Project Plan for the Highland Park Green Infrastructure Demonstration Project

Prepared for

EPA & TDEC
City of Chattanooga
Waste Resources Division
Consent Decree Program

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Acronyms and Abbreviations

BMPs	Best Management Practices
CD	Consent Decree
CSO	Combined Sewer Overflow
EPA	Environmental Protection Agency
GI	Green Infrastructure
NPDES	National Pollution Discharge Elimination System
LID	Low Impact Design
ROW	Right of Way
TCWN	Tennessee Clean Water Network
TSS	Total Suspended Solids

1.0 Introduction

1.1 Purpose

The purpose of this Project Plan is to provide an outline of the proposed improvements for the Highland Park Green Infrastructure Demonstration Project. This project is to be performed as part of the City of Chattanooga's (City) Consent Decree (CD) program. The CD is a settlement reached with the U.S. Environmental Protection Agency (EPA), the State of Tennessee and the Tennessee Clean Water Network (TCWN), which requires the City to improve the operation of its sewer system and to execute specific environmental projects such as this one. This project is to be funded wholly by the City per Section VII of the CD and described in Appendix D of the CD. This project is part of the State Civil Penalty portion of the CD and is also known as the "State Project."

The goal of this State Project is to improve water quality in the Dobbs Branch sub-watershed by installing Green Infrastructure (GI) stormwater systems to improve the quality and reduce the quantity of stormwater runoff in the Highland Park neighborhood of Chattanooga. Green Infrastructure is the use of environmentally friendly techniques to manage stormwater, such as incorporating vegetation to aid with filtration and evapotranspiration.

1.2 Project Background

This project is proposed to be constructed on selected streets located in the Highland Park Neighborhood of Chattanooga. The Highland Park Neighborhood was subdivided and platted in 1887 and many of the existing dwellings were built at the turn of the century in the Queen Anne and Colonial Revival styles. In 1946, Tennessee Temple University, a private Baptist school, was established in the neighborhood and is associated with the Highland Park Baptist Church.

Highland Park, like many other in-town neighborhoods, declined during the period of out-migration to the suburbs in the mid-20th Century. A neighborhood in transition, Highland

Park is a low-to-moderate income area with a diverse population. There are approximately 2,066 residents, the majority of whom are between the ages of 18 and 60, according to 2010 Census Tract figures.

An area once in decline, Highland Park has undergone a major transformation over the past 10 years, with a majority of homes zoned as single-family and redeveloped by young investors and a City supported nonprofit (Community Impact of Chattanooga).

One of the reasons the Highland Park area was chosen for this project is due to the neighborhood's history of community involvement.

1.3 Need for Project

Stormwater runoff is a major cause of water pollution. In an undeveloped environment, pervious ground surfaces filter and absorb stormwater from rain events as the runoff flows into nearby waters; however, in an urban setting with large amounts of impervious surfaces, much more of the rainwater is directly routed into traditional engineered stormwater collection systems. These engineered stormwater collection systems are often referred to as "grey infrastructure" and generally serve a single function: to quickly move excess rainfall from urban areas. "Green infrastructure," by contrast, helps protect and restore naturally functioning ecosystems and provide a framework for future development. In doing so, GI systems provide a diversity of ecological, social, and economic functions and benefits: enriched habitat and biodiversity; maintenance of natural landscape processes; cleaner air and water; increased recreational and transportation opportunities; and improved human health.

The traditional, engineered stormwater management practices of merely concentrating and piping runoff would undoubtedly result in the conveyance of contaminated urban runoff, which pollutes our waterways. One of the main goals of this project is to focus on the immediate capture, re-use and infiltration of runoff through innovative approaches that improve water quality and also reduce the volume and velocity flowing to waterways. The project will decrease the amount of existing impervious surface area, slow erosive stormwater flows and increase beneficial infiltration.

Stormwater runoff from the proposed project area contributes to the Dobbs Branch sub-watershed. Dobbs Branch is an impaired stream, listed on the 2012 State of Tennessee's 303(d) list. A main cause of pollution in Dobbs Branch is polluted urban runoff. The introduction of GI can help improve the water quality of Dobbs Branch by improving the quality of stormwater runoff from the urban area.

1.4 Project Approach and Goals

The project goals include not only improving the water quality and reducing the quantity of stormwater runoff, but also to build a partnership with the Highland Park Community. The City desires to include the members of the community who live and work in the area and will be affected and benefit from the improvements. There are also educational opportunities for the general public, students, municipalities, contractors and engineers, with the varying stormwater best management practices (BMPs) used.

In addition to improving the water quality of the Dobbs Branch sub-watershed and the Chattanooga Creek watershed, the proposed project can also be used as a model to show how GI BMPs can be utilized for future projects. The City can use the Highland Park Green Infrastructure Demonstration Project to demonstrate to developers, designers and members of the community how GI works and how using GI can help better the environment and Chattanooga.

The City is committed to providing community members in the Highland Park area with meaningful and timely information about the project during the preliminary design, through final design, and throughout the term of construction. The City welcomes the input of community members in an effort to develop environmentally friendly solutions that satisfy both the City's and the residents' interests in sustainable water quality. The Highland Park Green Infrastructure project will serve as a model for other neighborhoods and communities on how green infrastructure can be utilized successfully in urban settings.

2.0 Project Description

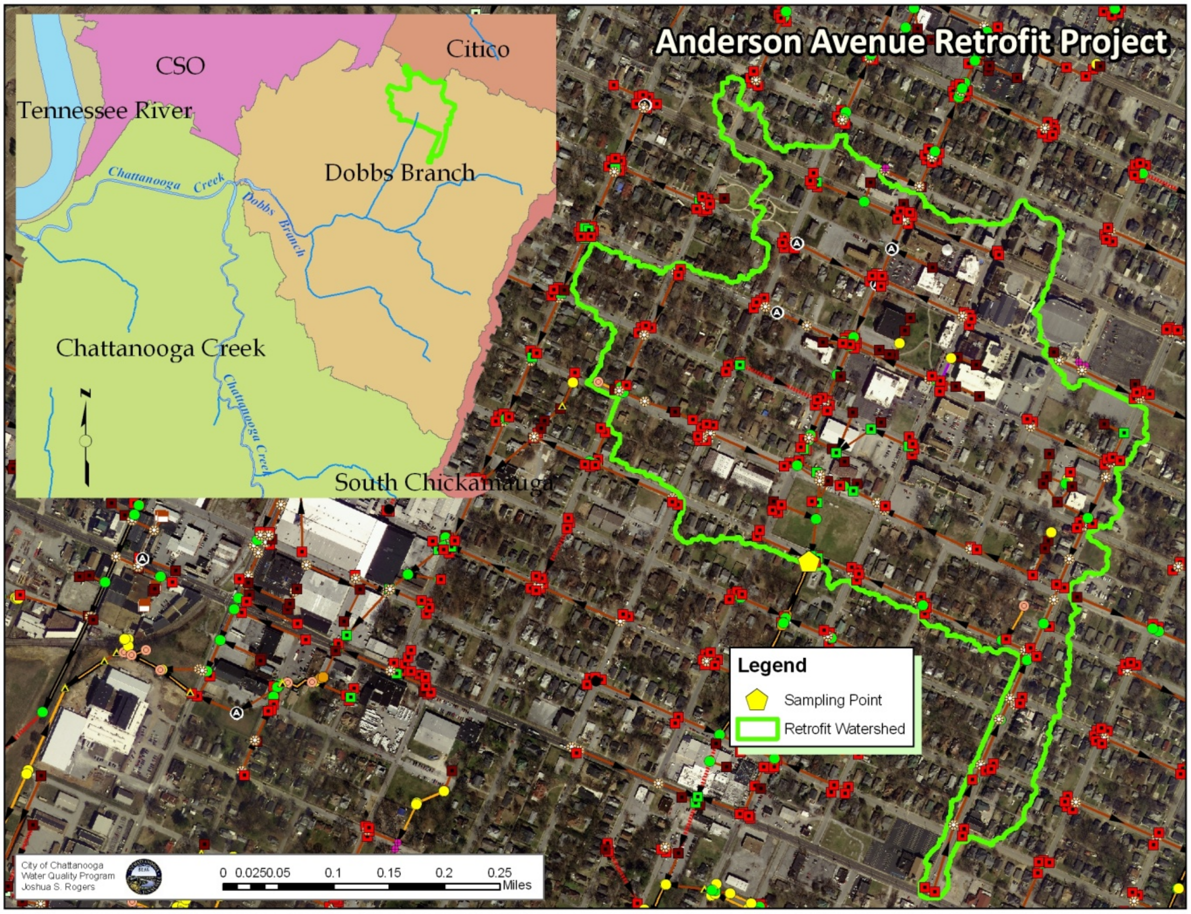
2.1 Project Location

The proposed project location is in the Highland Park Neighborhood of the City of Chattanooga, along two blocks of the Anderson Avenue right-of-way between South Holly Street and South Hawthorne Street. In addition, a one-block section of South Holly Street between Anderson Avenue and Vance Avenue is also proposed to be improved. Figure 2.1 shows a map of the proposed project area.

Figure 2.1
Project Location

This location is in the sub-watershed of Dobbs Branch, which is located within the Chattanooga Creek Watershed. This highly urbanized and fully-developed sub-watershed is located to the east of downtown Chattanooga and encompasses the campus of Tennessee Temple University. This sub-watershed is located within the Highland Park Neighborhood and is bounded on the north by Bailey Avenue, on the west by S. Highland Park Avenue, on the south by Anderson Avenue and on the east by S. Willow Street. The sub-watershed area is shown in detail in Figure 2.2.

Figure 2.2
Project Sub-watershed



2.2 Design Criteria

In order to meet regulatory and permit requirements, the City of Chattanooga is establishing design standards and methods to restore and preserve natural hydrologic regimes, minimize Combine Sewer Overflow (CSO) discharges to surface waters, and to improve the water quality in the surrounding areas. To help accomplish this, the City has developed the Rainwater Management Guide to provide guidance on stormwater management. This project will draw upon GI shown in the BMPs from the City of Chattanooga Rainwater Management Guide, which can be found at this link:

http://www.chattanooga.gov/public-works/44-public-works/989-resource-rain.

In choosing the BMPs for the proposed project, several design criteria were taken into consideration. Under the City's NPDES MS4 Permit, the first inch of rainfall should not be discharged into surface waters. For the improvements along Anderson Avenue, the GI proposed for this portion of the project will focus on practices that will concentrate on the one-inch (1") capture and infiltration of stormwater runoff. For the improvements along South Holly Street, the GI proposed focus on removing up to 80-percent of the total suspended solids (TSS) from runoff generated by a design storm up to and including 2.1-inches of rainfall over a 72-hour period.

In addition to these design criteria, the City also took into account the existing site conditions on Holly Street and Anderson Avenue, including the following:

- Width of Right of Way
- Location of existing trees
- Presence of on-street parking

City design professionals initially considered all GI practices and then focused on those deemed most effective after weighing the given existing beneficial systems alongside site limitations and restrictions and the chosen design criteria. For this project, the following BMPs are proposed:

- 5.3.1 Pervious Pavement
- 5.3.2 Subsurface Infiltration Beds
- 5.3.3 Infiltration Trenches
- 5.3.4 Bioretention
- 5.3.5 Vegetated Swales (Biofilters)
- 5.3.9 Runoff Capture and Reuse
- 5.3.11 Flow-through Planter Boxes
- 5.3.10 Constructed Stormwater Wetland Basins
- 5.3.12 Manufactured Devices

Excerpts from the Rainwater Management Guide on the selected BMPs can be found in Appendix A.

2.3 Proposed Improvements

The proposed concept for the project could use a variety of GI practices within the rights-of-way (ROW) of portions of Anderson Avenue and South Holly Street. It will serve as a model demonstration project for future construction projects within the city and can be used as a research site to gather performance data on the various GI practices that are implemented. The proposed concept is unique in this area as it addresses stormwater runoff at its source with the potential integration of private property improvements alongside public ROW improvements. Integration would be best achieved by working with and partnering with the homeowners throughout the project.

2.3.1 South Holly Street Improvements

The ROW for S. Holly Street between Vance Avenue and Anderson Avenue is fifty feet (50') wide. The existing conditions consist of approximately thirty feet (30') of asphalt pavement roadway, six-inch (6”) curbs and approximately four foot (4’) sidewalks. See Sheet 02 in Appendix B for the existing site conditions.

The proposed BMPs for this particular site include the following:

- 5.3.1 Pervious Pavement
- 5.3.2 Subsurface Infiltration Beds
- 5.3.9 Runoff Capture and Reuse
- 5.3.11 Flow-through Planter Boxes
- 5.3.12 Manufactured Devices

The existing layout of S. Holly Street is proposed to remain mostly unchanged. Currently no delineated parking spaces exist; therefore, residents park along the street. To accommodate GI practices, the roadway width will be lessened to accommodate delineated on-street parking areas. The current asphalt pavement is approximately 30’ wide. The design calls for 22’ of asphalt with the remaining to be pervious concrete. On-street parking is designed as pull-outs along the westerly side of the street with pavers as the proposed surface. See Sheet 06 in Appendix B for the proposed S. Holly Street site plan.

Tree boxes are to be utilized at the intersection of S. Holly Street and Vance Avenue. The existing concrete sidewalks are to remain. Portions that need to be removed or adjusted to match the current layout will be replaced with new concrete. Along the alignment within the ROW, there are landscape areas between the roadway/parking and sidewalk. These areas will accommodate infiltration beds, flow-through planter boxes and proprietary water quality devices.

Working in partnership to achieve the greatest benefit for local residents, urban runoff capture and reuse is proposed at seven residences along this alignment. Homeowners will be offered a variety of low-maintenance BMP’s that apply low impact development (LID) and sustainable landscaping concepts. These include, but are not limited to:

- Dry swales
- Rain barrels
- Rain gardens
- Native and/or drought-tolerant plants

If the homeowner chooses to install some or all of the LID improvements on their property, they will receive site-specific designs, manuals and training explaining how to best maintain the vegetation and features installed on their property.

2.3.2 Anderson Avenue Retrofit

The ROW on Anderson Avenue between S. Holly Street and S. Hickory Street (Block 01) is approximately eighty feet (80’). Between S. Hickory Street and S. Hawthorne Street (Block 02) it is approximately seventy feet (70’) wide. See Sheet 02 in Appendix B for the existing site conditions. Existing conditions consist of an asphalt pavement roadway with widths varying from approximately thirty feet (30’) to forty-five feet (45’), six-inch (6”) curbs and approximately four to five foot sidewalks. At this particular location, there were several existing opportunities including a large ROW, a large percentage of street runoff, and the presence of on-street parking by residents.

The proposed BMPs for this particular site include the following:

- 5.3.1 Pervious Pavement
- 5.3.2 Subsurface Infiltration Beds
- 5.3.3 Infiltration Trenches
- 5.3.4 Bioretention
- 5.3.5 Vegetated Swales (Biofilters)
- 5.3.9 Runoff Capture and Reuse
- 5.3.10 Constructed Stormwater Wetland Basins
- 5.3.12 Manufactured Devices

With these proposed measures, Anderson Avenue's layout could change from the existing purely functional layout to a more aesthetically pleasing and environmentally beneficial boulevard-type roadway. The existing roadway asphalt will be reduced from up to 45' of pavement to two twelve foot (12') wide asphalt pavement lanes separated by a median. The 12' lanes will be shared by vehicles and bicycles as this is a low-speed, residential roadway.

Currently there are no delineated parking spaces, and residents park along the street. On-street parking will be included along the boulevard as pull-outs with the proposed material as pavers. Block 01 will have parking pull-outs along both sides and Block 02 will have pull-outs located along the north side. See Sheets 07 and 08 in Appendix B for the proposed Anderson Avenue layout.

The majority of the proposed median in Block 01 is twenty-five feet (25') in width; the proposed median in Block 02 is seventeen feet (17') in width. Within these medians in the ROW, various BMP's are to be used to assist with the demonstration aspect of this project. Some of the BMP's to be implemented in the medians include the following:

- Infiltration beds
- Infiltration trenches
- Bioretention
- Biofilters
- Constructed stormwater wetland basins
- Manufactured devices
- Modular wetland systems

The existing concrete sidewalks are to be removed, as the improvements change the road layout. New five foot concrete sidewalks will be installed within the ROW, with a six to seven foot wide landscape area between the sidewalk and roadway. These areas will allow the use of the following:

- Infiltration beds
- Infiltration trenches
- Bioretention
- Biofilters

- Constructed stormwater wetland basins
- Manufactured devices
- Modular wetland systems

Again, working in a partnership with the local residents, runoff capture and reuse is proposed to be implemented for the fifteen homes along this alignment. Homeowners will be offered a variety of low-maintenance BMP's that apply LID and sustainable landscaping concepts, including (but not limited to):

- Dry swales
- Rain barrels
- Rain gardens
- Native and/or drought-tolerant plants

3.0 Project Implementation

In order to implement the Highland Park Green Infrastructure Demonstration Project, the City of Chattanooga will self-perform the planning and engineering design activities. Engineering design will include the preparation of project drawings and specifications. Upon approval of the design by EPA, the City will advertise the project and solicit bids from qualified contractors. Following the bid selection process, the City will contract with the chosen contractor to perform the proposed work.

Throughout the design and construction process, the City will work alongside members of the community to ensure the project goals are met and satisfy the community's needs. Major project milestones are provide Table 3.1 below, a detailed schedule is provided in Appendix C.

Table 3.1
Milestone Schedule

Milestone	Duration	Estimated Finish
Project Plan Community Meeting	One (1) Day	9/12/2013
Submit Project Plan to EPA	Six (6) months from Effective Date of Consent Decree	10/24/2013
Submit Engineering Plans to EPA	Six (6) months from approval of Project Plan	8/22/2014
Engineering Plans Community Meeting	One (1) Day	7/7/2014
Bid and Award of Construction Project	Five (5) months	4/6/2015
Construction Initiation Community Meeting	One (1) Day	4/21/2015
Construction	Twelve (12) months	5/24/2016
Submit Project Completion Report to EPA	48 months from submittal of Engineering Plans	9/3/2016
Community Workshop of Green Infrastructure Implementation	Six (6) months from Completion of Project	12/2/2016

4.0 Project Costs

The CD states the City shall spend not less than, two hundred and thirty eight thousand and two hundred dollars ($238,200) on this state environmental project, which is part of the civil penalty portion of the CD. No part of the expenditure for this State Project shall include federal or state funds, including federal or state low interest loans, contracts, or grants. Table 4.1 below provides budget-level cost estimates for the project.

Table 4.1
Project Costs

Item	Estimated Cost
Planning and Engineering	$100,000.00
Construction	$570,000.00
Post Construction	$28,500.00
Contingency (25% of Construction)	$142,500.00
Total	$841,000.00

5.0 Post Construction

5.1 Technical Workshop

Within six (6) months of the implementation of the State Project, Chattanooga will hold a technical workshop to train local engineers, designers, contractors, architects and developers on Green Infrastructure design. The workshop will use media and lessons gathered from the demonstration project to instruct the attendees.

5.2 Water Quality Monitoring

A monitoring program is to be implemented to enable the City to determine both the quantity of water infiltrated and the associated entrapment and reduction in pollutants. BMPs can be measured individually and in series to determine their effectiveness, operational and maintenance issues, and any additional benefits or unforeseen issues. It is anticipated that the monitoring will be accomplished via a partnership between the City, the neighborhood association and local universities. Monitoring results for this specific demonstration project can be collected and used to bring about equally efficient or even better designs for future GI projects throughout the City.

Appendix A
Stormwater Management BMP Excerpts

5.3.1 Pervious Pavement

Description

Pervious pavement consists of a pervious (permeable) surface typically composed of asphalt, concrete, pavers, reinforced turf, or rubber play surface overlain on a subsurface typically composed of open-graded stone storage or infiltration bed. Stormwater drains through the surface (see Figure 5.3.1-1), is temporarily held in the voids of the infiltration bed, and then slowly infiltrates into the underlying, uncompacted soils.

Figure 5.3.1-1. Rainfall drains directly through pervious asphalt pavement (left side of photo) but can be seen as runoff on standard impervious asphalt pavement (right side of photo).

Pervious pavement areas are well suited for parking lots, playgrounds, plazas, pathways, and other hardscape pavement areas. Stormwater runoff from other portions of the site can be conveyed into the stormwater bed for management. Pervious pavement can be used on low volume streets if conditions are suitable to control sediment and maintain the pervious pavement. If infiltration is not feasible or is limited, the subsurface bed can include an underdrain system for slow release. Pervious pavement systems can be designed to provide SOV, rate control, and water quality.

Pervious pavement should not be used in “hot spot” areas or areas where material may be stored on the pavement. It should be used with caution in high-traffic parking areas, such as convenience stores, due to traffic levels and high pollutant loads. It can be used in areas of heavy vehicle use, such as industrial areas, provided that the pervious pavement is properly designed for the loads it will carry. Pervious pavement often has limited shear strength and is not suitable for vehicles with heavy point loads (such as airplanes) or for use on steep slopes (greater than 6 percent).

BMP Functions Table

BMP	Applicability*	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Pervious Pavement	U/S/R	H	H	H	H	H	M	L	L	M

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features

- Pervious surface pavement material.
- Clean-washed, open-graded stone storage bed with minimum of 40 percent void space.
- Additional storage may be achieved through the use of perforated pipes set in the stone bed or proprietary stormwater storage products.
- Can be designed to capture entire volume of small storms and to provide peak rate control for larger storms.
- Often manages runoff from other portions of the site that can be conveyed into the stormwater bed.
- Large impervious areas should **not** be designed to discharge onto the pervious pavement because clogging may occur. These areas should be treated by vegetated BMPs (i.e., swales or filter strips) or sediment removal systems before discharge into the stormwater bed.
- Surface and stone bed must be designed for anticipated traffic loads.
- Level, uncompacted subgrade (see Figure 5.3.1-2).
- Nonwoven geotextile at soil/stone interface.
- Generally not recommended for traffic surfaces with slopes greater than 6 percent.
- Designed with alternate method to convey water into stormwater bed if pavement clogs.
- May include pipe distribution network.
- Always includes positive overflow.
- Should not be placed on compacted fill (fill with stone, as needed).
- When possible, infiltration beds should be placed on upland soils.

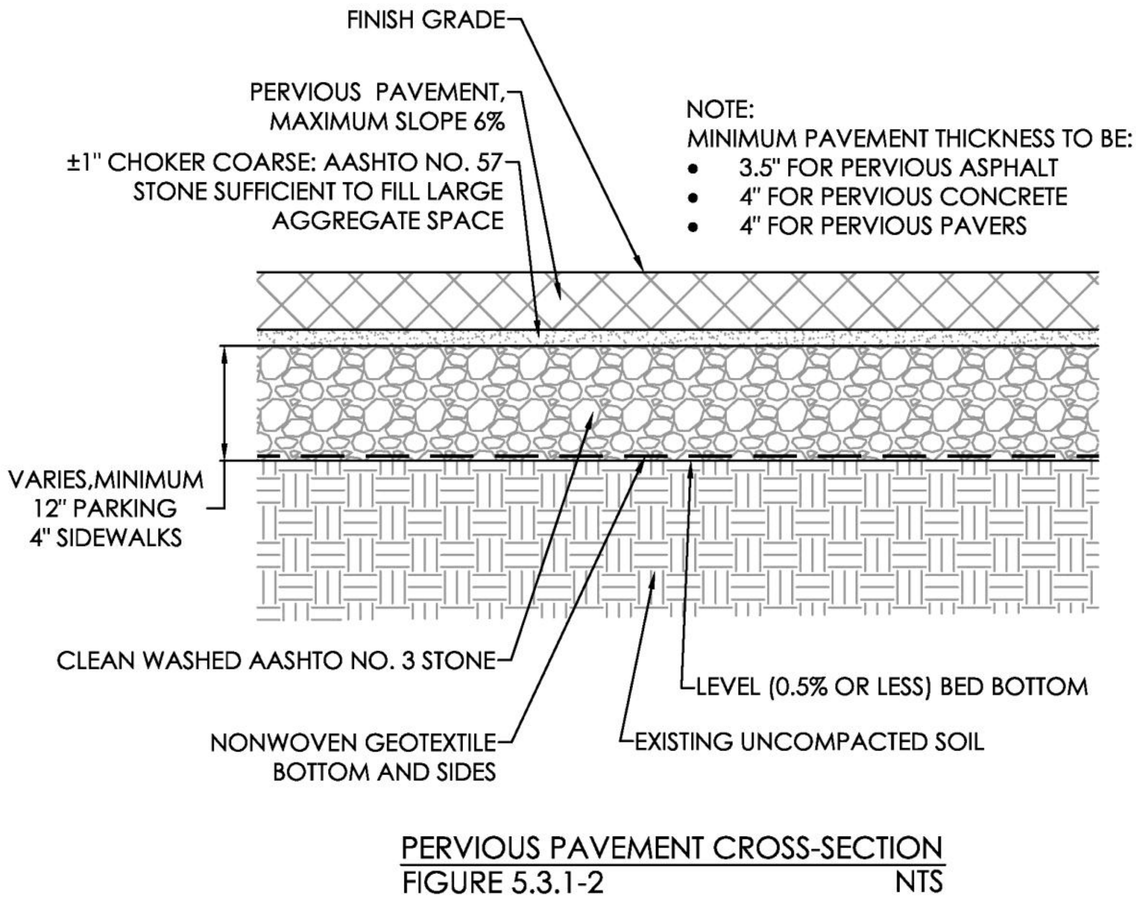


Figure 5.3.1-2. Pervious pavement cross-section. Pervious pavement beds should always be placed on level (0.5 percent slope or less) bed bottoms to prevent ponding in one area of the bed.

Applications

- Roadways, walkways, parking stalls
- Parking lots
- Playgrounds, plazas, terraces, and basketball and tennis courts
- Low volume streets
- Not suitable for hot spot areas unless designed for spill containment
- Not suitable for areas subject to high levels of sediment and debris

Advantages

- When used to provide volume reduction (SOV), may provide a Curve Number reduction and may reduce the peak rate requirements for the site.
- Reduces the space required for stormwater management by incorporating stormwater into the building program (parking, hardscape).
- Can manage a significant quantity of runoff and function as a regional system.
- Well suited to directly receive “clean” roof runoff.
- Can be designed to include peak rate control.
- Effective in contaminant reduction such as total suspended soils, metals, and oil and grease.
- Can be benched or terraced to accommodate slopes.
- Withstands freeze-thaw cycles and generally requires less winter maintenance than standard pavement.
- Lifespan comparable to traditional pavements and cost-effective when used to meet SOV requirements.

Disadvantages

- High clogging potential if runoff from high-sediment areas is not pretreated.
- Not suitable for pavements with high shear stress requirements or steep slopes.
- Requires alternate maintenance requirements from traditional asphalt (i.e., vacuuming, removal of vegetation between pavers, etc.).
- Must be offset from foundations/basements.
- Not applicable with high bedrock, high groundwater, or contaminated soils.
- Infiltration requires suitable site conditions.

Applications

Pervious pavement can be used in myriad ways in the urban and suburban environments, on residential, institutional, and commercial properties and within the public right-of-way. Potential applications include parking lots, parking stalls on roadways, alleys, sidewalks and paths, plazas, playgrounds, and athletic fields and courts. If pervious pavement is applied on residential lots, the property owner must be made aware that pavement is pervious.

Sidewalk: Pervious Concrete Pavement

Figure 5.3.1-3. Pervious concrete sidewalk. Constructing sidewalks with pervious concrete reduces impervious area. The sidewalk can also be designed to include a stormwater bed with capacity to receive runoff from adjacent impervious areas (i.e., driveways, roads). This is most applicable where sidewalks are level or mildly sloped (less than 3 percent).

Plaza: Pervious Pavers

Figure 5.3.1-4. Pervious concrete pavers for terrace area. Pervious pavers are ideal for plaza and terrace areas.

Parking Lot: Pervious Asphalt and Pervious Concrete Parking Lot

Figure 5.3.1-5. Pervious asphalt and pervious concrete parking lot. The University of North Carolina Chapel Hill park and ride lots include both pervious concrete and pervious asphalt.

Basketball Court: Pervious Asphalt

Figure 5.3.1-6. Pervious asphalt basketball court. Pervious asphalt on play surfaces does not form puddles and is quieter when balls bounce.

Types of Pervious Pavement

Figure 5.3.1-7a. Pervious Asphalt

Figure 5.3.1-7-b. Pervious Concrete

Figure 5.3.1-7-c. Concrete Pavers

Figure 5.3.1-7-d. Brick Pavers

Figure 5.3.1-7-e. Reinforced Turf or Gravel

There are several types of pervious pavement available, including proprietary products. The type of pervious pavement selected by the designer is a function of:

- Use and durability: This includes whether the pervious pavement will be subject to traffic loads, and the nature and extent of anticipated traffic loads.
- Appearance: Pervious pavers can be quite attractive while pervious concrete often has a coarse texture and cannot be "finished" like standard concrete.
- Cost: Pervious asphalt pavement is often the least expensive material, while pavers are often the most expensive.
- Maintenance: The amount of trash and debris may affect pervious pavement selection. Asphalt and concrete can be maintained by vacuum sweeping. Pervious pavers may require more maintenance for

debris removal (i.e., cigarette butts and small debris) and for the removal of vegetation between pavers.

Pervious Bituminous Asphalt

Pervious asphalt is similar to standard asphalt except that the aggregate fines (particles less than 0.60 micrometers [µm], or the No. 30 sieve) are kept to a maximum of 5 percent within the asphalt. Because of reduced fines, pervious asphalt has less shear strength than standard asphalt and is not suitable for heavy point loads. Improvements in open-graded highway overlays have led to improvements in pervious asphalt, including additives that increase the durability of the asphalt (i.e., PG 76-22 as specified by the American Association of State Highway and Transportation Officials [AASHTO], which includes a styrene-butadiene-styrene elastomer polymer binder). The use of fiber additives may also increase the shear strength of pervious asphalt.

Figure 5.3.1-8. It is important that pervious pavement be placed at the correct temperature as determined by the drain-down test for the asphalt mix.

One of the most critical components of a successful pervious asphalt installation is the application of a drain-down test (ASTM D6390) to determine the optimum asphalt temperature for placement. Asphalt binds differently to different types of aggregate (i.e., it binds better to limestone than granite). It is important to determine the optimum placement temperature for the aggregate in use to prevent drain-down (see Figure 5.3.1-8). Drain-down reduces the durability of the pavement at the surface and may create a clogging layer below the pervious asphalt.

Figure 5.3.1-9. Pervious asphalt at this commercial parking lot includes recycled rubber in the bituminous mix.

Pervious pavement may also include recycled asphalt or recycled rubber (see Figure 5.3.1-9). Detailed specifications and installation guidance on pervious asphalt can be obtained from the National Asphalt Pavement Association (NAPA) (http://www.asphaltpavement.org/).

Pervious Concrete

Pervious concrete has a reduced amount of fines and may have a different aggregate gradation than standard concrete. It has a coarser texture than standard concrete and has different requirements for mixing and placing. As with standard concrete, formwork is required for placement. Pervious concrete must be carefully rolled to prevent the concrete from forming an impermeable layer at the surface. Detailed specification and placement guidance is available from the National Ready Mix Concrete Association (http://www.nrmca.org/) and the Florida Concrete Association (http://www.fcpa.org/).

Pervious Concrete Pavers and Brick Pavers

Pervious concrete and brick pavers include openings or gaps filled with clean gravel for water to move into the gravel bed below the paver. The pavers may be interlocking or offset. There are a number of products available from different manufacturers, each with different guidance for installation. However, as with any paver, the pavers must include an edge restraint for installation. If the subgrade below the paver is compacted during construction, the pavers cannot infiltrate.

Figure 5.3.1-10. This standard asphalt path is 8 feet wide and includes a stone stormwater bed that is 14 feet wide to support an emergency vehicle. The grassed edges are constructed of reinforced turf grids over the stormwater bed. The bed receives runoff from the roof leaders of the adjacent building.

Reinforced Turf and Gravel

A number of products are available that consist of plastic grids that can be filled with either a sand/turf mix or a clean gravel mix. These products are especially useful in low-traffic areas, such as overflow parking lots or fire lanes (see Figure 5.3.1-10). Soil mixes must be carefully designed to allow drainage while also supporting vegetation. The designer may use the bioretention soils specifications for this purpose.

Pervious Rubber and Manufactured Pervious Mixes

In addition to manufactured grids and structural products to create pervious pavements, various manufactured materials are available for pervious pavements, including polymer bound pervious mixes composed of recycled rubber, glass, stone, and other materials. These products tend to be more costly but also provide an aesthetic that is often desired or needed. The products may or may not be suitable for traffic loads as indicated by the manufacturer. The use of pervious rubber surfaces (which are traditionally used in splash pools and similar installations) can provide an ideal stormwater management system and safe play surface in playground areas (see Figure 5.3.1-11).

Figure 5.3.1-11. Pervious rubber is an ideal material for a stormwater BMP constructed as part of a playground.

ITEM	RECOMMENDATION	REFERENCE SECTION
Drainage Area and Location Recommendations	Locate the pervious pavement so sediment laden runoff will not drain onto pavement surface. Locate so that bed bottoms are flat or have a maximum of 0.5% slope. Do not locate on fill material.	5.3.1.1
Concept Phase Loading Ratio (LR) (Recommended)	1:8 for South Chickamauga Watershed	5.3.1.5
	1:10 for all other Watersheds	
Concept Phase Surface Area Size (ft^2) (Recommended)	Impervious Drainage Area Managed (ft^2) / Loading Ratio	5.3.1.5
Entrance/Flow conditions	Surface Dispersed: Direct rainfall, sheetflow from standard pavement, or combined with pre-treatment (i.e., filter strip).	5.3.1.2
	Direct Connection (into stone bed): Recommended only for "clean" runoff such as roofs	
Pretreatment/Management of Sediment Trash and Debris	Required for high sediment drainage areas. See Filter Strip (BMP 5.3.6)	5.3.1.3
SOV Volume or Water Quality Volume Credit	Static Storage provided by Stone Storage (if applicable), Other structures (pipes, rain storage units, etc.)	5.3.1.4
Stone Storage Coefficient and Volume	0.4 Storage Volume = Stone Depth (ft) x Stone Area (ft2) x 0.4	5.3.1.4
Manufactured Storage Units Coefficient and Volume	0.85 - 0.95 Storage Volume = Manufactured Unit Depth (ft) x Manufactured Unit Area (ft2) x 0.85	5.3.1.4
Perforated Pipes Storage Coefficient and Volume	1.0 Storage Volume = Perforated Pipe Length (ft) x Perforated Pipe Area (ft2) x1.0	5.3.1.4
Stone Depths	Sidewalks and pedestrian paths: 4 inches minimum	5.3.1.5
	Vehicular paths: 12 inches minimum	
Pipe sizes for Overflow and Peak Rate	Minimum size 12 inch diameter. See Stormwater System Specifications	5.3.1.6
Freeboard in Stormwater Bed	2 inch minimum on smaller systems	5.3.1.7
	4 inch minimum on larger systems	
Conveyance Capacity	Peak rate 10-year, 24-hour rainfall event	5.3.1.6
Underdrain	Required if Infiltration Rate < 0.1 inches per hour	5.3.1.8
Setback from Structures	Required. See Stormwater Specification for Impervious Liner	Protocol 1
Coordination with Other Utilities	Required	Protocol 2
Infiltration Testing	Required	Protocol 3
Infiltration System Setbacks	Required	Protocol 4
Vegetation and Mulch	Required	Protocol 5
Inspection and Longterm Maintenance	Required	Chapter 8

Table 5.3.1-1. Pervious Pavement Design Criteria

Applicable Protocols and Specifications

The following Protocols and Specifications (see Appendices A through F) are applicable to pervious pavement and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing
- Protocol 4 Infiltration System Design and Construction Guidelines
- Stormwater System Specifications
  - Aggregates and Drainage Layers
  - Pipes
  - Control Structures
  - Geotextiles
  - Impervious Liners and Waterproofing

Design Considerations for Pervious Pavement

Pervious pavement can be a cost-effective and durable water management BMP that serves traditional functions. It is imperative that pervious pavement be designed and constructed properly. It is not applicable to all project types and locations.

