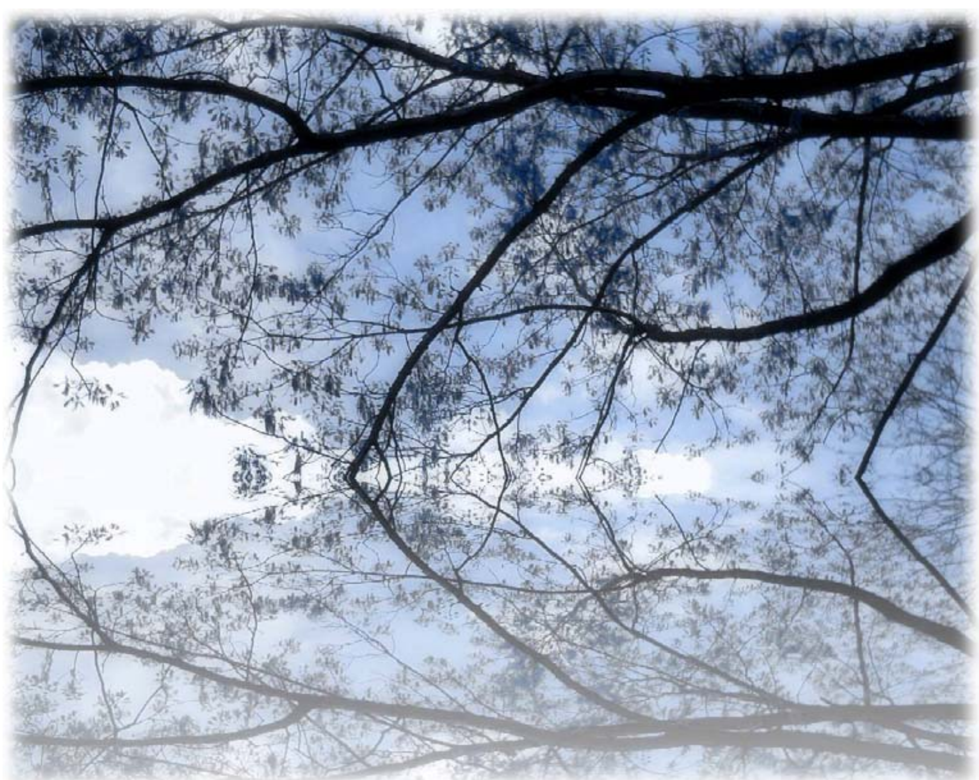
Pennsylvania Stormwater Best Management Practices Manual

DRAFT - JANUARY 2005

Section 6
Comprehensive Stormwater Management: Structural BMPs



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Section 6 Comprehensive Stormwater Management: Structural BMPs

6.1 Introduction

6.2 Groupings of Structural BMPs

6.3 Manufactured Products

6.4 Volume/Peak Rate Reduction by Infiltration BMPs

BMP 6.1 Porous Pavement with Infiltration Bed
BMP 6.2 Infiltration Basin
BMP 6.3 Subsurface Infiltration Bed
BMP 6.4 Infiltration Trench
BMP 6.5 Rain Garden / Bioretention
BMP 6.6 Dry Well / Seepage Pit
BMP 6.7 Constructed Filter
BMP 6.8 Vegetated Swale
BMP 6.9 Vegetated Filter Strip
BMP 6.10 Infiltration Berm & Retentive Grading

6.5 Volume/Peak Rate Reduction BMPs

BMP 6.11 Vegetated Roof
BMP 6.12 Rooftop Runoff – Capture & Reuse

6.6 Runoff Quality/Peak Rate BMPs

BMP 6.13 Constructed Wetland
BMP 6.14 Wet Pond / Retention Basin
BMP 6.15 Dry Extended Detention Basin
BMP 6.16 Water Quality Filter

6.7 Restoration BMPs

BMP 6.17 Riparian Buffer Restoration
BMP 6.18 Landscape Restoration
BMP 6.19 Soils Amendment & Restoration

6.8 Other BMPs and Related Structural Measures

BMP 6.20 Level Spreader
BMP 6.21 Special Detention Areas – Parking Lot, Rooftop

6.9 Protocols for Structural BMPs

Protocol 1. Infiltration Systems Guidelines
Protocol 2. Soil Evaluation and Investigation for Infiltration BMPs

6.1 Introduction

Twenty-one Structural BMPs have been listed and described in this section of the manual. As indicated in both Sections 4 and 5, many of these “structures” are natural system-based, including both vegetation and soils mechanisms as part of their functioning. In that sense, though classified as “structural,” they can and should be viewed as “green structures” or “green infrastructure.” More conventional “bricks and mortar” structures, of course, are also included in this section.

