on site requirements)
- Bioretention soil media

Bioswales can be designed with optional features such as:

- Check dams or terracing for steeper slopes
- Curb cuts or other inlet configurations (if area is curbed)

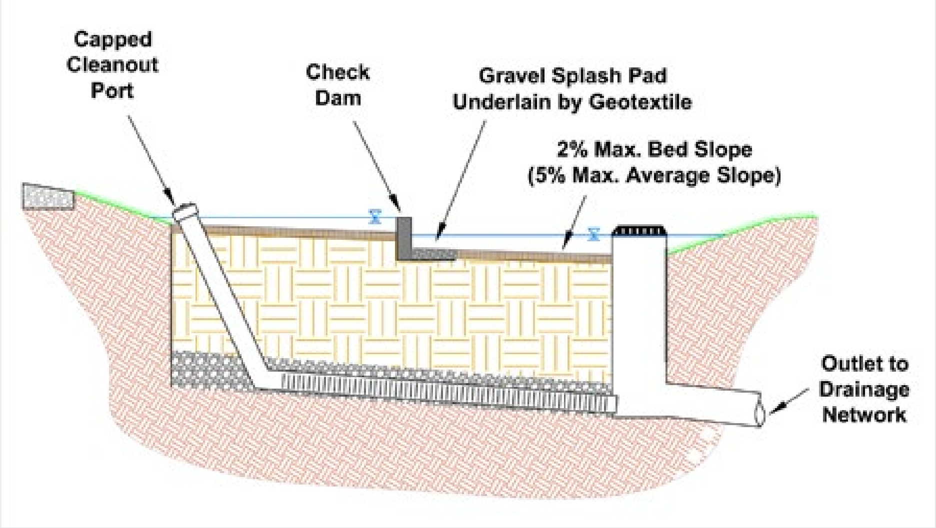


Figure 6-2. Cross-section of a bioswale designed with a check dam to control slope.

Design Considerations

Sizing

The area draining to a specific swale should typically be less than 100 feet in length and no more than 1 acre. If pretreatment is included, the maximum drainage area should be 5 acres. The bioswale should be designed to convey applicable storm events without generating erosive velocities.

Channel Geometry

The bioswale channel may be trapezoidal or parabolic in shape, with side slopes of 3:1 or flatter (note: rectangular shapes with stabilized vertical walls are generally referred to as planters; see section 6.4) and optimally a longitudinal slope with a 1 to 2 percent grade. A maximum 6-inch ponding depth is recommended. The bioswale media should be located in the center of a level area.

Inlet Design

If the perimeter of the swale is curbed, runoff can enter the swale through a curb cut opening. Inlet protection such as pea gravel or a splash pad should be installed to help dissipate the energy of the concentrated flow, thereby preventing erosion. In an uncurbed perimeter, flow may enter the bioswale as sheetflow directly or may be conveyed over a filter strip before entering the swale. If excessive sediment is expected, pretreatment such as a forebay area can also be included in the design to extend the life of the bioswale.

Bioswales

Key Design Features:

- Maximum drainage area: 5:1
- Bottom width of 2 to 8 feet
- Side slopes from 3:1 (H:V) to 5:1
- Longitudinal slope from 1% to 5%
- Maintain 0.5 to 1-foot freeboard without exceeding maximum permissible velocity
- Runoff from the designated water quality event should not overtop vegetated liner (vegetation used for treatment)
- Ensure vegetative cover is greater than 80%
- Till soil if compaction is evident

Vegetation

Bioswales can be planted with many types of vegetation, including:

- Grasses, such as turf grasses or tall grasses
- Herbaceous plants, such as sedges or rushes
- Shrubs and trees (typically found on the edges or slopes of bioswales)

Climate will affect plant selection. In drier areas, bioswales often use xeriscape vegetation. Xeriscaping is a method of landscaping that uses more drought-tolerant plantings so that minimal or no irrigation is needed in between rain events. Ideally, these plantings will also have low maintenance needs (e.g., requires no mowing or pruning). Bioswales that would receive significant quantities of salt-laden runoff should be landscaped with salt-tolerant species. Proper selection of plant species and support during establishment of vegetation should eliminate the need for fertilizers and pesticides.

Select vegetation that grows high enough to exceed desired design flow depth. Additionally, the vegetation should be moderately stiff and non-clumping to provide sufficient surface contact for water quality treatment and to avoid concentrated flow conditions. Riprap or landscape stone can also be used in bioswales, particularly at the edges to provide erosion protection.

Soils

Bioswales are usually excavated to a depth of 12 to 24 inches, tilled to improve infiltration potential, and then backfilled with a filter soil media mix (see section 4.7).

Maintenance Requirements

Bioswales should be inspected yearly at a minimum to monitor sedimentation and erosion. Bioswales planted with turf require more regular maintenance than bioswales planted with perennials and shrubs. Vegetation, including grasses, should be maintained at heights of approximately 4 to 6 inches. The maintenance cost is similar to traditional landscaping but may require initial training for workers. Follow the maintenance activities and minimum frequencies for Bioretention (see section 6.1), while also evaluating check dams for undercutting and soil substrate for channel formation (yearly).

Alisha Goldstein

Bioretention feature with grasses and flowering plants outside a public library in Cleveland, OH.

Alisha Goldstein

Bioswale designed with drought-tolerant plants in arid Tucson, AZ.

Performance

Bioswales remove pollution through three primary removal mechanisms: settling, filtering/infiltration and uptake/accumulation in plants. Using bioswales, it is possible to achieve a 40 percent annual runoff volume reduction (CWP and CSN, 2008; CWP 2007). Current data suggest that bioswales are effective in removing suspended solids. In contrast, studies have shown that bacteria levels are increased in the bioswale effluent. A possible explanation for the introduction of bacteria is waste from wildlife and the pets of nearby resident. Performance is improved when bioswales are built with a pretreatment device such as a filter strips because the sheet flows from parking lots or roadways are diffused.

For More Information—Bioswales

Biofiltration Swale: Design Guidance. California Department of Transportation (2012)

Standards for Green Infrastructure. City of New York Department of Environmental Protection (2020)

Biofilters for Storm Water Discharge Pollution Removal. Oregon Department of Environmental Quality (2003)

Jason Wright, Tetra Tech, Inc.

Roadside bioswale with curb-cut inlet in Greensboro, NC.

Jason Wright, Tetra Tech, Inc.

Bioswale at Los Angeles Zoo parking lot.

Abby Hall, USEPA

Bioswale next to a permeable pavement sidewalk in Seattle, WA.

Martina Frey, Tetra Tech, Inc.

Parking lot bioswale conveys runoff from a parking lot in Wilsonville, OR.

6.3 Stormwater Curb Extensions

Description

Stormwater curb extensions, also called stormwater bump outs, are modified traffic-calming devices that extend the curb into the roadway to reduce traffic speed and capture stormwater runoff from roadways and/or sidewalks. The area behind the curb is filled with a bioretention soil mix and vegetation similar to a bioretention cell or bioswale. The vegetation can be groundcover, shrubs or trees depending on site conditions, costs and design context.

This green infrastructure practice provides stormwater treatment and retention within the right-of-way. Curb extensions can be designed in several configurations to provide both filtration and retention. Pretreatment practices such as vegetated filters and sediment traps are recommended upstream of this practice.

Site Considerations

Stormwater curb extensions can be incorporated in new development and offer an ideal retrofit approach for existing streets. They can be installed upstream of storm sewer inlets and without any modifications to existing catch basins. Overflow from curb extensions can continue to flow down the street to storm sewer inlets. Their small footprint presents minimal disturbance to rights-of-way and provides flexibility in siting. Stormwater curb extensions can be placed in multiple locations along a street section or at intersections to minimize impact to parking (Figure 6-3). They are relatively inexpensive and, when sized correctly, are often capable of treating the entire runoff volume from the street on which they are located.

Implementing stormwater curb extensions can meet additional goals such as traffic calming. The presence of curb extensions narrows the pedestrian crossing distance, increases visibility of pedestrians, and has been shown to reduce vehicular speeds. They are also suitable in areas with steep-slope conditions because they can provide a 'backstop' for stormwater runoff. In addition, they provide landscaping opportunities to beautify the neighborhood.

Stormwater Curb Extensions

Advantages:

- Provides traffic calming and improves pedestrian safety
- Enhances site aesthetics
- Offers air quality and climate benefits that improve environmental health
- Reduces total volumetric runoff
- Provides water quality treatment
- Presents minimal disturbance to the area and existing infrastructure
- Reduces effective impervious area

Most suitable for:

- Neighborhood streets and some collectors
- Intersection
- Midblock
- Any length of roadway

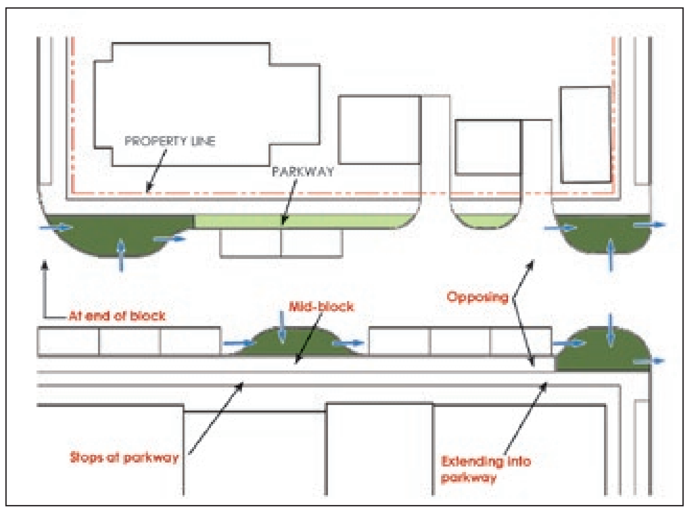


Image: Tetra Tech, Inc.

Figure 6-3. Potential locations for curb extension practices.

John Kosco, Tetra Tech, Inc.

Stormwater curb extension in State College, PA.

Overcoming Site Challenges

Stormwater curb extensions can be designed to overcome site constraints such as sloped landscapes and the presence of underlying utilities, while also enhancing safety and minimizing the loss of parking spaces. Common site challenges and design alternatives are described in Table 6-4.

Table 6-4. Stormwater curb extensions: site constraints and design alternatives

Challenge	Design alternatives and recommendations
Removal of on-street parking is required.	Minimize impact by selectively placing curb extensions at intersections or mid-block crossings.
Ensure safety for all modes of transportation.	Be conscious of street width, turning radii and sightlines for all users.
Prevent vehicles from driving onto the sidewalk and harming pedestrians.	Provide barriers such as bollards, planters or benches around stormwater curb extension.
Site slopes that are greater than 5%.	Incorporate terracing, diversion berms, or check dams to accommodate steeper-sloping sites.
Sites that are not stable or have high sediment loads.	Plan to include pretreatment practices to avoid high amounts of maintenance.
Conflict with underlying utility or fire hydrant.	Reorient the design.
Proximity to water table.	Recommended a 4-foot separation to water table with a minimum separation of 2 feet.