1. Location and Capture Area

Pervious pavement can be located:

- Close to the source of runoff to minimize the need for additional stormwater structures.
- As part of a “regional” or site stormwater management system, designed to capture runoff from a larger drainage area. This is especially applicable for large parking lot areas.

Pervious pavements are **not** recommended within floodplain areas where the deposition of fine sediment from flood events may damage the pervious nature of the material.

Drainage Area

Figure 5.3.1-12. The stormwater bed beneath this pervious concrete plaza was used as a temporary sediment basin (with basin bottom at least 2 feet above final stormwater bed bottom elevation) during construction of the site. After the surrounding site work was completed, the sediment was removed and the bed excavated to its final depth. The stormwater bed and overlying pervious pavement were then installed.

- It is critical that all pervious pavements be located so that sediment-laden runoff does **not** drain onto the pavement surface (see Figure 5.3.1-12). During construction, erosion and sediment control measures must be maintained until the site is fully stabilized. Sediment-laden runoff can clog both the pervious pavement surface and the underlying infiltration bed.
- Pervious pavement captures direct rainfall, however, runoff from adjacent areas can be directed into the subsurface bed for storage and management. The subsurface bed often has a greater stone subbase thickness for structural stability than is required for direct rainfall capture. Clean roof runoff can be discharged directly into a subsurface bed beneath a pervious parking lot (catch basins with sumps are recommended to capture sediment). Surface runoff from other impervious areas should be addressed with measures (i.e., filter strips, vegetated swales) to reduce excessive sediment before the runoff is discharged (usually via pipe) into the bed.
- It is **not** recommended that large impervious pavement areas drain directly onto a smaller pervious pavement area, because the sediment will tend to clog the smaller pervious pavement area.
- Pervious pavement with infiltration should not be used in hot spot areas where there is the potential for runoff with higher than average pollutant levels to enter the groundwater. Only the hot area is precluded from pervious pavement use; other portions of the site may be well-suited for pervious pavement use.

Slope

- Pervious pavement with infiltration should not be constructed on fill material, because compacted fill prevents infiltration.
- The bed bottom must be level or with a slope less than 0.5 percent. If needed, the subsurface infiltration bed may be benched or terraced on slopes (see Figures 5.3.1-13 and 5.3.1-14).

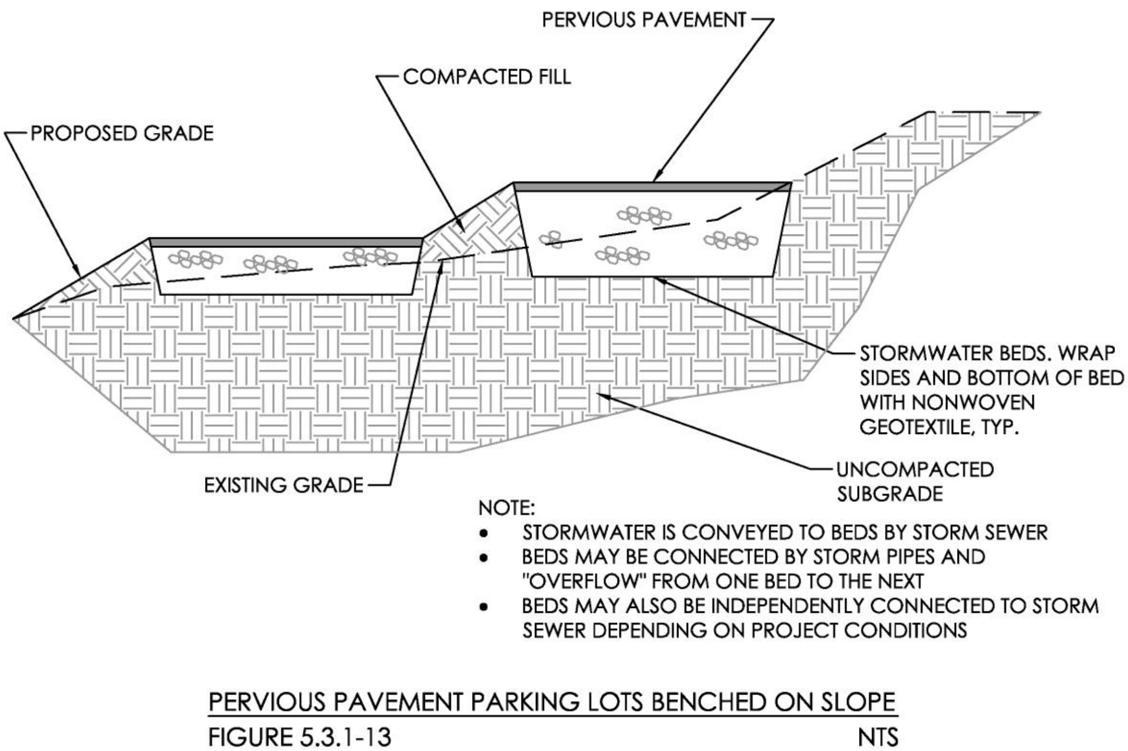


Figure 5.3.1-13. Pervious pavement beds can be terraced on a slope to provide level infiltration bed bottoms and to reduce the pavement slope.

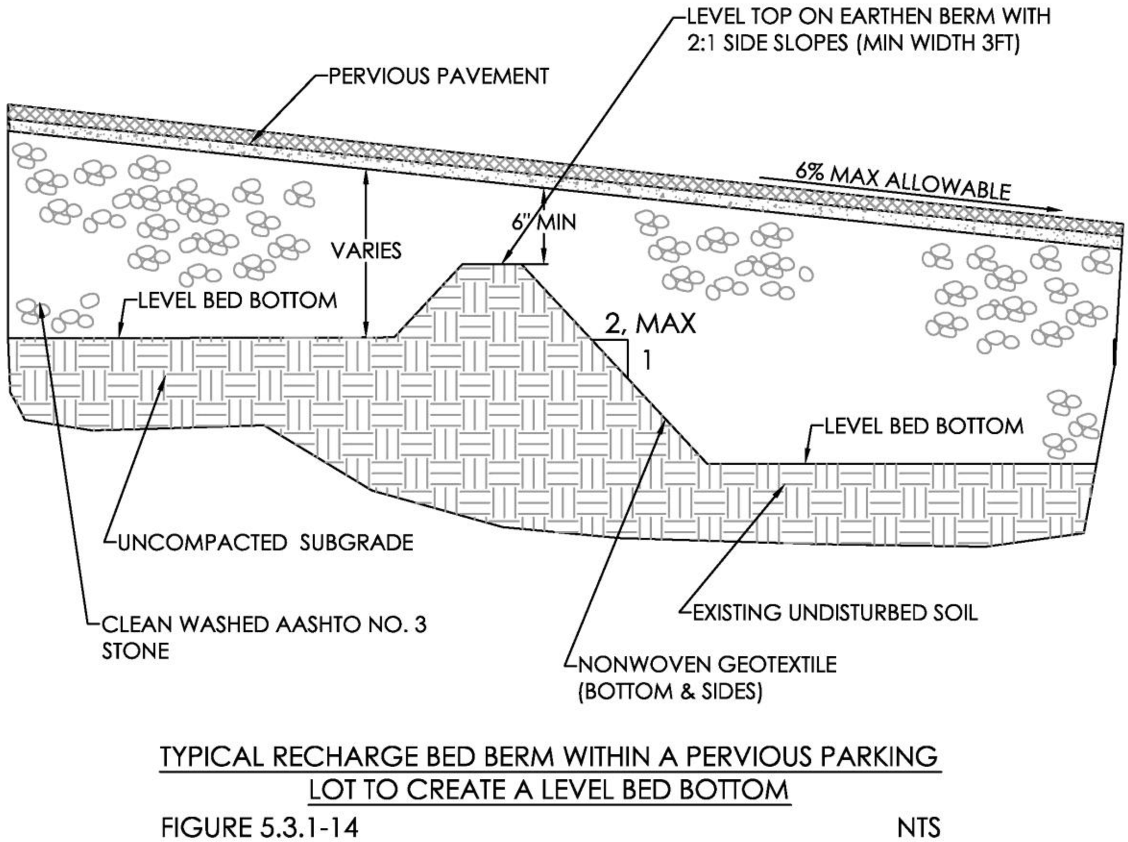


Figure 5.3.1-14. Berms can be used within a pervious pavement bed to create level infiltration areas within a single infiltration bed.

2. Entrance/Flow Conditions

- It is recommended that pervious pavement systems be designed with an alternate method for water to enter the stormwater bed, especially for larger systems such as parking lots. Options include open-graded stone edge treatments or inlets and trench drains. In the event that the bed surface is accidentally seal coated or becomes clogged, water can still enter the stormwater bed (see Figure 5.3.1-15).
- If runoff is collected from other surface drainage areas and discharged into the stormwater bed, it should be treated via a sumped inlet, water quality inlet, or other measure.
- It is **not** recommended that large impervious areas be discharged directly onto pervious pavement. The sediment loads may result in pavement clogging. Large impervious areas may be managed within the stormwater bed, but should be pre-treated.
- If large impervious areas will drain toward a pervious pavement, a vegetated filter strip should be used to reduce sediment flowing onto the bed. Alternately, water can be directed around the pavement via a berm or other grading design measure.

Figure 5.3.1-15. Pervious pavement can be constructed with an unpaved pervious edge treatment. In the event that the pavement is seal coated, clogged, or not functioning, runoff from the pavement can still enter the stormwater bed.

3. Management of Sediment, Trash, and Debris/Potential Clogging Issues

- Construction is the most critical period for pervious pavement, and it is essential that sediment-laden runoff be prevented from entering the bed or washing onto the pavement. Unstabilized areas cannot be allowed to discharge onto the pervious pavement.
- Pavement can be vacuumed to remove any sediment deposition from pervious asphalt or concrete. This should be done as soon as sediment deposition is observed.
- It is recommended that pervious asphalt and concrete be vacuumed twice per year.
- Roof runoff is generally lower in sediment and can be conveyed directly into a bed; however, a cleanout for roof leaders is required in the event that pipe clogging occurs.
- Runoff from roof areas that receive high amounts of leaf debris or other materials (such as deposition from equipment) should include sediment traps, or should be reconsidered. It may be preferable to discharge these roof areas to a vegetated swale or filter strip prior to discharge into the bed.

Figure 5.3.1-16. Extending the geotextile over the stone bed during construction of this pervious concrete sidewalk prevents sediment from entering the bed. In this example, the stone bed is wider than the sidewalk. It is designed to manage street runoff (from left) after treatment through a vegetated swale. Runoff sheet flows into the swale over the curb after construction of the final pavement course.

- Pervious pavement should **not** be pressure washed; pressure washing will only force sediment farther into the pavement or into the stormwater bed.

4. Storage and Stay-on-Volume

Pervious pavement that **only manages the rainfall that lands on the pavement can be excluded from the impervious area for purposes of calculating SOV**. This is especially applicable for pervious pavements such as pervious paver walkways.

For pervious pavement that includes a stormwater bed and that receives runoff from other areas, the **storage** capacity of the pervious pavement bed is measured as the volume **below** the lowest discharge invert (overflow) (see Figure 5.3.1-17).

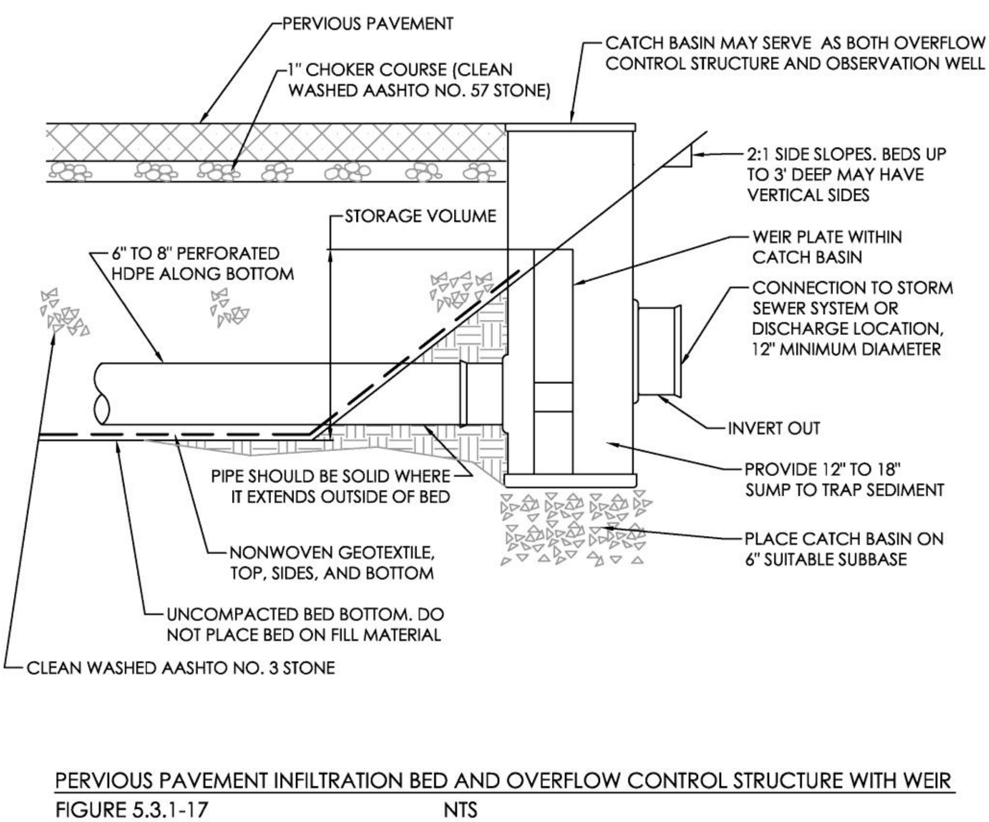


Figure 5.3.1-17. A catch basin with a weir can serve as an overflow control structure for the stormwater bed beneath a pervious pavement. The SOV depth is controlled by the weir. Larger storms overtop the weir and are conveyed to the storm sewer or appropriate discharge point. The designer should always confirm that the water level will never be high enough to saturate or move upward through the pervious pavement.

Storage Volume (ft^3) =

Bed Length (ft) x Bed Width (ft) x Bed Depth (ft) Below Overflow Elevation x Void Ratio

Void ratios are generally:

- 0.40 for clean-washed aggregate such as AASHTO No. 3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer
- 1.0 for the interior volume in perforated pipes within the bed

The **SOV** is a function of the storage volume available for the 1-inch or 1.6-inch storm. See Chapter 3 for more information on SOV.

5. Area, Stone Bed Depth, and Dimensions

The size and surface area of the pervious pavement area and infiltration bed are usually a function of the pavement requirements rather than the stormwater needs. The amount of parking, paths, and other pavements required for site program needs usually determine the extent of pervious pavement area.

The minimum depth of the stone bed beneath the pavement is a function of the structural stability needs of the pavement, and should be determined by the design engineer based on anticipated use. The stone bed depth may be increased as needed to accommodate additional stormwater storage volume. As a general rule, the aggregate bed for a light vehicle area constructed on uncompacted subgrade should not be less than 12 inches in depth, provided that the aggregate (such as a clean-washed AASHTO No. 3 [angular 1½- to 2½-inch aggregate]) can provide stability. Higher traffic loads may require additional bed depth. Sidewalks and paths should not be constructed with less than 4 inches of aggregate. In each application, the appropriate bed depth for stability and traffic load must be determined by the designer.

Alternate storage media designed for stormwater systems (i.e., modular units) may be used; however, the designer must verify that all such products are suitable for use when traffic loads apply. The designer is responsible for the proper structural design of each installation according to material selected and project traffic loads.

Because the aggregate subbase will often provide more volume storage than is necessary to manage the direct rainfall onto pervious pavement, the stormwater bed can be designed to serve as a site BMP that captures runoff from other impervious areas and portions of the site. This is often very cost-effective. For infiltration systems, it is important **not** to concentrate too much stormwater in one location for management. This can lead to accelerated clogging from sediment, high water depths that may compress soils, and soils that do not dry out between storms (and change structure). It also provides soil/water contact for water quality improvement. A basic design rule is to design pervious pavement with a surface area that is a ratio of the impervious and compacted pervious areas draining to the stormwater bed. The amount of rainfall volume must also be considered. The following ratios based on design rainfall depth can be used to estimate pervious pavement area:

1-inch Rainfall
1:10 ratio of surface area to impervious drainage area

1.6-inch Rainfall
1:8 ratio of surface area to impervious drainage area

Stormwater beds can be designed for deeper water depths during the larger, and less frequent, peak rate storm events (if necessary) to provide peak rate mitigation. The detention capacity of the bed can be analyzed and a hydrograph routed through the bed in the same manner as for a detention basin (taking into account the volume as a function of stone or media porosity).

The bed depth of water storage is primarily determined by the rainfall depth managed and the loading ratio, and influenced to a lesser extent by the infiltration rate. **There is no specific limit on the maximum width or length of an infiltration bed beneath pervious pavement. However, designers are discouraged from designing excessively deep infiltration beds (more than 5 feet for the SOV capacity), even in areas with high infiltration rates, due to concerns that the pressure at greater water depths may compact or alter the underlying soil.** There is no depth limit on non-infiltrating, slow-release beds.

Beds can be designed for short-term, deeper water depths during the larger, and less frequent, peak rate storm events if necessary to provide peak rate mitigation.

Proprietary products may be used as storage media, and as a substitute for stone subbase; however, all products must be approved by the City. There are a number of modular subsurface, plastic, interlocking storage units that provide higher void space and comparable structural stability as AASHTO No. 3, but they may be more costly.

6. Overflow and Peak Rate

All stormwater beds beneath pervious pavements must provide a safe means for water to exit the system when large storms generate more stormwater runoff than the bed can hold. The inclusion of a positive overflow route ensures that flooding risks and related property damage are minimized. The positive overflow route is often in the form of a modified inlet box with an internal concrete weir (or weir plate, see Figure 5.3.1-18), or simply an overflow pipe at an invert higher than the inlet pipe invert. This maximizes the volume managed by the bed, while providing sufficient cover for overflow pipes. When water overtops the weir, it discharges via a pipe to the storm sewer or to another approved discharge point.

Figure 5.3.1-18. Structures can be purchased with weirs at the desired elevations that allow the small storm volume to be retained while larger flows can safely be conveyed (also see Figure 5.3.1-17).

The overflow structure can be designed to function as a detention rate control structure for peak rate control, and can be modeled or evaluated as a detention system. Temporarily higher effective water depths are acceptable during large storm events managed for peak rate control. The catch basins can be used as overflow structures in large storms, and as rate control structures in larger storm events if the bed is constructed with sufficient capacity.

The minimum allowable diameter of an overflow pipe is 12 inches unless otherwise approved by the City.

Peak Rate Control and Infiltration Credit

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by both the SOV and the infiltration volume that occurs during a portion of a 24-hour storm event. This allows the designer to account for runoff that was captured by applying low-impact development and to develop a representative lower Curve Number. This procedure is described in Chapter 7.

When adjusting the Curve Number, the infiltration volume can be estimated as the infiltration that occurs during 12 hours of a 24-hour design storm. This will ensure that estimated infiltration volumes are not greater than the actual volume captured within the BMP.

Infiltration Volume (ft^3) = Pervious Pavement Bottom Area (ft^2) x Infiltration Rate (in/hr) x 1/12 x 12 hours

7. Freeboard

It is essential that pervious pavement systems be designed so that there is **never an opportunity for the water level to saturate the pervious surface material**. This is essential to the long-term stability and durability of the pervious surface. For this reason, it is recommended that all pervious pavement be designed with a freeboard within the stormwater bed such that the water level never reaches the top of the bed or surcharges the bed. A minimum freeboard of 2 inches is recommended on smaller systems such as sidewalks and 4 inches on larger systems such as parking lots.

8. Underdrain

An underdrain system is used to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty the bed of water, or if the bed is underlain by an impervious liner and designed only for slow release. Underdrain systems should discharge to the existing stormwater system or a location approved by the City. Underdrain systems must be included in the design if the native soil infiltration is less than 0.1 inch per hour, or if the bed is designed for slow release. See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

9. Waterproofing

In some instances where pervious pavement systems are designed to infiltrate, there may be concerns about impacts on adjacent structures such as basements or on the subbase of adjacent paved surfaces. The system may also be designed with an underdrain for slow-release of flows rather than infiltration if there are concerns regarding lateral movement of water from the sides or bottom of the subsurface infiltration beds. For all pervious pavement systems, the designer must evaluate the impact of the system on adjacent structures and utilities as defined in Protocol, 1 Setbacks from Structures and Protocol 2, Coordination with Other Utilities. The liner if applied must meet the guidelines provided in the Stormwater Specification.

Where pervious pavement immediately adjoins standard pavement, a liner or waterstop should be employed to prevent water from entering the standard pavement subbase (see Figure 5.3.1-19).

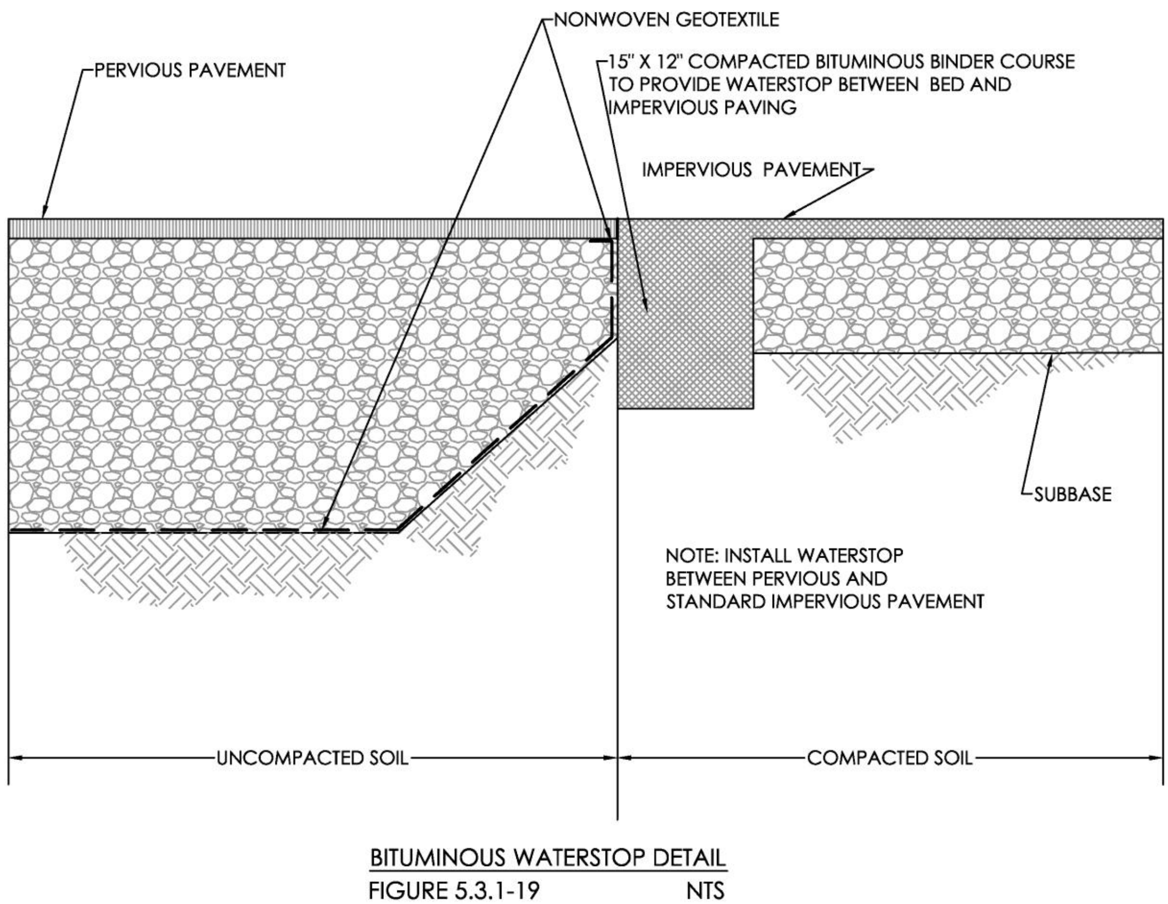


Figure 5.3.1-19. A bituminous waterstop can be used to prevent lateral movement of water between standard and pervious asphalt.

10. Water Quality/Total Suspended Solids

Pervious pavement systems that can capture and manage the required SOV through infiltration are considered to meet all water quality requirements. Pervious pavement beds that are underdrained, but can capture the required water quality volume as defined in Chapter 7, are also considered to provide water quality treatment. See Chapter 7 for additional discussion, and the Subsurface Infiltration Bed Worksheet for calculations.

Sizing Calculations Worksheet for Pervious Paving

(Link to Worksheet)

Construction Considerations

For the best success, pervious pavement systems should not be installed until site construction is complete and site stabilization has occurred. Pervious pavement systems completed before site stabilization **must** be protected from receiving sediment-laden runoff. Runoff should be directed around the completed pervious pavement system until site stabilization has occurred. **Sediment-laden water must not be allowed to enter pervious pavement systems or to drain onto pervious pavement surfaces.**

The excavated capacity of the stormwater bed may be used as a temporary sediment trap area during construction. The bed should not be excavated to final grade until the system is converted from a sediment trap to a stormwater bed. It is recommended that the sediment trap bottom elevation be 2 feet above the final stormwater bed elevation. Underdrained infiltration beds may be used as sediment traps during construction to the final bed bottom elevation.

Construction Sequence Example

Step 1 Excavate and Prepare Subgrade

a. Do **not** compact or subject pervious pavement locations to excessive construction equipment traffic during construction. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.
b. Initial excavation of infiltration beds can be performed during rough site grading. When performing initial excavation, do not grade bottom beyond 2 feet above the final bed bottom elevation. Complete final excavation only after all disturbed areas in the drainage area have been stabilized, or after the bed is adequately protected from receiving sediment-laden water (i.e., with erosion and sediment control measures around the BMP).
c. Remove fine materials and/or surface ponding in the grading bottom, caused by erosion, with light equipment and scarify the underlying soils to a minimum depth of 6 inches with a York rake or equivalent by light tractor.
d. Leave earthen berms between infiltration beds (if used) in place during excavation. These berms do not require compaction if proven stable during construction. Constructing berms with fill is discouraged. If necessary, key constructed berms into the subbase and compact to 95 percent density. All constructed berms shall be designed by a qualified engineer.
e. Bring subgrade of infiltration bed to line, grade, and elevations indicated. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All infiltration beds should be level grade on the bottom.
f. Halt excavation and notify engineer immediately if evidence of sinkhole activity or unanticipated bedrock or groundwater conditions are encountered, or other site conditions that may affect infiltration bed design or performance become evident.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Place the stormwater overflow structure on suitable subgrade to prevent settling. Install overflow structure, inlet pipes, curbs, and other stormwater structures as appropriate before placement of stone storage bed.
b. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the infiltration bed before completion and site stabilization.
c. Maintain drainage overflow pathways during construction, while infiltration bed is closed, to provide for drainage during storm events.
d. Infiltration bed conditions should be observed by the design engineer, following excavation and grading and prior to placement of geotextile and aggregate materials, to confirm that construction requirements have been met. Documentation must be provided to the City (see Appendix I).

Figures 5.3.1-20a and b. Geotextile and perforated distribution pipes are placed on an uncompacted subgrade, and stone is placed without compacting the bed bottom. Distribution pipes can be designed to extend through berms within the bed.

Step 3 Install Infiltration Bed

a. Place geotextile and bed aggregate immediately after approval of subgrade preparation and installation of structures. Install geotextile in accordance with manufacturer's standards and recommendations. Overlap adjacent strips of geotextile a minimum of 16 inches and secure at least 4 feet outside of the bed to prevent any runoff or sediment from entering the storage bed. This edge strip should remain in place until all bare soils contiguous to beds are stabilized and vegetated. Once the site is fully stabilized, cut excess geotextile along bed edges back to gravel edge.

Figure 5.3.1-21: Although the subgrade is uncompacted to allow for infiltration, the stone bed is placed in layers and rolled to provide a suitable subbase for construction vehicles and future traffic loads.

b. Place clean-washed, uniformly graded aggregate in the bed in maximum 8-inch lifts. Compact each layer lightly while keeping construction equipment off the bed bottom as much as possible.
c. Once bed aggregate is installed to the desired grade, install a 1-inch layer of choker base course (AASHTO No. 57) aggregate uniformly over the surface. This ensures an even surface for paving.

Step 4 Install Pervious Pavement

a. Install pervious pavement in accordance with specifications and/or manufacturer's requirements.
b. Test the pavement surface for permeability by applying clean water at the rate of at least 5 gallons per minute per square foot (gpm/ft^2) over the surface, using a hose or other distribution device. All applied water should directly infiltrate without ponding or creating surface runoff.
c. As required for pervious asphalt and concrete, protect pervious pavement from vehicle access for the duration indicated in the specifications.

Operations and Maintenance

It is recommended that signage be installed at all pervious pavement installations to ensure institutional memory that the pavement is pervious and should not be repaved, seal-coated, etc.

Special Maintenance Considerations:

- Prevent Clogging of Pavement Surface with Sediment
  - Vacuum pavement twice per year.
  - Maintain planted areas adjacent to pavement.
  - Immediately clean any soil deposited on pavement.
  - Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface.
  - Clean inlets draining to the subsurface bed twice per year.
- Snow/Ice Removal
  - Pervious pavement systems generally perform better and require less treatment than standard pavements.
  - Abrasives such as sand or cinders should not be applied on or adjacent to pervious pavement.
  - Snow plowing is acceptable but should be done carefully (i.e., the blade should be set slightly higher than usual).
  - Salt application is acceptable, although more environmentally benign deicers are preferable.
- Repairs
  - The surface should never be seal coated.
  - Damaged areas less than 50 square feet can be patched with pervious or standard asphalt.
  - Larger areas should be patched with an approved pervious asphalt.

Winter Maintenance

Winter maintenance for a pervious parking lot may be necessary, but is usually less intensive than that required for a standard asphalt lot. By its very nature, a pervious pavement system with a subsurface aggregate bed has superior snow melting characteristics than standard pavement. The underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on pervious pavement. Therefore, ice and light snow accumulation are generally not as problematic. However, snow will accumulate during heavier storms. Abrasives such as sand or cinders should not be applied on or adjacent to the pervious pavement. Snow plowing is acceptable, provided it is done carefully (i.e., by setting the blade slightly higher than usual, about an inch). Salt is acceptable for use as a deicer on the pervious pavement, although nontoxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferable.

Repairs

Potholes in the pervious pavement are extremely unlikely, although settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a declivity could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The declivity can also be filled with pervious mix. If an area greater than 50 square feet is in need of repair, approval of patch type must be sought from either the engineer or the owner. Under no circumstance is the pavement surface to ever be seal coated. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

5.3.2 Infiltration Bed

Description

An infiltration bed captures and temporarily stores stormwater runoff in a media bed that is located beneath an impervious surface or beneath an engineered layer of soil and vegetation. Infiltration beds capture and store stormwater runoff until it infiltrates into the subsurface below. The storage media may consist of clean-washed, open-graded stone aggregate, proprietary stormwater products, or perforated pipes set in a stone bed.

Infiltration beds are well suited for expansive level areas such as athletic fields, plazas, and pavement areas that are not suitable for a porous pavement surface (see Figures 5.3.2-1a and b). Infiltration beds can also be located under landscaped areas. Stormwater runoff from other portions of the site can be conveyed into the stormwater bed for management. If infiltration is not feasible or is limited, an infiltration bed can include an underdrain system for slow release. Infiltration beds can be designed to provide SOV, rate control, and water quality.

Figures 5.3.2-1a and b. An infiltration bed beneath a school athletic field provides stormwater management for the site and building while providing a level playfield area. Storm drain pipes convey roof runoff to the bed, and perforated pipes distribute the runoff through the bed. Small storms infiltrate while large storms discharge to the storm sewer at a mitigated flow rate.

BMP Functions Table

BMP	Applicability*	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Infiltration Bed	U/S/R	H	H	H	H	H	L	L	L	M

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features (See Figure 5.3.2-2)

- Often designed to capture volume of small storms and to provide peak rate control for larger storms.
- Often built to provide regional stormwater management.
- Clean-washed, open-graded stone storage bed with minimum of 40 percent void space.
- Additional storage may be achieved through the use of perforated pipes set in the stone bed or proprietary stormwater storage products.
- Surface material above bed may be pervious or impervious.
- Compacted fill material **may** be placed above bed.
- Level, uncompacted subgrade.
- Nonwoven geotextile at soil/stone interface, including top of bed to prevent soil movement into stormwater bed.
- Designed with method to convey water into stormwater bed.
- May include perforated pipe distribution network within bed.
- Sediment removal required for runoff from parking lots, roads, or other high pollutant source drainage areas.
- Always includes positive overflow.
- Should not place on compacted fill (fill with stone, as needed).
- When possible, place infiltration beds on upland soils.

Applications

- Athletic and recreational fields
- Parking lots and driveways where porous pavement is not appropriate or feasible
- Plazas and open spaces

- Below existing or proposed open space areas
- Beneath areas of fill material to achieve infiltration where major grade changes are required, such as on slopes
- Between impervious areas and downslope vegetation, such as woods or wetlands, where it is important to maintain soil moisture conditions after development

Advantages

- When used to provide volume reduction (SOV), may provide a Curve Number reduction and may reduce the peak rate requirements for the site.
- Well suited to directly receive "clean" roof runoff.
- Does not preclude use of the space (active recreation/parking).
- Can manage a significantly large quantity of runoff and function as a regional system.
- Effective for maintaining soil moisture conditions for downslope planting areas, wooded slopes, or wetlands.
- Flexible dimensions to fit conditions.
- Excellent retrofit capability (see Figure 5.3.2-5)
- Can be benched or terraced to accommodate slopes.
- Cost effective

Disadvantages

- High clogging potential if runoff from high sediment areas is not pretreated.
- Not visible and may be "forgotten."
- Must be offset from foundations/basements.
- Infiltration requires suitable site conditions (i.e., adequate soil infiltration rate).