Although 21 Structural BMPs may seem like an especially long list, the list could easily have grown much longer, if the many different variations of each BMP were included separately. For example, Vegetated Swales have several different variations on the central theme; these variations have been included in this section with some explanation and reference made as to how and when such variations can be successfully applied. On the other hand, some of the Structural BMPs are quite similar to others – even to other Non-Structural BMPs (e.g., 5.2 Protect/Conserve/Enhance Riparian Areas and 6.17 Riparian Buffer Restoration), though it was ultimately decided that they merited separate treatment. As long as the Structural List might be at the present time, even more BMPs can be expected to emerge – which is as it should be.

Each BMP is outlined using approximately the same structure or outline as has been applied to the Non-Structural BMPs.

6.2 Groupings of Structural BMPs

Structural BMPs can be grouped according to the primary, though not exclusive, stormwater functions, as follows:

Volume/Peak Rate Reduction by Infiltration BMPs
Volume/Peak Rate Reduction BMPs
Runoff Quality/Peak Rate BMPs
Restoration BMPs
Other BMPs

In all cases, these stormwater functions are linked to the Recommended Site Control Guidelines which are presented in Table 3-4 in Section 3. Because of the importance of Volume/Peak Rate Reduction, most of the Structural BMPs fall into this category, not surprisingly with many of these BMPs being infiltration-oriented; these BMPs also happen to provide excellent water quality performance as well. Volume/Peak Rate functions also can be provided a smaller group of increasingly important Structural BMPs such as Vegetated Roofs and Roof Capture/Reuse (e.g., rain barrels and cisterns). Certain BMPs provide water quality and peak rate control functions, without any significant control of volume. The Restoration BMPs and Other BMP categories provide a mix of stormwater functions, and although these BMPs have not been frequently used in the past, they can offer real potential for many Pennsylvania municipalities in the future.

Lastly, two special lists of instructions, or Protocols, have been developed specifically for use with all infiltration-oriented structural BMPs:

Protocol 1: Infiltration System Guidelines
Protocol 2: Soil Evaluation and Investigation for Infiltration BMPs

Both of these Protocols follow the individual BMPs in this section. These instructions should be followed whenever infiltration-oriented BMPs are being developed. The Protocols set forth a variety of actions which should be taken, which are common to all infiltration-oriented BMPs, in order to make sure that proper site conditions and constraints are being adequately addressed, proper design considerations are being taken, and proper construction specifications are integrated into the overall design of the BMP. An especially important aspect of these instructions focuses on full and careful testing of the soil, thereby necessitating a separate Protocol that addresses soil testing and analysis in great depth. If these Protocols are followed, the risk of failed infiltration-oriented BMPs will be minimized, if not eliminated.

One of the most challenging technical issues considered in this Manual involves the selection of BMP's that have a high degree of NPS reduction or removal efficiency. In the ideal, a BMP should be selected that has a proven NPS pollutant removal efficiency for all pollutants of importance, especially those that are critical in a specific watershed (as defined by a TMDL or other process). Both Non-Structural BMP's in Section 5 and Structural BMP's in Section 6 are rated in terms of their pollutant removal performance or effectiveness. The initial BMP selection process analyzes the final site plan and estimates the potential NPS load, using Table 2-2 and Appendix A. The required reduction percentage for representative pollutants (such as 85% reduction in TSS and TP load and 50% reduction in the solute load) is achieved by a suitable combination of Non-Structural and Structural BMP's. This process is described in more detail in Section 9.

6.3 Manufactured Products

A variety of manufactured product suppliers, distributors, and manufacturers have provided extensive product information to PADEP during the course of this manual preparation process. Information has been provided thus far by:

ACF Environmental, Inc.
Terre Hill Corporation
Clearwater Technologies, Inc.