For More Information—Stormwater Curb Extensions

Northeast Fremont Street Green Street Project. City of Portland Bureau of Environmental Services (2007)

San Francisco Better Streets: Curb Extensions (Bulb-outs). City and County of San Francisco (2015)

City of Philadelphia Green Streets Design Manual. City of Philadelphia (2014)

Tennessee Permanent Stormwater Management and Design Guidance Manual: Urban Bioretention. Tennessee Department of Environment and Conservation (2015)

Alisha Goldstein

Parking impacts minimized by using a mid-street stormwater curb extension in the Barton Creek neighborhood, Seattle, WA.

Alisha Goldstein

Black and yellow-striped bollards placed around a stormwater curb extension ensures safety for motorists in Tucson, AZ.

Components: Stormwater Curb Extension

A stormwater curb extension typically consists of (Figure 6-4):

- Low-profile vegetation
- Curb cuts (berms, inlet deflectors or pavement modifications are often used to direct flow towards curb-cut inlets)
- Bioretention soil media

Stormwater curb extensions can be designed with optional features such as:

- Forebays
- Check dams or terracing for steeper slopes
- Underdrains
- Overflow structures

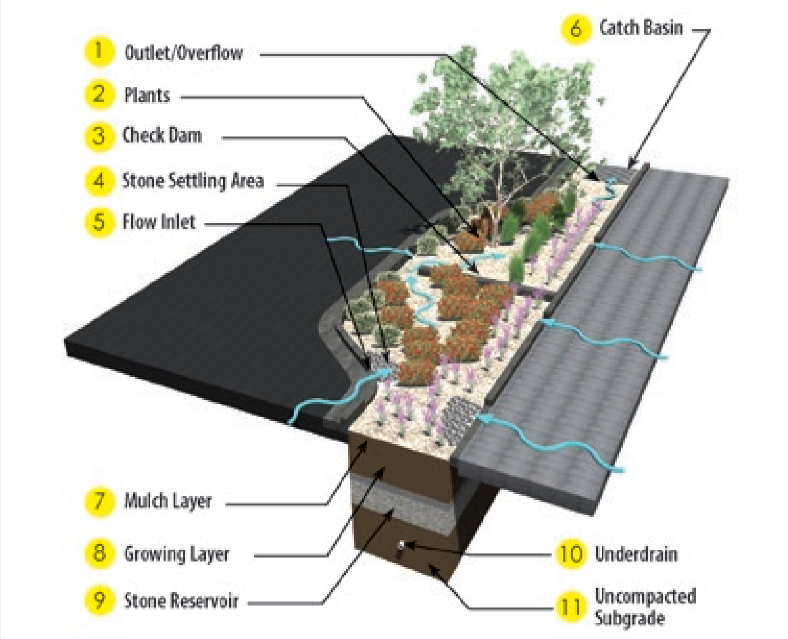


Image: Tetra Tech, Inc.

Figure 6-4. Components of a stormwater curb extension.

Design Considerations

Inlet Design

Runoff for uncurbed roads and sidewalks is generally conveyed via direct sheet flow or shallow concentrated flow into stormwater curb extensions; curbed roads and sidewalks require curb cuts to direct the flow. Alternatively, runoff may enter via an existing or proposed inlet, typically located at a low point or depression in a road or parking lot.

A curb cut should be made where the majority of the flow will enter; in some cases, more than one curb cut might be necessary to capture flows from multiple locations. For more information on curb cuts, see section 4.4.

Berms, inlet deflectors, or pavement modifications (e.g., depressions), can be used to direct flow to the curb cuts or inlets (particularly those at a 90-degree angle). The following elements should be evaluated when determining the dimensions and shape of the curb cut opening: ponding depth, spread of flow, slope and design storm event. To protect the media around the inlet from scouring and erosion, a concrete splash pad or a course of riprap or gravel should be installed just inside the curb cut to dissipate the flow as it enters.

A curb opening can be designed with a forebay structure to capture sediment. Concrete pads are typically used as forebays to help remove sediments. Hand removal of sediments from a small concrete pad is much easier than removing sediments from a mulch and soil layer or a pretreatment forebay filled with stone or gravel.

Stormwater Curb Extensions

Key Design Features

- Include low-profile vegetation
- Level storage bed bottoms
- Mark curb cuts to be highly visible to motorists
- Work around existing utilities
- Refer to bioretention key design features

Sizing

The surface area of the curb extensions is typically 5 to 10 percent of the drainage area.

Underdrains

Stormwater curb extensions can be designed with or without an underdrain. Systems with poor underlying soil typically include an underdrain to ensure drainage within a set time period. The underdrain can be placed a few feet above the bottom of the practice to create internal water storage to promote infiltration. Even with this storage layer, practices with underdrains provide less water quantity reduction than practices without them.

Overflows

Overflows are typically conveyed through an overflow curb cut at the downstream end of a curb extension. If an overflow structure is incorporated into the design (typically with an underdrain), it should be sized to pass the design storm event. Grates on the top of overflow inlets should be sized to exclude trash and animals while allowing stormwater to drain at a steady pace. The structure should be large enough to provide access to clean out the outflow pipe or the underdrain. The top of the overflow structure should be at the maximum ponding depth.

Vegetation

Vegetation selection for stormwater curb extensions is similar to a bioretention cell (see section 6.1). Selected vegetation should be low profile (typically 36 inches or less at maturity) to allow unimpeded sightlines for pedestrians and motorists.

Soils

Native soils are typically excavated to a depth of 18 to 24 inches and tilled to improve infiltration potential. The curb extension is then backfilled with a bioretention filter media mix.

USEPA

Runoff enters the upper end of this curb extension, and the overflow volume exits through an opening on the lower end and drops into a storm drain.

Horsley Witten

Densely planted low-growing grasses fill a stormwater curb extension in Portland, OR.

Martina Frey, Tetra Tech, Inc.

Mature grasses and a tree pit treat stormwater in a curb extension in Gresham, OR.

Maintenance Requirements

Maintenance of curb extensions is similar to that of a bioretention practice (see section 6.1) In addition, evaluate the condition of curb extension perimeter and inflow/outflow points. Repair or replace as needed. Yearly inspections are recommended at a minimum.

Performance

Similar to bioretention cells, stormwater curb extensions use the physical, chemical and biological processes in plants and soils to absorb and treat pollutants and help maintain the hydrologic balance of an area. Research has shown that stormwater curb extensions are highly efficient at removing pollutants, with results similar to a bioretention cell. Refer to the performance statistics for bioretention in section 6.1 for more information.

Stormwater curb extensions promote stormwater infiltration and retention in the soils, as well as interception, uptake and evapotranspiration by the plants. As a result, curb extensions are able to provide significant reductions in both peak flow rates and annual stormwater volume.

Tetra Tech, Inc.

Stormwater curb extension decreases crossing distance and improves intersection safety in the Capitol Hill neighborhood in Seattle, WA.

Jason Wright, Tetra Tech, Inc.

Mid-street stormwater curb extension in a neighborhood in Kansas City, MO.

Abby Hall, USEPA

End-of-street stormwater curb extensions in a neighborhood in Portland, OR.

6.4 Stormwater Planters

Description

Stormwater planters are becoming common components of municipal stormwater programs. Planters are narrow, flat-bottomed landscape areas that are typically rectangular in shape with vertical walls. Planters usually receive runoff from surrounding impervious areas, including rooftop areas, sidewalks and roadways. Constructed from a variety of different materials, they can be configured in different ways to effectively capture and treat incoming flows. The two primary types of planter boxes are:

- **Infiltration planters.** These have open bottoms and allow stormwater to infiltrate into the subsoil beneath. As stormwater percolates through the planter box soil, pollutants are removed by filtration, absorption and adsorption, and chemical and biological uptake. Infiltration planters are appropriate to use in well-drained soils. Infiltration planters have a greater potential for runoff reduction than do flow-through planters.

- **Flow-through planters.** These have impervious bottoms or are placed on impervious surfaces. Once the soil in flow-through planters is saturated, excess water is collected in an underdrain to be discharged to the conveyance system or to another green infrastructure practice. They are appropriate for soils with poor drainage, prior contamination or high seasonal groundwater table.

Stormwater Planters

Advantages:
- Enhance site aesthetics
- Reduce total volumetric runoff
- Provide some water quality treatment
- Reduce effective impervious area
- Widely applicability in ultra-urban areas

Most suitable* for:
- Sidewalk areas
- Buffer zone between sidewalk and street
- Areas with expanses of impervious surface where bioretention is not an option

* Typically applied in urban locations

Site Considerations

Stormwater planters are ideal for urban or ultra-urban areas where space is limited or in areas with steep slopes. Planters are also ideal for retrofit projects because they can be built between driveways, entryways, utilities and trees, adjacent to buildings and parking lots, and in rights-of-way. They can be used to capture surface runoff from roadways or be connected to a downspout from a rooftop. They should be placed reasonably close to the source of runoff.

Planters can be situated either aboveground (receiving water via surface flow) or belowground (receiving water via underdrains). In rights-of-way, aboveground planters can be designed with a perimeter seating for pedestrians. Belowground planters can be equipped with fences and/or adjacent benches to provide a pedestrian-oriented streetscape. They can be built singularly or in series.

Horsley Witten

Curb cuts in the sidewalk and street allow for runoff to flow into this stormwater planter in Portland, OR.

Stormwater planters are typically not used in low- to medium-density settings because the hardscape infrastructure required increases the cost of the practice, so it is generally not as cost effective as bioretention or bioswales. Planters are typically used in areas where site constraints and right-of-way use patterns require confined and protected practices. Because these practices are normally in urban places where space is a constraint, their performance is limited by the capacity of the planter.

Overcoming Site Challenges

Stormwater planters can be designed to overcome site challenges such as high pedestrian activity, safety concerns, or high-sediment-load runoff (Table 6-5).

Table 6-5. Stormwater planters: site constraints and design alternatives

Challenge	Design alternatives and recommendations
High pedestrian activity or vehicle traffic.	Provide pedestrian bridges to allow for crossings in the sidewalk. Aboveground planters can provide a seat wall for pedestrians.
Belowground planters are perceived as safety risk for pedestrians.	Install tree fences, barriers and/or benches to provide protection around planter.
Sites that are not stable or have high sediment loads.	Incorporate pretreatment practices to avoid high amounts of maintenance.


USEPA

Sidewalk planters are equipped with bridges to provides access to parking areas in Seattle, WA.