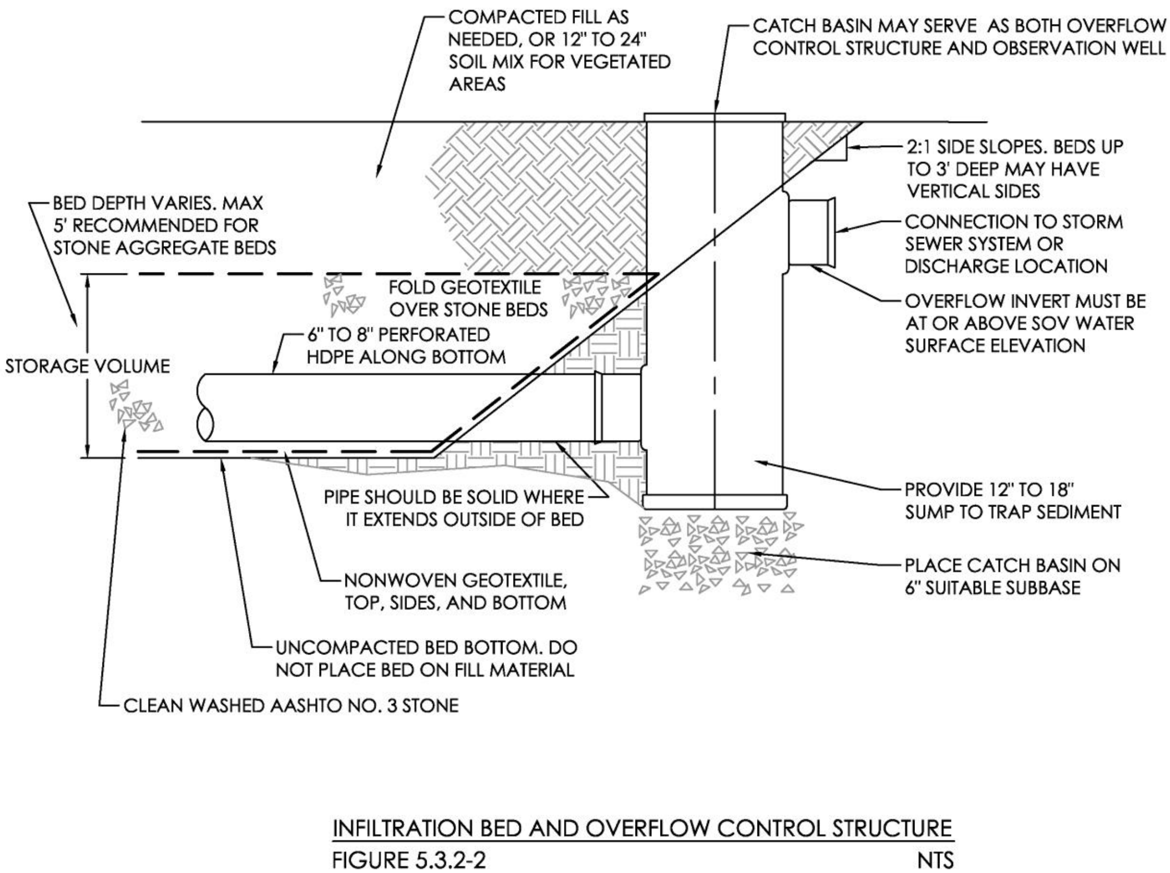


Figure 5.3.2-2. Infiltration bed cross-section. This cross-section shows an infiltration bed at the overflow structure. Runoff from the SOV fills the stormwater bed. In this example, the outflow pipe invert is at the top of the bed and serves to "back up" the water within the bed. Once the bed is full, larger storms discharge from the overflow pipe. A weir across an outflow pipe or within the outflow structure can also achieve the goal. The perforated pipe connection to the catch basin structure ensures that water will pass into the structure directly once the bed is full.

Applications

An infiltration bed can be "hidden" beneath a variety of surfaces such as athletic and other recreational fields, driveways, parking lots, and plazas. They are ideal in areas with limited space for stormwater management. Combining uses, such as integrating an infiltration bed into a design for a basketball court or rubber surface playground, can also be cost-effective.

Residential Infiltration Bed

Figures 5.3.2-3a and b. Infiltration beds were incorporated into standard asphalt driveways in this suburban residential development. Standard asphalt was chosen for ease of maintenance and to prevent homeowners from inadvertently "seal coating" porous pavement. Roof leaders convey runoff directly into beds. The sumped catch basin serves to connect the bed to the storm sewer and may also collect driveway and surface runoff. The roof leaders from the house include cleanouts.

Institutional Infiltration Bed

Figure 5.3.2-4. An infiltration bed beneath large athletic fields at Purdue University serves as a regional stormwater system for the campus. The two football practice fields are nearly 3 acres in area and capture runoff from the fields as well as nearly 10 acres of parking lots and roads. Runoff from parking lots and roads is pretreated with bioretention and vegetated swales before being discharged into the bed.

Landscaped Areas

Figure 5.3.2-5. This landscaped area is underlain by an infiltration bed. The bed receives runoff from the upslope impervious areas.

Urban Greening Infiltration Bed

Figure 5.3.2-6. This urban park plaza is built above an infiltration bed that completely underlies the plaza. Runoff is both piped into the bed from adjacent areas and is able to enter the bed through the porous pavers around the perimeter of the plaza.

Applicable Protocols and Specifications

The following Protocols and Specifications (see Appendices A through F) are applicable to infiltration beds and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing

- Protocol 4 Infiltration System Design and Construction Guidelines
- Stormwater System Specifications
  - Aggregates and Drainage Layers
  - Pipes
  - Control Structures
  - Geotextiles
  - Impervious Liners and Waterproofing

Design Considerations for Infiltration Beds

Infiltration beds can be designed beneath various surfaces, from vegetated to impervious. They can be integrated into new development or as part of a retrofit project in both urban and suburban areas. The key design components for infiltration beds discussed below allow design flexibility to ensure maximum performance.

1. Location and Capture Area

Infiltration beds can be located:

- Close to the source of runoff to minimize the need for additional stormwater structures.
- As part of a "regional" or site stormwater management system, designed to capture runoff from a larger drainage area (see Figure 5.3.2-7).

In both instances, stormwater is conveyed into the bed via pipes or other measures.

Figure 5.3.2-7. This diagram of the athletic fields at Purdue indicates how runoff from streets and parking areas is directed through bioretention areas and vegetated swales before being directed to the infiltration bed. Overflow from the vegetated systems is piped into the bed in this "treatment train" approach.

Slopes

- Infiltration beds should not be constructed on fill material, because compacted fill will prevent infiltration.

- Where fill is required to achieve desired site grades, infiltration beds can be located beneath the compacted fill. This allows the bed to be constructed on native soil material (see Figure 5.3.2-8).
- The bed bottom must be level or with a slope less than 0.5 percent. If needed, the infiltration bed may be benched or terraced on slopes, similar to the examples for porous pavement (see Figure 5.3.2-9).

Figure 5.3.2-8. This supermarket parking lot required a level surface. Infiltration beds were placed at the native soil interface, beneath the fill material and parking lot.

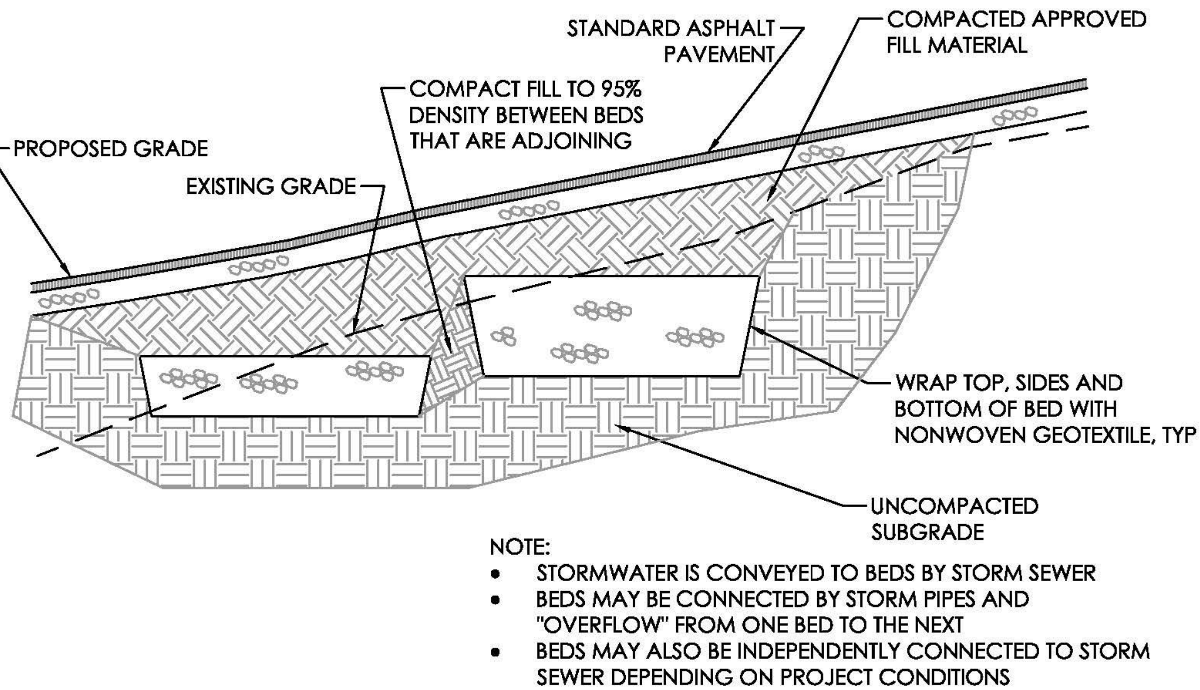


Figure 5.3.2-9. Cross-section of infiltration beds on slope and beneath fill material.

<u>Drainage Area</u>

- The type of land use in the drainage area must be carefully considered. Roof runoff is generally “clean” with regard to sediment and is ideal for discharge to an infiltration bed. Runoff from other areas such as parking lots must be treated with sediment-reduction measures (such as vegetated swales and filter strips) before runoff is discharged into the bed.
- Infiltration beds should not be used in hot spot areas where there is the potential for runoff with higher than average pollutant levels to enter the groundwater. Only the hot spot area is precluded from the infiltration bed; other portions of the site may be well-suited for infiltration bed use.

2. Entrance/Flow Conditions

Stormwater runoff must be conveyed into an infiltration bed, usually with storm sewer pipes. Pipes may end within and discharge directly into a small bed, or continue through the bed as a continuously perforated pipe to better distribute water in a large bed (see Figure 5.3.2-10).

If the surface of the bed is vegetated, adequate soil cover (a minimum of 12 to 24 inches) must be installed to support the proposed landscape vegetation. The soil cover can allow surface runoff to permeate through the soil and into the infiltration bed. An infiltration bed may be placed below compacted fill material and impervious surfaces. When a bed is placed below compacted fill, stormwater must be conveyed into the bed via pipes and structures.

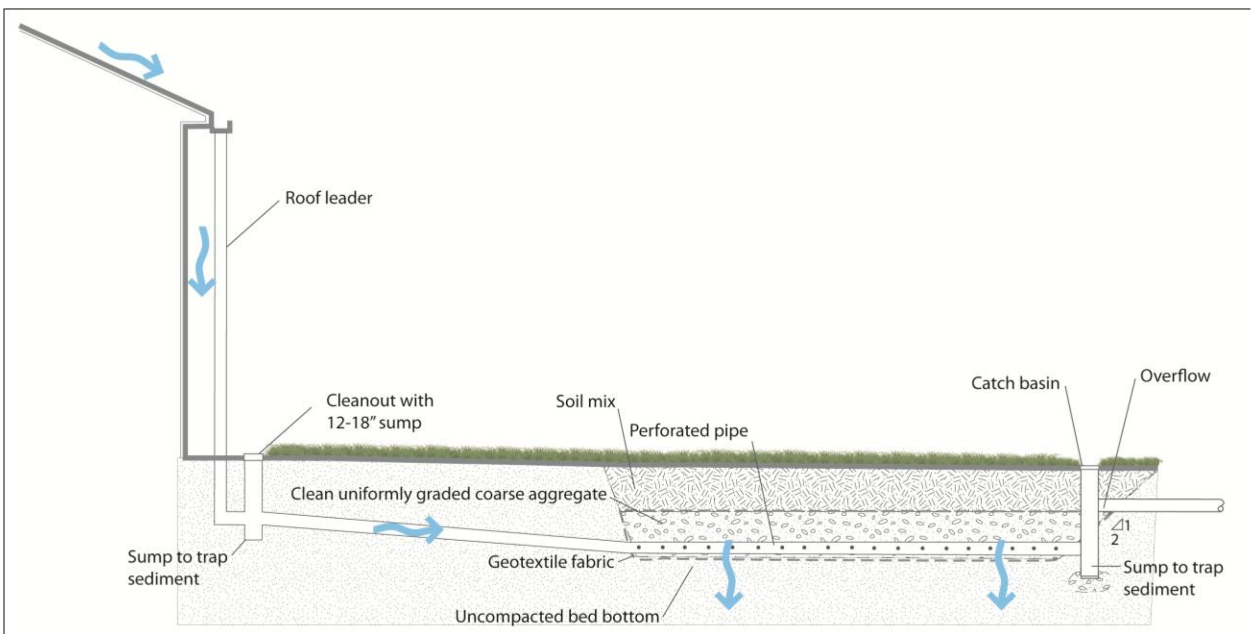


Figure 5.3.2-10. Conveyance of runoff into stormwater infiltration bed. Pipes may discharge directly into the bed or continue through the bed as a continuously perforated pipe.

3. Management of Sediment, Trash, and Debris

In areas of high sediment load, measures should be provided to prevent the movement of suspended material into the infiltration bed. Sediment can clog an infiltration bed and limit its functional lifespan.

- Roof runoff is generally lower in sediment and can be conveyed directly into a bed; however, a cleanout for roof leaders is required in the event that pipe clogging occurs.

- Runoff from roof areas that receive high amounts of leaf debris or other materials (such as deposition from equipment) should include sediment traps, or should be reconsidered. It may be preferable to discharge these roof areas to a vegetated swale or a filter strip prior to discharge into the bed.
- In areas of high trash or with specific concerns such as plastic shopping bags, entrance conditions should include a screen to prevent material from entering the infiltration bed. The designer must consider the site-specific conditions and adjacent land uses in each application.
- Water quality inserts or sumped inlets can reduce the amount of sediment from parking areas and low-traffic streets (see Figure 5.3.2-11). For high-traffic streets, the designer may wish to consider discharge to a vegetated system such as a filter strip or vegetated swale before discharge into the infiltration bed. Water quality inserts can also be used but must be maintained. Clogging of unmaintained inserts may result in ponding on the roadway. This potential hazard should be considered by the design engineer.

Figure 5.3.2-11. Water quality inserts can be used to reduce sediment and prevent trash from entering a stormwater infiltration bed. Water quality inserts require regular maintenance. (http://www.gaelwolf2.com/dnrec/trib_times_2004_4_catch_basin_inserts.htm, Aug. 24, 2012)

- If a large infiltration bed includes a perforated pipe distribution system, one or more cleanouts should be installed to allow access to the distribution pipes.

4. Storage and Stay-on-Volume

As shown on Figure 5.3.2-12, the **storage** capacity of an infiltration bed is measured as the volume **below** the lowest discharge invert (overflow).

Storage Volume (ft^3) =

Bed Length (ft) x Bed Width (ft) x Bed Depth (ft) Below Overflow Elevation x Void Ratio

Void ratios are generally:

- 0.40 for clean washed aggregate such as AASHTO No. 3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer
- 1.0 for the interior volume in perforated pipes within the bed

The SOV is a function of the storage volume available for the 1-inch or 1.6-inch storm.

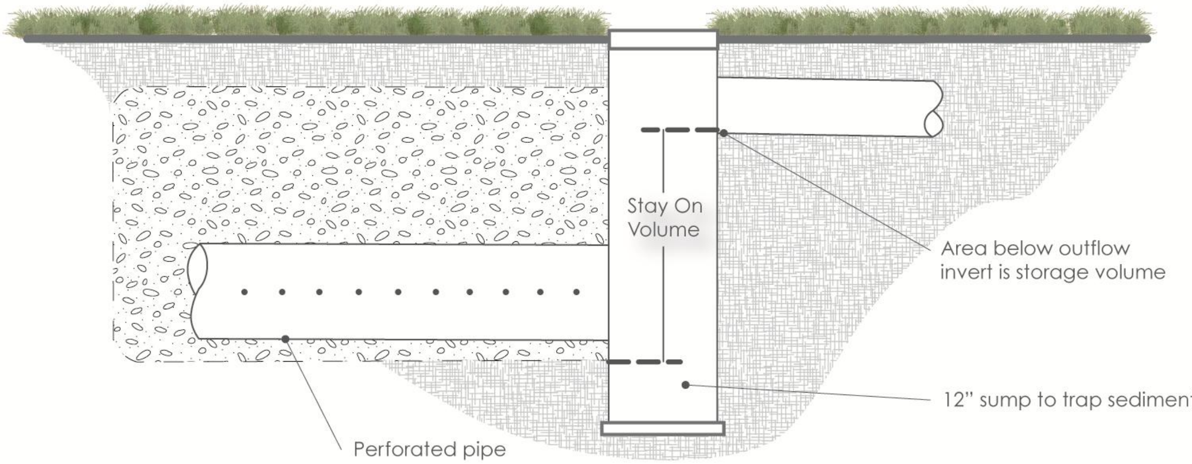


Figure 5.3.2-12. Storage capacity of stormwater infiltration bed is estimated below the overflow elevation.

5. Area and Dimensions

The size and area of an infiltration bed are a function of the drainage area that will discharge into the bed. For infiltration systems, it is important **not** to concentrate too much stormwater in one location for management. This can lead to accelerated clogging from sediment, high water depths that may compress soils, and soils that do not dry out between storms (and change structure). It also provides soil/water contact for water quality improvement. A basic rule-of-thumb is to design an infiltration bed with a surface area (footprint) that is a ratio of the impervious and compacted pervious areas that drain to it. The amount of rainfall volume must also be considered. The following ratios based on design rainfall depth can be used to estimate the surface area of a subsurface infiltration bed:

<u>1-inch Rainfall</u>

1:10 ratio of infiltration bed surface area to impervious drainage area

1.6-inch Rainfall

1:8 ratio of infiltration bed surface area to impervious drainage area

The land use type draining into an infiltration bed should be considered in bed area design. It is **strongly** discouraged that beds receiving runoff from high-sediment areas such as streets and high-use parking lots exceed the recommended ratios. The recommended ratios can be increased when managing runoff from clean roof areas, especially in areas with high (greater than 1 inch per hour) infiltration rates. “Clean” and “dirty” runoff should not be mixed if possible, although this is not always feasible.

The bed depth of water storage is primarily determined by the rainfall depth managed and the loading ratio, and influenced to a lesser extent by the infiltration rate. **There is no specific limit on the maximum width or length of an infiltration bed. However, designers are discouraged from designing excessively deep infiltration beds (greater than 5 feet for the SOV capacity), even in areas with high infiltration rates, because of concerns that the pressure at greater water depths may compact or alter the underlying soil.** There is no depth limit on non-infiltrating, slow-release beds.

Beds can be designed for short-term, deeper water depths during the larger, and less frequent, peak rate storm events if necessary to provide peak rate mitigation.

Proprietary products may be used as storage media and as a substitute for stone subbase; however, all products must be approved by the City. A number of modular subsurface, plastic, interlocking storage units provide higher void space and comparable structural stability as AASHTO No. 3, but may be more costly (see Figures 5.3.2-13).

Figures 5.3.2-13(a and b) This "on-line" infiltration bed is constructed of "RainStore" units to increase storage capacity. This bed was installed as a retrofit to reduce downstream erosion and flooding.

6. Overflow and Peak Rate

All infiltration beds must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the bed can hold. The inclusion of a positive overflow route ensures that flooding risks and related property damage are minimized. The positive overflow route is often in the form of a modified inlet box with an internal weir plate, or simply an overflow pipe at an invert higher than the bottom of the infiltration bed. This maximizes the volume managed by the bed, while providing sufficient cover for overflow pipes. When water overtops the weir, it discharges via a pipe to the storm sewer or to another approved discharge point.

The overflow structure can be designed to function as a detention rate control structure for peak rate control, and can be modeled or evaluated as a detention system. Temporarily higher effective water depths are acceptable during large storm events managed for peak rate control. The catch basins can be used as overflow structures in large storms, and as rate control structures in larger storm events if the bed is constructed with sufficient capacity.

The minimum allowable diameter of an overflow pipe is 12 inches unless otherwise approved by the City.

Peak Rate Control and Infiltration Credit

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by both the SOV and the infiltration volume that occurs during a portion of a 24-hour storm event. This allows the designer to account for runoff that was captured by applying LID, and to develop a representative lower Curve Number. This procedure is described in Chapter 7.

When adjusting the Curve Number, the infiltration volume can be estimated as the infiltration that occurs during the first 12 hours of a 24-hour design storm. This will ensure that estimated infiltration volumes are not greater than the actual volume captured within the BMP.

Infiltration Volume (ft^3) = Bioretention Bottom Area (ft^2) x Infiltration Rate (in/hr) x 1/12 x 12 hours

7. Freeboard

Infiltration beds can be designed without freeboard and be allowed to completely fill provided that other conditions, such as adjacent pavement subbase, are considered. Because infiltration beds often serve as peak rate detention facilities, they are often designed with additional capacity above the SOV storage volume. The designer should always confirm that an infiltration bed will not surcharge, but has adequate capacity for conveyance of large events.

8. Underdrain

An underdrain system is used to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty the bed of water, or if the bed is underlain by an impervious liner and designed only for slow release. Underdrain systems should discharge to the existing stormwater system or to a location approved by the City. Underdrain systems must be included in the design if the native soil infiltration rate is less than 0.1 inch per hour, or if the bed is designed for slow release. See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

9. Waterproofing

In some instances, infiltration beds may be designed to infiltrate, but there may be concerns about impacts on adjacent structures such as basements, or impacts on the subbase of adjacent paved surfaces. For all subsurface infiltration beds, the designer must evaluate the impact of the system on adjacent structures and utilities as defined in Protocol 1, Setbacks from Structures and Protocol 2, Coordination with Other Utilities. The liner, if applied, must meet the guidelines provided in the Stormwater Specification. In many situations, a partial liner (i.e., one side of a bed) will adequately protect structures.

Utility pipes or conduits may pass through the bed if required, but the designer is encouraged to avoid utility crossings if possible. Where a new or existing utility passes through a stormwater bed, a waterstop should be installed along the utility as it exits the bed to prevent movement of water along the utility bedding material.

10. Water Quality/Total Suspended Solids

Infiltration beds that can capture and manage the required SOV through infiltration are considered to meet all water quality requirements. Infiltration beds that are under drained but can capture the required water quality volume as defined in Chapter 7 are also considered to provide water quality treatment. See Chapter 7 for additional discussion, and the Infiltration Bed Worksheet for calculations.

Sizing Calculations Worksheet for Subsurface Infiltration Beds

(Link to Worksheet)

Construction Considerations

Infiltration beds can be installed:

1. Early in the construction process, but should not receive **any** site runoff until site construction is complete and site stabilization has occurred. Runoff should be directed around the completed infiltration bed until site stabilization has occurred. Sediment-laden water should not be allowed to enter infiltration beds. The designer must consider stormwater management during construction.

2. The stormwater bed may be constructed after site construction is substantially complete and site stabilization has occurred. During construction of the site, areas reserved for infiltration beds **must** be protected and should be fenced or barricaded to prevent the movement of equipment over the proposed infiltration area. This is similar in practice and intent to protecting an onsite septic system disposal field from vehicle compaction.

The excavated capacity of an infiltration bed may be used as a temporary sediment trap/stormwater measure during construction. The bottom elevation during use as a sediment measure should be a minimum of 1 foot higher than the final infiltration bed bottom elevation. At the time of conversion from a sediment measure to an infiltration bed, any sediment and the remaining 1 foot of material should be removed for construction of the infiltration bed.

Construction Sequence Example

Step 1 Excavate and Prepare Subgrade

a. Do **not** compact or subject pervious pavement locations to excessive construction equipment traffic during construction. Protect areas from vehicular traffic during construction with construction fence, silt fence, compost sock, or other means acceptable to the City (see Figure 5.3.2-13, which shows a construction area delineated with construction fence to keep vehicular traffic isolated).
b. If alternate storage media is used in lieu of stone aggregate, provide a suitable stone subbase and do **not** compact bed bottom.
c. Infiltration beds can be installed at any time during the construction process provided that sediment-laden runoff is prevented from entering the bed. Do not allow runoff from any disturbed areas in the drainage area to discharge into the bed until these areas have been stabilized.
d. Remove fine materials and/or surface ponding in the graded bottom, caused by erosion, with light equipment and scarify the underlying soils to a minimum depth of 6 inches with a York rake or equivalent by light tractor.
e. Construct earthen berms (if used) between infiltration beds by excavating the beds and leaving existing material in place between the beds as a “berm.”
f. Bring subgrade of infiltration bed to line, grade, and elevations indicated on the plans. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All infiltration beds shall be level grade on the bottom (not greater than 0.5 percent slope).
g. Halt excavation and notify engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater conditions, or other site conditions that may affect infiltration bed design or performance are encountered.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Place the stormwater overflow structure on suitable subgrade to prevent settling (i.e., compacted subgrade and compacted suitable subbase material). Install overflow structure, inlet pipes, curbs, and other stormwater structures as appropriate before placement of stone storage bed.
b. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the infiltration bed before completion and site stabilization.
c. Maintain drainage overflow pathways during construction, while the infiltration bed is closed, to provide for drainage during storm events.
d. Infiltration bed conditions should be observed by the design engineer, following excavation and grading and prior to placement of geotextile and aggregate materials, to confirm that construction requirements have been met. Documentation must be provided to the City (see Appendix I).

Step 3 Install Infiltration Bed

a. Place geotextile and bed aggregate immediately after approval of subgrade preparation and installation of structures. Geotextile shall be placed in accordance with the manufacturer's standards and recommendations. Overlap adjacent strips of geotextile a minimum of 16 inches.
b. Place clean (washed), uniformly graded aggregate or other storage media in the bed in maximum 8-inch lifts. Spread the aggregate with equipment running over the aggregate and pushing toward bare soil. Lightly compact each aggregate layer while keeping construction equipment off the bed bottom as much as possible.
c. Following placement of storage media, place geotextile over the **top** of the bed to prevent soil movement into the bed. Place and secure geotextile to prevent soil movement through the overlap areas.
d. Place soil or other material above the storage bed.

Operations and Maintenance

All properly designed and installed subsurface infiltration beds will require annual maintenance, although they require less maintenance than other BMPs.

- Inspect and clean all inlets and catch basins biannually.
- Confirm that standing water does not remain in the bed after more than 96 hours without precipitation.
- Clean any pipes of connections that contain debris using a vacuum system. Do not wash material and debris into the bed.

5.3.3 Infiltration Trench

Description

An infiltration trench consists of a linear trench of open-graded aggregate or media that can capture, hold, and infiltrate stormwater (see Figures 5.3.3-1a and 1b). Its functions are similar to a stormwater infiltration bed except that it may also serve as part of a conveyance system, especially during larger storm events. Infiltration trenches capture and store stormwater runoff until it infiltrates into the subsurface below. The storage media may consist of clean-washed, open-graded stone aggregate, proprietary stormwater products, or perforated pipes set in a stone trench.

Very often, an infiltration trench is an effective method for conveying stormwater while also providing stormwater volume capture. In suitable areas, a stormwater pipe can be constructed as an infiltration trench. For an “on-line” trench that is part of a conveyance system, small storms are captured by the trench while large storms are conveyed through the BMP (infiltration trench). As a result, infiltration trenches, when used as part of a larger stormwater conveyance system, can be one of the most cost-effective BMPs.

Infiltration trenches are well suited to linear areas such as along roads, where they may be “on-line” (where all flows go through the trench) or “off-line” (where larger storms are intended to bypass the trench).

Infiltration trenches that are parallel to the road are generally only cost-effective on slopes of 5 percent or less. On steeper roads, infiltration trenches can be constructed perpendicular to the road and along the contour if space is available.

In situations where infiltration is not feasible, a stormwater trench may include an underdrain system for slow release. Underdrained trenches can work very well as roadside retrofits in urban areas, and are highly beneficial in CSO areas to reduce runoff volume during rainfall periods.

Figures 5.3.3-1a and b. Infiltration trench during installation and afterwards.

BMP Functions Table

BMP	Applicability*	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Infiltration Trench	U/S/R	H	H	M	H	H	M	L	L	M

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features (see Figure 5.3.3-2)

- Linear in nature and generally designed to capture runoff from small (1.6 inches or less) rainfall events.
- The trench may capture all or only a portion of the SOV.
- Often built “on-line” as part of a stormwater conveyance system.
- Water is conveyed into the trench, usually with pipes or other structures.
- Always includes an overflow control structure and the capacity to safely convey or bypass larger storm events.
- Usually limited in maximum width (6 feet or less) and depth (4 feet or less), although this may vary according to conditions.
- Minimum trench width is 3 feet.
- The length, width, and depth may be a function of “available space” for the infiltration trench.
- Clean-washed, open-graded aggregate storage trench with minimum of 40 percent void space.
- Perforated pipe is used within the trench.
- Surface material above trench may be pervious or impervious.
- Compacted fill material may be placed above the trench.
- Level, uncompacted subgrade in the trench bottom.
- Nonwoven geotextile at soil/stone interface, including top of trench to prevent soil movement into the trench.
- Designed with a method to convey water into the stormwater trench.
- Prior sediment removal is required for runoff from parking lots, roads, or other high sediment source drainage areas.
- Should not be placed on compacted fill if designed for infiltration.
- When possible, place infiltration trenches on upland soils.

Applications

- As part of a stormwater conveyance system in segments where there is limited grade change
- Road shoulders, medians, alleys, and sidewalks
- Parking lot edges
- Individual home lots
- As a component to “connect” larger BMPs
- Useful as a retrofit when replacing sidewalks, repairing roads, etc.

Advantages

- Very cost-effective when part of a stormwater conveyance system.
- When used to provide volume reduction (SOV), may provide a Curve Number reduction and may reduce the peak rate requirements for the site.
- Well suited to directly receive “clean” roof runoff.
- Effective for maintaining soil moisture conditions for planting areas or wooded slopes.
- Can enhance health and longevity of street trees if properly designed.
- Landscape features may be built above an infiltration trench; it does not preclude other uses of the surface space.

Disadvantages

- High clogging potential if runoff from high-sediment areas is not pretreated.
- Limited capacity for volume storage due to size.
- Not visible and may be “forgotten.”
- Must be offset from foundations/basements.
- May encounter utility conflicts in roadway right-of-way applications, especially in retrofit situations.
- Must be designed to prevent damage to pavement subbase material from infiltration.

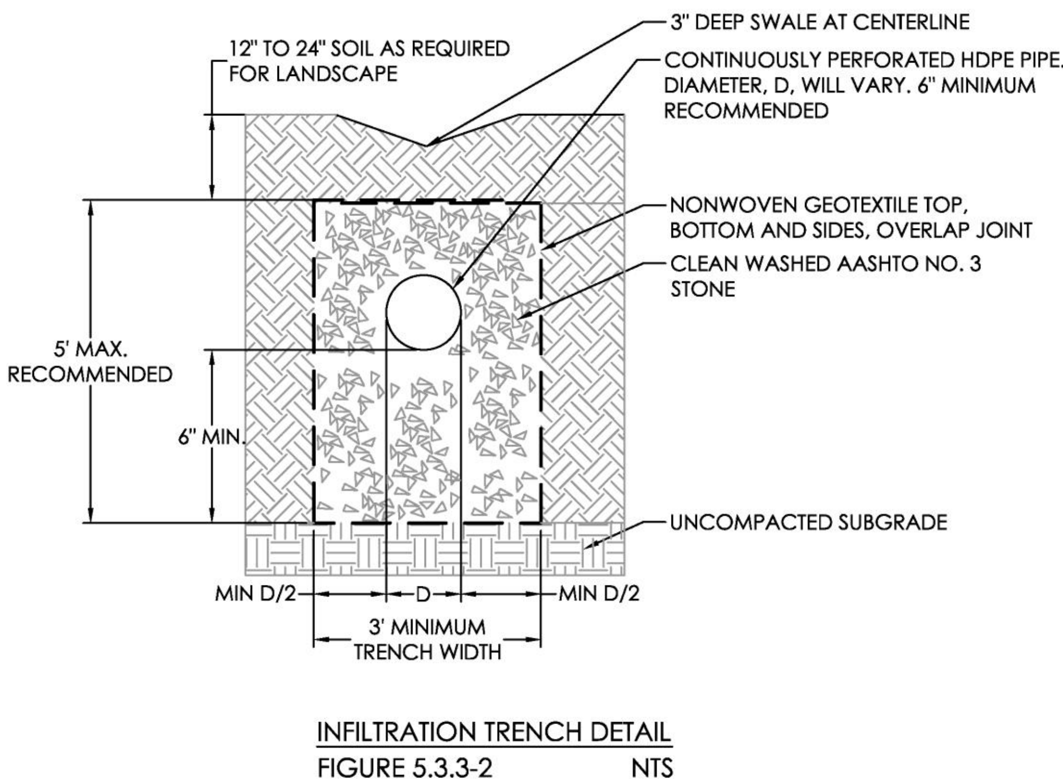


Figure 5.3.3-2. Typical infiltration trench cross-section.

Applications

An infiltration trench is often a “leaky pipe” by intention. In small, linear areas, the stormwater conveyance system can be designed to reduce runoff volume by allowing small storm events to partially or entirely infiltrate within the trench. Infiltration trenches are well-suited to the linear nature of roads.

Roadside Infiltration Trench

Figures 5.3.3-3a and b. Infiltration trenches were incorporated into an existing storm sewer system within the road at the Washington National Cathedral (Washington, DC). The trench is lined with an impervious liner along the asphalt edge to prevent damage to the roadway subbase from water movement. Overlain by standard asphalt, runoff enters the trench through stormwater inlets.

Infiltration Trench as Part of Conveyance System

Figure 5.3.3-4. The subgrade storm sewers beneath the lawn at this university campus include infiltration trenches "on-line" as part of the storm sewer system. This is appropriate where the grade is relatively level and the storm sewer is constructed along the contour, as shown here.

Urban Greening Infiltration Trench

Figure 5.3.3-5. Tree trenches capture street runoff, via curb inlets, and improve urban greening and streetscapes, especially in ultra-urban locations.

Applicable Protocols and Specifications

The following Protocols and Specifications (see Appendices A through F) are applicable to infiltration trenches and must be addressed:

- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing
- Protocol 4 Infiltration System Design and Construction Guidelines
- Protocol 5 Planting Guidelines

- Bioretention Soil Specifications
- Stormwater System Specifications
  - Aggregates and Drainage Layers
  - Pipes
  - Control Structures
  - Geotextiles

    Impervious Liners and Waterproofing

Design Considerations for Infiltration Trenches

Infiltration trenches are a linear BMP. The key design components for infiltration trenches discussed below allow design flexibility to ensure maximum performance. A trench may capture only a portion of the SOV, but be part of a larger system that meets volume requirements.

1. Location and Capture Area

Locate infiltration trenches:

- Close to the source of runoff (if possible) to minimize the need for additional stormwater structures.
- Between larger BMPs or as part of the stormwater conveyance system.
- To capture small drainage areas, generally less than 10,000 square feet. If necessary, use several connected infiltration trenches or combine with other BMPs to address larger areas.

Infiltration trenches can be located beneath or within roadways or impervious paved areas with proper design. When located in or adjacent to pavement, the following site-specific conditions should be considered:

- Saturated conditions in the trench cannot create saturation under or within the impermeable pavement subbase. This is especially important when infiltration trenches are adjacent to standard impervious pavement.

Figure 5.3.3-6. Impervious liners can be used to prevent lateral movement of water beneath standard pavement.

- Water levels in the trench should never be high enough to saturate the subbase of overlying impervious areas (through the top of the trench). Provide for controlled overflow and maximum water surface elevation.
- When located adjacent to pavement, the maximum water level must be lower than the pavement subbase. Alternatively, a secured impervious liner can be used to prevent lateral water movement (see Figure 5.3.3-6).

Slopes

- Infiltration trenches should not be constructed on fill material, because compacted fill will prevent infiltration. Slow release (underdrained) infiltration trenches may be built in fill material.
- The trench bottom must be level or with a slope less than 0.5 percent. If needed, the infiltration trench may be benched or terraced on slopes.
- Grade changes can often be accommodated by a series of connected infiltration trenches that "step" down the hill. (See BMPs 5.3.1 and 5.3.2 for "stepped" details.)

Drainage Area

- The type of land use in the drainage area must be carefully considered. Roof runoff is generally "clean" with regard to sediment and is ideal for discharge to an infiltration trench. Runoff from other areas, such as parking lots, must be treated with sediment-reduction measures, such as sediment traps in inlets or inlet water quality inserts, before runoff is discharged into the trench (see Figure 5.3.3-7).
- Infiltration trenches should not be used in hot areas where there is the potential for runoff with higher than average pollutant levels to enter the groundwater. Only the hot area is precluded from infiltration; other portions of the site may be well-suited for infiltration trench use.