One company, ACF Environmental, Inc., in particular has provided this information and taken the time to organize its products to coordinate with the structure of this manual. Many of these products can be used in conjunction with the Non-Structural BMPs set forth in Section 5 as well as the Structural BMPs in Section 6. In many, if not most cases, proper application and use of these manufactured products can further the stormwater management goals and objectives that are at the core of this manual and the new PADEP program. At the same time, it was decided that these products did not fit into the manual as either Non-Structural or Structural BMP generic types per se. It should be noted also that Pennsylvania does not have a review and testing function established within state government at this point, as a few other states have developed, which provides for thorough testing and rating of these manufactured products. The interested reader/user is directed to other sources, such as:

Environmental Technology Evaluation Center (EvTEC) of The Civil Engineering Research Foundation (CERF), including their Stormwater Best Management Practices (BMPs) Verification Program - information available at http://www.cerf.org/evtec/index.htm & http://www.cerf.org/evtec/eval/wsdot_qr.htm

U.S. EPA's Environmental Technology Verification Program (ETV) - information available at http://www.epa.gov/etv/

The University of New Hampshire's Center for Stormwater Technology Evaluation and Verification (CSTEV) - information available at http://www.unh.edu/erg/cstev/index.htm#

The Chesapeake Bay Program's Innovative Technology Task Force (ITTF) - information about the program as well as many useful links to other programs available at http://www.chesapeakebay.net/info/innov_tech.cfm

New Jersey's Energy and Environmental Technology Verification Program - results available through the New Jersey Corporation for Advanced Technology (NJCAT) at http://www.njcat.org/

Although PADEP would like to develop an electronic bulletin board designed to array any and all such information in the future, simply as an information clearinghouse (with no evaluation function), this Manual is simply providing all of this information in an appendix, together with any/all guidance and explanation provided by the respective providers. This information is caveated as follows:

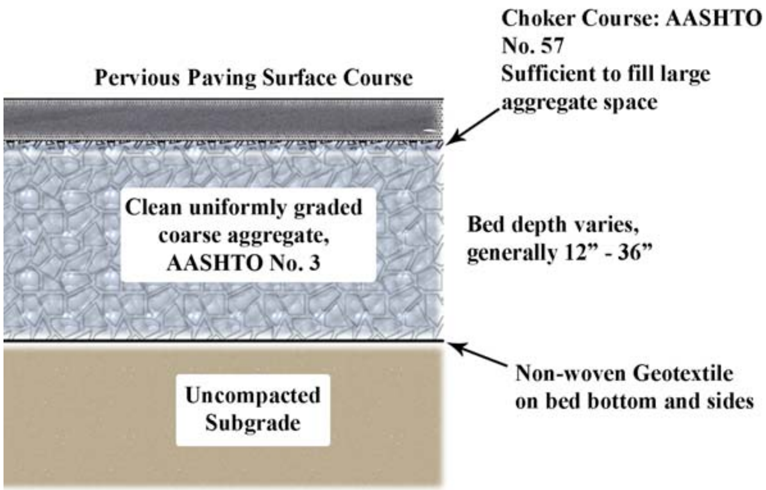
Disclaimer: The technology descriptions contained in this document including, but not limited to, information on technology applications, performance, limitations, benefits, and cost, have been provided by vendors. No attempt was made to examine, screen or verify company or technology information. The Pennsylvania Department of Environmental Protection has not confirmed the accuracy or legal adequacy of any disclosures, product performance, or other information provided by the companies appearing here. The inclusion of specific products in this document does not constitute or imply their endorsement or recommendation by the Pennsylvania Department of Environmental Protection.

But do consider using these products, as in many cases, the products can be quite cost effective and provide an excellent headstart in the stormwater management planning process. Again, PADEP hopes to be able to provide more evaluative guidance on these manufactured in the future, as budget allows.

6.4 Volume/Peak Rate Reduction by Infiltration BMPs

Volume/Peak Rate Reduction by Infiltration BMPs

BMP 6.1: Porous Pavement with Infiltration Bed



Porous pavement consists of a permeable surface course underlain by a uniformly-graded stone bed which provides stormwater management. The surface course may consist of porous asphalt, porous concrete, or various porous structural pavers laid on uncompacted soil.