Horsley Witten

Interconnected stormwater planters include protective walls alongside the parking lane in Niagara Falls, NY.


Kary Phillips, Tetra Tech, Inc.

A pedestrian-friendly sidewalk planter includes safety rails and a metal sidewalk bridge in Baltimore, MD.

Components: Stormwater Planter

A stormwater planter typically consists of (Figure 6-5):

- Vertical walls, typically made of a durable material that is context-appropriate
- Access point such as a curb cut or downspout connection
- Vegetation
- Bioretention soil media

Stormwater curb extensions can be designed with optional features such as:

- Splash pad
- Underdrains
- Overflow structures
- Liners

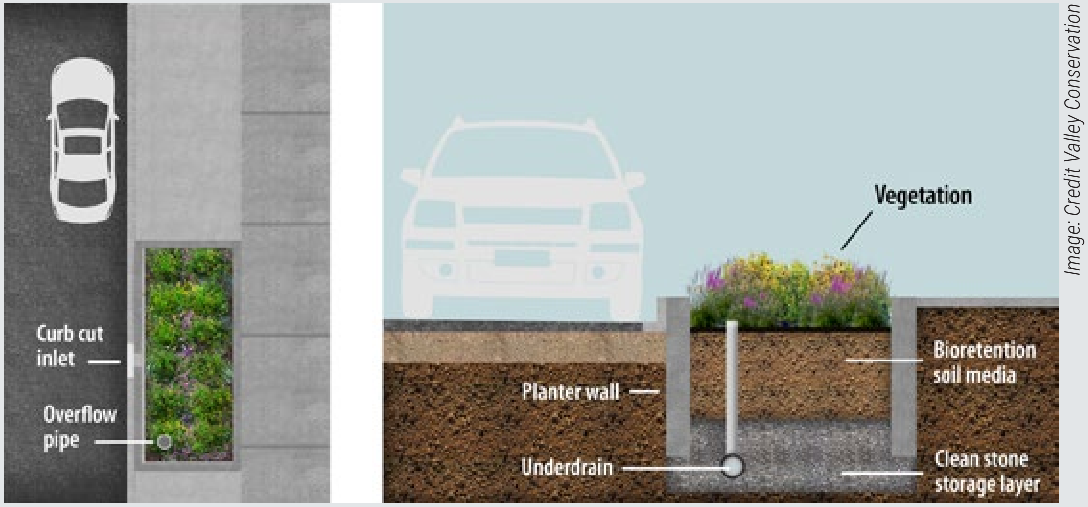


Figure 6-5. Stormwater planters, unit plan view (left) and cross section (right).

Design Considerations

Hardscape Materials

Stormwater planters may be constructed of any durable material, such as stone, concrete, brick, plastic lumber or wood. Stand-alone planter boxes are typically constructed of pre-cast or cast-in-place concrete or other materials used in the nearby streetscape.

Sizing

Stormwater planters should be sized appropriately for storage volume requirements and available space. The space needed for planter boxes might not be available in all situations within the urban environments. Minimum sizing requirements will depend on local stormwater regulations. A typical planter box may have an interior size of 2 feet by 2 feet with a depth of 12 inches (of which 6 inches is for storage depth) and slope of less than 0.5 percent. For infiltration planters, at least 2 feet of infiltration medium should be included between the bottom of the practice and any underlying constraint (e.g., solid rock, high groundwater table).

Inlet Design

Planters placed in rights-of-way typically have curb cut inlets that capture flows from roadways and/or have notches in the planter walls to receive sidewalk runoff. Planters that are installed adjacent to buildings receive flows from downspouts; to reduce scour and erosion, these inlets typically have a splash pad or a course of stone at the base to dissipate flow energy.

Stormwater Planters

Key Design Features

- Infiltration rate of soil will determine size and site applicability
- Runoff should drain within 3 to 4 hours after storm event
- Provide a flow bypass for winter conditions

Liners

Flow-through planters typically use an impermeable liner or other impervious bottom to prevent runoff from infiltrating into native subsoils. Planters that are adjacent to buildings should also have a waterproofing membrane on the sides of the planter to protect the building's foundation.

Vegetation

Vegetation selection for stormwater planters is similar to a bioretention cell (see section 6.1). They generally include a variety of shrubs, small trees and native herbaceous species that are appropriate for the streetscape. Some designers are using sedum and other green roof plants (e.g., the National Institute of Medicine in Bethesda, MD).

Stormwater planters in Washington, DC, are designed in a series to collect and treat road runoff while allowing adequate pedestrian access to the street and sidewalk.

Soils

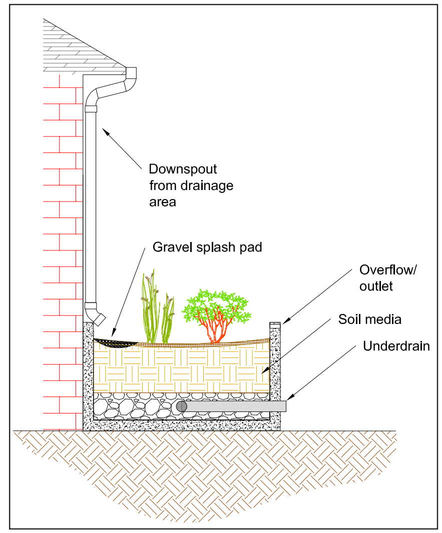
Belowground stormwater planters are typically excavated to a depth of 18 to 24 inches and tilled to improve infiltration potential or backfilled with a bioretention soil mix. Use backfill to enhance infiltration, especially if the native soils do not have a minimum infiltration rate of 0.5 inches per hour. Aboveground stormwater planters are filled with 18 to 24 inches of a bioretention soil mix.

Performance

Stormwater planters exhibit water quality benefits similar to those of bioretention, which mimic nature by employing a rich diversity of native plant types and species. In addition to improving water quality and reducing runoff quantity, the locally adapted vegetation exhibits good tolerance to pests, diseases and other environmental stressors.

Maintenance Requirements

The maintenance requirements for a planter are influenced by site conditions such as frequency of sediment build-up or growth of vegetation. The maintenance activities and frequencies outlined for bioretention (see section 6.1) should be followed for stormwater planters. Inspect the planter box for structural integrity at least yearly.



A stormwater planter can be designed to capture and treat roof runoff.

Roof downspout is directed into a stormwater planter in Emeryville, CA.

For More Information—Stormwater Planters

City of Philadelphia Green Streets Design Manual. City of Philadelphia (2014)

Stormwater Planters. Oregon State University Extension Service (2018)

Low Impact Development Approaches Handbook: Flow-Through Planter. Oregon Clean Water Services (2009)

6.5 Stormwater Tree Systems

Description

Stormwater tree systems (i.e., pits and trenches) consist of a tree or shrub, bioretention soil media, and a gravel reservoir to intercept and capture stormwater. The tree pit can be designed as an infiltration practice. If infiltration is not desirable because of a groundwater contamination threat, poorly draining native soils, or a high groundwater table, systems can be designed with an underdrain that directs treated runoff to a downstream practice or stormwater conveyance system.

Stormwater tree systems typically receive road runoff through a curb cut, catch basin or stormwater inlet. Captured runoff temporarily ponds on the surface before infiltrating and filtering through a bioretention soil media and/or a stone reservoir. These practices improve water quality through filtration and adsorption, reduce peak discharge through subsurface storage, and can reduce runoff volume through the uptake and evapotranspiration by trees. If designed for infiltration, these practices achieve additional reductions of runoff and peak flow. Types of stormwater tree systems include:

- **Tree Pits.** Stormwater tree pits are typically installed upstream of existing catch basins to improve water quality through filtration and adsorption before directing runoff to a downstream stormwater management practice or conveyance system. Unlike tree trenches, tree pits only include one tree or shrub. A number of proprietary tree pit systems on the market include pretreatment sumps and/or subsurface structural supports. These structural elements preserve volume for soil media while also providing support for sidewalks.

- **Expanded Tree Pit.** An expanded tree pit has a contiguous bioretention cell designed to collect and treat stormwater. It is also referred to as a tree box filter, tree box, or bioretention tree pit. Because these systems generally have surface volumes that permit ponding, they achieve more stormwater reduction and treatment than tree pits. Tree pits have an average lifespan of 25 years, although vegetation might need to be replaced more frequently (LIDC 2005).

- **Tree Trench.** The stormwater tree trench is a variation of the tree pit. Tree trenches include a stone storage layer, bioretention soil media and multiple trees planted in sequence with a common gravel trench for water storage. Tree trenches are most commonly designed as off-line structures. Multiple design variations are available, but typically a catch basin captures runoff and conveys it through a perforated pipe in the gravel trench. Water is stored in the trench and is taken up by the trees and the underlying soil, if designed for infiltration.

Stormwater Tree Systems

Advantages:
- Reduce runoff volume and delay peak flows
- Enhance site aesthetics
- Shade and shelter individuals and buildings
- Reduce air temperature
- Reduce cooling and heating costs
- Capture/reduce air pollutants
- Evapotranspire runoff
- Reduce noise pollution
- Improve psychological health
- Provide a sense of place
- Simple to install
- Available in multiple sizes

Most suitable* for:
- Sidewalk areas
- Buffer zone between sidewalk and street
- Medians
- Parking lots

* Typically applied in urban locations

Horsley Witten

A tree pit captures runoff in a parking lot in Lawrence, KS.

Overcoming Site Challenges

Stormwater tree systems can be designed to overcome site challenges such as a high groundwater table, insufficient soil volume or concerns for soil upheaval (Table 6-6).

Table 6-6. Stormwater tree systems: site constraints and design alternatives

Challenge	Design alternatives and recommendations
High groundwater table or poor-draining native soils	Design practice with an underdrain to convey excess runoff to a downstream practice or stormwater conveyance system.
Compacted soils	Either rototill or mix compacted soil with soil amendments, or entirely replace soil with structural soils or modular structural cells.
Tree pit depths great enough to pose a pedestrian fall risk	Install fences, barrier and/or benches to provide protection around the tree pit.
Underground or aboveground utility present	Select trees with mature heights under the average height of overhead utilities (typically 30 feet). Provide adequate clearance of underground utilities, which should be protected from water and root penetration.
Insufficient soil volume to ensure proper tree growth	Construct root paths to an adjacent open space or add structural cells that can support sidewalks or pavement while providing space for soil below ground.
Proximity to buildings	Incorporate an impermeable liner or underdrain into the design to prevent infiltration into the building foundation.
Limited sidewalk width	When necessary, place paving stones, cobbles, or porous rubber as a surface material around the trees outside the root ball area.
Concern for sidewalk upheaval	Provide areas for unrestricted root growth beneath the surface using root paths or structural soils below the sidewalk. Ensure that trees are planted below grade.