Figure 5.3.3-7. If a catch basin is used to collect street runoff into a tree trench, the inlet must include a sump and a water quality insert to control sediment. This tree trench is built with a porous pavement sidewalk. (Also see Figures 5.3.11a and b.)

2. **Entrance/Flow Conditions**

Stormwater runoff must be conveyed into an infiltration trench, usually with storm sewer pipes. Pipes usually continue through the trench as a continuously perforated pipe. A cleanout or pipe access through a structure should always be provided for future pipe cleaning if necessary. **The minimum diameter of the continuously perforated pipe within the trench is 6 inches.** If the trench must convey large storms ("on-line" infiltration trench), the designer must confirm that the overflow capacity from the trench is adequate to meet City conveyance requirements (see Overflow discussion). For "on-line" infiltration trenches, it is recommended that the pipe be located in the upper portion of the trench, with storage provided below.

Trenches that are "off-line" receive runoff until the trench is full, at which point stormwater runoff must be designed to "bypass" the trench and be managed by other methods (see Figure 5.3.3-8). A trench may also be designed with entrance conditions that constrict the rate of flow into the trench, such that high flow rates from high-intensity rainfall cannot enter the trench.

Figure 5.3.3-8. This roadway trench is designed with catch basins to capture and convey runoff into the trench. When the trench is full, flows cannot enter the trench and continue to the next catch basin that conveys the runoff to the larger combined sewer system.

3. **Management of Sediment, Trash, and Debris**

In areas of high sediment load, all infiltration trenches **must** include measures to prevent the movement of material into the trench. Sediment can clog an infiltration trench and limit its functional lifespan (see Figure 5.3.3-9).

- Roadside infiltration trenches **must** include sediment-reduction practices (such as sumps, water quality inserts, and trash screens). Additionally, roadside trenches must be approved with a maintenance plan that identifies the method and frequency of maintaining the roadside trench.
- Roof runoff is generally lower in sediment and can be conveyed directly into a trench; however, a cleanout for roof leaders is required in the event that pipe clogging occurs.
- Runoff from roof areas that receive high amounts of leaf debris or other materials (such as deposition from equipment) should include sediment traps, or should be reconsidered. It may be preferable to discharge these roof areas to a vegetated swale or a filter strip prior to discharge into the trench.

- In areas of high trash or with specific concerns such as plastic shopping bags, entrance conditions should include a screen to prevent material from entering the infiltration trench. The designer must consider the site-specific conditions and adjacent land uses in each application.
- Water quality inserts or sumped inlets can reduce sediment from parking areas and low-volume streets. High-volume streets should discharge to a vegetated system such as a filter strip or vegetated swale before discharge into the trench.
- Cleanouts should be installed as necessary to allow access at "both ends" of the distribution pipes, if these pipes cannot be accessed through inlets or other structures.

Figure 5.3.3-9. Lack of inlet maintenance can prevent water from entering an urban tree trench.

4. Storage and Stay-on-Volume

An infiltration trench may be designed to capture the SOV, but often the trench may be able to capture only a portion of the SOV. In this situation, the remaining SOV and water quality volume must be managed by downstream BMPs.

The storage capacity of an infiltration trench is measured as the volume below the lowest discharge invert (overflow).

Storage Volume (ft^3) =

Trench Length (ft) x Trench Width (ft) x Trench Depth (ft) Below Overflow x Void Ratio

Void ratios are generally:

- 0.40 for clean-washed aggregate such as AASHTO No. 3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer
- 1.0 for the interior volume in perforated pipes within the trench

The **SOV** is a function of the storage volume available for the 1-inch or 1.6-inch storm.

Infiltration Volume (ft^3) = Trench Bottom Area (ft^2) x Infiltration Rate (in/hr) x 12 hours x 1/12

5. Surface Area and Dimensions

The size and surface area of an infiltration trench may be a function of the drainage area that will discharge to the trench. It is important **not** to concentrate too much flow in one location. This can lead to accelerated clogging from sediment, high water depths that may compress soils, and soils that do not dry out between storms (and change structure). A basic rule-of-thumb is to design an infiltration trench with a surface area that is a ratio of the impervious and compacted pervious areas draining to it. The amount of rainfall volume must also be considered. The following ratios based on design rainfall depth can be used to estimate the dimensions for an infiltration trench:

<u>1-inch Rainfall</u>

1:10 ratio of trench surface area to impervious drainage area

<u>1.6-inch Rainfall</u>

1:8 ratio of trench surface area to impervious drainage area

For example, an infiltration trench that receives runoff from 5,000 square feet of roadway and is designed for the 1-inch rainfall would be:

5,000 square feet / ratio of 10 = 500 square feet of infiltration trench

The trench depth of water storage is a function of the rainfall depth managed and the loading ratio, and influenced to a lesser extent by the infiltration rate. Very often the storage depth of an infiltration trench will be limited by site conditions (i.e., the elevation of the downstream stormwater system to which the trench connects). Trench depth may also be limited by topography and slope.

The minimum recommended width for infiltration trenches is 3 feet. Designers are strongly discouraged from designing infiltration trenches that are more than 5 feet deep. Excavation and placement of trench material may become difficult at deeper depths. Applicable health and safety requirements must be adhered to in the installation of any trench.

A 5-foot-deep stone infiltration trench (with 40 percent void space) can provide 2 feet of runoff storage:

2 feet of water / 0.40 void space = 5-foot stone storage trench

Additional storage may be available in the conveyance pipe if the pipe volume is lower than the control invert from the trench (see Overflow discussion).

Proprietary products may be utilized as storage media and as a substitute for stone subbase; however, all products must be approved by the City. An example is use of modular subsurface, plastic, interlocking storage units, which provide higher void space and structural stability comparable to AASHTO No. 3 aggregate, but may be more costly.

The land use type draining into an infiltration trench should be considered in trench area design. It is **strongly** discouraged that trenches receiving runoff from high-sediment areas such as streets and high-use parking lots exceed the recommended loading ratios. The recommended ratios can be significantly increased when managing runoff from clean roof areas. “Clean” and “dirty” runoff should not be mixed if possible.

If the surface of the trench is vegetated, adequate soil cover must be maintained above the infiltration trench to support successful vegetation. Minimum cover over pipes for structural integrity is required.

6. Overflow and Peak Rate

All infiltration trenches must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the trench can hold. The inclusion of a positive overflow route ensures that flooding risks and related property damage are minimized.

The positive overflow route is often in the form of a modified inlet box with an internal concrete weir (or weir plate), or simply an overflow pipe at a higher invert elevation. This maximizes the volume managed by the trench, while providing sufficient cover for overflow pipes. When water overtops the weir, it discharges via a pipe to the storm sewer or to another approved discharge point (see Figure 5.3.3-10).

The overflow structure can be designed to function as a detention rate control structure for peak rate control, and can be modeled or evaluated as a detention system. Temporarily higher effective water depths are acceptable during large storm events managed for peak rate control. Infiltration trenches do not usually have sufficient capacity for significant detention storage/mitigation.

The minimum allowable diameter of an overflow pipe is 12 inches unless otherwise approved by the City. The overflow structure must have capacity to meet the conveyance requirements of the City.

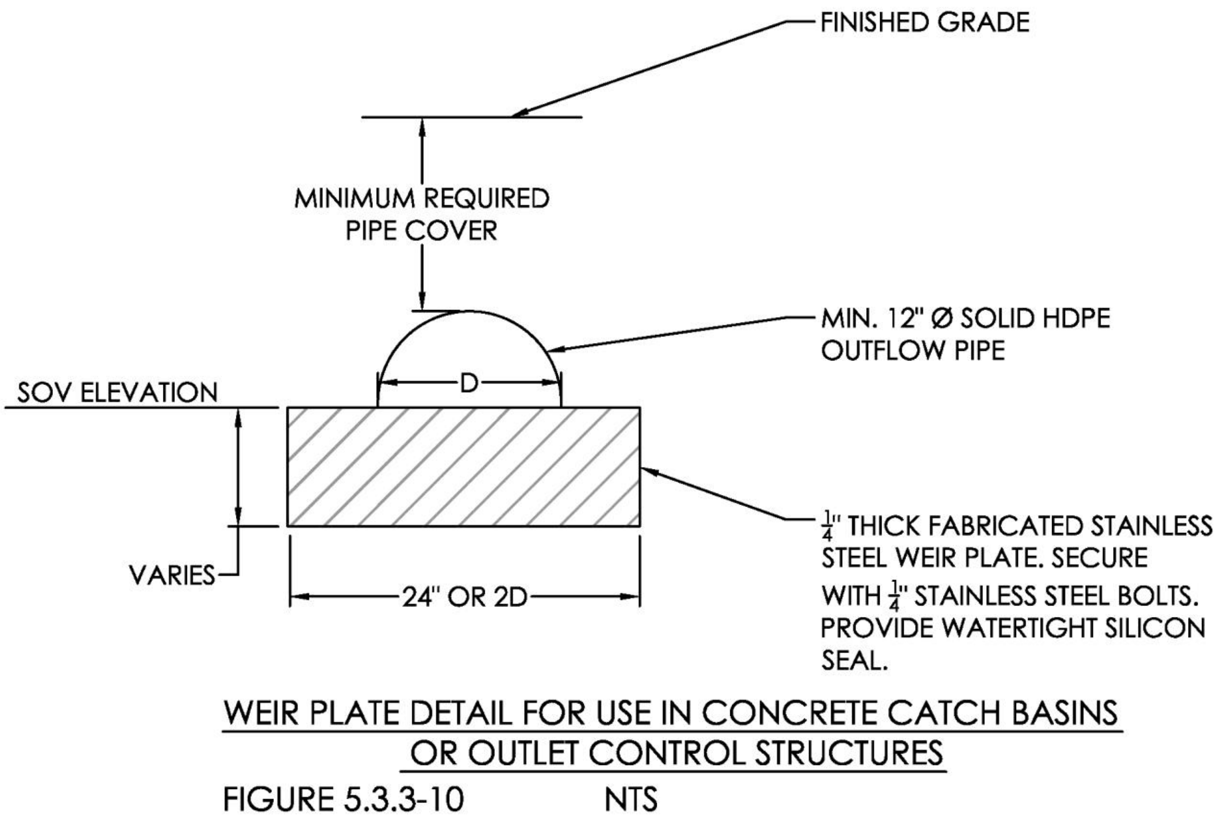


Figure 5.3.3-10. In an infiltration trench, placement of a weir plate over a portion of the outflow pipe allows the trench to capture small storms and maintain minimum cover over the pipe. The designer must confirm that large storms are conveyed through the trench.

<u>Peak Rate Control and Infiltration Credit</u>

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by both the SOV and the infiltration volume that occurs during a portion of a 24-hour storm event. This allows the designer to account for runoff that was captured by applying LID, and to develop a representative lower Curve Number. This is described in Chapter 7.

When adjusting the Curve Number, the infiltration volume can be estimated as the infiltration that occurs during 12 hours of a 24-hour design storm. This will ensure that estimated infiltration volumes are not greater than the actual volume captured within the BMP.

Infiltration Volume (ft^3) = Trench Bottom Area (ft^2) x Infiltration Rate (in/hr) x 1/12 x 12 hours

7. **Freeboard**

Infiltration trenches can be designed without freeboard and be allowed to completely fill provided that other conditions, such as adjacent pavement subbase, are considered. The designer must always provide an alternate means to manage flows that bypass or overflow a trench.

8. **Underdrain**

The underdrain system is used to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty the trench of water. If water does not exit the trench quickly enough, the system will back up through the inlet structures, and water may remain in the trench between storm events. Underdrain systems should discharge to the existing stormwater system or to a location approved by the City. Underdrain systems must be included in the design if the native soil infiltration is less than 0.1 inch per hour. See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

9. **Waterproofing**

In some instances, infiltration trenches may be designed to infiltrate, but there may be concerns about impacts on adjacent structures, such as basements, or impacts on the subbase of adjacent paved surfaces. For all infiltration trenches, the designer must evaluate the impact of the system on adjacent structures and utilities as defined in Protocol 1, Setbacks from Structures and Protocol 2, Coordination with Other Utilities. The liner, if applied, must meet the guidelines provided in the Stormwater Specification. In many situations, a partial liner (i.e., one side of a trench) will adequately protect structures.

10. **Water Quality/Total Suspended Solids**

Infiltration trenches that can capture and manage the required SOV through infiltration are considered to meet all water quality requirements. Infiltration trenches that are underdrained must be sized to provide water quality treatment. See Chapter 7 for additional discussion, and the Infiltration Trench Worksheet for calculations.

11. **Stormwater Tree Trenches and Green Infrastructure**

Stormwater tree trenches are a variation of infiltration trenches that are especially applicable in urban areas and as urban roadway retrofits. An infiltration trench can incorporate tree planting areas within the trench or between connected segments of the trench. Specific design considerations for tree trenches include the following (see Figures 5.3.3-11a and b):

- Urban trees require sufficient soil volume for growth and health. This can be achieved by providing adequate soil volume within the tree pit, or by providing adequate soil above the infiltration trench so that the root systems can extend into this soil (see Figure 5.3.3-12).
- Placing tree trenches adjacent to pervious areas (or extending the soil) will also improve tree health and success.
- The stormwater tree trench should not create extended saturated conditions for the root systems.
- The tree trench soil must have sufficient structural stability for placement under pavements and other structures. Soils used in tree trench applications must meet Bioretention Soil Specifications (Appendix F).

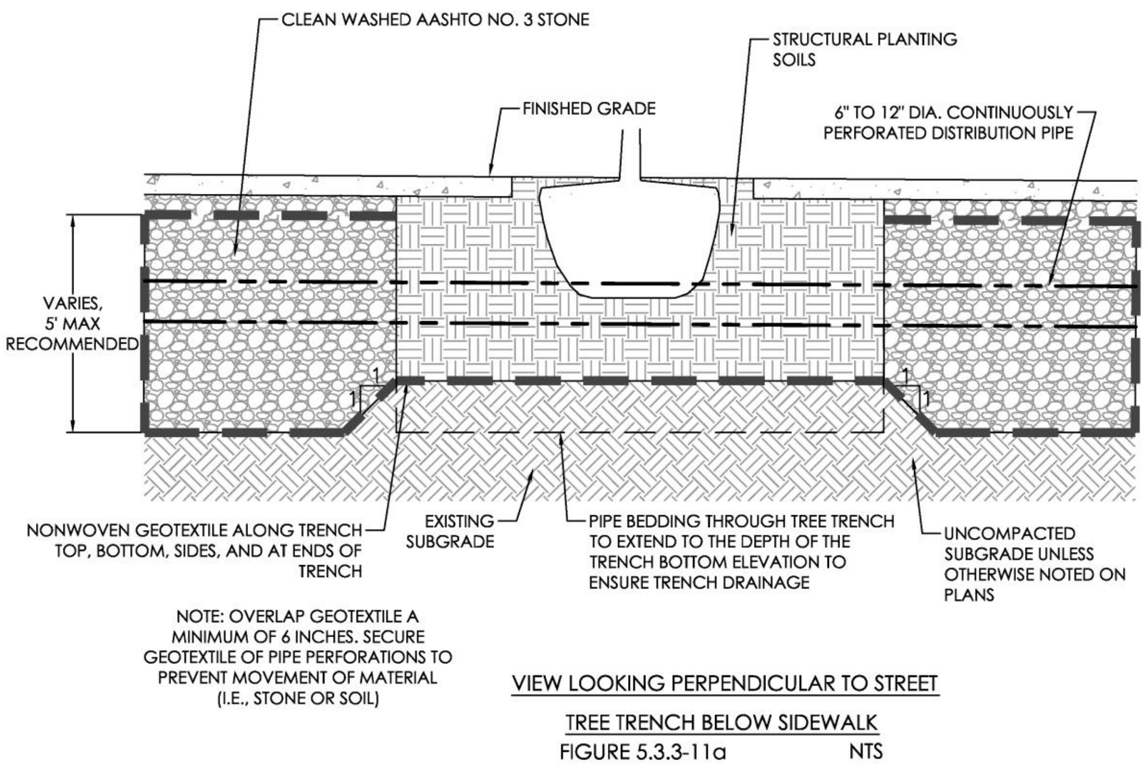
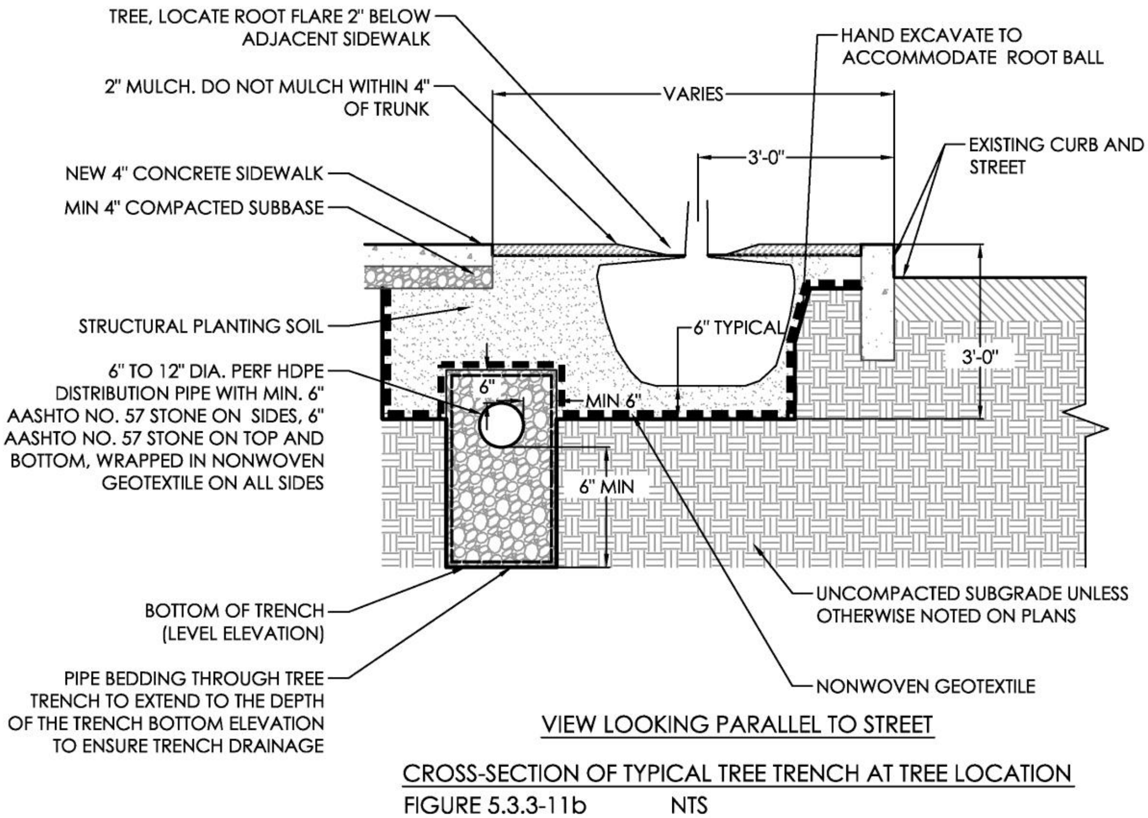


Figure 5.3.3-11a. Typical urban tree trench detail.



Figures 5.3.3-11b. Typical urban tree trench detail.

Figure 5.3.3-12. Between the trees in this stormwater tree trench, the soil is extended beneath the porous pavers to provide additional soil volume for the trees.

Sizing Calculations Worksheet for Infiltration Trenches

(Digital link to worksheet or reference on where to find worksheet on City web page)

Construction Considerations

Infiltration trenches can be installed:

1. Early in the construction process, but should not receive any site runoff until site construction is complete and site stabilization has occurred. Runoff should be directed around the completed trench until site stabilization has occurred. Sediment-laden water should not be allowed to enter infiltration trenches.

2. The infiltration trench may be constructed after site construction is substantially complete and site stabilization has occurred. During construction of the site, areas reserved for infiltration beds **must** be protected and should be fenced or barricaded to prevent the movement of equipment over the proposed infiltration area. This is similar in practice and intent to protecting an onsite septic system disposal field from vehicle compaction.

Construction Sequence Example

Step 1 Excavate and Prepare Subgrade

a. Do **not** compact or subject pervious pavement locations to excessive construction equipment traffic during construction. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.
b. If alternate storage media is used in lieu of stone aggregate, provide a suitable stone subbase for material but do **not** compact trench bottom.
c. Infiltration trenches can be installed at any time during the construction process provided that sediment-laden runoff is prevented from entering the trench. Do not allow runoff from any disturbed areas in the drainage area to discharge into the bed until these areas have been stabilized.
d. Remove fine materials and/or surface ponding in the graded bottom, caused by erosion, with light equipment and scarify the underlying soils to a minimum depth of 6 inches with a York rake or equivalent by light tractor.
e. Leave earthen berms (if used) between infiltration trenches in place during excavation. These berms do not require compaction if the berms were constructed by excavating the trenches between the berms, and are comprised of native material that is collected during construction. The construction of berms by placing fill is discouraged. If necessary, constructed berms shall be keyed into the subbase and compacted to 95 percent density.
f. It is recommended to place trees on native material in tree trenches to avoid settlement.
g. Bring subgrade of infiltration trench to line, grade, and elevations indicated on the plans. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All infiltration trenches shall be level grade on the bottom.
h. Halt excavation and notify engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater conditions, or other site conditions are encountered that may affect infiltration trench design or performance. Unanticipated utility crossings may be encountered in urban tree trenches along roadways.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Place the stormwater overflow structure on suitable subgrade to prevent settling. Install overflow structure, inlet pipes, curbs, and other stormwater structures as appropriate before placement of stone storage bed.
b. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering infiltration trench before completion and site stabilization.
c. Maintain drainage overflow pathways during construction, while infiltration trench is closed, to provide for drainage during storm events.
d. Infiltration trench conditions must be observed by the design engineer, following excavation and grading and prior to placement of material, to confirm that construction requirements have been met (see Figure 5.3.3-13). Documentation of engineering observation must be provided to the City (see Appendix I).

Figure 5.3.3-13. The bottom of an infiltration trench is level and uncompacted. The design engineer should observe conditions before the trench material is placed.

Step 3 Install Infiltration Trench

a. Place geotextile and trench aggregate immediately after approval of subgrade preparation and installation of structures (see Figure 5.3.3-14). Geotextile shall be placed in accordance with the manufacturer's standards and recommendations. Overlap adjacent strips of geotextile a minimum of 16 inches.
b. Place clean-washed, uniformly graded aggregate or other storage media in the trench in maximum 8-inch lifts. Compact each layer while keeping construction equipment off the trench bottom as much as possible.

Figure 5.3.3-14. Non-woven geotextile placed between trench and soil prevents movement of soil into trench.

c. Following placement of storage media, place geotextile over the top of the trench to prevent soil movement into the trench. Place and secure geotextile to prevent soil movement.

Operations and Maintenance

All properly designed and installed infiltration trenches require regular annual maintenance, although they require less maintenance than other BMPs:

- Inspect and clean all inlets and catch basins annually.
- Maintain overlying vegetation in good condition and immediately revegetate any bare spots.
- Prohibit vehicular access on vegetated infiltration trenches and avoid excessive compaction by mowers. If access is needed, use of permeable, turf reinforcement should be considered.

5.3.4 Bioretention

Description

Bioretention areas are vegetated, shallow surface depressions that use the interaction of plants, soil, and microorganisms to store, treat, and reduce runoff volume, and to reduce the flow rate of stormwater runoff. Small bioretention areas are often referred to as rain gardens. Bioretention areas designed for infiltration can also be referred to as bioinfiltration areas, while those that cannot infiltrate and must discharge via an underdrain are sometimes referred to as biofiltration areas.

Bioretention areas are generally flat and include engineered or modified soils that allow drainage of stormwater through soils. Plants are a critical component of bioretention and improve the soil structure and porosity through the establishment of root systems and microbial communities.

Bioretention provides stormwater management by capturing runoff in the shallow surface depression. Water then drains through the bioretention soils during small, frequent rainfall events. A bioretention area may include a stone storage bed beneath the soils. Bioretention systems **always** include a positive drainage overflow structure to safely convey large rainfall events from the bioretention area.

Water that has drained through a bioretention area may infiltrate into the subsoil or discharge at a controlled flow rate through an underdrain system (or a combination of both).

Figures 5.3.4-1a and b. Bioretention area immediately following construction and after three years of establishment.

BMP Functions Table

BMP	Applicability*	Volume Reduction*	Water Quality (TSS)	Peak Rate Reduction	Recharge*	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden*	Cost*
Bioretention	U/S/R	L/H	H	M	L/H	H	M	H	L/M/H	L/M/H

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features

- Shallow ponding of water (surface storage) is limited in depth and duration. Standing water does not remain visible for more than a few hours after rainfall has ceased.
- Captures the runoff from small (1.6 inches and less) rainfalls events, and the first portion of larger rainfall events.
- Always includes an overflow control structure or design to allow large storm events to bypass or discharge at a controlled flow rate without passing through the soils.
- The surface area and size are directly correlated to the contributing drainage area size and land use, especially impervious surfaces.
- Are generally small (less than 1,000 square feet) or comprised of several interconnected bioretention areas.
- Are generally level at the water surface. Constructed on a level uncompacted subgrade.
- May include an underlying aggregate drainage bed.
- Should not be placed on compacted fill if infiltration is required.
- When possible, bioretention should be placed on upland soils.
- Biofiltration areas that cannot infiltrate must include a low-flow slow-release system. Lined and slow-release systems may be constructed on compacted fill material.

Applications

- Road shoulders, medians, and cul-de-sacs
- Parking islands and edges
- Individual home lots
- Shared facilities in common areas for individual lots
- Common areas in multifamily housing and commercial office areas

- Institutions, such as schools, libraries, and public facilities
- In parks and along open space edges

Advantages

- Integrates stormwater into the landscape
- Improves aesthetics
- Flexible dimensions to fit conditions
- Creates habitat
- Excellent retrofit capability
- Cost-effective

Disadvantages

- Built on areas that are generally level (or graded level).
- Steep slopes may require larger footprint to create level grading.
- Vegetation and soils must be protected from damage and compaction.
- Infiltration requires suitable site conditions.
- Salt use may impact vegetation and soils.
- Maintenance is required to maintain both performance and aesthetics.

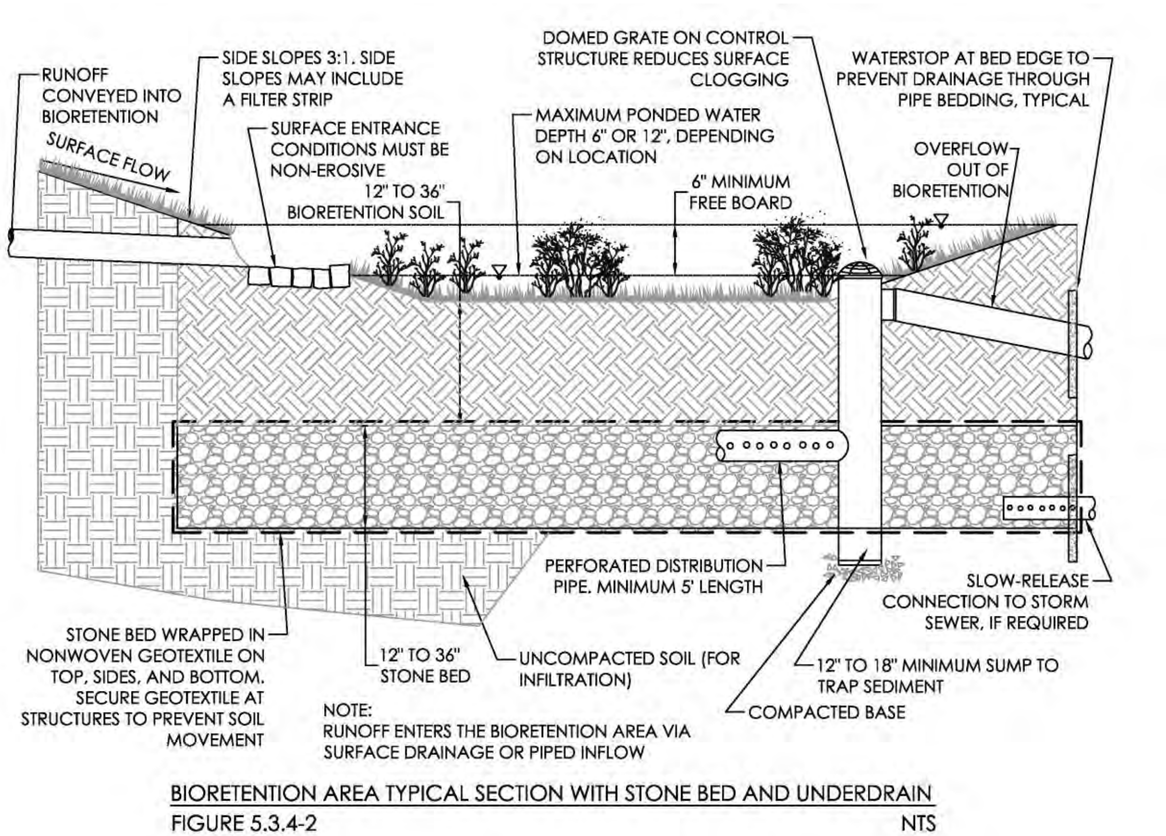


Figure 5.3.4-2. Typical bioretention detail (infiltration).

Applications

Bioretention basins are versatile, effective, and aesthetically pleasing stormwater management devices that are applicable to a variety of site characteristics.

Residential Bioretention Area

Figure 5.3.4-3. Residential bioretention that manages runoff from a single home. Roof leaders are directly connected to the bed.

Roadside Bioretention Area

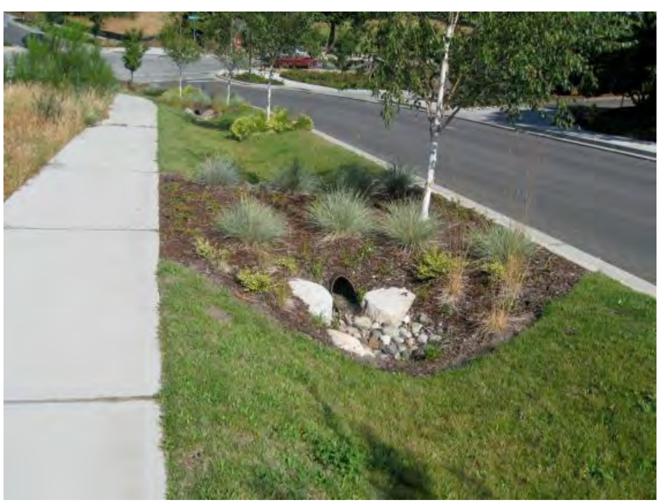


Figure 5.3.4-4. Roadside bioretention in a residential neighborhood that manages street runoff (located in public right-of-way).

Institutional Bioretention Area

Figure 5.3.4-5. Institutional bioretention area at an urban schoolyard (adjacent to porous rubber play surface).

Commercial Bioretention Area

Figure 5.3.4-6. Commercial bioretention (rain garden) in parking lot.

Applicable Protocols and Specifications

The following Protocols and Specifications (see Appendices A through F) are applicable to bioretention and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing
- Protocol 4 Infiltration System Design and Construction Guidelines
- Protocol 5 Planting Guidelines
  - Bioretention Soil Specifications
  - Stormwater System Specifications
  - Aggregates and Drainage Layers
  - Pipes
  - Control Structures
  - Geotextiles
  - Impervious Liners and Waterproofing

Bioretention Design Criteria

ITEM	RECOMMENDATION	REFERENCE SECTION
Maximum Drainage Area (Recommended)	Generally 10,000 square feet or less of impervious area per bioretention area. Several bioretention areas may be interconnected or placed in series to create larger systems.	5.3.4.1
Concept Phase Loading Ratio (LR) (Recommended)	1:8 for South Chickamauga Watershed	5.3.4.5
	1:10 for all other Watersheds	
Concept Phase Surface Area Size (ft^2) (Recommended)	Impervious Drainage Area Managed (ft^2) / Loading Ratio	5.3.4.5
Entrance/Flow conditions	Surface Dispersed: Grading must prevent concentrated flow paths	5.3.4.2
	Surface Concentrated: Provide erosion control at entrance	
	Direct Connection (into stone bed): Recommended only for "clean" runoff such as roofs	
Pretreatment/Management of Sediment Trash and Debris	Required for high sediment drainage areas (i.e. parking lots). See Filter Strip (BMP 5.3.6)	5.3.4.3
SOV Volume or Water Quality Volume Credit	Static Storage provided by: Surface Ponding, Soil Storage, Stone Storage (if applicable), Other structures (pipes, rain storage units, etc.)	5.3.4.4
Surface Ponding Depths	Maximum 6 inches for high use areas (near pedestrians and public) Maximum 12 inches for less used areas (limited access)	5.3.4.5
Soil Storage Coefficient and Volume	0.2 Storage Volume (ft^3) = Soil Depth (ft) x Soil Area(ft^2) x 0.2	5.3.4.4
Bioretention Soil Layer Depths	Minimum 12 inches Maximum 36 inches	5.3.4.5
Stone Storage Coefficient and Volume	0.4 Storage Volume = Stone Depth (ft) x Stone Area (ft^2) x 0.4	5.3.4.4
Stone Depths	Minimum 12 inches	5.3.4.5
	Maximum 36 inches	
Pipe sizes for Overflow and Peak Rate	Minimum size 6 inch diameter. See Stormwater System Specifications	5.3.4.6
Freeboard	6 inches	5.3.4.7
Conveyance Capacity	Peak rate 10-year, 24-hour rainfall event	5.3.4.6
Underdrain	Required if Infiltration Rate < 0.1 inches per hour	5.3.4.8
Setback from Structures	Required. See Stormwater Specification for Impervious Liner	Protocol 1
Coordination with Other Utilities	Required	Protocol 2
Infiltration Testing	Required	Protocol 3
Infiltration System Setbacks	Required	Protocol 4
Vegetation and Mulch	Required	Protocol 5
Inspection and Longterm Maintenance	Required	Chapter 8

Design Considerations for Bioretention

Designed appropriately, bioretention can be implemented on a myriad of development sites. The key design components for bioretention discussed below allow design flexibility to ensure maximum performance from this multi-purpose BMP.

Figure 5.3.4-7. Bioretention in a supermarket parking lot takes advantage of typically underutilized space between parked vehicles.

1. Location and Capture Area

Human activity influences the location of bioretention areas. The following site-specific conditions should be considered:

- Select location to prevent vegetation damage and soil compaction from pedestrian traffic or unintended vehicle compaction. Ideal locations are often located to the side or downhill of high vehicle or pedestrian traffic areas. Consider locating bioretention areas in places that are generally “not used” such as traffic islands; between parked cars in parking lots; along edges of public playgrounds, school yards, and plazas; in courtyards; and in place of traditional landscape planting areas.
- If necessary, provide for pedestrian passage and maintenance access. This will prevent unintended damage to soils and vegetation.
- Use structures, barriers, and plantings to limit access and prevent damage to soils and vegetation. Low fences, curbs, and woody vegetation are examples.
- Locate bioretention area to prevent future conflicts for space, and provide public access if necessary. Long-term maintenance is more likely if bioretention area is readily visible.

Figure 5.3.4-8. Cobbles in the bioretention area allow for easy and safe pedestrian crossing without disturbing soils and vegetation.