Site Considerations

Tree pits and tree trenches are ideal for urban and ultra-urban environments because they help to reduce the urban heat island effect, improve air quality, enhance community aesthetics and create a walkable environment that is safe, healthy and comfortable. Street trees can induce traffic calming if planted to create vertical walls that frame the street and guide motorists along a defined edge, or if they are planted in street medians to better divide opposing traffic flows (Burden 2006).

Tree pits and tree trenches are widely applied in retrofit situations because they can be installed within the sidewalk (although the sidewalk must not be encroached upon to a point that pedestrian traffic is affected). These practices are most commonly seen on sidewalks of urban or commercial streets; however, they are also applicable in parking lots.

Expanded tree boxes are another practice worth considering. This practice involves the use of a vault or other structural device to provide larger volumes for additional retention and room for the tree roots to expand. The use of these systems promotes the growth of healthy mature trees and can provide significant stormwater retention or detention volume.

Because of their relatively rigid shape, these practices are not typically suitable in residential or rural applications, where more natural-looking practices such as bioswales or bioretention practices are generally more appropriate and cost-effective. Tree pits can be part of a treatment train and can receive inflow from a pretreatment practice to enhance sediment and trash removal.

Design Considerations

Siting

Evaluating existing site conditions, such as soils, hydrology, topography, vegetation patterns and invasive species, is necessary to determine the proper placement and design requirements for planting a tree. For example, minimal availability of planting surface areas would influence species selection and require soil modification to support plant growth and health. Plants should be located as far from the curb as possible to prevent injury from salt, sand and snow. Along roadways, it is important to anticipate activities such as mowing and snow storage when situating trees.

There must be a setback from the road to maintain line-of-sight requirements, including for street signs, signals and lights—especially at intersections, curb cuts and medians.

Slope

For longitudinal slopes greater than 5:1 (H:V), consider a terraced approach.

Hardscape Materials

A number of design options are available for the tree pit enclosure. To maximize root growth, shallow concrete barriers can define the edge of the practices, allowing for uninhibited root growth in all directions and maximizing infiltration. Enclosed vaults may be used where infiltration is not desirable, where there is soil or groundwater contamination, or where a high groundwater table is a concern. Vaults used in tree pits can be rectangular or cylindrical. Other design variations include bottomless tree vaults or vaults with some sides left open to encourage root growth.

Stormwater Tree Systems

Key Design Features

- Select appropriate tree species
- Allow sufficient root zone growth area
- Provide mechanism for funneling stormwater runoff to the tree
- Ensure proper spacing and avoid conflicts with utilities, buildings and pedestrian traffic
- Provide high infiltrative capacity to prevent ponding after 72 hours

Components: Tree Systems

Although there are many design variations, a stormwater tree system (Figure 6-6) typically consists of:

- Tree boxes
- One or more trees or shrubs
- Bioretention soil media
- Gravel reservoir
- An underdrain

Optional design components include:

- Pretreatment sump
- Impermeable liner
- Connection to subsurface chambers
- Observation well (if needed)
- Overflow outlet

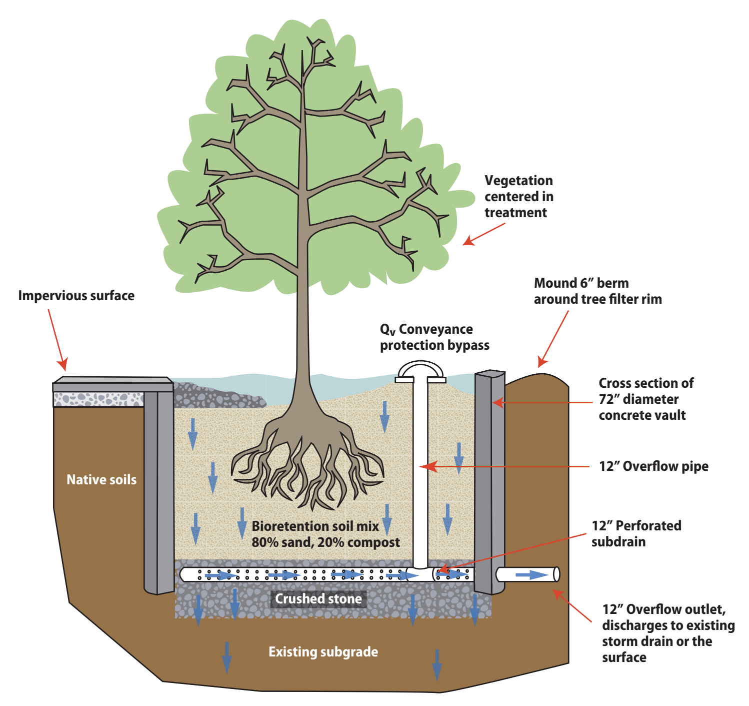


Figure 6-6. Stormwater tree pit schematic.

Image: University of New Hampshire Stormwater Center

Space Requirements

To reach mature growth, trees require sufficient soil volume with ample void space. The recommended soil volumes depend on the size and the number of trees sharing the soil bed. Although no universal standard for soil volume requirements for expected mature tree size exists in arboriculture, it is generally accepted that a large-sized tree (16 inches diameter at breast height) needs at least 1,000 cubic feet of uncompacted soil (USEPA 2013). If soil volume is insufficient for root establishment, tree growth will be stunted and roots may be forced to grow upward, causing heaves in the sidewalk. If retention is an objective, sufficient volume for tree root growth and continued retention should be included in the design.

Different designs can be used separately or in conjunction with one another in challenging situations (i.e., utility conflicts or limited sidewalk area) to provide ample space.

- The tree is surrounded by an open, unpaved soil area that can be planted or covered with mulch. This method requires more street space than the other two methods.
- The tree is provided with root paths that use aeration or drainage strips to guide root growth under the pavement. Root paths may connect adjacent green spaces.
- The tree is provided with a specially designed soil area to promote root growth under the pavement. A variety of solid and permeable pavements can be used to cover the soil. The underlying soil may consist of structural soils or modular structural cells.

Structural or soils cells offer void space for root growth while providing load support to meet pavement design requirements. Structural soils are composed of crushed stone, clay loam and a hydrogel stabilizing agent, which can be compacted to meet pavement design requirements. The stone provides void space for root growth.

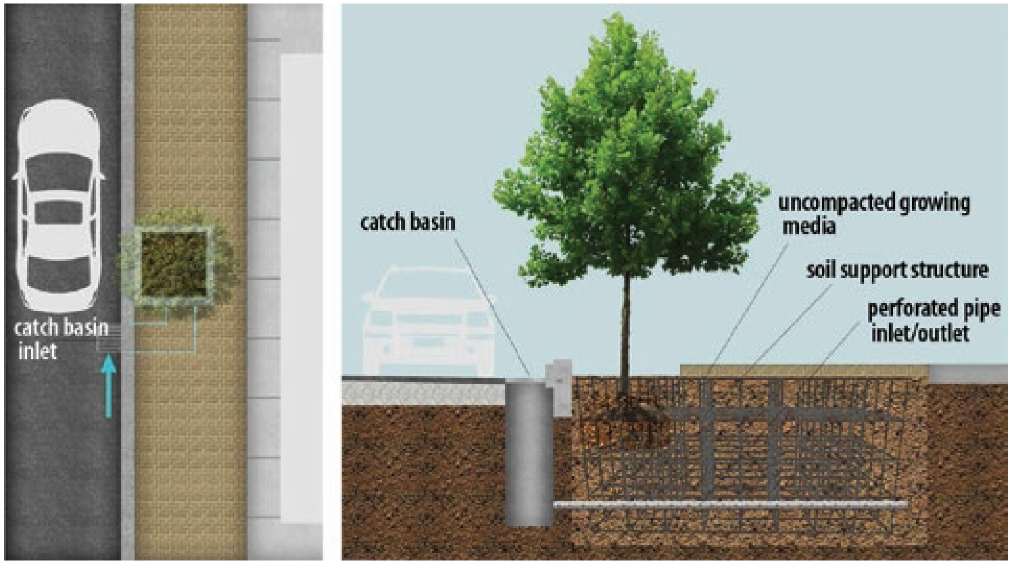


Figure 6-7. Cross section of tree box with a structural support system under the sidewalk.

Modular structural cells are typically constructed of plastic or fiberglass and are designed to support pavement and loading requirements (Figure 6-7). Soil is added to the cell framework, which provides structural support for root growth. Structural cells are more commonly used in locations that have inadequate volumes of soil for tree growth or where highly compacted soils do not allow for root growth (typically under paved areas).

Optional Design Considerations

Alternative designs can help accommodate site-specific conditions or goals. In addition to the enclosed vault option cited above, an impermeable liner around the sides and on the bottom can be combined with an underdrain system to inhibit infiltration in cases where foundation flooding problems or the presence of underground utilities or contaminated soils make infiltration undesirable. Setbacks to existing buildings and foundations should be considered when determining the desirability of infiltration. Tree pits and tree trenches can be designed to connect to subsurface infiltration structures to provide additional storage and groundwater recharge. Additionally, planting trees in groups can reduce wind impacts and create shade.

Inlet

Water typically enters tree trenches through a catch basin, but can also enter from curb inlet or from permeable paving on the sidewalk above the storage trench. The stormwater then flows through a perforated distribution pipe or an underdrain into the filter media.

Underdrains

Tree pits are typically designed with an underdrain to provide filtration of small volumes of stormwater before discharging to the existing storm drain system or a downstream practice. Where soils have an infiltration rate greater than 0.5-inch per hour, tree pits can be designed to infiltrate (and underdrains are not needed). However, underdrains may be advisable when there is an underground conflict with utilities or issues with potential groundwater contamination due to resident soils. If adjacent land uses have a high potential to discharge soluble pollutants of concern, infiltration systems might not be appropriate.

Vegetation

Tree pits contain a single tree or shrub; tree trenches could contain multiple trees or shrubs in series. Native vegetation species should be selected based on soil conditions and the historic plant community in the area. To provide maximum tree canopy benefits, street trees should be planted near each other whenever possible while maintaining sufficient area for each tree's individual root growth. For sites in cold climates near roadways, it is essential to select trees that have a high tolerance for pollutants and salt. Salt spray has been shown to affect areas over 30 feet away from the road (MHD 2006). Potential thermal impacts from adjacent structures should also be evaluated when selecting tree species and designing tree box planters.

Ideally for reforestation and afforestation, plantings should provide a multi-layer canopy structure of about 50 percent large trees and 50 percent small trees and shrubs (Hinman 2005). Using a diversity of plant types and sizes (e.g., evergreens, deciduous trees, shrubs) will increase the pest and disease resistance (MHD 2006). For many sites, a ratio of two evergreens to one deciduous tree will provide a mix similar to native forests (Hinman 2005).