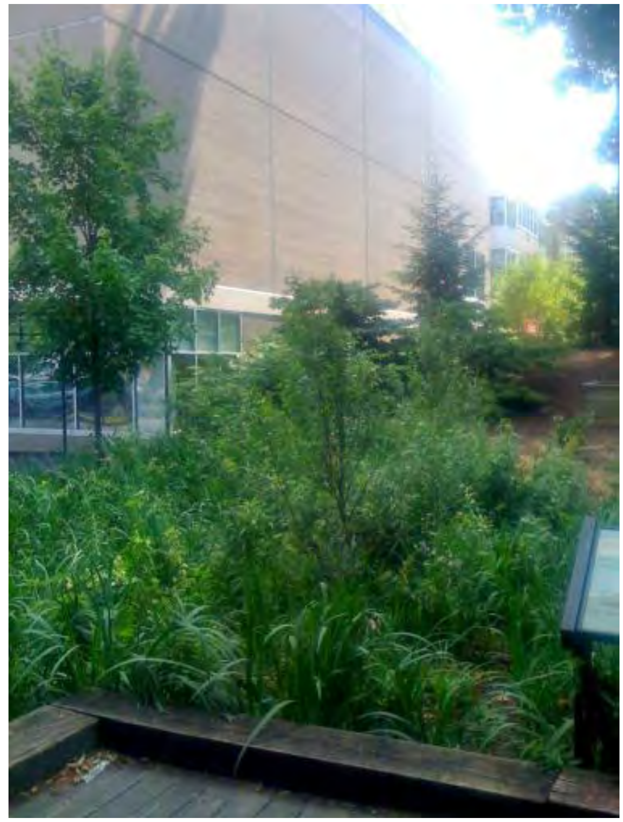


Figure 5.3.4-9. A low wood curb along a bioretention area protects the vegetation.

Locate bioretention areas:

- Close to the source of runoff. Bioretention areas should not receive excessive amounts of drainage from undisturbed areas.
- To capture runoff from impervious areas and highly compacted pervious areas such as athletic fields and lawns.
- To capture smaller drainage areas. If necessary, use several connected bioretention areas to address larger areas.

Figure 5.3.4-10. A bioretention area in the public right-of-way avoids homeowner conflicts such as decks, pools, and swing sets and also allows for public access and visibility.

2. Entrance/Flow Conditions

Captured runoff may enter a bioretention area in one of three ways:

a. Through dispersed surface flow such as along a depressed curb, lawn area, or edge of pavement. Careful grading is essential to prevent concentrated flow points and potential erosion. For bioretention adjacent to existing impervious pavement, such as in a retrofit installation or modification to an existing site, it is recommended that the adjacent pavement be milled and repaved/replaced to provide a uniform edge and dispersed sheet flow into the bioretention area.
b. Through a concentrated discharge location such as a trench drain, outlet pipe, or curb cut. Bioretention soils and mulch are highly erosive. Entrance velocities should not exceed 1 foot per second unless designed with entrance measures to prevent erosion. Cobble splash blocks, small level spreaders, and turf reinforcement materials are options. Supporting entrance velocity calculations are required for all concentrated surface discharges into bioretention areas.

c. Via a direct connection (such as a pipe) into the underlying stone storage bed. This is a good option for "clean" runoff discharging at high velocities. For example, a roof leader may be connected directly to a stone storage bed (see Figure 5.3.4-14).

Figure 5.3.4-11. Edge conditions at a school allow for direct surface flow from the play area to the adjacent bioretention area.

Figure 5.3.4-12. Edge conditions in a commercial parking lot allow for direct and unconcentrated surface flow into the adjacent bioretention area.

3. Management of Sediment, Trash, and Debris

In areas of high sediment load, bioretention areas should include measures to prevent the movement of material into the bioretention area. Sediment can clog a bioretention area and limit its functional lifespan.

For surface runoff into a bioretention area, a vegetated filter strip (BMP 5.3.6) can reduce sediment. For aesthetic purposes in manicured landscapes, the filter strip should be incorporated along the edges and within the bioretention landscape area.

For piped runoff into the surface of a bioretention area, a small sump within a cobble splash block or similar measure will provide for ease of maintenance in sediment removal.

Storm sewer pipes are not recommended for conveyance of stormwater with high levels of trash, debris, leaf litter, or other materials that may cause clogging unless regular maintenance and cleaning of pipes are ensured. Trench drains, curb cuts, and visible surface entrances require maintenance. Maintenance is more likely to occur if clogging conditions are visible.

In areas of high trash or with specific concerns such as plastic shopping bags (a common concern in commercial areas), entrance conditions may include a screen to prevent material from entering the bioretention area. Plant selection should consider the amount and type of trash that may enter the bioretention area. Items such as windblown plastic shopping bags that adhere to vegetation should be considered when selecting plants. Relatively deep (greater than 6 inches) bioretention areas in commercial shopping areas and along busy roadways tend to inadvertently collect shopping carts and debris. The designer must consider the site-specific conditions and adjacent land uses in each application.

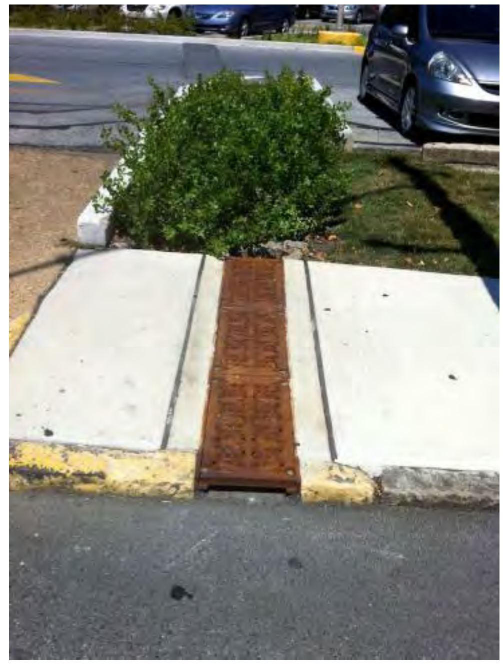


Figure 5.3.4-13. A trench drain collects and directly conveys street runoff into the bioretention area.

Figure 5.3.4-14. Roof leaders convey runoff below the walkway directly into an adjacent bioretention area. The walk is graded so that runoff sheet flows into the bioretention area. A small filter strip captures any coarse sediment from the walk.

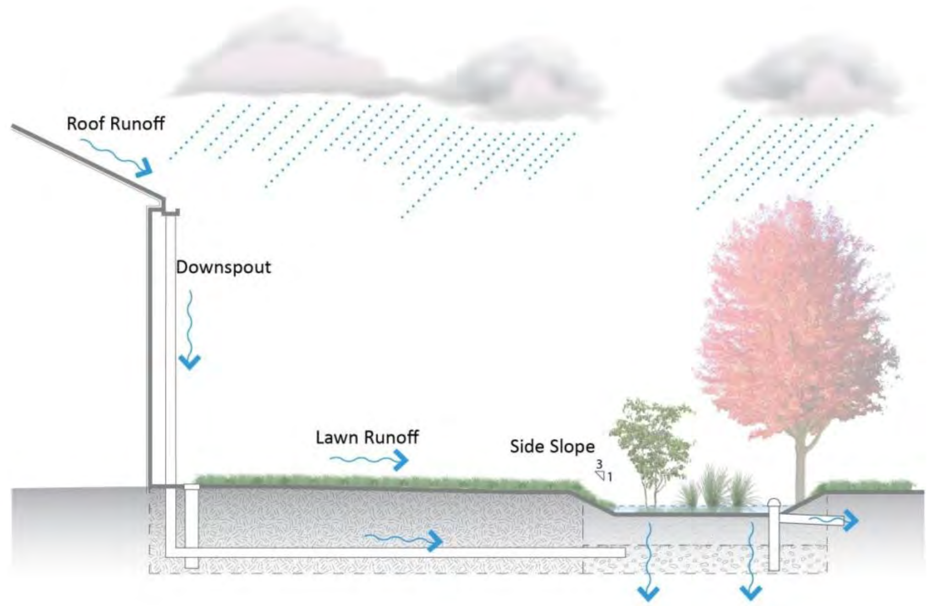


Figure 5.3.4-15. Roof leaders can convey high-velocity flows from the roof directly into the stone bed to prevent erosive conditions.

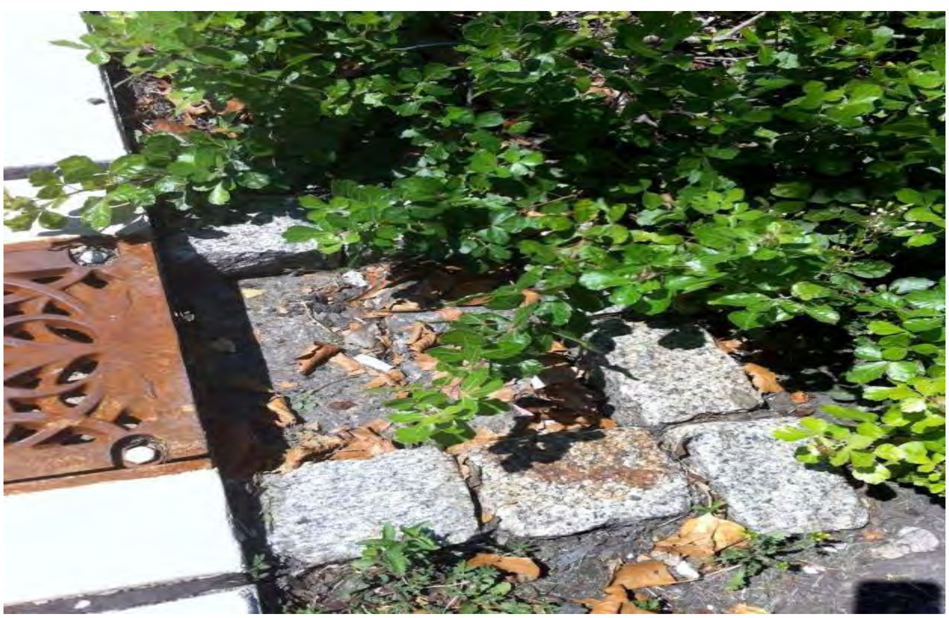


Figure 5.3.4-16. A cobble splash block prevents the movement of sediment into the bioretention area and also allows for routine cleaning and maintenance.

4. Storage and Stay-on-Volume

A bioretention system provides volume management within the surface ponding area, the bioretention soil area, and the stone storage bed (if applicable). Because water must move **through** the bioretention soils, the storage volume is **not** defined by the discharge pipe invert. This is different than non-vegetated BMPs.

The **SOV** is a function of the storage volume available for the 1-inch or 1.6-inch storm.

Storage Volume (ft^3) =

Surface Water Volume + Soil Storage Volume + Stone Storage Volume

Surface Water Volume: Available surface water storage between soil surface and overflow structure (always equal to or less than 12 inches). The designer should consider the bed side slopes when estimating volume.

Soil Storage Volume: This is the bioretention soil volume x 0.20 void space ratio.

Soil Storage Volume (ft^3) = Soil Area (ft^2) x Soil Depth (ft) Below Overflow x Void Ratio

Stone Storage Volume: This is the stone storage volume x 0.40 void space ratio.

Stone Storage Volume (ft^3) = Stone Area (ft^2) x Stone Depth (ft) Below overflow x Void Ratio

Void ratios are generally:

- 0.20 for bioretention soils
- 0.40 for clean-washed aggregate such as AASHTO No. 3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer

5. Surface Area and Dimensions

The size and surface area of a bioretention system may be a function of the drainage area that will discharge to the bioretention system. It is important not to concentrate too much flow in one location. A basic rule-of-thumb is to design a bioretention system with a surface area that is a ratio of the impervious and compacted pervious areas draining to it. The amount of rainfall volume must also be considered. The following ratios based on design rainfall depth can be used to estimate a bioretention area:

1-inch Rainfall

1:10 ratio of surface area to impervious drainage area

1.6-inch Rainfall

1:8 ratio of surface area to impervious drainage area

One of the benefits of bioretention is that the dimensions of the system may be adjusted to fit into an available location. A bioretention area may be long and linear when located in a parking lot, circular when located within a cul-de-sac, or varied in dimensions to support a landscape design. As long as the runoff can disperse through the bioretention system and sufficient surface area is provided, dimensions can be flexible.

With an estimate of the required bioretention area and SOV, the designer can estimate the depth of water, soil, and if necessary, stone storage using the Sizing Calculations Worksheet.

The recommended depths for surface water storage, soil storage, and stone storage are:

Surface Water Storage Depth:

- **6 inches maximum in high-use areas** (along streets, at schools, in public landscapes, etc.)
- **12 inches in less used areas** (away from frequent public access)

Bioretention Soil Depth: Between 12 and 36 inches

Stone Storage Depth: Between 12 and 36 inches

6. Overflow and Peak Rate

Bioretention designs must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the depression can hold. The inclusion of a positive overflow route ensures that flooding risks and related property damage are minimized.

The positive overflow route is often in the form of a domed riser, with an invert at the maximum allowable surface ponding level. The overflow must discharge to the storm sewer or to another approved discharge point. **The minimum allowable diameter of an overflow pipe is 6 inches for bioretention areas.**

A structure (i.e., outlet or weir) or vegetated swale that discharges to an approved discharge point may also be used. An inlet with an internal weir maximizes volume storage when the outlet pipe and inlet pipe cannot be placed to ensure sufficient storage (i.e., the bed is shallow, or slopes do not permit), as shown on Figure 5.3.4-17.

All overflows must safely convey the 10-year/24-hour storm.

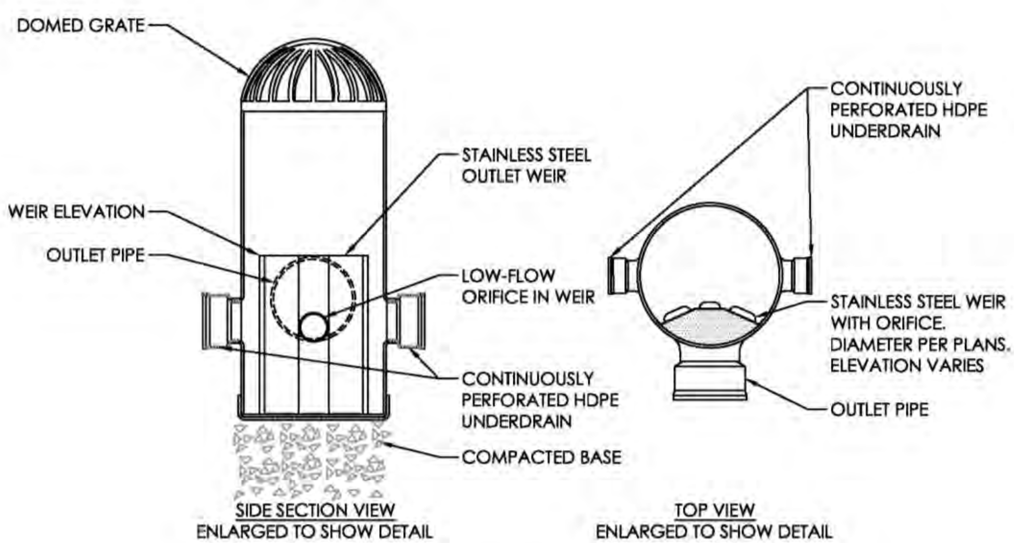


Figure 5.3.4-17. An inlet with an internal weir can also provide maximum volume storage within a bioretention or other area while allowing for safe conveyance. A number of manufactured products are available for this purpose.

The overflow structure should be easily visible from outside the bioretention area. Bioretention control structures can become clogged with vegetation at the inlet grate if maintenance is neglected. A domed inlet will reduce the likelihood of this problem occurring. A visible structure will facilitate ease of maintenance and ensure awareness of clogged inlet grates.

Peak Rate Control and Infiltration Credit

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by both the SOV and the infiltration volume that occurs during a portion of a 24-hour storm event. This allows the designer to account for runoff that was captured by applying LID, and to develop a representative lower Curve Number. This procedure is described in Chapter 7.

When adjusting the Curve Number, the infiltration volume can be estimated as the infiltration that occurs during 12 hours of a 24-hour design storm. This will ensure that estimated infiltration volumes are not greater than the actual volume captured within the BMP.

Infiltration Volume (ft^3) = Bioretention Bottom Area (ft^2) x Infiltration Rate (in/hr) x 1/12 x 12 hours

7. Freeboard

It is recommended that bioretention areas include a minimum of 6 inches of freeboard above the overflow route.

8. Underdrain

The underdrain system is used to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty the basin of water**. Underdrain systems must be included in the design if the native soil infiltration is less than 0.1 inch per hour or if the system is lined with an impervious liner** and intended for slow release only. Underdrains must be located at the intended bottom of the bioretention system (i.e., below soils and stone if applicable). See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

Bioretention systems may require very low discharge rates to achieve water quality discharge between 48 and 72 hours. Constructing a very small orifice will often achieve this, but a small orifice is easily subject to clogging.

One method for achieving a low discharge rate is to install a perforated pipe at the bottom elevation of the bioretention area. If the pipe is located in the bioretention soils, it must be set in clean-washed gravel and wrapped in non-woven geotextile to prevent soil movement. A perforated low-flow pipe can be set directly in a stone stormwater bed. The perforated pipe connects to a stormwater structure (such as a catch basin) with a transition coupling for a very small orifice. Various products are available for this purpose.

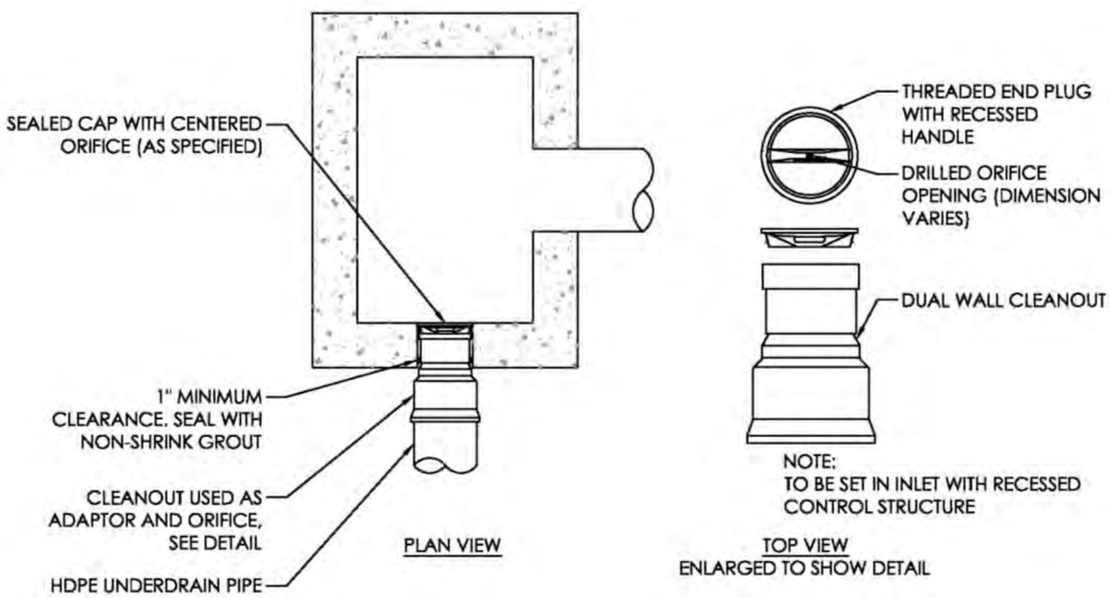


Figure 5.3.4-18. This coupling device can allow an "orifice" connection to a storm structure, providing an extended low discharge rate for underdrained systems.

9. Waterproofing

In some instances, bioretention areas may be designed to infiltrate, but there may be concerns about impacts on adjacent structures, such as basements, or on the subbase of adjacent paved surfaces. The system may be designed with an underdrain for slow release of flows rather than infiltration, but there may be concerns regarding lateral movement of water from the sides of the bioretention area. For all bioretention areas, the designer must evaluate the impact of the system on adjacent structures and utilities as defined in Protocol 1, Setbacks from Structures and Protocol 2, Coordination with Other Utilities. The liner, if applied, must meet the guidelines provided in the Stormwater Specification. In many situations, a partial liner (i.e., one side of a trench) will adequately protect structures.

10. Bioretention Soils

The soils used in the bioretention basin are a crucial factor in determining its performance. If an inadequate soil specification is used, or if the specification is prepared, installed, or maintained poorly, the runoff may infiltrate either too quickly or not quickly enough. If the soil infiltration rate is too low, the result is that runoff short-circuits the system and exits via the overflow without treatment or detention. If the soil infiltration rate is too high, the runoff will not have enough contact with the soil media to provide adequate water quality treatment, and it may be difficult to maintain healthy vegetation.

The Bioretention Soil Specification detailed in Appendix F of this document is required for use in all bioretention designs.

To provide adequate water quality treatment, the bioretention soil layer must be a minimum of 12 inches deep; however, greater depths of up to 36 inches are preferred.

Bioretention soils must never be placed when wet or during wet weather. Soils should be protected from saturation until plant installation, and from sediment deposition into the bioretention area. If necessary, the bioretention area can be protected by installing erosion and sediment control measures immediately upslope. Compost socks works very well for this purpose.

11. Bioretention Mulch

The type and application of mulch used in bioretention systems are important, and all systems must use mulch that meets the requirements of the Planting and Mulching Guidelines in Protocol 5 (Appendix E). The use of woodchips, which may “float,” is directly prohibited.

12. Vegetation

The type of plant and planting plan for bioretention systems must comply with Protocol 5 (Appendix E) of this manual.

Zone 1: Soils subject to both flooding and periodic drought.

Zone 2: Soils periodically moist or saturated during heavier storms.

Zone 3: Frequently saturated soils and occasional standing water (not for periods beyond 72 hours). An area of periodic or frequent standing or flowing water. Plants must tolerate periods of drought.

13. Water Quality/Total Suspended Solids

Bioretention systems that can capture and manage the required SOV through infiltration are considered to meet all water quality requirements. Bioretention systems that are underdrained must be sized to provide water quality treatment. See Chapter 7 for additional discussion.

Sizing Calculations Worksheet for Bioretention

(Digital link to worksheet or reference on where to find worksheet on City web page)

Bioretention Project Example

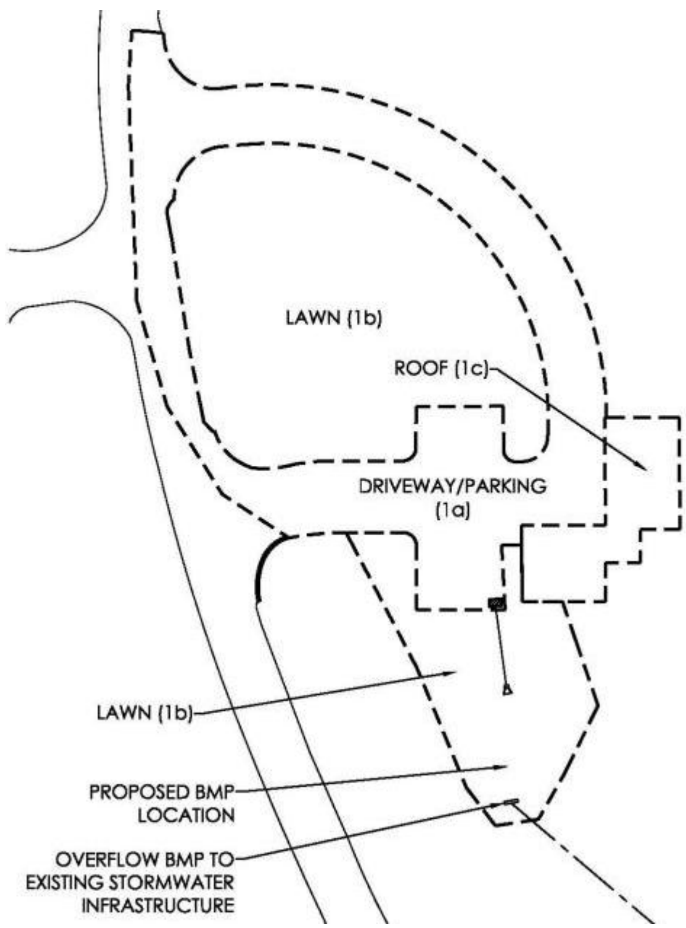


Figure 5.3.4-19. Bioretention project example.

Construction Considerations

For the best success, bioretention areas should not be installed and planted until site construction is complete and site stabilization has occurred. Bioretention areas completed before site stabilization **must** be protected from receiving sediment-laden runoff. Runoff should be directed around completed bioretention areas until site stabilization has occurred. Sediment-laden water should not be allowed to enter bioretention soils or infiltration beds.

The excavated capacity of an infiltration bioretention area may be used as temporary sediment trap areas during construction as long as the temporary grade is not within 2 feet of the final infiltration bottom elevation. Underdrained bioretention areas may be used as sediment traps during construction to the final bed bottom elevation.

Figure 5.3.4-20. A trench drain outlet is closed to prevent sediment-laden water from entering the bioretention area until site stabilization occurs.

Construction Sequence Example

Step 1 Excavate and Prepare Subgrade

a. Do **not** compact or subject bioretention system locations to excessive construction equipment traffic during construction. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.

b. Initial excavation of bioretention areas can be performed during rough site grading. When performing initial excavation, do not grade beyond 2 feet above the final bioretention bottom elevation. Complete final excavation only after all disturbed areas in the drainage area have been stabilized.
c. Remove fine materials and/or surface ponding in the graded bottom, caused by erosion, with light equipment and scarify underlying soils to a minimum depth of 6 inches with a York rake or equivalent by light tractor.
d. Bring subgrade of bioretention area to line, grade, and elevations indicated on the plans. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All bioretention areas shall be level grade on the bottom.
e. Halt excavation and notify engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater conditions, or other site conditions that may affect infiltration trench design or performance are encountered. Unanticipated utility crossings may be encountered in urban bioretention areas along roadways.

Figure 5.3.4-21. An underdrained bioretention area is used as a sediment trap during construction.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Place the stormwater overflow structure on suitable subgrade to prevent settling. Install overflow structure, inlet pipes, curbs, and other stormwater structures as appropriate before placement of stone storage bed and bioretention soils.
b. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering infiltration trench before completion and site stabilization.
c. Maintain drainage overflow paths during construction, while bioretention area is closed, to provide for drainage during storm events.
d. Bioretention conditions must be observed by the design engineer following excavation and grading, and prior to placement of material, to confirm that construction requirements have been met. Documentation must be provided to the City (see Appendix I).

Figure 5.3.4-22. Installation of distribution pipes in bioretention area.

Figure 5.3.4-23. A curb cut is closed to prevent sediment-laden water from entering the bioretention area until site stabilization occurs.

Step 3 Install Bioretention Area

a. For bioretention areas with a subsurface storage/infiltration bed, place geotextile on the bottom and sides of excavated area immediately after approval of subgrade preparation and installation of structures. Place geotextile in accordance with manufacturer's standards and recommendations. Overlap adjacent strips of geotextile a minimum of 16 inches.
b. Place clean-washed, uniformly graded aggregate (AASHTO No. 3, No. 57 or approved substitute with at least 40 percent void space) or other storage media in the trench in maximum 6-inch lifts. Lightly compact each layer with a hand roller or tamp while keeping construction equipment off the trench bottom as much as possible.
c. Following placement of storage media, place geotextile over the top of the trench to prevent soil movement into the trench. Place and secure geotextile to prevent soil movement.
d. Place planting soil immediately after approval of subgrade preparation/stone bed installation. Remove any accumulation of debris or sediment that takes place after approval of subgrade and prior to installation of planting soil at no extra cost to the owner.
e. Install planting soil (exceeding all criteria) in 8-inch maximum lifts and lightly compact (tamp with backhoe bucket). Keep equipment movement over planting soil to a minimum – do not over compact. Install planting soil to grades indicated on the drawings.
f. Plant trees and shrubs according to the supplier's recommendations and only from early April through the end of June or from early September through late October.
g. Install 2 to 3 inches of shredded hardwood mulch (minimum age of 6 months) or compost mulch evenly as shown on plans. Do not apply mulch in areas where ground cover is to be grass or where cover will be established by seeding.

h. Protect bioretention areas from sediment at all times during construction. Hay bales, diversion berms, and/or other appropriate measures shall be used at the toe of slopes adjacent to bioretention areas to prevent sediment from washing into these areas during site development.
i. Notify engineer when the site is fully vegetated and the soil mantle is stabilized. The engineer shall inspect the bioretention basin drainage area at his/her discretion before the area is brought online and sediment control devices are removed.

The contractor shall provide a one-year 80 percent care and replacement warranty for all planting beginning after installation and inspection of plants.

Figure 5.3.4-24. Planting soil is carefully placed in 8-inch lifts to avoid over compaction.

Figure 5.3.4-25. Inlet protection is placed over a domed riser to prevent sediment from entering the system.

Operations and Maintenance

All properly designed and installed bioretention systems require regular annual maintenance:

- While vegetation is being established, pruning and weeding may be required.
- Detritus may need to be removed approximately twice per year. Perennial grasses can also be cut down or mowed at the end of the growing season.
- Mulch should be replaced when erosion is evident. Once every two to three years, the entire area may require mulch replacement (remove old mulch first).
- Bioretention systems should be inspected annually for sediment buildup, erosion, vegetative conditions, etc.
- During periods of extended drought, bioretention systems may require watering approximately every 10 days.
- Bioretention systems should not be mowed on a regular basis, but mowed according to the maintenance schedule if indicated.
- Trees and shrubs should be inspected twice per year to evaluate health.
- Vegetation should be controlled and maintained as needed.
  - To avoid soil compaction, weeds should be removed by hand.
- Debris and sediment should be removed as needed.
- Mulch or soil should be replaced when evidence of erosion is encountered.

5.3.5 Vegetated Swales

Description

A vegetated swale is a landscaped channel, often broad and shallow with trapezoidal or parabolic geometry and a slight longitudinal slope, used to convey and treat stormwater runoff. Vegetated swales are densely planted with grasses, shrubs, and often trees, and can be used to improve water quality and reduce flow rates (see Figure 5.3.5-1). Vegetated swales are a commonly used first BMP in a "treatment train" approach to improve water quality. Depending on design, vegetated swales can also reduce volume. Specifically, if the swale includes berms or check dams such that water is retained and allowed to infiltrate, a vegetated swale can provide volume management.

Figure 5.3.5-1. This vegetated swale in a residential area is broad and shallow. Curb cuts allow street runoff to enter the swale.

BMP Functions Table

BMP	Applicability	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Vegetated Swales	U/S/R	H	H	M	M	M	M	M	L	L

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

Key Design Features

- Minimum flat bottom width of 2 feet (see Figure 5.3.5-2).
- Maximum bottom width of 10 feet.
- Side slopes at 3:1 maximum, 4:1 adjacent to pedestrian areas.
- Longitudinal slope at 2 percent maximum; up to 8 percent with check dams.
- Average recommended flow depth of 4 inches.
- Maximum ponding depth of 12 inches behind check dams.
- Minimum freeboard of 4 inches.
- Overall depth from top of sidewalls to bottom is generally not less than 10 inches or more than 24 inches.
- Planted in grasses and shrubs, and may include trees.
- Bioretention soil criteria apply.
- Minimum vegetation height of 4 inches is recommended.
- Trapezoidal or parabolic in shape (equations provided may be used for either).
- Entrance and conveyance flow conditions must be controlled to minimize erosion.
- Recommended maximum flow rate at entrance is 2 feet per second. Higher flow rates may be accepted with use of turf reinforcement mats or other materials to prevent erosion.
- Curb cuts and pipes may be used to direct runoff into the swale; however, the designer must demonstrate that entrance conditions will not be erosive. Splash blocks and other measures should be used at entrance locations as needed.
- Must convey 10-year/24-hour storm flow rate at non-erosive velocities. Alternatively, the swale may be designed to limit the flow rate of water entering the swale to maintain non-erosive conditions.
- The surface area, size, and slope are a function of the flow rates from the contributing drainage area.
- Erosive conditions must be prevented during germination and establishment of vegetation.
- The use of temporary or permanent stabilization fabrics or materials is recommended.

- May be designed to intentionally lengthen time of concentration and corresponding peak flow rate.
- Vegetated swales may include berms and check dams to facilitate shallow ponding of water (surface storage) that is limited in depth and duration. Standing water does not remain visible for more than a few hours after rainfall has ceased. Vegetated swales that include berms or check dams can provide volume reduction.
- Earthen check dams function best when constructed by excavation. Swales constructed of fill may be prone to failure.

Applications

- Pretreatment for a volume-reducing BMP (such as upstream of an infiltration trench or bioretention area)
- Road and highway shoulders and medians
- Parking islands and edges
- To convey water to or from a BMP, and to connect BMPs
- As an alternative to a curb and gutter system

Advantages

- Improves water quality and reduces flow velocities.
- Integrates stormwater into landscape.
- Improves aesthetics.
- Flexible dimensions to fit conditions.
- Reduces temperature impacts from impervious surfaces.
- Excellent retrofit capability.
- Cost-effective.
- May be designed to manage SOV.

Disadvantages

- Can create erosion problems if not properly designed, constructed, and maintained.
- Limited flow velocities permitted.
- Should not convey large drainage areas. Multiple swales (in segments) may be required.
- Not appropriate for project sites where spills may occur.
- Vegetation and soils must be protected from damage and compaction.
- Salt use may impact vegetation and soils.

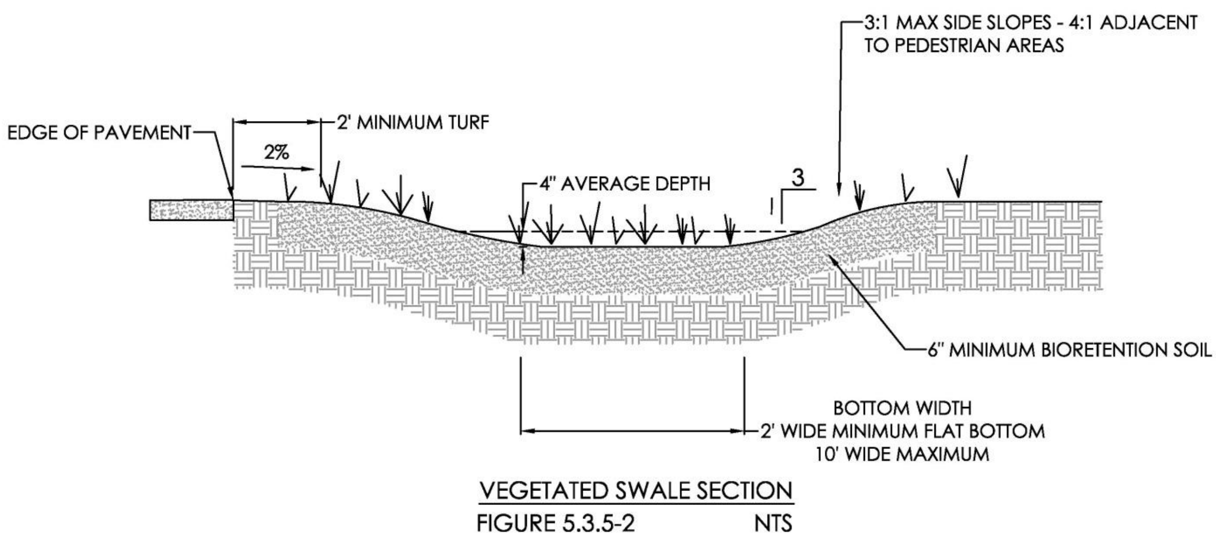


Figure 5.3.5-2. Cross-section of a vegetated swale.

Applications

Industrial Vegetated Swales

Figure 5.3.5-3. This manufacturing facility includes vegetated swales between parking areas to manage runoff.

Swales with Check Dams on Slopes

Figure 5.3.5-4. This vegetated swale on a slope includes stone check dams to slow runoff and earthen check dams to retain runoff.

Residential Vegetated Swales

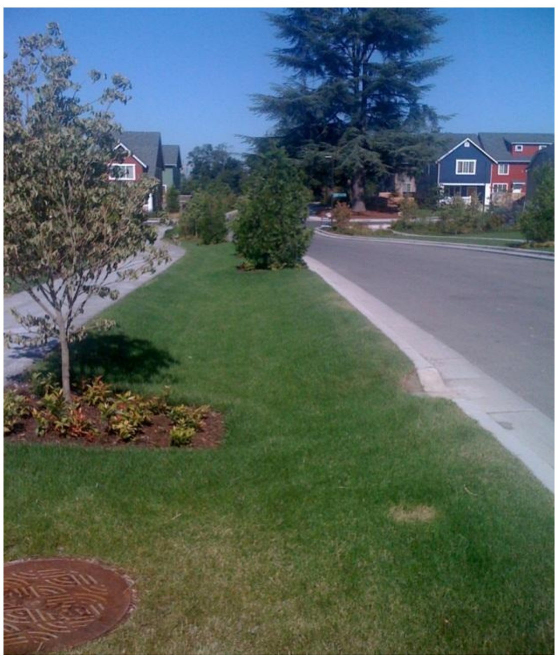


Figure 5.3.5-5. Curb cuts allow street runoff into a vegetated swale in a residential neighborhood.

Commercial Vegetated Swales

Figure 5.3.5-6. The parking lot vegetated swale at this commercial center is designed for pedestrian crossings.

Applicable Protocols and Specifications

The following protocols and specifications (see Appendices A through F) are applicable to vegetated swales and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing (for swales intended to infiltrate)
- Protocol 4 Infiltration System Design and Construction Guidelines (for swales intended to infiltrate)
- Protocol 5 Planting and Mulching Guidelines
- Appendix F Bioretention Soil Specifications
- Stormwater System Specifications

– Aggregates and Drainage Layers
– Pipes
– Control Structures
– Geotextiles
– Impervious Liners and Waterproofing

Design Considerations for Vegetated Swales

1. Location and Capture Area

- Vegetated swales may be subject to erosion and channelization if flow velocities create erosive conditions. Depending on slope and available space for a vegetated swale, it may be necessary to limit the drainage area directed to the swale.
- If necessary, a series of swales separated by berms or check dams may limit velocity (see Figure 5.3.5-7). Berms can also provide locations for pedestrian crossings.
- When located adjacent to pedestrian areas, the side slopes of the swale are recommended to be 4:1.
- When located adjacent to parking areas, a recommended setback width of 2 feet (minimum) of lawn or level area adjacent to the swale allows passengers to exit vehicles without stepping into the swale.
- Areas where side slopes or berms would need to be constructed with fill should be avoided. Such slopes are prone to erosion and/or structural damage.
- Pedestrian passage and maintenance access should be provided for, if necessary. This will prevent unintended damage to soils and vegetation.

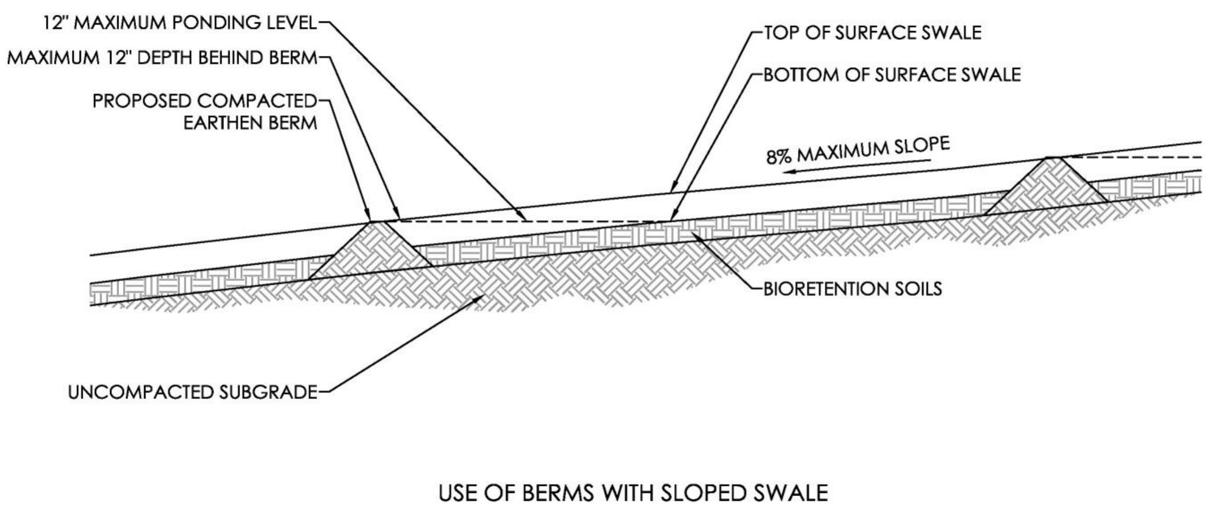


Figure 5.3.5-7. Longitudinal section of a swale with berms.

2. Entrance/Flow Conditions

It is important that entrance conditions or distributed flow into a vegetated swale be non-erosive.

- Dispersed surface flow (sheet flow) along a depressed curb, lawn area, or edge of pavement with careful grading will prevent concentrated flow points and potential erosion.
- Concentrated discharge velocities into vegetated swales (i.e., through a trench drain, outlet pipe, or curb cut) should not exceed 2 feet per second unless the entrance is designed with erosion prevention measures such as cobble splash blocks, level spreaders, and/or turf reinforcement materials.
- A turf reinforcement mat (TRM) or other stabilization fabric is recommended on slopes greater than 6 percent or when flows into the vegetated swale exceed 2 feet per second and are not slowed by other measures.
- Supporting entrance flow velocity calculations are required for all concentrated discharges into vegetated swales to demonstrate non-erosive conditions.

Figure 5.3.5-8. A series of splash blocks prevents erosion on the side of this vegetated swale as runoff enters from a parking lot via a trench drain.

3. Management of Sediment, Trash, and Debris

In areas of high sediment load, vegetated swales must include measures to prevent the movement of material into the swale. Sediment can clog a vegetated swale and limit its functional lifespan.

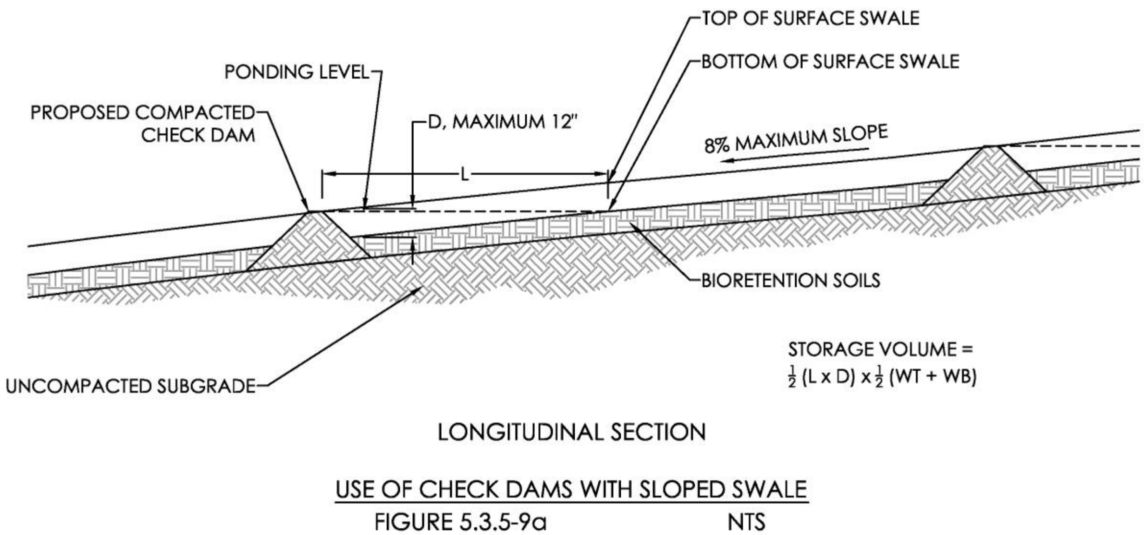
- Trench drains, curb cuts, and visible surface entrances require maintenance. Maintenance is more likely to occur if clogging conditions are visible. In areas of high trash or with specific concerns such as plastic shopping bags, entrance conditions may include a screen to prevent material from entering the vegetated swale. The designer must consider the site-specific conditions and adjacent land uses in each application.
- Site conditions should be considered when choosing vegetation. In areas of high debris, avoid plantings that will trap materials such as trash and paper bags.

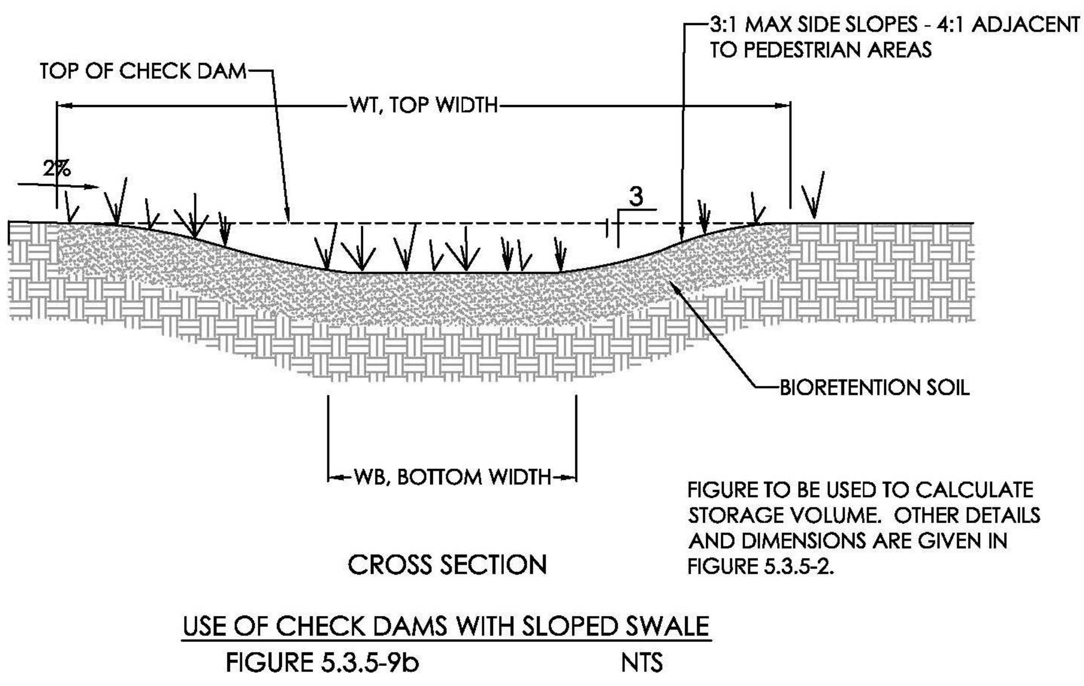
4. Storage and Stay-on-Volume

A vegetated swale is generally a conveyance and water quality BMP. However, swales with check dams may be designed to capture SOV behind the check dam.

- Water depth behind a check dam should not exceed 12 inches.
- Both surface storage and bioretention soil storage can be considered. The expected void ratio for bioretention soils is 0.20.
- The designer must consider the slope of the swale and the depth of water storage at the check dam when calculating SOV.

  Storage Volume = ½ (Length of Swale Impoundment Area (L) x Depth of Check Dam (D)) x ½ (Top Width of Check Dam (WT) + Bottom Width (WB) of Check Dam)





Figures 5.3.5-9a and b. Section of a vegetated swale with check dams.

Figures 5.3.5-10. A simple level spreader of perforated pipe can direct flow into a vegetated swale and prevent erosive conditions at the entrance.

5. Swale Dimensions

The dimensions of a vegetated swale must convey the required flow rate at a velocity that is non-erosive. A swale should be sized to convey the 10-year/24-hour storm (or 10 year peak runoff if using the Rational Method) for swale sizing)unless an alternate conveyance path for high flows is available. It is recommended that the velocity not exceed 1 foot per second unless supporting calculations are provided to demonstrate that erosive conditions will not occur through the use of TRMs or other measures.

Determining swale dimensions can be an iterative process. The flow capacity of a vegetated swale is a function of the longitudinal slope, resistance to flow (Manning's n), and cross-sectional area. The flow depth should not exceed 4 inches. The swale bottom width is calculated based on Manning's equation for open channel flow:

$$Q = 1.49 / n\ A\ R^{0.67}\ S^{0.5}$$

Where:

Q = flow rate (cubic feet per second)

n = Manning's roughness coefficient (unitless; assume 0.15 for grass, 0.20 for dense vegetation)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft) = area/wetted perimeter
S = longitudinal slope (ft/ft)

The first step is to estimate the swale bottom width. For shallow flow depths in swales, channel side slopes are ignored and the swale bottom width is estimated as:

$$b = Q\, n/1.49\, y^{0.67}\, s^{0.5}$$

Where:
b = bottom width of swale (ft)
Q = design flow rate (cubic feet per second)
n = Manning's roughness coefficient (unitless; assume 0.15 for grass, 0.20 for dense vegetation)
y = design depth (ft)
s = slope (ft/ft)

If the bottom width is less than 2 feet, adjust the flow depth. If the bottom width is more than 10 feet (or allowable width per site conditions), it may be necessary to limit the flow rate or adjust the slope (if feasible).

If the bottom width is between 2 feet and 10 feet, the second step is to determine the flow velocity:

$$V = Q / A$$

Where:
V = design flow velocity (feet per second)
Q = design flow rate (cubic feet per second)
A = cross-sectional area determined by:

A = by + zy where
z = side slope (ft/ft)
y = design depth (ft)
b = bottom width of swale (ft)

If the velocity exceeds 2 feet per second, or the channel bottom width is less than 2 feet or more than 10 feet, the designer must modify the proposed dimensions until the design criteria are met.

Figure 5.3.5-11. Vegetated swales may be planted in grasses or denser vegetation.

6. Freeboard

Vegetated swales must contain a minimum of 4 inches of freeboard without creating erosive velocities.

7. Underdrain

An underdrain system is used in swales with check dams to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty excess ponded water, or if infiltration is not feasible. If water does not exit the swale quickly enough, the system will back up and flood adjacent properties. It is not recommended that surface water remain visible in residential areas for more than

24 hours. All underdrain systems must discharge the water quality volume (WQv) between 48 and 72 hours. See Chapter 7 for more information on WQv.

Underdrain systems must be included in the design if native soil infiltration is less than 0.1 inch per hour. See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

8. Check Dams

Check dams are used to create shallow pools of water that reduce the velocity of runoff through the swale while also promoting infiltration. Check dams may measure 4 to 12 inches in height and extend the full width of the swale. Quantity and placement of check dams depend on the slope and required volume storage. Earthen check dams created by excavation, rather than by placement of fill, are recommended. For constructed check dams, stone is recommended.

Flows through a stone check dam vary based on stone size, flow depth, flow width, and flow path length through the dam. Flow through a stone check dam shall be calculated using the following equation:

$$q = h^{1.5} / (L / D + 2.5 + L^{2})^{0.5}$$

Where:

q = flow rate exiting check dam (cubic feet per second/ft)
h = flow depth (ft)
L = length of flow (ft)
D = average stone diameter (ft) (more uniform gradations are preferred)

For low flows, check-dam geometry and swale width are actually more influential on flow than stone size. The average flow length through a check dam as a function of flow depth can be determined by the following equation:

$$L = (ss) \times (2\,d - h)$$

Where:

ss = check dam side slope (maximum 3:1)
(side slope is entered into the equation as rise over run, so a maximum 3:1 side slope would be entered as 3)
d = height of dam (ft)
h = flow depth (ft)

When swale flows overwhelm the flow-through capacity of a stone check dam, the top of the dam should act as a standard weir (use standard weir equation, although a principal spillway, 6 inches below the height of the dam, may also be required depending on flow conditions). If the check dam is designed to be overtopped, appropriate selection of aggregate will ensure stability during flooding events. In general, one stone size for a dam is recommended for ease of construction. However, two or more stone sizes may be used, provided a larger stone (e.g., R-4) is placed on the downstream side, since flows are concentrated at the exit channel of the weir. Several feet of smaller stone (e.g., AASHTO #57) can then be placed on the upstream side. Smaller stone may also be more appropriate at the base of the dam for constructability purposes.

9. Waterproofing

Infiltration from vegetated swales, in certain applications, may raise concerns about the impact on nearby structures, such as basements, or adjacent paved surfaces. In all vegetated swale designs, the designer must appraise the effect of the design on adjacent structures and utilities. See Protocol 1, Setbacks from Structures and Protocol 2, Coordination with Other Utilities for further guidelines. If an impervious liner is incorporated into the design, the liner must meet the criteria provided in the Stormwater Specifications.

10. Water Quality/Total Suspended Solids

Vegetated swales designed to capture and manage the required SOV through infiltration are considered to meet all water quality requirements.

Construction Considerations

For the best success, vegetated swales should not be installed until site construction is complete and site stabilization has occurred. Vegetated swales completed before site stabilization **must** be protected from receiving sediment-laden runoff. Runoff should be directed around the completed vegetated swale until site stabilization has occurred. Sediment-laden water should not be allowed to enter swales.

Construction Sequence Example

Step 1 Excavate Swale

a. Do **not** compact or subject existing subgrade in vegetated swale locations to excessive construction equipment traffic. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.
b. Rough grade the vegetated swale. Excavating equipment should operate from the side of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade (where an

infiltration trench is not proposed), 18 inches shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil shall be thoroughly deep-plowed into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil.

c. Halt excavation and notify the engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater, or other site conditions are encountered that may affect infiltration bed design or performance.

Step 2 Install Overflow Structure and Other Stormwater Structures

a. Close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the vegetated swale before completion and site stabilization.
b. Maintain drainage overflow pathways during construction, while the vegetated swale is closed, to provide for drainage during storm events.

Step 3 Install Vegetated Swale and Check Dams

a. Construct check dams, if required.
b. Grade vegetated swale to line, grade, and elevations indicated. Accurate grading is essential for swales. Even the smallest non-conformities may compromise flow conditions. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. Bioretention soil shall be placed immediately after approval of subgrade preparation.
c. Remove any accumulation of debris or sediment that takes place after approval of subgrade prior to installation of planting soil at no extra cost to the owner.
d. Install bioretention soil in 8-inch maximum lifts and lightly compact (tamp with backhoe bucket). Keep equipment movement over planting soil to a minimum – do not over compact. Install planting soil to grades indicated on the drawings.
e. Seed and vegetate according to plans, and stabilize bioretention soil. Plant the swale at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.
f. Stabilize freshly seeded swales with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded swales shall be required for at least the first 75 days following the first storm event of the season. If runoff velocities are high, consider sodding the swale or diverting runoff until vegetation is fully established.
g. Protect the vegetated swale from sediment at all times during construction. Hay bales, diversion berms, and/or other appropriate measures shall be used at the toe of slopes adjacent to the vegetated swale to prevent sediment from washing into these areas during site development.

h. Notify engineer when the site is fully vegetated and the soil mantle stabilized. The engineer shall inspect the vegetated swale drainage area at his/her discretion before the area is brought online and sediment control devices are removed.

   If a vegetated swale is used for runoff conveyance during construction, regrade and reseed immediately after construction and stabilization have occurred. Any damaged areas must be fully restored to ensure future functionality of the swale.

Figure 5.3.5-12. This vegetated swale is stabilized with a temporary turf reinforcement mat until vegetation is established. Careful erosion control is maintained through erosion control materials on the other portions of the site.

Operations and Maintenance

A properly designed and installed vegetated swale requires relatively minimal maintenance.

- While vegetation is being established, pruning and weeding may be required.
- Detritus may also need to be removed approximately twice per year. Perennial grasses can be cut down or mowed at the end of the growing season.

- Inspect vegetated swales annually for sediment buildup, erosion, vegetative conditions, etc.
- Inspect for pools of standing water; dewater and discharge to a sanitary sewer at an approved location.
- Mow and trim vegetation according to maintenance schedule to ensure safety, aesthetics, and proper swale operation, or to suppress weeds and invasive species; dispose of cuttings in a local composting facility.
- Mow only when swale is dry to avoid rutting.
- Inspect for uniformity in cross-section and longitudinal slope, and correct as needed.
- Inspect swale inlet (curb cuts, pipes, etc.) and outlet for signs of erosion or blockage, and correct as needed.

The following should be done only as needed:

- Plant alternate grass species in the event of unsuccessful establishment.
- Reseed bare areas and install appropriate erosion control measures when native soil is exposed or erosion is observed.
- Rototill and replant swale if drawdown time is less than 48 hours.
- Inspect and correct check dams when signs of altered water flow (channelization, obstructions, etc.) are identified.

5.3.9 Runoff Capture and Reuse

Description

Rainwater can be used as a resource when it is captured from rooftops and other impervious surfaces, stored in rain barrels or cisterns, and reused as non-potable water (see Figure 5.3.9-1). Captured rainwater can be used for landscape irrigation, fire needs, toilet flushing, or other greywater uses. Roof runoff is generally cleaner and more suitable than runoff from parking lots and roads, which require additional treatment and maintenance to address sediment. Air conditioning condensate (although not part of runoff) can also be captured for reuse instead of being discharged to the storm sewer. Runoff capture and reuse reduces the volume and peak flows associated with stormwater runoff.

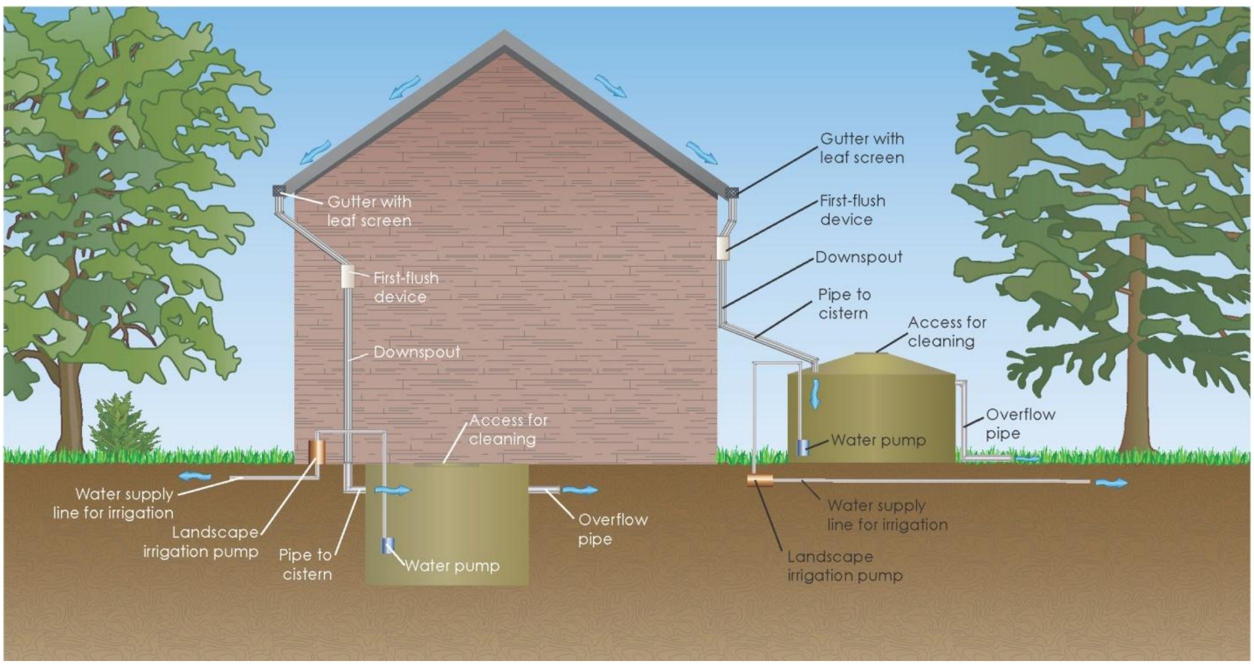


Figure 5.3.9-1. Roof runoff can be captured in cisterns above or below grade and used for irrigation or non-potable water needs.

BMP Functions Table

BMP	Applicability*	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden*	Cost*
Runoff Capture and Reuse	U/S/R	H	H	H	L	H	L	L	M/H	M/H

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features
(see Figure 5.3.9-2)

- Cisterns may be above- or below-ground tanks made from a variety of materials including wood, concrete, plastic, stone, or modular storage units.
- The volume of runoff generated from the contributing area must be considered.
- Contributing areas must be evaluated for potential pollutants including metals, fungicides, and herbicides. Roofs should not include copper or be treated with fungicides or herbicides.
- Storage devices should be sized to store the appropriate runoff volume from the contributing capture area and reuse needs should be adequate to drain the cistern within 96 hours to ensure that sufficient storage is available for subsequent rainfall events.
- When used for greywater reuse (such as toilet flushing), a backup water supply is required to supplement the system during dry periods.
- Collection and reuse systems must include an emergency overflow for large storm events.
- Cisterns must be watertight, vented, completely covered or screened, composed of non-reactive materials, and be approved for potable water storage, although runoff cannot be used for potable needs without treatment. This includes irrigation water that has any human contact (i.e., sprinklers).
- Distribution lines and other system appurtenances must be clearly labeled as non-potable water.
- If the storage device is open to the air, a screen or other cover is necessary to prevent mosquito breeding.
- Spigots or hose bibs at above-grade cisterns should be labeled “NON-POTABLE” and be equipped with an atmospheric vacuum breaker.
- Safety labels should be placed on cisterns stating “NON-POTABLE” and “DROWNING HAZARD.”
- Backflow preventers must be installed on water service lines from cisterns.

- Storage tanks should be placed in cool, shaded areas to help prevent the growth of algae.
- All collection and redistribution of stormwater runoff have the potential to cause human pathogenic issues. All capture and reuse BMPs that involve human contact must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. Both ultraviolet (UV) and ozone disinfection systems are available for this purpose.

Applications

- Residential
- Commercial
- Institutional: schools, universities, libraries, etc.
- Brownfields
- Uses: irrigation, toilet flushing, fire storage
- Toilet flushing in high-use buildings (i.e., schools, visitor centers) is one of the most effective reuse methods.

Advantages

- Provides volume reduction.
- Contributes to peak rate reduction.
- Reduces potable water needed for irrigation, toilet flushing, or other applications.
- Visible cisterns increase public awareness.

Disadvantages

- Water held within a cistern must be emptied between storms to provide volume reduction for the next storm.
- Treatment of water for reuse may be necessary depending on the contaminants in the contributing drainage area. Reusing runoff for potable uses is not recommended in the U.S., unless water is treated to all required water quality standards.
- Pumps may be required. Note: there are proprietary systems that automate the emptying before the next storm event.

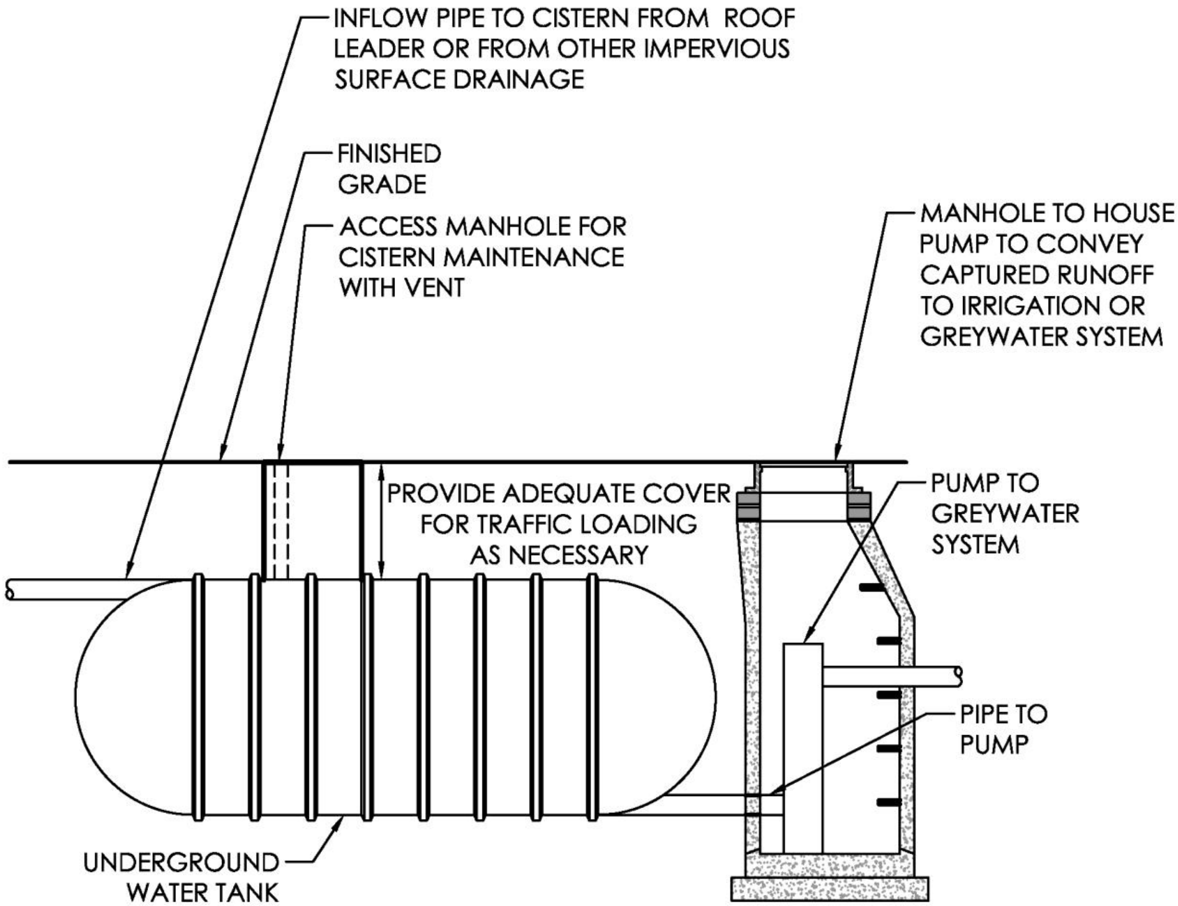


Figure 5.3.9-2. Cross-section of an underground cistern.

Applications

Runoff capture and reuse may be implemented on a variety of sites in urban and suburban environments, on residential, institutional, and commercial properties. Potential applications include office buildings, schools, libraries, multi-family residential buildings, and mixed-use areas for irrigation, fire suppression systems, toilet flushing, or other greywater uses.

Residential Rain Barrel

Figure 5.3.9-3. Rain barrels generally do not capture very large amounts of runoff, but are useful for increasing public awareness of stormwater issues.

Decorative Cistern Capture and Reuse

Figure 5.3.9-4. Cisterns can be decorative as well as functional, as is this cistern capturing runoff from a library roof. The cistern, located outside the children's library, is essentially a rain barrel with a slow-release discharge to the landscape.

Capture and Reuse for Toilet Flushing

Figure 5.3.9-5. This wooden cistern captures roof runoff at a research facility. The water is used for both toilet flushing and research needs. The captured runoff was more suitable and required less treatment for research use than the available potable water supply.

Indoor Cistern Capture and Reuse

Figure 5.3.9-6. This cistern is located indoors. Roof runoff is captured for toilet flushing within the building.

Applicable Protocols and Specifications

The following Specifications (see Appendix F) are applicable to runoff capture and reuse and must be addressed:

- Stormwater System Specifications
  - Aggregates and Drainage Layers
  - Pipes
  - Control Structures
  - Geotextiles
  - Impervious Liners and Waterproofing

Design Considerations for Runoff Capture and Reuse

The key design components for runoff capture and reuse are discussed below.

1. Location and Capture Area

- Contributing drainage areas must be considered to determine if sufficient runoff will enter cisterns to provide the necessary water demands.
- Often, contributing drainage areas are rooftops. Consideration of roof pitch, roofing materials, and large overhanging trees must be made when evaluating capture and reuse.
- Roofs made of copper or that are treated with fungicides or herbicides should not be used for rainwater capture and reuse.
- Pavement areas, such as parking lots, sidewalks, or roadways, may also be captured for irrigation reuse but may require more treatment.

2. Entrance/Flow Conditions

- When runoff enters a rain barrel or cistern through roof leaders, it should pass through a first-flush diverter that is self-draining with a cleanout (see Figure 5.3.9-7).
- Runoff captured from paved surfaces may enter a subsurface cistern through stormwater structures and piping, or after first passing through a water quality, pretreatment BMP. A first-flush diverter with a cleanout should be a part of the piping system conveying runoff to the cistern (see Figure 5.3.9-7).

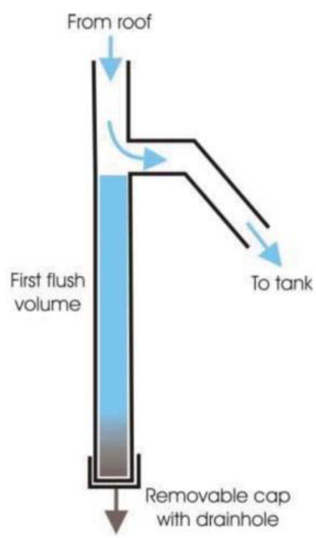


Figure 5.3.9-7. Simple first-flush diverter
(http://cehi.org.lc/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/RWHCEHI.pdf).

3. Management of Sediment, Trash, and Debris

- Screens should be used on gutters, inlets, and outlets to limit debris entering the system.
- A first-flush diverter may be used to prevent leaf litter and other debris from rooftops from entering cisterns.
- Captured runoff has the potential to collect sediment, metals, dust, bird waste, and other foreign components that may contribute to pathogenic growth, discolor collected water, or add an odor to reused water. These concerns may be minimized by avoiding collection of water from areas with large overhanging trees and installing gutter guards to prevent leaf litter and other large debris from entering the cistern from roofs.
- Regular inspection and cleaning of both the distribution system and the cistern tank itself will prevent contamination of reuse systems from sediment, trash, and debris.

4. **Storage and Stay-on-Volume**

A rain barrel or cistern provides volume management within the storage device only. The size of the storage device is dependent on the contributing drainage area.

The **SOV** is a function of the storage volume available within the storage device for the 1.0-inch or 1.6-inch storm. The portion of the project roof that is tributary to the storage device would be **considered to meet 100 percent of the SOV only if the collected volume of water is completely used by the intended reuse application within 72 hours of a rainfall event.**

5. **Area and Dimensions**

- The number of rain barrels or the size of the cistern required will be determined by the drainage area, the intended capture goal, and the usage needs of the reuse application (see Figure 5.3.9-8).
- The designer must select a pump of adequate capacity to meet the flow requirements for the reuse system.

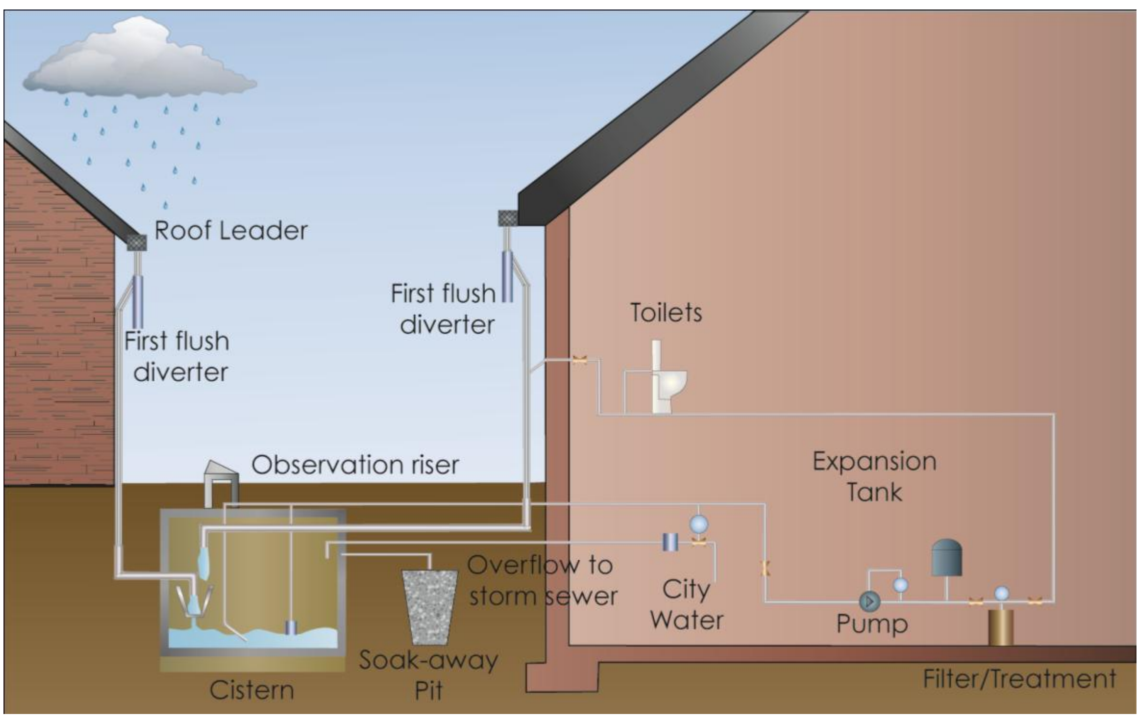


Figure 5.3.9-8. Runoff from residential buildings can be reused for irrigation, toilet flushing, or other greywater uses, such as washing machines.