To foster a forest-type microclimate on altered, disturbed landscapes, pioneer species that thrive in infertile soils can be planted first. Establishing these faster-growing varieties of plants before others mimics the natural succession pattern and will create an environment that will provide shade cover to enable more difficult-to-establish species to develop (MHD 2006).

Reforestation and Afforestation

Improving the tree canopy on a large scale can be a form of reforestation or afforestation. Reforestation is the replacement of trees that were previously lost to construction or deforestation. Afforestation is the planting of a new tree community in an area where they have been absent for a significant period of time, such as an old farm field (Prince George's County 2005). These practices involve planting trees on existing turf or barren ground, with the goal of establishing a mature forest canopy that will intercept rainfall, increase evapotranspiration rates and enhance soil infiltration rates. Reforestation and afforestation require large land areas and are therefore most suited for sites near existing forests, along waterways or steep slopes, and along existing highways or other roads.

Kary Phillips, Tetra Tech, Inc.

Stormwater catch basin tree pit, Charlottesville, VA.

Soils

In addition to the space requirements mentioned earlier, soils should remain uncompacted so water and nutrients can infiltrate into void spaces. It might be necessary to enhance the existing soil with fertile topsoil, especially for reforestation projects. To increase the permeability of native soil, a compost-amended soil can be added. Care should be taken to prevent soil compaction during planting.

Structural soils are engineered soil-on-gravel mixes that are designed to support tree growth and serve as a sub-base for pavements. They are typically 70% to 80% angular gravel, 20% to 30% clay loam soil and a small amount of hydrogel (~3%), which provides 20% to 25% void space.

Bioretention soil mixes are commonly used for extended tree pits. The University of New Hampshire Stormwater Center (UNHSC) recommends a bioretention soil mix that is comprised of 80% sand and 20% compost to maximize permeability while providing minimum organic content. UNHSC also recommends 3 feet of bioretention soil mix. Supporting material for the *Minnesota Stormwater Manual* suggests 50% to 65% coarse sand, 25% to 35% topsoil and 10% to 15% compost (MPCA 2013).

Performance

Trees retain water, improve water quality and offer many other community benefits when properly planted. Trees generally absorb the first 30% of precipitation events through their leaf system and release it through evaporation.Up to an additional 30% of precipitation is absorbed into the ground and is taken in and held by the root structure before being absorbed and released to the air as transpiration (Burden 2006). Trees also enhance water quality by using nutrients for plant processes at the surface and within the soil media. The soil matrix removes pollutants as well through chemical binding of charged particulates, biological uptake by microbial communities in the soils and physical removal through filtration.

USEPA

Tree pits treat stormwater runoff at a park in Portland, OR.

For More Information—Stormwater Tree Systems

Urban Street Trees- 22 Benefits Specific Applications. Dan Burden, Glatting Jackson and Walkable Communities, Inc. (2006)

Stormwater, Trees, and the Urban Environment. Charles River Watershed Association (2009)

Minnesota Stormwater Manual: Trees. Minnesota Pollution Control Agency (2013)

Green Infrastructure Practices: Tree Boxes (Fact Sheet FS1209). Rutgers University Cooperative Extension, New Jersey Agricultural Experiment Station (2013)

Regular Inspection and Maintenance Guidance for Bioretention Systems/Tree Filters. University of New Hampshire Stormwater Center (2009)

Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management. USEPA Office of Wetlands, Oceans and Watersheds (2013)

Stormwater Trees: Technical Memorandum. USEPA Great Lakes National Program Office (2016)

i-Tree: Tools for Assessing and Managing Community Forests. U.S. Forest Service

Quantifying the Benefits of Urban Forest Systems as a Component of the Green Infrastructure Stormwater Treatment Network. Kuehler et al. *Ecohydrology* (2017)

The Role of Trees in Urban Stormwater Management. Berland et al. *Landscape and Urban Planning* 162:167–177 (2017)

Maintenance Requirements

Maintenance of street trees is performed by arborists, landscape professionals, homeowners or volunteers. For an extended tree pit, refer to the maintenance recommendations for bioretention. Supplemental irrigation might be required during initial tree establishment. Table 6-7 outlines long-term recommended maintenance activities that should be conducted for stormwater tree systems.

Alisha Goldstein

Trees are planted in groves connected by trenches in this parking lot at the Maplewood Mall, MN. Tree trenches extend 8 to 12 feet wide and 4 feet deep for a total of 1 mile in length. Angled curbs were designed to allow snow plows to roll smoothly over them.

Table 6-7. Recommended maintenance activities for stormwater tree systems

	Activity	Frequency	Additional advice
Debris	Inspect planter box structural integrity.	Annually	Any damaged components should be repaired or replaced.
	Remove sediment or trash that has accumulated.	Two to four times per year	
	Inspect underdrains for obstructions.	Annually	Backflush if obstructions are found.
Vegetation	Weed invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing. For reforestation and afforestation project, remove ferns and grasses that would compete with tree seedlings.	Annually (preferably in spring)	If the survival rate of planted vegetation falls below 80% during this 3-year period, the cause of plant mortality should be investigated and corrected. Possible causes could be poor soils, soil compaction, or improper plant species selection (Hinman 2005).
	Check tree system after storm event to ensure stormwater is not ponding after 24 to 72 hours (check local codes).	As needed	If ponding does occur, either increase the infiltrative capacity of the soils or add an underdrain.
	Prune trees, including the removal of dead and diseased limbs and clear overgrowth to maintain street sign visibility, pedestrian vertical clearance, and line of sight on curved roads and intersections.	Annually	
	Protect tree from deer or other wildlife using tree guards or fencing.	As needed	
Soil	Turn or till soil, especially if compaction occurs.	As needed	If maintenance efforts are unsuccessful, the soil media and underdrain might need to be removed and replaced.
	Evaluate soil substrate for channel formation and proper root growth.	Annually	
	Remove and properly dispose of the previous mulch layer, or rototill into the soil surface and add new mulch layer.	Every 2 years (preferably in spring)	Do not exceed 3 inches in depth for mulch layers. Avoid blocking inflow entrance points with mounded mulch or raised plantings. Once a full groundcover is established, mulching might not be necessary.

6.6 Infiltration Trenches

Description

Infiltration trenches are excavated linear areas that are filled with layers of stone and sand wrapped in geotextile fabric. The trench is covered with stone, gabion, sand, or grassy surface with surface inlets. Stormwater is stored in the stone reservoir and slowly infiltrates through the bottom and sides of the trench, thereby reducing stormwater volume and peak discharge. As the water flows into the existing subsurface, pollutants and sediments are filtered out to improve water quality of the discharge. Underdrains can be included if native soil has lower permeability than desired. This system requires pretreatment to remove suspended solids.

Site Considerations

Infiltration trenches are ideal for linear transportation, linear parking lots and retrofit applications due to their relatively small foot print compared to the water storage capabilities. At minimum, they are generally 24 inches wide and 3 to 12 feet deep. Infiltration trenches are applicable only for small drainage areas, typically of less than 5 acres (RIDEM and CRMC 2010). They are typically implemented at the ground surface to intercept overland flows.

Infiltration trenches can also be installed below roadways or impervious areas with proper design. The design must prevent infiltration into the subbase of the pavement; therefore, it should slope slightly away from the subbase or be located at a depth below the subbase. Infiltration trenches can be used in a site's upland areas to reduce the amount of runoff downstream.

For More Information—Infiltration Trenches

Infiltration Trench. City of San Diego (2011)

Infiltration. Stormwater Manual (Chapter 3.8). District of Columbia (2013)

Best Management Practice Fact Sheet 8: Infiltration Practices (Publication 426-127). Virginia Cooperative Extension (2013)

Infiltration Trenches

Advantages:

- Reduce total volumetric runoff
- Provide water quality treatment for fine sediment, trace metals, nutrients, bacteria and organics
- Reduce downstream flooding and localized flooding
- Reduce the size and cost of downstream stormwater control facilities
- Provide groundwater recharge
- Avoid loss of parking spaces when designed underground
- Appropriate for small sites and where space is limited

Most suitable* for:

- Any length of roadway
- Parking lot
- Median

* Typically used on collector or arterial roads

Horsley Witten

Infiltration trench with grass cover.

Overcoming Site Challenges

Infiltration systems can be designed to overcome multiple site challenges (Table 6-8).

Table 6-8. Infiltration trenches: site constraints and design alternatives

Challenge	Design alternatives and recommendations
Sites that are not stable or have high sediment loads	Plan for pretreatment practices to avoid frequent and intensive maintenance.
Low permeability of native soils or compacted soils	Consider adding an underdrain that modifies the practice to be more of a soil filter or sand filter (i.e., converting to a different BMP).
Cold climates	Design the maximum effective depth for runoff below the frost line to allow infiltration to occur through the winter months.
Sites with high pollutant loads (i.e., potential hotspots) or contaminated soil	Avoid placing infiltrating systems due to concerns of groundwater contamination. Recommend practices include extensive pretreatment and/or impervious liner.
Proximity to water table	Maintain a recommended 2-foot separation to water table (3 feet preferred in some regions) and a minimum of 2 feet from the bottom of the infiltration trench to the bedrock (10 feet for fractured bedrock).
Proximity to drinking water wells	Trenches should be set back a minimum of 150 feet from public drinking water wells to limit groundwater contamination.
Proximity to building foundations	Trenches should be situated 100 feet upgradient or 10 feet downgradient to avoid potential seepage.

Infiltration Trench

Key Design Features

- Permeable filter fabric/material surrounds the stone on both sides of the trench
- An observation well allows for frequent inspection

Components: Infiltration Trench

An infiltration trench (Figure 6-8) typically consists of:

- An observation well
- Clean washed stone (typically 0.75 to 1.5-inch in diameter)
- A filter layer using either filter fabric, pea gravel (typically 3/8 inch) or sand
- Permeable filter fabric or sand filter on sides of trench

Optional design components include:

- Turf or grass cover
- Washed sand filter at bottom of practice for final filtration and even disbursement
- An elevated underdrain to promote internal storage and detention
- An impermeable liner (only in highly polluted areas)

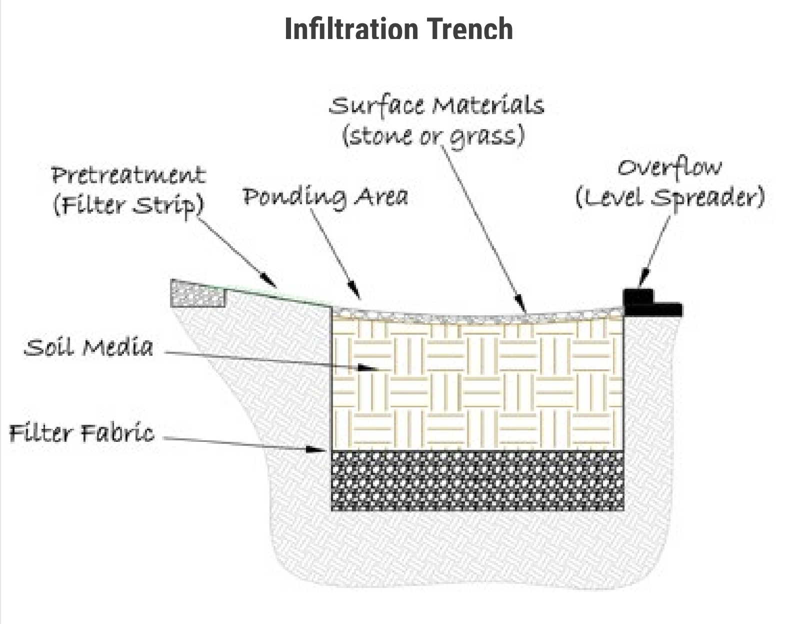


Image: Tetra Tech, Inc.

Figure 6-8. Stormwater infiltration trench schematic.

Design Considerations

Inlet Design

Runoff can enter an infiltration trench through sheet flow or piped inflow. To prevent clogging from sediment, pretreatment is required. When sheet flow is draining to the system, pretreatment might include a grass filter strip or gravel apron. If inflow is piped in, pretreatment might include a sediment forebay or a flow-through structure that collects sediment before conveying the water to the system. For areas with high pollutant loads, an oil and grit separator or similar device may be necessary. See Chapter 5 for descriptions of a number of pretreatment practices. Source control strategies, such as the elimination of excessive sanding/salting practices, should also be pursued. To ensure stormwater distribution in the stone trench, a perforated rigid pipe of at least 8-inch diameter can be connected to the inlet.

Slopes

Infiltration trenches are feasible if adjacent side slopes range from 2 to 15 percent. Slopes must be sufficiently steep to convey runoff to the practice, but must not cause erosion. To prevent underground infiltration trenches from draining into the subbase of the adjacent pavement, they should be sloped slightly away from or be located below the subbase.

Filter Layer

Filter fabric is used around the sides of the trench to define the system and prevent any potential contamination of runoff that is not completely treated. A filter layer should be incorporated into the top of the trench (6 to 12 inches below the surface) to prevent clogging from sediment carried in runoff but not removed by pretreatment and/or soil migration into the stone layer if turf or grass cover is included. Including filter fabric close to the surface minimizes maintenance and reconstruction needs if clogging occurs above the liner, as this portion can easily be removed and replaced. An alternative to filter fabric is the use of pea gravel or sand in the top 1 foot of the trench. The pea gravel improves sediment filtering and maximizes pollutant removal.

Observation Well

An observation well should be installed at the lower end of the infiltration trench to monitor how the system drains after large storms and to verify that the system is not clogged. The well should consist of a perforated PVC pipe with a 4- to 6-inch diameter that is constructed flush with the ground elevation and fitted with a lockable well cap. For larger trenches, which might require pumping to remove sediment, a 12- to 36-inch diameter PVC pipe is recommended to facilitate maintenance.

Backfill

The aggregate for the trench should consist of a clean aggregate with a maximum diameter of 3 inches and a minimum diameter of 1.5 inches. Void space should be in the range of 30 to 40 percent.

Vegetation

Infiltration trenches may be bare gravel or may be covered by turf or grass. Use a no-mow or low-maintenance seed mix for grass-covered trenches.


Horsley Witten

Infiltration trench (gravel) adjacent to a roadway.

Maintenance Requirements

These activities should be performed every 6 months and after every major storm (MADEP 2008). Suggested maintenance activities and frequencies are provided in Table 6-9. Additional maintenance is needed for pretreatment practices.

Performance

Infiltration trenches reduce stormwater volume, reduce peak discharge and improve water quality. By providing infiltration, these systems can promote groundwater recharge, contribute to baseflow for streams and help maintain the natural hydrologic balance that existed on the site before development. As the water filters through the system and into the existing subsurface, pollutants and sediments are removed and the water quality of the discharge improves. The primary pollutant removal mechanisms are settling, physical straining and filtration.

Minnesota Pollution Control Agency

Infiltration trench adjacent to a Minnesota roadway.

Table 6-9. Recommended maintenance activities for infiltration trenches

	Activity	Frequency	Additional advice
Debris	Inspect and remove sediment that has accumulated in the top foot of stone aggregate.	Two to four times per year	
	Inspect underdrains for obstructions.		If obstructions are found, backflush the obstructions.
Vegetation	Mow turf or grass. Remove invasive and exotic species, preferably using nonchemical methods such as hand pulling and hoeing.	Yearly (preferably in spring)	If at least 50% vegetation coverage is not established after 2 years, provide additional plantings.
	Check trench after storm events to ensure stormwater is not ponding after 72 hours.	After major storms	If ponding does occur, check for clogging and/or evaluate the infiltrative capacity of the soils.
Media	Check water levels, drawdown time and water quality using the observation well.	Two to four times a year	If the bottom of the trench is clogged, all of the stone aggregate and filter fabric must be removed. If clogging appears only at the surface, remove and replace the first layer of stone aggregate and filter fabric.

6.7 Subsurface Infiltration and Detention

Description

Subsurface infiltration and detention practices are subsurface systems that capture, temporarily store and slowly release stormwater to reduce runoff peak discharge. They provide stormwater quality treatment by decreasing sediment mobilization, transport and deposition, and they encourage biochemical processes in the underlying soils. Additionally, the water from these systems can be harvested and treated for other uses such as landscape irrigation or as a water source for fountains and ice skating rinks.

Design variations for subsurface infiltration and detention systems vary by materials, configuration and layouts, which are specified by manufacturers. **Subsurface infiltration systems** consist of an infiltrative chamber system typically made of precast concrete or plastic that includes perforated pipes, galleys and chambers. The chambers can store large volumes of runoff which is allowed to slowly infiltrate into the ground. **Subsurface detention practices** temporarily store runoff before releasing it to a downstream practice or conveyance system. Although not designed for water quality benefits, these systems do provide some water quality improvement through sedimentation.

The typical elements of a subsurface system include infiltration pits, chambers, perforated pipes and galleys:

- **Infiltration pits.** This system consists of a precast barrel with uniform perforations. The barrel will sit on top of stone and will be backfilled with stone to promote infiltration. To create a sump for collection of sediment, the perforations should not extend to the bottom of the barrel. Pits may be placed in series to allow the overflow of one to be conveyed to the next pit in sequence.
- **Chambers.** Chambers consist of prefabricated modular or cylindrical cells surrounded by crushed, washed stone. If designed for infiltration, the chambers will have open bottoms or perforations. If designed solely for retention, the chambers are typically encased in an impermeable liner or are constructed of nonperforated pipes and are then discharged to an outlet control structure.

Subsurface Infiltration and Detention

Advantages:

- Capture and store large volumes of runoff
- Are suitable for highly urbanized area with limited surface space availability
- Reduce downstream flooding and localized flooding
- Provide groundwater recharge
- Quick installation process

Most suitable* for:

- Parking lot
- Sidewalks
- Roadways

* As long as maintenance access to these systems is available

- **Perforated Pipes.** A perforated pipe system acts like a leaching bed and consists of rows of perforated pipes that dose a leaching bed.
- **Galleys.** Galleys are concrete rectangular vaults or systems of interlocking modular units. If designed for infiltration, the rectangular vaults will have perforations.

Horsley Witten

Subsurface chambers, during and after (top right) installation.

Design Considerations

Inlet Design

Stormwater typically enters subsurface practices through a catch basin or curb inlet (USEPA 2001). It can also enter the subsurface pit through porous pavement. Pretreatment is essential to prevent sediment or debris from migrating into and clogging the infiltration bed. Filter strips and modified catch basins (see Chapter 5) are good options for pretreating runoff entering subsurface infiltration and detention practices.

Materials

Many prefabricated subsurface infiltration or detention products are available. Systems can be constructed of concrete, steel or plastic (USEPA 2001). When determining the type of material to use for subsurface infiltration or detention structures, design engineers should consider the loading requirements and the available area. For example, steel and plastic require more fill than does concrete to maintain strength under compression. Large concrete structures provide more storage than pipes, but pipes are more versatile in their angling and arrangement (USEPA 2001). Enough stone should be included in the storage areas to prevent subsidence.

Overflows

Subsurface structures are typically designed to drain fully within 72 hours to provide adequate pollutant removal while also ensuring the system drains between rain events (MADEP 2008). Water standing for longer than 5 days can lead to potential mosquito breeding (Connecticut Department of Environmental Protection 2004). Detention systems must have outlet pipes sized to release stored runoff at the required rates.

Observation Well

An observation well, or manhole access for chamber systems, should be included to monitor how the system drains after large storms and to verify that the system is not clogged. The observation well should be placed at the invert of the stone bed and in the middle of the system.

Components: Subsurface Systems

A subsurface infiltration system (Figure 6-9) typically consists of:

- Inlet
- Pretreatment
- Perforated pipe
- Chamber
- Observation well
- Aggregate fill

Optional design component:

- Impermeable liner

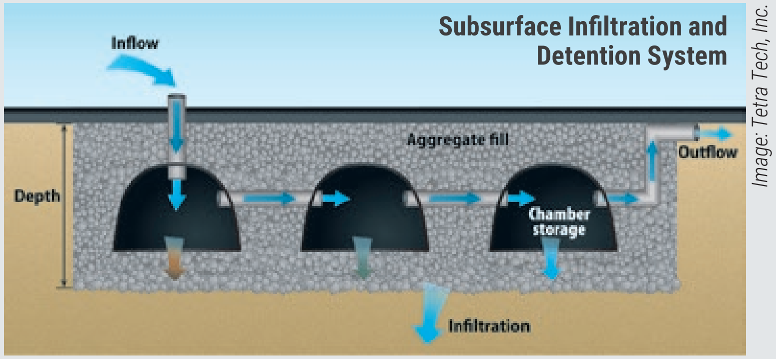


Figure 6-9. Subsurface infiltration and detention system schematic.

Vegetation

Trees or shrubs with long tap roots should not be planted within the immediate vicinity of subsurface structures.

Soils

The bottom of infiltrating practices should be level to promote evenly dispersed infiltration.
During construction, any area intended for infiltration should not be compacted. Erosion and sediment control techniques should be implemented during construction to prevent any sheet flow or windblown sediment from entering the infiltration area. Subsurface infiltration rates should typically be at least 0.5 inch per hour for infiltration practices.