6. **Overflow and Peak Rate**

- All rain barrels and cisterns must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the storage device can hold, or bypass the system when it is full. The cistern can be designed to slowly drain to the landscape between storm events to provide capacity if it is not completely used. The overflow should convey runoff to an approved discharge point.
- The size of the overflow device or orifice should be equal in area to the total of all inlet orifices.

Peak Rate Control Credit

- For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by the SOV during a portion of a 24-hour storm event. This is described in Chapter 7.

7. **Waterproofing**

- Cisterns must be watertight and seams should be checked regularly for leaks.

8. **Water Quality / Total Suspended Solids**

- All capture and reuse BMPs must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water.
- All cisterns should be shaded to the maximum extent possible to help prevent algal growth.

Sizing Calculations Worksheet for Runoff Capture and Reuse

(Link to worksheet)

Construction Considerations

- Prior to installing a rain barrel or cistern, clean roofs, gutters, and downspouts and install effective leaf screens.
- Install rain barrels and cisterns on level surfaces.
- For elevated cisterns, consider head required to provide necessary pressure for the designed reuse.
- Follow the manufacturer’s instructions for rain barrel or cistern installation.

Operations and Maintenance

All runoff capture and reuse systems require regular maintenance to ensure proper functioning.

- All parts of rain barrels and cisterns should be inspected twice annually to make sure they are operable and that there are no leaks.
- Detritus and other debris should be removed regularly from gutters, downspouts, and other screens and filters to prevent system clogging.
- Tanks should be cleaned once per year with a non-toxic cleanser.
- Backflow preventers should be checked annually for proper functioning.
- Complex systems may require pumps, valves, and other appurtenances that may require increased maintenance to ensure functionality.

5.3.11 Stormwater Planter Box

Description

Planter boxes are structures, either elevated or at ground level, which are filled with bioretention soils and plants to capture, detain, and filter stormwater runoff through physical, biological, and chemical processes. Planter boxes are commonly constructed of concrete, concrete masonry units, or brick. Planter boxes can be placed adjacent to the external downspouts of a building to receive rooftop runoff, as shown on Figure 5.3.11-1, or along streets to receive runoff from impervious surfaces such as sidewalks or roadways. Planter boxes are similar to bioretention in function, but tend to be more structural in design and appearance.

Figure 5.3.11-1. A downspout from an existing building is disconnected to a stormwater planter box.

Planter boxes may be designed with open bottoms to infiltrate water (infiltration planter box). Planter boxes may also be designed with an impervious bottom to discharge directly to the storm sewer system after temporarily detaining and treating runoff (flow-through planter box). All planter boxes must be designed with a positive drainage overflow connection to a secondary stormwater management system or storm sewer.

Planter boxes often are designed to provide temporary surface ponding prior to runoff filtering through the soils. Planter boxes may also include an underlying stone stormwater bed to increase stormwater capacity.

BMP Functions Table

BMP	Applicability*	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden*	Cost*
Stormwater Planter Box	U/S	L	M	H	M	H	M	L	M/H	L/M

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Rating varies based on design considerations.

Key Design Features
(see Figure 5.3.11-2)

- Use a combination of surface ponding, soil storage, vegetation, and potentially, stone storage and infiltration to treat stormwater runoff.
- Capture the runoff from the small (1.6 inches and less) rainfalls events, and the first portion of larger rainfall events.
- The surface area and size are directly correlated to the contributing drainage area size and land use, especially impervious surfaces. A planter box may not always be able to capture the full SOV.
- Should be level at the bottom.
- Inflow velocities at downspouts or curb cuts may require energy dissipation, such as a stone or concrete splash block, or other velocity control measures to prevent erosion.
- May be designed for infiltration by placing with an open bottom on uncompacted subgrade.
- Planter boxes adjacent to buildings to receive roof runoff should not be designed for infiltration to protect building foundations and basements.
- Planter boxes that cannot infiltrate **must** include a low-flow slow-release system. Lined and slow-release systems may be constructed on compacted fill material.
- Always include an overflow control structure or design to allow large storm events to bypass or discharge at a controlled flow rate without passing through the soils.

Applications

Planter boxes may be installed on virtually any site, but are most useful at providing stormwater management in highly urbanized areas where space is limited:

- Along roadways, sidewalks, and parking stalls
- Rooftop runoff – adjacent to or near buildings
- Treatment of stormwater runoff in urban, high-density residential and commercial sites

Advantages

- Allows for treatment of stormwater runoff in areas where space for larger BMPs is limited.
- Provides water quality treatment within a small footprint.
- Can be incorporated into a larger stormwater management system or "treatment train."
- Excellent option to provide partial SOV capture and improve water quality.
- Well suited for retrofit projects.
- Applicable to small drainage areas.

Disadvantages

- May not provide full management of SOV. However, can be combined with other BMPs to meet SOV.
- May be maintenance intensive.
- May be subject to vandalism and/or accumulated trash/debris, requiring additional maintenance.
- Highly structural nature may be cost-prohibitive in certain applications.

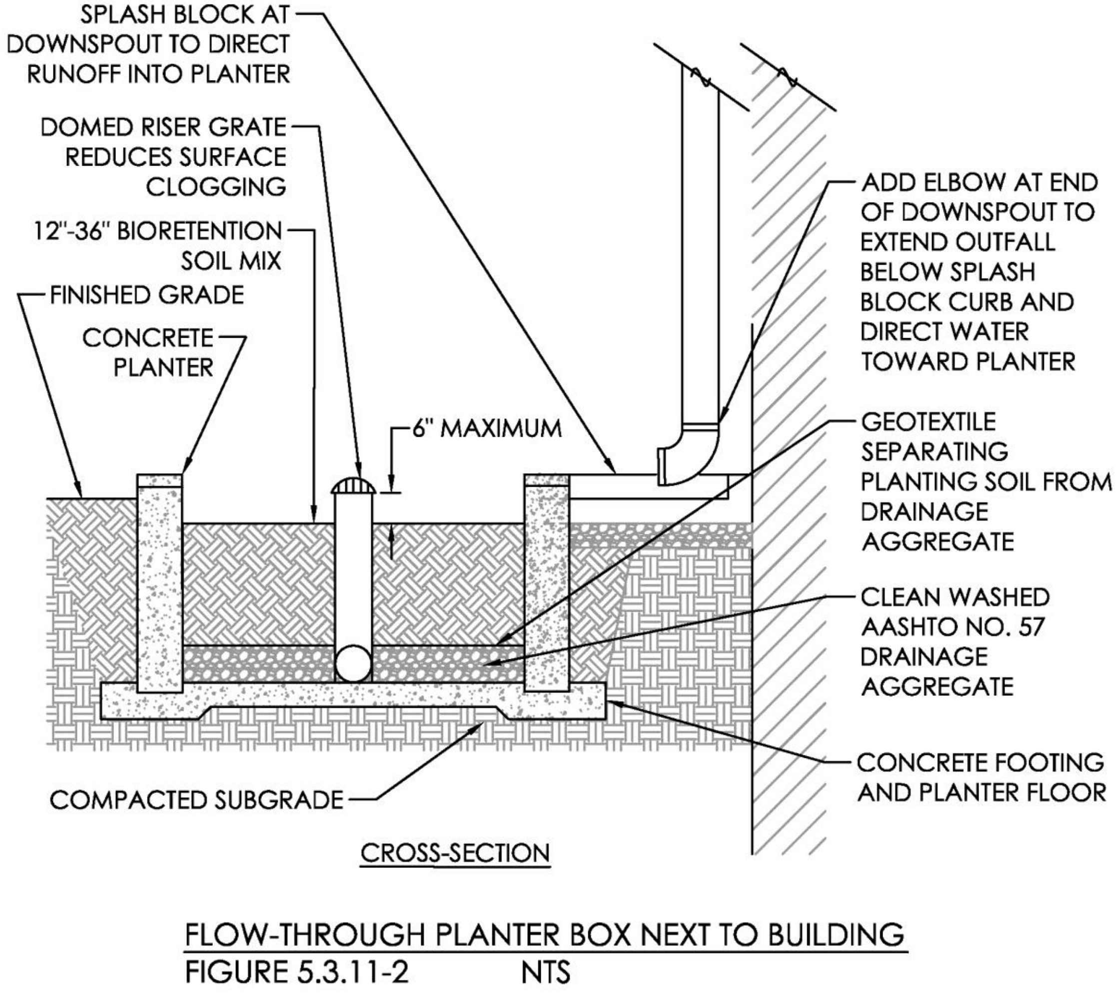


Figure 5.3.11-2. A typical cross-section for a flow-through planter box.

Applications

Planter boxes may be used in myriad ways in the urban and suburban environments, on residential, institutional, and commercial properties and within the public right-of-way. Potential applications include capturing roof runoff directly adjacent to buildings, within or along parking lots, adjacent to parking stalls on roadways, sidewalks and paths, plazas, playgrounds, and athletic fields and courts.

Streetside Planter Box

Figures 5.3.11-3a and b. This street was retrofitted to incorporate infiltration planter boxes within the right-of-way. Runoff enters the planter boxes through curb cuts.

Parking Lot Planter Box

Figure 5.3.11-4. Infiltration planter box within a parking lot, during construction. Water will enter through curb cuts, which are closed during construction. Note that the asphalt around the planter box was milled and repaved, allowing it to drain to the curb cuts following construction.

Institutional Planter Box

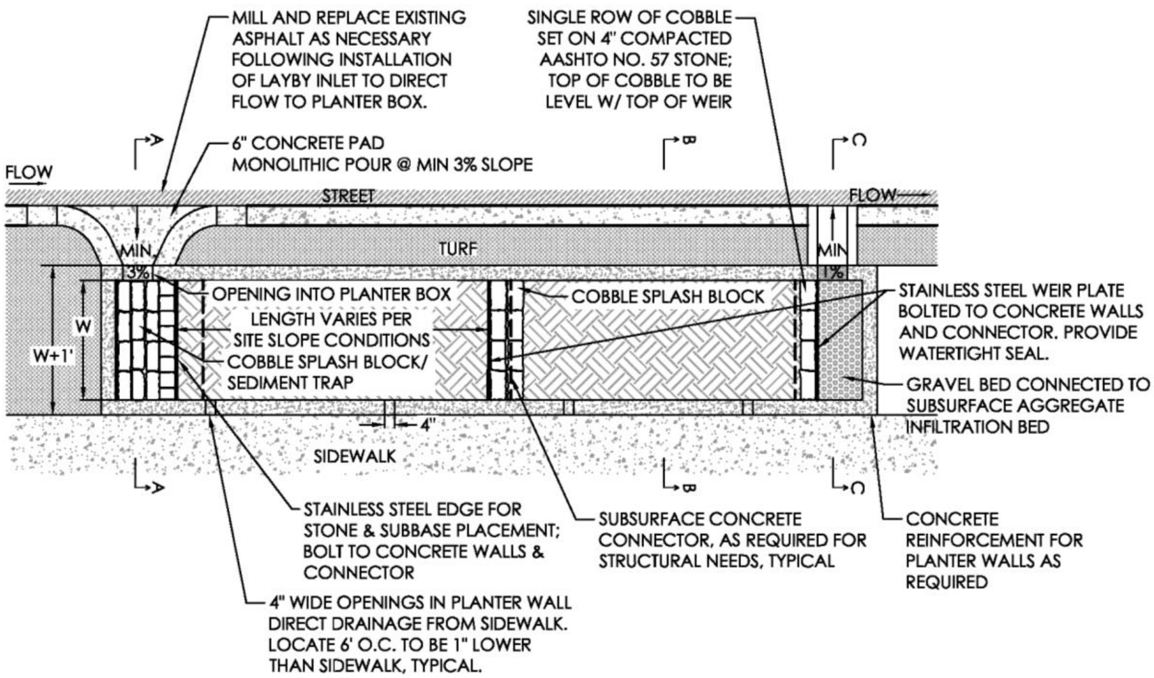
Figure 5.3.11-5. Flow-through stormwater planter boxes adjacent to this library receive roof runoff and provide plantings within the hardscape seating area. Overflow from these planter boxes is directed to a bioretention area (right side of photo). River cobbles (not shown) were added to eliminate any tripping hazard in a high-use area by reducing the depth of the planter box edge to the finished surface.

Variations

Curb Extensions/Curb Bump-Out

Large planter boxes constructed within and along a street are also referred to as “curb extensions” or “curb bump-outs.” These are sometimes constructed within over-wide drive aisles to capture stormwater as well as to provide traffic calming. Curb extensions function in the same way as planter boxes in that they are curbed vegetated areas with soil and potentially stone for stormwater storage. Curb cuts allow the entry of roadway and sidewalk runoff to sheet flow into the system.

Curb bump-outs and curb extensions must be structurally designed with consideration of the traffic loads both during and after construction. Examples of curb extension planter box design details are shown on Figures 5.3.11-6 through 5.3.11-9.



STREETSIDE PLANTER BOX EXAMPLE (SLOPES ≤ 5%) WITH INFILTRATION BED PLAN VIEW
FIGURE 5.3.11-6 NTS

Figure 5.3.11-6. Example of streetside planter box (plan view). Weirs are used to “step” the sections of the planter box down the slope.

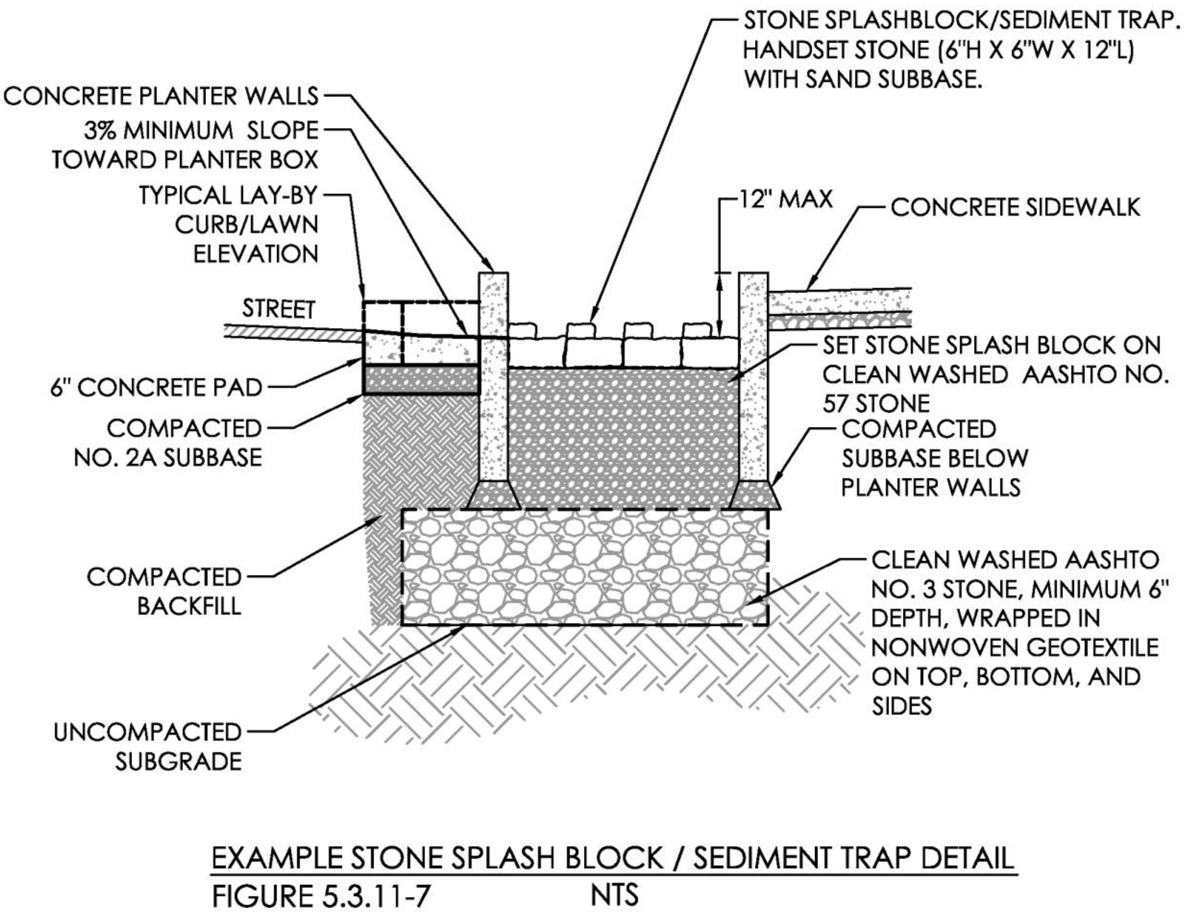


Figure 5.3.11-7. Example of the entrance conditions into a streetside planter box (cross-section A-A').

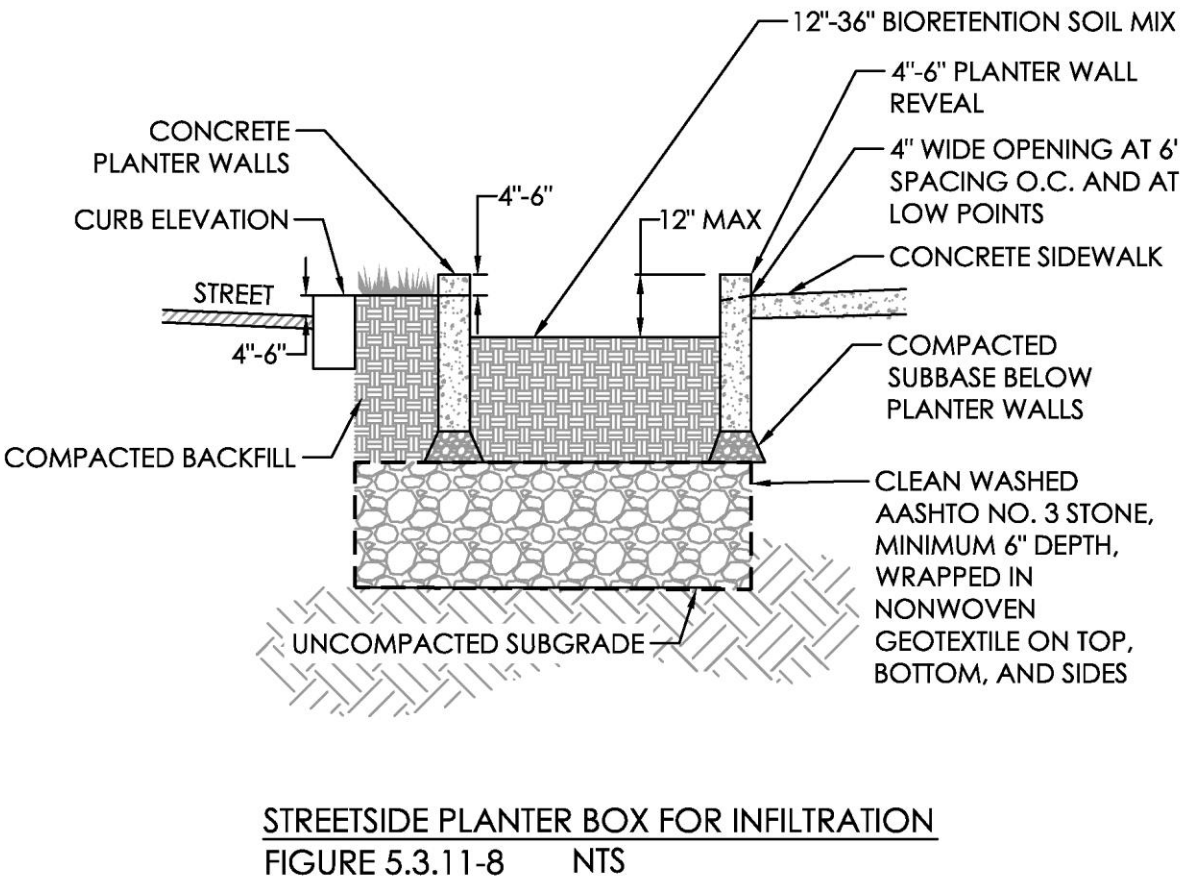
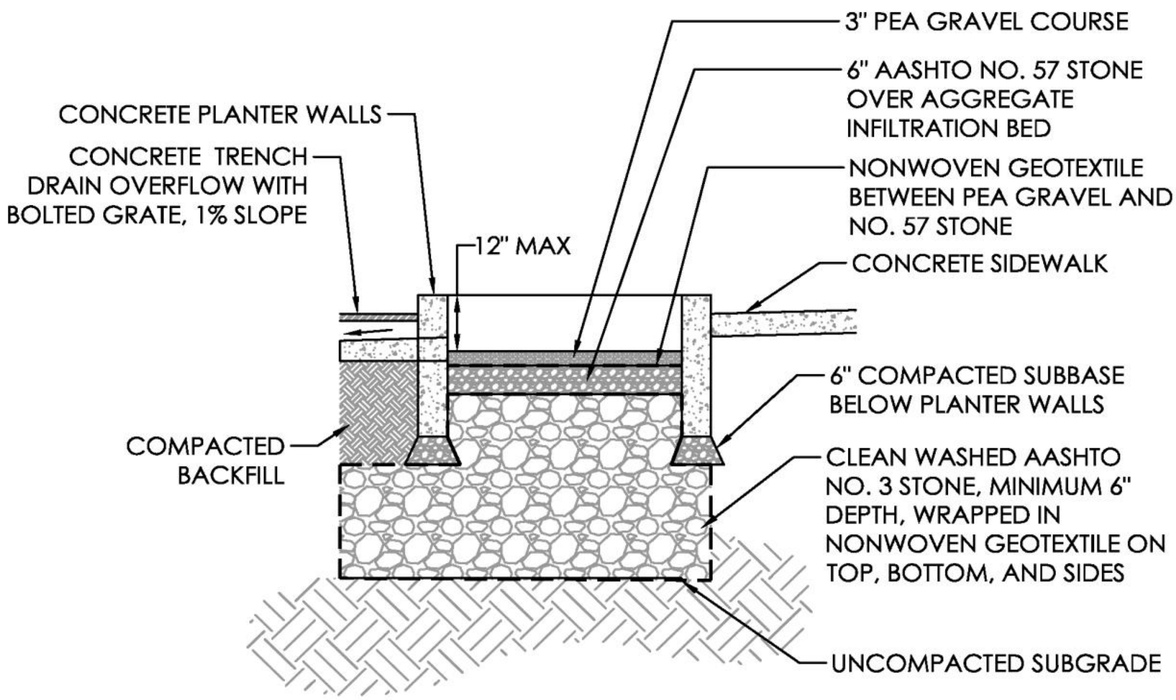


Figure 5.3.11-8. Example cross-section streetside planter box (cross-section B-B'). This planter box includes an underlying stone storage bed to increase storage capacity.



OVERFLOW FROM STREETSIDE PLANTER BOX
FIGURE 5.3.11-9 NTS

Figure 5.3.11-9. Example of the overflow (exit) from a streetside planter box (cross-section C-C'). In this application, a gravel connection to the underlying stone bed is provided.

Applicable Protocols and Specifications

The following Protocols and Specifications (see Appendices A through F) are applicable to planter boxes and must be addressed:

- Protocol 1 Setbacks from Structures
- Protocol 2 Coordination with Other Utilities
- Protocol 3 Site Evaluation and Infiltration Testing
- Protocol 4 Infiltration System Design and Construction Guidelines
- Protocol 5 Planting and Mulching Guidelines

- Appendix F
  - Aggregates and Drainage Layers
  - Stormwater System Specifications
  - Bioretention Soil Specifications
  - Pipes
  - Control Structures
  - Geotextiles
  - Impervious Liners and Waterproofing

Design Considerations for Planter Boxes

The key design components for planter boxes discussed below allow design flexibility to ensure maximum performance from this BMP.

1. Location and Capture Area

- When possible, the planter box should be located directly downstream of the existing stormwater source to maximize runoff capture.
- Planter boxes shall be constructed a minimum of 2 feet behind the curb if they are located adjacent to on-street parking. If planters are constructed in an area where there is no parking or loading, they may be constructed directly behind the curb.
- Planter boxes may intrude into the walking zone a maximum of 1 foot. A minimum walkway width of 4 feet must be maintained, 5 feet is preferred, and even greater may be required on high-volume pedestrian streets. ADA requirements must be followed.
- Planter boxes may not be placed adjacent to a designated handicapped parking space.
- Planter boxes are best suited to capture smaller drainage areas and may only capture a portion of the SOV.
- If applicable, consider linking subsurface storage beds to complementary BMPs as part of a larger system, or "treatment train," to achieve additional stormwater and streetscaping benefit.

2. Entrance/Flow Conditions

Runoff can enter a planter box from roof leaders or through stormwater pipes, sheet flow, or curb cuts. All planter boxes must be designed to receive flow that will not cause scour or erosion at the soil surface. Roof drains and concentrated flows should be directed onto a stabilized surface within the planter box, such as a splash block or cobbles, to minimize entrance velocities.

Curb cuts or trench drains are sometimes used to convey runoff from the street to stormwater planters. Curb cuts are used when planter boxes are constructed directly behind the curb (see Figure 5.3.11-10). Trench drains are used when the planter is set back from the curb and water must be conveyed under an area with pedestrian access. Concrete aprons can be placed on the street side of curb cuts or trench drains to facilitate capture. Splash blocks or another energy dissipater should be placed on the planter side of the trench drain to prevent erosion (see Figure 5.3.11-11). To capture sidewalk runoff, notches may be cut in planter walls every few feet, depending on grade and the size of contributing drainage areas.

Figure 5.3.11-10. Curb cuts convey street runoff into and out of this streetside planter box. Overflow from the planter box is captured by the downstream storm sewer inlet.

3. Management of Sediment, Trash, and Debris

Planter boxes may often collect sediment, leaf litter, trash, and other debris, so they may require frequent inspection and maintenance for removal of accumulated trash and debris. In areas of high trash or with specific concerns such as plastic shopping bags (a common concern in commercial areas), the entrance conditions may include a screen to prevent material from entering the planter box. Plant selection should consider the amount and type of trash that may enter the planter box. Items such as windblown plastic shopping bags that adhere to vegetation should be considered when selecting plants.

Figure 5.3.11-11. A concrete splash block at a downspout to a flow-through planter box prevents erosive conditions at the soil surface.

All plants, entry points, and structural components should be inspected and maintained in accordance with Chapter 8 of this manual.

4. Storage and Stay-on-Volume

A planter box provides volume management within the surface ponding area, the bioretention soil area, and the stone storage bed (if applicable). Because water must move **through** the bioretention soils, the entire volume is storage. This is different from non-vegetated BMPs, such as pervious pavement wherein the pavement section is excluded.

The **SOV** is a function of the storage volume available for the 1.0-inch or 1.6-inch storm.

Storage Volume (ft^3) =

Surface Water Volume + Soil Storage Volume + Stone Storage Volume

Surface Water Volume: Available surface water storage between soil surface and overflow structure (always equal to or less than 6 inches).

Soil Storage Volume: This is the bioretention soil volume x 0.20 void space ratio.

Soil Storage Volume (ft^3) = Soil Area (ft^2) x Soil Depth (ft) Below Overflow x Void Ratio

Stone Storage Volume: This is the stone storage volume x 0.40 void space ratio.

Stone Storage Volume (ft^3) = Stone Area (ft^2) x Stone Depth (ft) Below Overflow x Void Ratio

Void ratios are generally:

- 0.20 for bioretention soils
- 0.40 for clean-washed aggregate such as AASHTO No. 3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer

5. Area and Dimensions

One of the benefits of planter boxes is that they can be adjusted to fit the dimensions of very small spaces such as narrow spaces adjacent to buildings, along walkways and streets, and adjacent to parking areas. Planter box surface depth and curb requirements should always be considered to avoid creating trip hazards for pedestrians. The bottom of each planter box should be level.

Planter boxes are typically designed to have some surface ponding and soil storage, and they sometimes are designed with stone storage below the planting soil. By constructing the planter box without a liner or concrete bottom, a planter box may be designed for infiltration.

A basic guideline is to plan for a planter box with a surface area that does not exceed a rule-of-thumb ratio of the impervious and compacted pervious areas draining to it. The amount of rainfall volume must also be considered. The following ratios based on design rainfall depth can be used to estimate a planter box area:

1-inch Rainfall
1:10 ratio of surface area to impervious drainage area

1.6-inch Rainfall
1:8 ratio of surface area to impervious drainage area

The dimensions of ponding depth, planting soil depth and width, and stone depth and width within a planter box are a function of the quantity and velocity of stormwater it is intended to receive, and the available space for construction. The designer should estimate the depth of water, soil, and stone storage using the Sizing Calculations Worksheet.

As a general rule-of-thumb, planter boxes should meet the following guidelines:

- Surface ponding depths should not be greater than 6 inches, especially when constructed in pedestrian areas.
- Planting soils should be a minimum of 12 inches in depth and should be adequate to support the vegetation types selected for planting.
- The internal dimensions of a planter box will vary based on site conditions and the desired stormwater capture.
- If stone storage is required, the footprint of the stone may extend outside of the limits of the planter box if it is constructed without a bottom.

The recommended depths for surface water storage, soil storage, and stone storage are:

Surface Water Storage Depth: 6 inches maximum in high-use areas (along streets, at schools, in public landscapes, etc.)

Bioretention Soil Depth: Between 12 and 36 inches

Stone Storage Depth: Minimum 6 inches

6. Overflow and Peak Rate

All planter boxes must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the planter box can hold. The inclusion of a positive overflow route ensures that flooding risks and related property damage are minimized.

The positive overflow route is often in the form of a domed riser or grated pipe that is placed within a planter box at the maximum ponding depth elevation (see Figure 5.3.11-12). The domed riser or grated pipe may create a direct connection of the planter box surface to the subsurface soil or stone, and it may also serve as a positive overflow connection designed to allow high flows to be conveyed through the device to an approved discharge point. **The minimum allowable diameter of an overflow pipe for small**

planter boxes (such as adjacent to buildings) is 4 inches. All overflows must safely convey the 10-year peak rate. Designs should also ensure that in the event that an overflow pipe becomes clogged or a rain event larger than a 10-year event occurs, then overflows will have a safe emergency escape route rather than being allowed to flood buildings or other structures.

Figure 5.3.11-12. A grated pipe in a stormwater planter box provides overflow to existing storm sewer when ponding above the designed water level occurs on the surface (similar to Figure 5.3.11-2).

Planter boxes designed with surface entry points, such as through curb cuts or trench drains, may be graded such that, once full, they do not receive any more water and flow back onto the contributing surface to a complementary BMP or other approved discharge point.

Peak Rate Control and Infiltration Credit

For the purposes of site peak rate control, the designer may adjust the curve number value based on the volume managed by both the SOV and the infiltration volume that occurs during a portion of a 24-hour storm event. This will allow the designer to account for runoff that was captured by applying LID, and develop a representative lower curve number. This is described in Chapter 7.

When adjusting the curve number, the infiltration volume can be estimated as the infiltration that occurs during 12 hours of a 24-hour design storm. This will ensure that estimated infiltration volumes are not greater than the actual volume captured within the BMP.

Infiltration Volume (ft^3) = Planter Box Bottom Area (ft^2) x Infiltration Rate (in/hr) x 1/12 x 12 hours

7. Freeboard

It is recommended that planter boxes include a **minimum of 4 inches of freeboard** above the overflow route. Higher freeboard may create a deeper planter box surface, which may be undesirable in pedestrian areas. The designer should consider the potential for flooding onto sidewalks or other areas and provide control measures.

8. Underdrain

When a planter box is not designed for infiltration but is constructed with a liner or an impermeable box structure, an underdrain is required. The underdrain is used to ensure that water moves through the system so water does not pond for excessive time periods on the surface or become stagnant below grade. **Underdrain systems must be included in the design if the native soil infiltration is less than 0.1 inch per hour or if the system is lined with an impervious liner** and intended for slow release only. Underdrains must be located at the intended bottom of the planter box system (i.e., below soils and stone if applicable). See Protocol 3 for the infiltration testing procedure and Protocol 4 for infiltration system guidelines.

Planter boxes require very low discharge rates when managing the water quality volume. However, planter boxes are generally small in area and it may be difficult to construct an underdrain that can extend the discharge rate over more than 48 hours. Planter boxes that capture less than 1,000 square feet of impervious drainage are assumed to provide water quality volume with a discharge of the water quality storm between 24 and 48 hours.

9. Waterproofing

Planter boxes are uniquely able to fit into spaces where space limits the use of other BMPs, such as adjacent to structures and roadways. When planter boxes are designed near existing infrastructure or buildings, they should be designed with a liner or impermeable box structure to prevent water from causing damage to foundations and other infrastructure components (see Figure 5.3.11-13). The liner, if applied, must meet the guidelines provided in the Stormwater Specification. It is recommended that planter boxes adjacent to buildings be fully lined. Other planter boxes, such as along streets and parking lots, may be designed to discharge through the bottom of the planter box provided that the requirements of Protocol 1, Setbacks from Structures, and Protocol 2, Coordination with Other Utilities are met.

Figure 5.3.11-13. A waterproof liner is placed in the stormwater planter box to protect the adjacent building.

10. Bioretention Soils

Planter boxes should have soils adequate to support vegetation and stormwater absorption, and should meet the intent of the soils specified in Appendix F – Bioretention Soil Specification. If the planter box is intended to infiltrate, it is essential that the native subsoil within the infiltration footprint is not compacted with construction equipment.

Planter box bioretention soils must never be placed when wet or during wet weather. Soils should be protected from saturation until plant installation, and from sediment deposition into the planter box.

11. Vegetation

The type of plant and planting plan for planter boxes must comply with Protocol 5 (Appendix E) of this guide. Plants appropriate to the aesthetic and visibility needs of planter boxes should be specified. When located along streets, plant material selection must consider visibility for traffic needs. Plants cannot grow to block signs or obstruct views.

12. Water Quality/Total Suspended Solids

Planter boxes that can capture and manage the required SOV through infiltration are considered to meet all water quality requirements. Planter boxes that are underdrained must be sized to provide water quality treatment. See Chapter 7 for additional discussion.

Sizing Calculations Worksheet for Planter Boxes

(Link to worksheet)

Construction Considerations

Planter boxes should be built in the final phase of construction to prevent damage.

No sediment-laden waters should enter the planter box at any time. The planting of vegetation should coincide with the plant's growth cycle to promote successful establishment, and the planter box should be protected from runoff entering until the vegetation is adequately established.

Construction Sequence Example

Step 1 Excavate Planter Box

a. Protect planter box area from sediment and stormwater runoff during construction.
b. Excavate to the bottom elevation of the system, either the bottom of soil, the bottom of the stone, or the bottom of the structural box. If the planter box is designed for infiltration, care should be taken not to compact the existing subsoil.