Infiltration Trench

Key Design Features

- Provide an accessible maintenance entry point
- Include an observation well to allow for inspection
- Size the chamber according to the storm design volume

Maintenance Requirements

Because these systems are below ground, they are more difficult to maintain and clean than aboveground practices (USEPA 2001). These systems should therefore be located in areas where maintenance vehicles such as vacuum trucks can easily operate and excavate, if needed (RIDEM and CRMC 2010). Key maintenance practices needed are presented in Table 6-10.

Table 6-10. Recommended maintenance activities for subsurface infiltration and detention systems

	Activity	Frequency	Additional advice
Debris	Conduct observation well inspection of system to verify drainage times.	As needed	Monthly during the first year of infiltration to ensure functionality
	Remove sediment or trash that has accumulated to prevent clogging of pretreatment practices and inlets.	Two to four times per year	If excessive clogging builds up, the system should be excavated and replaced.


Hazen and Sawyer

Perforated pipes in New York, NY.

Performance

Subsurface infiltration and detention practices reduce both the volume of runoff and pollutant loads in runoff. Furthermore, the practices help recharge groundwater and reduce the size of downstream stormwater management practices. Subsurface infiltration provides water quality improvement through filtration into underlying soils.

These practices can be included as part of a series of stormwater management and treatment practices, called a treatment train. Detention practices can slow runoff volumes and slowly release them to downstream practices that will provide additional water quality improvement. Subsurface infiltration chambers can be used to provide additional storage volume and groundwater recharge as part of a treatment train (Connecticut Department of Environmental Protection 2004).

For More Information—Subsurface Detention

Subsurface Detention. Stormwater Management Practice Guidance (Chapter 4.8). Philadelphia Water Department (2018)

Infiltration Practices. Stormwater Design Specification No. 8. Virginia Department of Environmental Quality (2013)

6.8 Permeable Pavement

Description

Permeable pavements are paving systems that allow runoff to infiltrate through void space instead of becoming surface runoff. Water filters through void spaces within the paved surface into a stone reservoir and eventually infiltrates into the existing ground below. Where infiltration is not possible, permeable pavement systems can be designed with an underdrain that will convey treated runoff to another stormwater management practice or storm drain system.

Permeable pavement systems reduce runoff volumes and peak discharges by providing internal storage, and they improve water quality by filtering and infiltrating stormwater into the ground. Pretreatment is strongly recommended upstream of the practice to reduce sediment loads and to prevent debris from entering the system and clogging the drainage spaces between the pavers or the permeable surface. Some practitioners argue that "runon" from upland sources should be avoided or prohibited. Recommended pretreatment techniques are filter strips and swales (see Chapter 5).

Types of Permeable Pavement:

Porous Asphalt

Porous asphalt is a hot-mix asphalt with a reduced amount of sand or fines, which allows for increased interconnected pore space for water to drain through the pavement into a crushed stone reservoir and base. To maintain proper infiltration rates through the paving layer, the amount of asphalt binder in the mix must be minimized to prevent clogging of voids.

- **Permeable friction course (PFC)** is an application of porous asphalt over standard asphalt. PFC is also known as open-graded friction course on some highways. A PFC is a thin layer of porous asphalt, typically 1 to 2 inches thick, which is laid over standard asphalt. The stormwater travels through the voids in the permeable PFC asphalt until it reaches the impermeable asphalt boundary below and then flows towards the adjacent road perimeter. The principal purpose of this layer is to reduce hydroplaning by quickly removing precipitation from the pavement surface. The application of PFC leads to shorter stopping distances for cars, quicker surface drying periods, less splash and spray during precipitation (ASCE 2015). Additionally, PFC reduces the amount of pollutants discharged, reduces noise and improves safety for motorists.

Permeable Pavement

Advantages:

- Reduces runoff volume and peak discharge rates
- Increases groundwater recharge through infiltration
- Avoids loss of parking spaces
- Reduces occurrence of freezing puddles and black ice and requires less applied deicer

Most suitable for:

- Parking lots
- Parking lanes
- Driveways
- Sidewalks
- Walking paths
- Low-traffic roads
- Biking lanes
- Parkways
- Road shoulders on higher-volume roads

Low Impact Development Center

Permeable friction course on the shoulder of I-293 in New Hampshire.

Pervious Concrete

The design of pervious concrete differs from standard concrete because the fines have been removed from the concrete mix and different cementitious materials and chemicals have been added, such as fly ash and air-entraining agents. When installed, pervious concrete looks similar to conventional concrete except it typically has a rougher surface and allows for infiltration into the ground. Pervious concrete is also available in precast concrete panels that are placed together on site.

Pavers

Pavers are pre-cast paving units that are arranged to leave void spaces between the pavers. These voids are filled with sand, fine gravel, or are planted with turf or grass to allow for water to infiltrate through the pavers into the underlying stone reservoir. Many types of pavers are available, including the following three:

- **Permeable interlocking concrete pavement (PICP).** PICP is comprised of a layer of durable concrete pavers separated by joints that are filled with small stones. The blocks are impervious, but the joints permit infiltration to the stone reservoir. The joints, or interlocking shapes, can vary from simple notches to built-in concrete joint spacers. PICPs are highly attractive, durable, easily repaired, require low maintenance and can withstand heavy vehicle loads
- **Concrete grid pavement (CGP).** CGP is an extensive concrete grid that uses large spaces filled with stone aggregate or with sod or turfgrass. The reinforced concrete structure provides stability for bearing the weight of vehicles; the stone or sod-filled spaces provide permeability. Unlike PICP, concrete grid pavements are generally not designed with an open-graded, crushed stone base for water storage and thus have lower infiltrative rates. Moreover, grids are for intermittently trafficked areas such as overflow parking areas and emergency fire lanes.
- **Grass pavers (turf blocks).** Grass pavers are a type of open-cell unit paver in which the cells are filled with soil and planted with turf. The pavers can be made of concrete or synthetic material. The pavers serve to distribute the weight of traffic evenly and prevent compaction of the underlying soil.

Porous Recycled Surface Products

These products are generally more attractive than porous asphalt and are suitable for pedestrian and light vehicular traffic loads. They are typically highly reflective, colorful porous paving systems that provide greater design flexibility. Constructed of a porous, hard surface paving made from recycled glass, waste granite, rubber, aggregates and/or other recycled material, they are often bound together with a proprietary pigmented binder. Similar to porous pavement, this design alternative allows runoff to drain through the paved surface into a crushed stone reservoir.

Alisha Goldstein

Permeable paver installation in parking lanes in Louisville, KY.

USEPA

Permeable interlocking concrete pavement, Chicago, IL.

USEPA

Pervious concrete trench in the center of an alley, Chicago, IL.

Site Considerations

Generally, permeable pavement is recommended for low-volume and low-speed applications with limited turning traffic. The use of permeable paving can potentially reduce the size and extent of downstream stormwater collection, conveyance and detention. Because permeable pavement systems provide their own stormwater management, they can be used to maximize drivable surface area. Permeable pavements can be designed for only a partial area of the design site and installed in combination with impermeable pavement such as in the parking lane of a street or in the parking stalls of a parking lot. It is not recommended to drain impermeable surfaces onto the permeable areas due to clogging concerns.

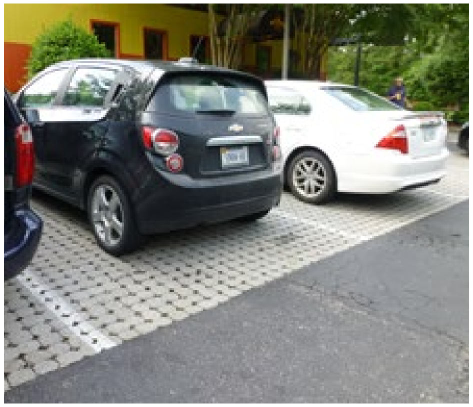
Permeable pavements are generally not appropriate for high-traffic or high-speed areas because they have lower load-bearing capacity than conventional pavement; however, interlocking pavers have been used in high-load installations in cargo ports and airports. Although pavers tend to be more costly to install than other paving systems, they are easier to repair because small sections can be removed and replaced (San Mateo County 2020). In contrast, damaged permeable pavement is difficult to repair because it is made in large batches. When selecting the type of material, consider the traffic volume, type of use and expected maintenance frequency.

Care should be taken to not place permeable pavements adjacent to land uses or areas that could contribute high sediment or organic material loadings (e.g., heavily wooded or landscaped areas where leave, mulch or soil can wash off and clog the pavement).

Overcoming Site Challenges

Permeable pavement systems can be designed to overcome site challenges such as a high groundwater table, high-traffic areas, or steep slopes (Table 6-11).

Kary Phillips, Tetra Tech, Inc.



Permeable pavement in parking stalls in Williamsburg, VA.

Abby Hall, USEPA

Concrete grid pavers in Emeryville, CA.

Table 6-11. Permeable pavement: site constraints and design alternatives

Challenge	Design alternatives and recommendations
Potential groundwater contamination or proximity to water table or bedrock	Line the subsurface reservoir with an impermeable liner. For areas where there is a potential for hazardous spills (e.g., gas stations, loading docks), permeable pavement is not recommended
Cold climate	Avoid applying sand, which can clog the surface of the material. Do not use areas with permeable pavement as plowed snow storage areas.
Conflict with underground utilities	Offset infiltration trenches away from utility lines.
High-traffic or high-speed areas	Permeable pavements are not recommended because they have lower load-bearing capacity than conventional pavement.
Steep slopes	Construct subgrade check dams, baffles, or terraces to provide a level area for storage area.
Low permeability of native soils or compacted soils	Replace or amend soils to improve permeability.
Low structural capacity of clay soils	Increase the subbase depth and/or add geogrids to provide additional support.

Components: Permeable Pavement

Permeable pavement components (Figures 6-10 and 6-11) typically consist of:

- **Pavers or pervious pavement.** 4 to 6 inches of permeable material (e.g., asphalt or concrete) with 10 to 25 percent void space. Paver thickness is determined by loading rates.
- **Choker course for porous asphalt.** 1 to 2 inches of small-sized, open-graded aggregate below the paver/pavement layer. Provide a level bottom to promote even infiltration through the practice.
- **Open-graded base reservoir.** 3 to 4 inches of crushed stones (typically ¾–³⁄₁₆ inch in size) with a high void content to maximize the storage of infiltrated water and to create a capillary barrier to winter freeze/thaw.
- **Open-graded subbase reservoir.** Thickness depends on water storage requirement and traffic loads. Uniformly graded, clean and washed coarse aggregate (¾–2½ inch in size with 40 percent void space) are used. Might not be required in pedestrian or residential driveway applications.
- **Subgrade.** The infiltrative capacity of the aggregate determines how much water exfiltrates from the subgrade to the surrounding soils. An uncompacted subgrade is preferable.

Optional design components include:

- **Underdrain**
- **Impermeable liner** for conditions where infiltration is undesirable.
- **Geotextile or other filter material** such as pea gravel placed between the subbase and the subgrade to prevent the migration of soil.
- **Observation well** to enable visual monitoring and inspection of the system for maintenance.

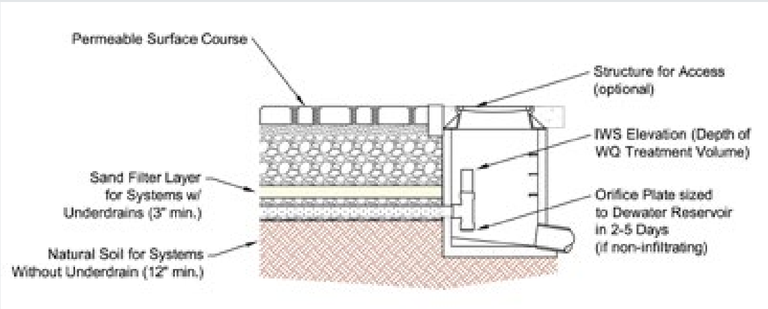


Image: Tetra Tech

Figure 6-11. Permeable interlocking concrete pavement cross-section.

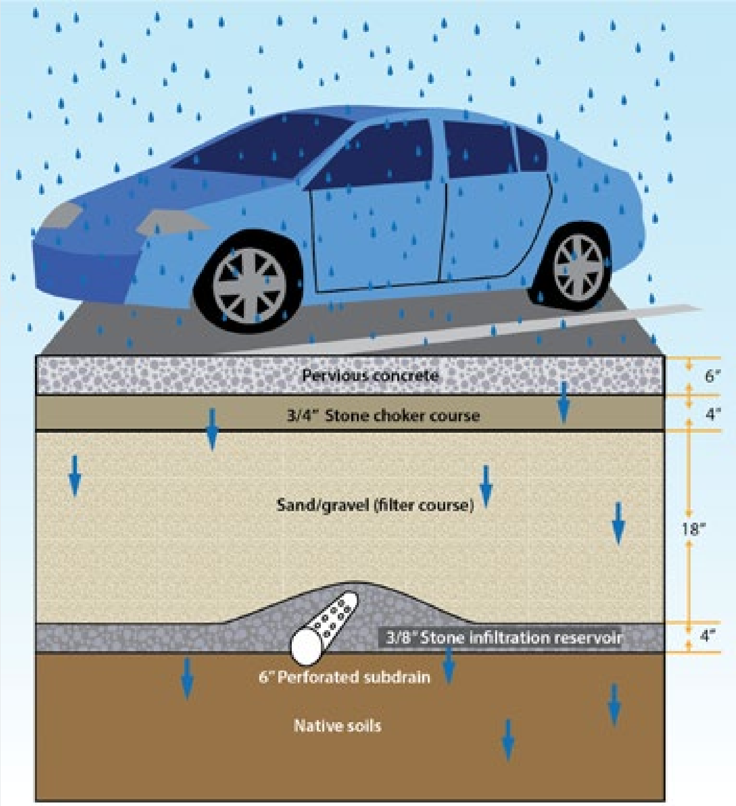


Image: University of New Hampshire Stormwater Center

Figure 6-10. Typical pervious concrete pavement cross- section.

Permeable Pavement

Key Design Features

- Level storage bed bottoms
- The surface permeability should be greater than 20 inches per hour.
- Pretreatment highly recommended to remove sediment-laden runoff.
- Load-bearing capacity of subgrade determines design depth.
- Infiltrative capacities of permeable pavement and aggregate in subgrade layers.

Design Considerations

Materials

Permeable and conventional pavements require similar materials and construction techniques with a few exceptions. Permeable pavement requires greater depth of the aggregate subbase to provide additional stormwater volume storage. A geotextile material might be required in areas of unstable soils or when the groundwater table is high (University of New Hampshire Stormwater Center 2012; MADEP 2008; RIDEM and CRMC 2010). Permeable pavement should not be installed during rain or over frozen base material. To maximize infiltration, avoid compacting subgrade soil during installation. If compaction is needed to support vehicle loads, compaction density and subsequent soil infiltration should be assessed in a test pit(s) on the site to determine an acceptable soil density and its contribution to soil strength and infiltration.

Sizing

The at-grade contributing drainage area into permeable pavement should generally not exceed twice the surface area of the permeable pavement (runon from permeable areas is not recommended due to potential for clogging of permeable pavement). This guideline helps reduce the rate of surface sedimentation. The 2:1 ratio can be increased to no greater than 5:1 if at least one of these conditions exists:

- Permeable pavement is receiving runoff from roofs as it tends to be very low in sediment.
- Runoff from adjacent impervious surfaces remains unburdened with sediment due to effective pretreatment before entering the permeable pavement.

Slopes

The permeable pavement subbase should be installed on level ground. For slopes greater than 3 to 5 percent, check dams, baffles or terraces can be built as part of the subgrade to provide a level area for storage area. Otherwise, there will be little storage capacity. If excavations are necessary to provide adequate storage, utilities might need to be relocated to maintain adequate clearance.

Performance

Permeable pavement systems reduce stormwater peak discharge and runoff volume by storing runoff within the subbase layers as it slowly infiltrates. A larger reservoir layer allows more runoff volume to be stored within the practice. As the runoff filters through the varying layers, the water quality of the runoff is also improved.

PFCs, a use of permeable asphalt, achieve very little runoff volume or peak flow reduction because they are not tied to any underground storage (NCHRP 2009). However, they have been found to achieve significant removal of sediment-bound pollutants, with effluent total suspended solids concentrations in the range of 10 milligrams per liter (Eck et al. 2012). In addition to pollutant removal, PFCs act as a level spreader, dissipating stormwater velocity and limiting erosion.

Alisha Goldstein

Permeable pavers used in the parking lane of a roadway in Ann Arbor, MI.

Maintenance Requirements

The primary goal of permeable pavement maintenance is to keep the surface clean and free of debris to maintain efficiency. If drainage voids or openings in the surface are not regularly cleaned and vacuumed, the pavement surface and/or underlying infiltration bed can become clogged with fine sediments. Signs should be posted indicating that sanding is not required and that construction and hazardous materials vehicles should not drive on permeable pavement. Key maintenance needs are outlined in Table 6-12; these activities might need to occur more often depending on the frequency and size of storm events.

For More Information—Permeable Pavement

Soak Up the Rain: Permeable Pavement. USEPA (2015)

Permeable Pavement Systems. Stormwater Manual (Chapter 3.5). District of Columbia (2013)

Federal Highway Administration Tech Briefs:

Porous Asphalt Pavements with Stone Reservoirs. (2015)

Permeable Interlocking Concrete Pavement. (2015)

Permeable Concrete Pavements. (2016)

Table 6-12. Recommended maintenance activities for permeable pavement

	Activity	Frequency	Additional advice
Debris	Inspect for proper drainage and potential deterioration.	4 to 6 months after installation and then annually	
Debris	Remove sediment or trash that has accumulated to prevent clogging from pretreatment practices and inlets.	Two to four times per year	
Debris	Perform vacuum sweeping.	Twice per year	
Debris	Conduct power hose washing.	Twice per year	Recommended after sweeping and vacuuming. Inspect the aggregate and refill with clean stone or gravel if necessary.
Debris	Inspect adjacent areas, which should be kept well-landscaped to prevent soil washout and to minimize the risk of sediment, mulch, grass clippings, etc., from inadvertently clogging the permeable pavement.	Annually	Design pretreatment elements between landscaped areas and permeable pavement sections to collect sediment and other organics.
Debris	Reseed bare spots on grass pavers.	As needed	
Debris	Inspect surface for cracks or settling; replace any cracked or broken sections.	Annually	
Cold Weather	Avoid the use of salt and sand for snow treatment to maintain permeability and prevent clogging.		
Cold Weather	Carefully perform snow plowing.		Set blade slightly higher than usual or attach rollers to the bottoms of snowplows to prevent catching the edges of pavers.
Cold Weather	Minimize the accumulation of snow piles on the permeable pavement to prevent the settling of sediments and pollutants on the surface, which could lead to clogging.		

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1. What is the primary goal of green streets?
   - Increase vehicle traffic efficiency
   - Reduce stormwater runoff and improve water quality
   - Expand roadways for public transportation
   - Eliminate pedestrian pathways

2. Which of the following is NOT a benefit of green streets?
   - Reducing urban heat island effects
   - Improving pedestrian safety
   - Increasing vehicle speed limits
   - Enhancing property values

3. What percentage of land in large U.S. cities is covered by impervious surfaces like roads and sidewalks?
   - 10-20%
   - 25-60%
   - 70-85%
   - 90-100%

4. Which of the following is a stormwater management practice associated with green streets?
   - Impermeable concrete surfaces
   - Bioretention cells (rain gardens)
   - Increasing curb height
   - Widening roads

5. How do green streets contribute to groundwater recharge?
    - By directing stormwater into sewer systems
    - Through infiltration of runoff into soil
    - By channeling all water into rivers
    - By preventing water absorption

6. What is one major transportation typology that green infrastructure practices are applied to?
    - Expressways
    - Arterial roads
    - Private driveways
    - Toll booths

7. Which of these is a commonly used green infrastructure practice for stormwater management?
    - Asphalt paving
    - Permeable pavement
    - Concrete sidewalks
    - Elevated highways

8. Why is vegetation an important component of green infrastructure?
    - It increases road surface hardness
    - It improves aesthetics but has no functional purpose
    - It aids in stormwater infiltration and pollutant removal
    - It reduces the need for storm drains

9. Which organization played a major role in developing the Green Streets Guidelines?
    - NASA
    - EPA
    - Department of Energy
    - National Highway Safety Administration

10. What is one economic benefit of implementing green streets?
    - Increased stormwater treatment costs
    - Higher vehicle maintenance costs
    - Enhanced property values and reduced infrastructure expenses
    - Higher energy consumption

11. Which pollutant is commonly found in stormwater runoff from roads?
    - Nitrogen and phosphorus
    - Oxygen
    - Sulfur dioxide
    - Helium

12. What feature is often included in parking lots to improve stormwater management?
    - Concrete barriers
    - Underground drainage tunnels
    - Permeable pavement
    - Extra-wide curbs

13. Which of the following best describes the purpose of a bioswale?
    - To increase pedestrian traffic
    - To filter and slow stormwater runoff using vegetation and soil
    - To prevent soil infiltration
    - To expand roadways

14. How does green infrastructure help with urban heat islands?
    - By reflecting more sunlight
    - By absorbing and cooling water runoff
    - By increasing paved surfaces
    - By eliminating vegetation

15. What is a key consideration when designing green streets?
    - Increasing vehicle speeds
    - Ensuring pedestrian safety and stormwater control
    - Expanding parking areas
    - Removing vegetation