Step 2 Install Planter Box

a. Construct planter box sides (and bottom) as required (see Figure 5.3.11-14).
b. Place geotextile at the bottom elevation of the excavated area for an infiltration planter box. For a flow-through planter box, place liner or waterproof constructed box (see Figure 5.3.11-15).
c. Install underdrain system if required.
d. Install stormwater piping and structures at specified elevations. Ensure that all stormwater structures are protected from sediment.
e. Fill planter box with planting soil and/or stone at elevations specified in the design (see Figure 5.3.11-15). Complete final grading of the planter box after the top layer of soil is added. Lightly tamp down soil.
f. Construct splash blocks at entry points to the planter box.
g. Construct curb cuts and/or trench drains into the system if applicable.
h. Seed and vegetate according to plans. Plant the planter box at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation may be needed in periods of little rain or drought.
i. Mulch planted area with compost mulch to prevent erosion while plants become established.
j. Protect planter boxes from sediment at all times during construction.
k. Before erosion and sediment control measures are removed or downspouts are disconnected in a planter box, verify that vegetation is sufficiently established.

Figure 5.3.11-14. A stormwater planter box during construction. The sidewalls of the planter box are constructed once the final surface grade outside the box is met.

Figure 5.3.11-15. A stormwater planter box that includes a stone bed during construction with geotextile to separate the soil and stone.

Operations and Maintenance

Both the structural components and vegetation within planter boxes require routine inspection and maintenance. Plants may require additional water during extremely dry periods and care should be exercised to ensure that appropriate measures are taken to protect plantings during periods of frost and other damaging weather events.

All inflow and outflow structures must be inspected and maintained to ensure removal of accumulated sediment and debris. See Chapter 8 for additional guidance.

5.3.12 Manufactured Devices (Proprietary Devices)

Description

Manufactured devices are pre-fabricated devices that implement technologies ranging from filtration and adsorption to vortex separation and settling to treat stormwater prior to discharge from a site.

There are many manufactured devices marketed by proprietary vendors to treat stormwater runoff. Common types of manufactured devices include hydrodynamic devices, catch basin inserts, cartridge filters, and biotreatment devices. Manufactured devices provide stormwater treatment with varying degrees of effectiveness.

Manufactured devices are effective as a water quality treatment component of a stormwater treatment system, or treatment train, which includes volume-reducing BMPs.

BMP Functions Table

BMP	Applicability	Volume Reduction	Water Quality	Peak Rate Reduction	Recharge	Runoff Temperature Mitigation	Heat Island	Habitat Creation	Maintenance Burden	Cost
Manufactured Devices*	U/S/R	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H

KEY: U = Urban; S = Suburban; R = Rural; H = High; M = Medium; L = Low

*Ratings vary between manufactured products and their application in design.

Key Design Features

- Hydraulic flow capacity of each manufactured device must match that of design storm event flows to achieve desired performance.
- Incorporate into a stormwater system or treatment train for optimal performance.
- Manufacturer installation, operation, and maintenance instructions must be followed to ensure performance.

Applications

- Roadways, walkways, and parking stalls
- Parking lots

- Playgrounds, plazas, and basketball and tennis courts
- As part of multifamily housing and commercial office areas
- Institutional: schools and university campuses

Advantages

- Can be used in areas with restricted space.
- Can be used in areas with limited infiltration capacity.
- May be engineered to target specific pollutants.

Disadvantages

- Performance is highly dependent on matching hydraulic flow capacity to that of design storm event flow rates.
- Devices are not typically visible and may be “forgotten.”
- More frequent maintenance may be required as compared to traditional technologies.
- Review time may be longer for evaluation of projected performance (third-party verified pollutant removal rates).

Applications

Manufactured devices may be used in urban and suburban environments, on residential, institutional, and commercial properties, and within the public right-of-way. Potential applications include roadways, alleys, sidewalks and paths, plazas, playgrounds, and athletic fields and courts. Manufactured devices may be implemented on virtually any project site if they are designed and constructed to meet the manufacturer’s specifications.

Applicable Protocols and Specifications

The following must be submitted to the City at the time of application: manufacturer specifications; engineering drawings of the assembled device; manufacturer’s installation, operation, repair, and maintenance instructions and recommended schedule; and any other information relevant to the application of the specific manufactured device from the manufacturer. Third-party verification of device performance must also be submitted to the City for review and consideration prior to approval.

Design Considerations for Manufactured Devices

Vendors are continually expanding and updating manufactured devices; design guidance from each applicable vendor should be consulted prior to design. At a minimum, manufactured devices must meet the following criteria:

- Selected manufactured devices must have 80 percent minimum treatment effectiveness for the removal of total suspended solids.
- Selected manufactured devices must not pond water for more than 72 hours following a storm event.
- Selected manufactured devices must not degrade water quality by resuspending floatable debris, or total suspended solids, or by leaching pollutants during subsequent storm events.
- Selected manufactured devices must not be constructed at a depth that is inaccessible by a vacuum truck/hose for cleaning and maintenance.
- Selected manufactured devices must provide a mechanism to bypass flows during storm events that exceed the water quality design peak flow rate for the device.
- Selected manufactured devices must provide a mechanism by which flows may be diverted for isolation of the device during maintenance and repair.

1. Location and Capture Area

Designed properly, manufactured devices may be incorporated on a variety of sites. With regard to hydrodynamic devices, it is important to control inflow rates. To do this, it is crucial to understand the hydraulic capacity of the device and the flow rates from contributing drainage areas.

2. Entrance/Flow Conditions

The primary design consideration for most manufactured devices is the peak rate of runoff entering the device. Devices that rely on vortex separation and/or filtration must be designed with careful consideration of peak rates of inflow into the device.

All manufactured hydrodynamic devices must be located such that inflow velocities do not exceed the maximum treatment flow rate specified by the vendor.

Upstream conveyance structures (pipes, swales, etc.) should be designed to discharge into manufactured devices at velocities no greater than the vendor-recommended maximum flow rate.

3. Freeboard

All manufactured devices must meet vendor construction specifications, including sump and freeboard requirements.

4. Management of Sediment, Trash, and Debris

Manufactured devices must not degrade water quality by resuspending floatable debris or total suspended solids or by leaching pollutants during subsequent storm events. Careful hydraulic design and diligent maintenance are required for ensured performance of manufactured devices.

5. Storage and Stay-on-Volume

Manufactured devices designed to treat runoff through filtration and/or settlement must carefully consider storage capacity and discharge velocity to ensure water is retained in the device for an appropriate length of time to allow for pollutant removal.

6. Overflow

All manufactured devices must be capable of conveying larger storms without resuspending floatable debris and/or accumulated sediment.

7. Water Quality/Total Suspended Solids

Manufactured devices must have an 80 percent minimum treatment effectiveness for total suspended solids (at the flow rate specified, when applicable), and be certified by an independent, third-party testing laboratory prior to consideration by the City. All manufactured devices should be field tested (laboratory testing of field-collected samples) and monitored after installation to ensure achievement of 80 percent total suspended solids removal.

Construction Considerations

All manufactured devices must be constructed in accordance with vendor-recommended construction specifications.

Operations and Maintenance

Operation and maintenance of manufactured devices must be performed in accordance with vendor-recommended construction specifications.

Specifications

A copy of all relevant vendor specifications must be submitted to the City prior to stormwater management plan approval.

Appendix B
Proposed Project Site Plans

Appendix B-1
Sheet 02 – Existing Site Conditions

CITY OF CHATTANOOGA CORPORATION SEAL TENNESSEE

CITY OF CHATTANOOGA

DEPARTMENT OF PUBLIC WORKS

ENGINEERING DIVISON

ADMINISTRATOR: LEE NORRIS

CITY ENGINEER: WILLIAM C. PAYNE, P.E.

ANDERSON AVENUE RETROFIT

EXISTING SITE CONDITIONS

NO.	DATE	REVISION	SIG.

CONTRACT#	S-11-001
SCALE:	1"=40'
DRAWN:	KLP
DESIGN:	MH
CHECKED:	MH

JOHN T. KINDER — REGISTERED ENGINEER — STATE OF TENNESSEE — NO. 20753

TN REGISTRATION NO. 20753

SHEET: 2 OF 8

Appendix B-2
Sheet 04 – Overall Site Improvements

CITY OF CHATTANOOGA

DEPARTMENT OF PUBLIC WORKS

ENGINEERING DIVISON

ADMINISTRATOR: LEE NORRIS

CITY ENGINEER: WILLIAM C. PAYNE, P.E.

ANDERSON AVENUE RETROFIT

OVERALL SITE IMPROVEMENTS

NO.	DATE	REVISION	SIG.

CONTRACT#	S-11-001
SCALE:	1"=30'
DRAWN:	KLP
DESIGN:	MH
CHECKED:	MH

JOHN T. KINDER REGISTERED ENGINEER STATE OF TENNESSEE NO. 20753

TN REGISTRATION NO. 20753

SHEET: 4 OF 8

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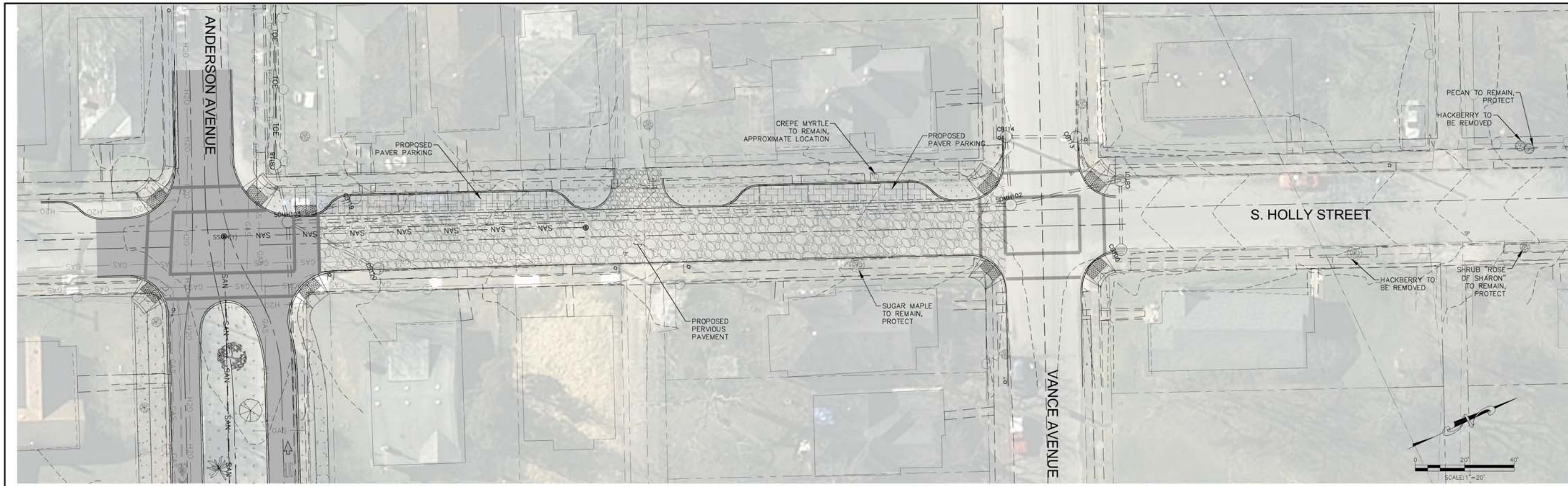
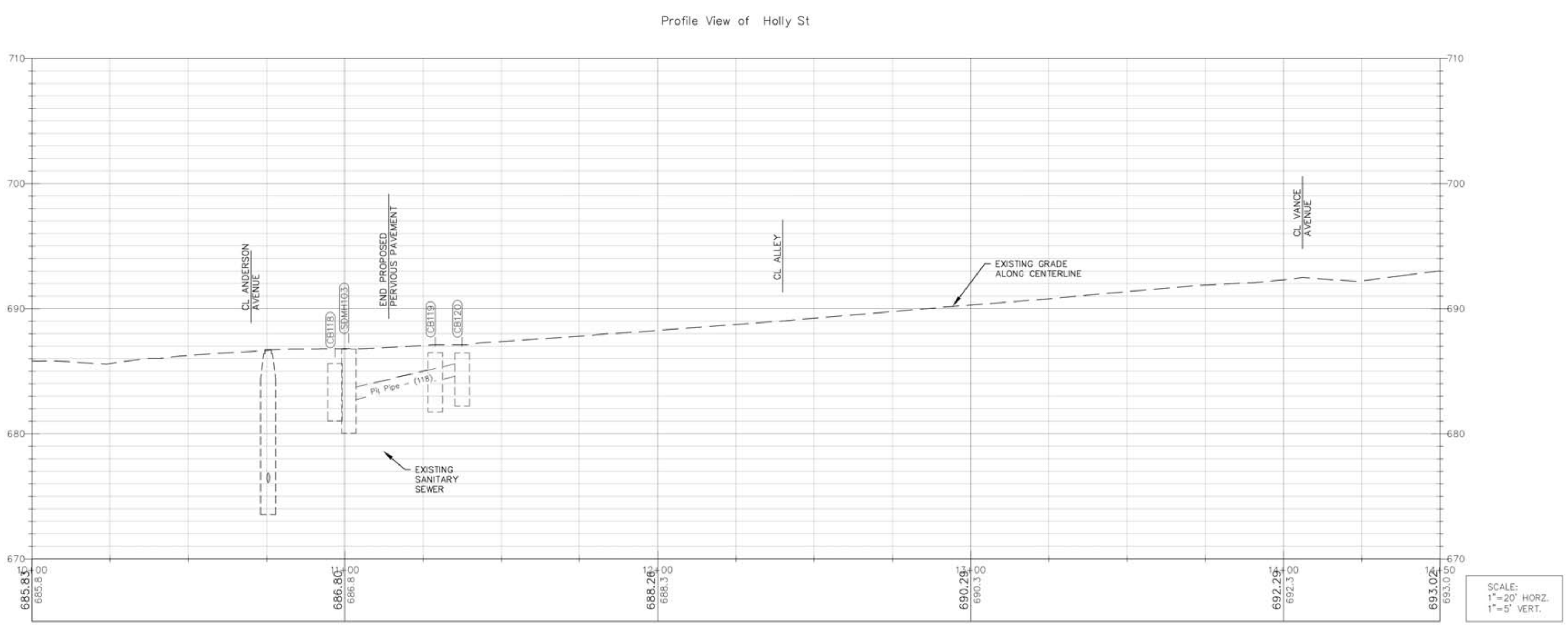
Appendix B-3
Sheet 06 – Holly Street Plan and Profile





CITY OF CHATTANOOGA

DEPARTMENT OF PUBLIC WORKS

ENGINEERING DIVISON

ADMINISTRATOR: LEE NORRIS

CITY ENGINEER: WILLIAM C. PAYNE, P.E.

ANDERSON AVENUE RETROFIT

HOLLY STREET PLAN AND PROFILE

80% TSS DEMONSTRATION SITE

NO.	DATE	REVISION	SIG.

CONTRACT#	S-11-001
SCALE:	1"=20'
DRAWN:	KLP
DESIGN:	MH
CHECKED:	MH

JOHN T. KINDER, STATE OF TENNESSEE

TN REGISTRATION NO. 20753

SHEET: 6 OF 8

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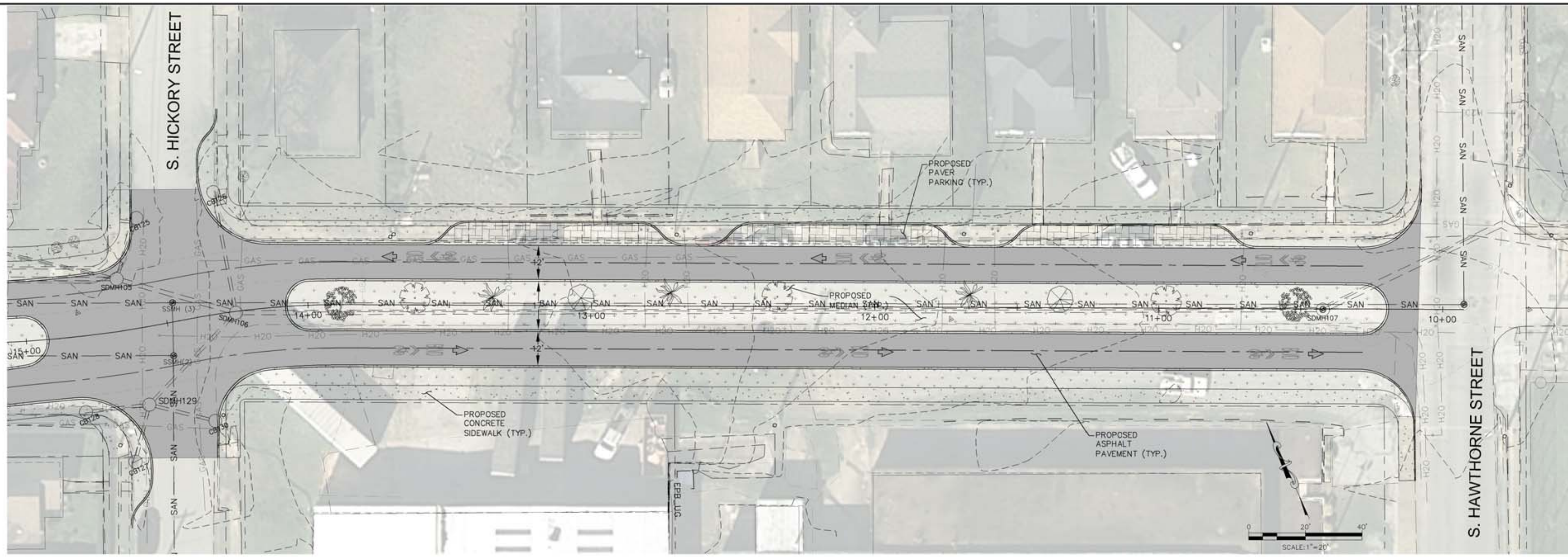
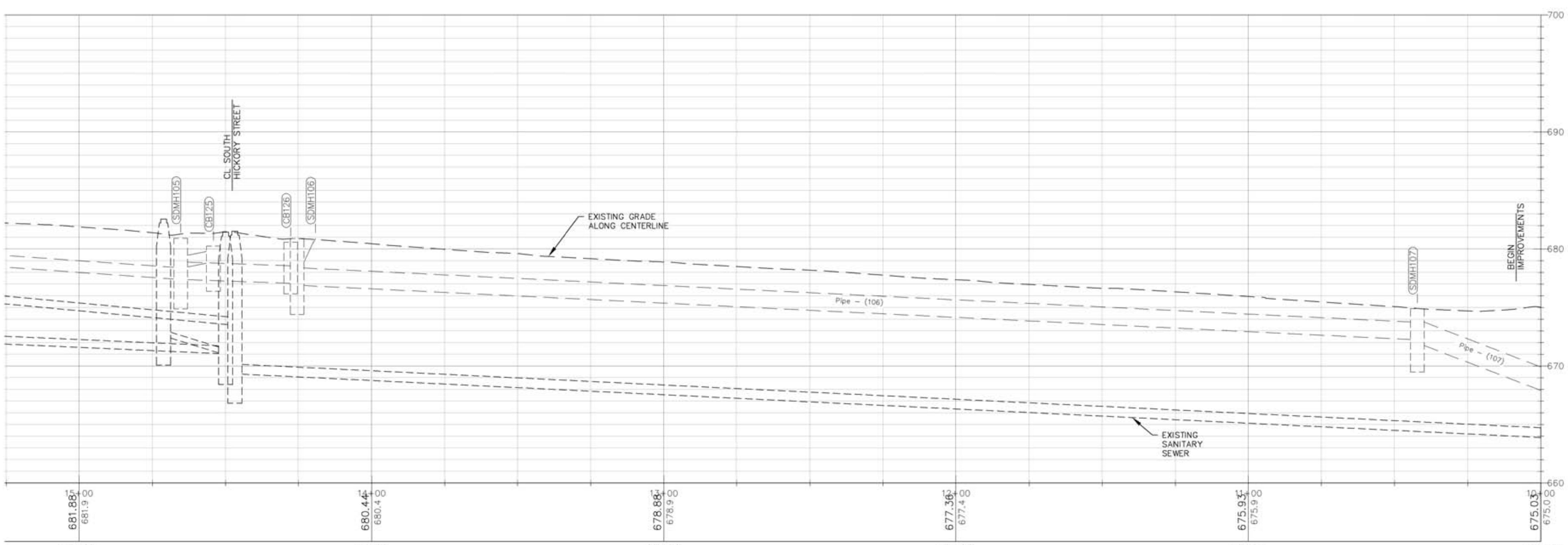
Appendix B-4
Sheet 07 – Anderson Avenue 01 Plan and Profile



Profile View of Anderson Ave



SCALE:
1"=20' HORZ.
1"=5' VERT.

CITY OF CHATTANOOGA
DEPARTMENT OF PUBLIC WORKS
ENGINEERING DIVISON

ADMINISTRATOR: LEE NORRIS
CITY ENGINEER: WILLIAM C. PAYNE, P.E.

ANDERSON AVENUE RETROFIT
ANDERSON AVENUE 01 PLAN AND PROFILE
1" CAPTURE DEMONSTRATION SITE

NO.	DATE	REVISION	SIG.

CONTRACT#	S-11-001
SCALE:	1"=20'
DRAWN:	KLP
DESIGN:	MH
CHECKED:	MH

TN REGISTRATION NO. 20753

SHEET: 7 OF 8

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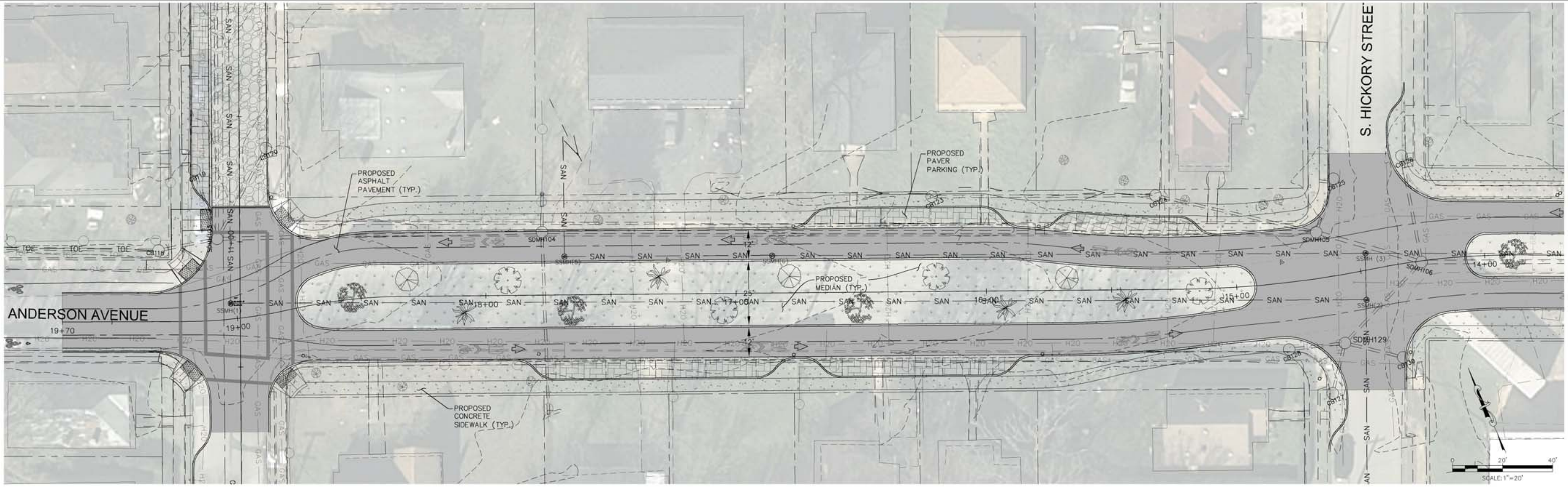
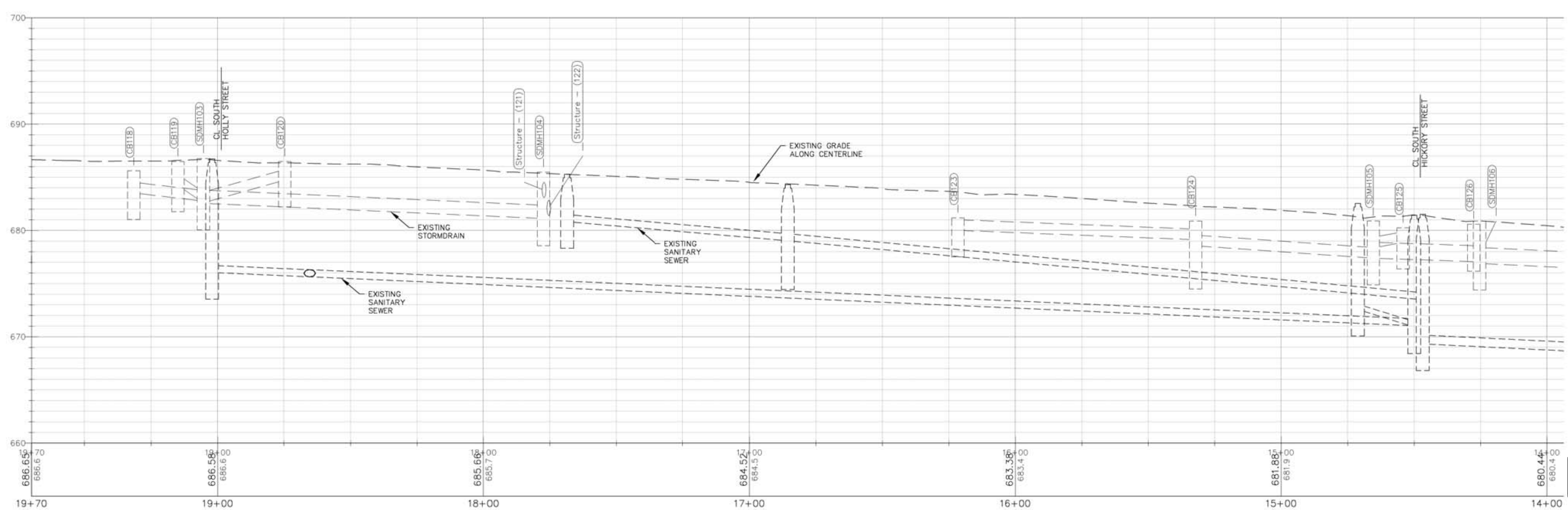
Appendix B-5
Sheet 08 – Anderson Avenue 02 Plan and Profile



Profile View of Anderson Ave



SCALE:
1"=20' HORZ.
1"=5' VERT.

CITY OF CHATTANOOGA

DEPARTMENT OF PUBLIC WORKS

ENGINEERING DIVISON

ADMINISTRATOR: LEE NORRIS

CITY ENGINEER: WILLIAM C. PAYNE, P.E.

ANDERSON AVENUE RETROFIT

ANDERSON AVENUE 02 PLAN AND PROFILE 1" CAPTURE DEMONSTRATION SITE

NO.	DATE	REVISION	SIG.

CONTRACT#	S-11-001
SCALE:	1"=20'
DRAWN:	KLP
DESIGN:	MH
CHECKED:	MH

JOHN T. KINDER
STATE OF TENNESSEE
TN REGISTRATION NO. 20753

SHEET: 8 OF 8

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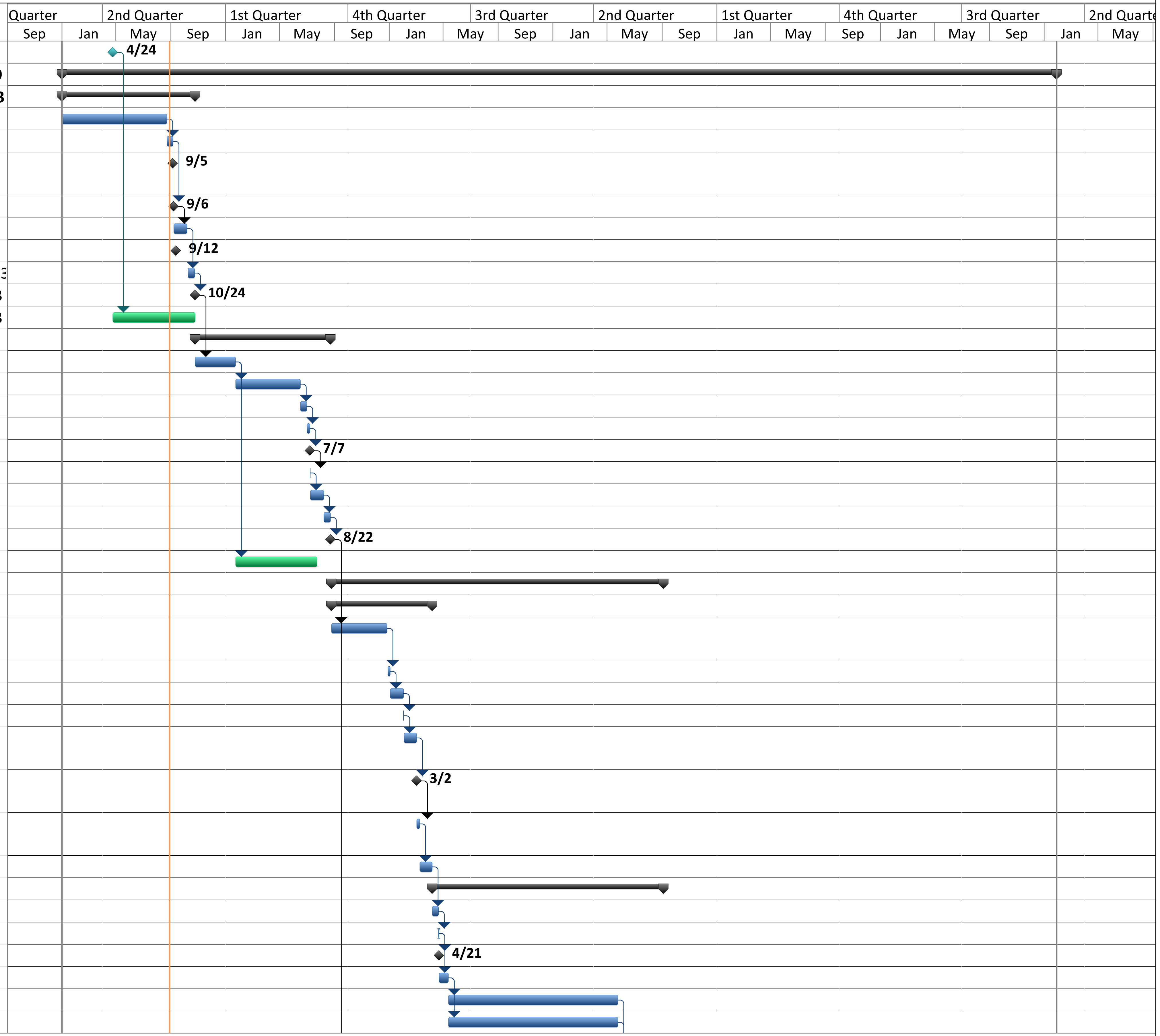
Appendix C
Detailed Project Schedule

CIty of Chattanooga
Highland Park Green Infrastructure Demonstration Project

ID	Task Mode	Task Name	Duration	Start	Finish
1		CD Effecive Date	0 days	Wed 4/24/13	Wed 4/24/13
2		**Total Project**	**1585 days?**	**Tue 1/1/13**	**Mon 1/28/19**
3		**Task 1 Complete Project Plan Execution**	**213 days**	**Tue 1/1/13**	**Thu 10/24/13**
4		Project Plan	168 days	Tue 1/1/13	Thu 8/22/13
5		PM Team Review of Deliverable	10 days	Fri 8/23/13	Thu 9/5/13
6		Neighborhood Leadership Community Meeting	0 days	Thu 9/5/13	Thu 9/5/13
7		Submit Project Plan to PDR	1 day	Fri 9/6/13	Fri 9/6/13
8		Public Review of Project Plan	30 days	Sat 9/7/13	Sun 10/6/13
9		Community Meeting	0 days	Thu 9/12/13	Thu 9/12/13
10		Review and Consider Public Comments	15 days	Wed 10/9/13	Wed 10/23/13
11		Submit Project Plan to EPA	0 days	Thu 10/24/13	Thu 10/24/13
12		Task 1 CD Duration	184 days	Wed 4/24/13	Thu 10/24/13
13		**Task 2 Complete Engineering Plans**	**216 days?**	**Fri 10/25/13**	**Fri 8/22/14**
14		EPA review of Project Plan	3 mons?	Fri 10/25/13	Wed 1/22/14
15		Engineering Plans	103 days	Thu 1/23/14	Mon 6/16/14
16		PM Team Review of Deliverable	10 days	Tue 6/17/14	Mon 6/30/14
17		Finalize Deliverable	5 days	Tue 7/1/14	Mon 7/7/14
18		Community Meeting	0 days	Mon 7/7/14	Mon 7/7/14
19		Submit Engineering Plans to PDR	1 day	Tue 7/8/14	Tue 7/8/14
20		Public Review of Engineering Plans	30 days	Wed 7/9/14	Thu 8/7/14
21		Review and Consider Public Comments	15 days	Fri 8/8/14	Fri 8/22/14
22		Submit Engineering Plans to EPA	0 days	Fri 8/22/14	Fri 8/22/14
23		Task 2 CD Duration	182 days	Thu 1/23/14	Wed 7/23/14
24		**Task 3 Project Implementation**	**530 days**	**Mon 8/25/14**	**Sat 9/3/16**
25		**Bid and Award**	161 days	**Mon 8/25/14**	**Mon 4/6/15**
26		EPA Review and Approval of Engineering Plans	3 mons	Mon 8/25/14	Fri 12/26/14
27		Prepare Advertisement for bids	5 days	Mon 12/29/14	Fri 1/2/15
28		Advertisement for bids	30 days	Sat 1/3/15	Sun 2/1/15
29		Conduct Pre-bid meeting	1 day	Mon 2/2/15	Mon 2/2/15
30		Answer RFI's & prepare addendum during bid	20 days	Tue 2/3/15	Mon 3/2/15
31		Conduct bid opening & certify bid tabulation	0 days	Mon 3/2/15	Mon 3/2/15
32		Evaluate bids & make recommendation of award	5 days	Tue 3/3/15	Mon 3/9/15
33		Conform & execute contract docs	20 days	Tue 3/10/15	Mon 4/6/15
34		**Construction**	**369 days**	**Tue 4/7/15**	**Sat 9/3/16**
35		Issue NTP	10 days	Tue 4/7/15	Mon 4/20/15
36		Pre-construction Meeting	1 day	Tue 4/21/15	Tue 4/21/15
37		Community Meeting	0 days	Tue 4/21/15	Tue 4/21/15
38		Shop drawings review	15 days	Wed 4/22/15	Tue 5/12/15
39		Construction Administration	270 days	Wed 5/13/15	Tue 5/24/16
40		On-site Project Representative	270 days	Wed 5/13/15	Tue 5/24/16



ID	Task Mode	Task Name	Duration	Start	Finish
41		Project Closeout and Record Document Review	20 days	Wed 5/25/16	Tue 6/21/16
42		Project Completion Report	20 days	Wed 6/22/16	Tue 7/19/16
43		Submit Project Completion Report to PDR	0 days	Tue 7/19/16	Tue 7/19/16
44		Public Review of Projection Completion Report	31 days	Wed 7/20/16	Fri 8/19/16
45		Review and Consider Public Comments	15 days	Sat 8/20/16	Sat 9/3/16
46		Submit Project Completion Report to EPA	0 days	Sat 9/3/16	Sat 9/3/16
47		Task 3 CD Duration	1440 days	Sat 8/23/14	Wed 8/1/18
48		**Task 4 GI Design Workshop**	**65 days**	**Sun 9/4/16**	**Fri 12/2/16**
49		EPA Review of Project Completion Report	3 mons	Sun 9/4/16	Fri 12/2/16
50		Prepare Workshop Items	20 days	Mon 9/5/16	Fri 9/30/16
51		Advertise GI Design Workshop	90 days	Sun 9/4/16	Fri 12/2/16
52		Conduct GI Design Workshop	0 days	Fri 12/2/16	Fri 12/2/16
53		Task 4 CD Duration	6 mons	Thu 8/2/18	Mon 1/28/19