Key Design Elements

- Surface with significant permeability (> 8" per hr)
- Open-graded subbase with minimum 40% void space
- Surface and stone bed suitable for design traffic loads
- Uncompacted sub-grade
- Underlain by nonwoven geotextile
- Level bed bottoms
- Generally not recommended for traffic surfaces with slope >5%.
- Provide positive stormwater overflow from beds
- Do not place bed bottom on compacted fill; fill with stone, as needed
- Protect from sedimentation during construction
- Line bed with nonwoven geotextile
- Provide perforated pipe network along bed bottom for distribution
- Allow 3 ft buffer between bed bottom and seasonal high ground water table and 2 ft for bedrock
- When possible, place infiltration beds on upland soils

Potential Applications

Residential:	**YES***
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES***
Retrofit:	**YES***
Highway/Road:	**LIMITED**

**Applicable with specific considerations to design*

Stormwater Functions

Volume Reduction:	**High**
Recharge:	**Med/High**
Peak Rate Control:	**High**
Water Quality:	**High**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

Porous pavement bed consists of a porous surface course underlain by a stone bed of uniformly graded and clean-washed course aggregate, 1-1/2 to 2-1/2 inches in size, with a void space of at least 40%. The porous pavement may consist of porous asphalt, porous concrete, or pervious pavement units. Stormwater drains through the surface, is temporarily held in the voids of the stone bed, and then slowly exfiltrates into the underlying, uncompacted soil mantle. The stone bed is designed with an overflow control structure so that during large storm events peak rates are controlled, and at no time does the water level rise to the pavement level. A layer of nonwoven geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The bed bottoms should be level and uncompacted. If new fill is required, it should consist of additional stone and not compacted soil.

Figure 6.1-1 Porous pavement at the Morris Arboretum, photo taken during Hurricane Floyd, (CA, 1983)

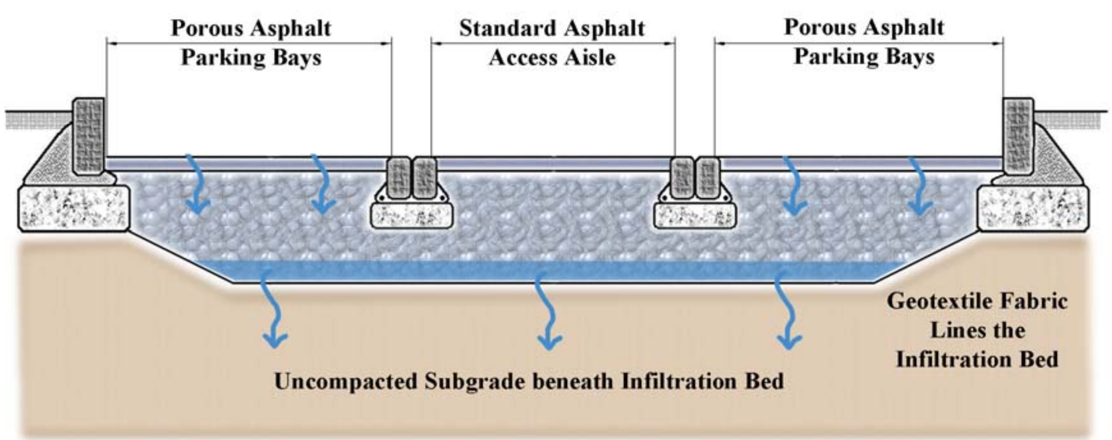


Figure 6.1-2 Cross-section through the Morris Arboretum parking lot, (CA, 2004)

Porous pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Porous pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement. Porous pavement roadways have seen wider application in Europe and Japan than in the U.S., although at least one U.S. system has been constructed. In Japan and the U.S., the application of an open-graded asphalt pavement of 1" or less on roadways has been used to provide lateral surface drainage and prevent hydroplaning, but these are applied over impervious pavement on compacted soil-grade. This application is not porous pavement.

Properly installed and maintained porous pavement has a significant life-span, and existing systems that are more than twenty years in age continue to function. Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not adversely affect porous pavement.

Porous pavement is most susceptible to failure difficulties during construction, and therefore it is important that the construction be undertaken in such as way as to **prevent**:

- Compaction of underlying soil
- Contamination of stone subbase with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto porous surface or into constructed bed

Staging, construction practices, and erosion and sediment control must all be taken into consideration when using porous pavements.

Studies have shown that porous systems have been very effective in reducing contaminants such as total suspended solids, metals, and oil and grease. When designed, constructed, and maintained according to the following guidelines, porous pavement with underlying infiltration systems can dramatically reduce both the rate and volume of runoff, recharge the groundwater, and improve water quality.

In northern climates, porous pavements have less of a tendency to form black ice and often require less plowing. Sand and gravel should never be used on porous pavements, although salt may be used on porous asphalt, and commercial deicers may be used on porous concrete. Porous asphalt and concrete surfaces provide better traction for walking paths in rain or snow conditions.

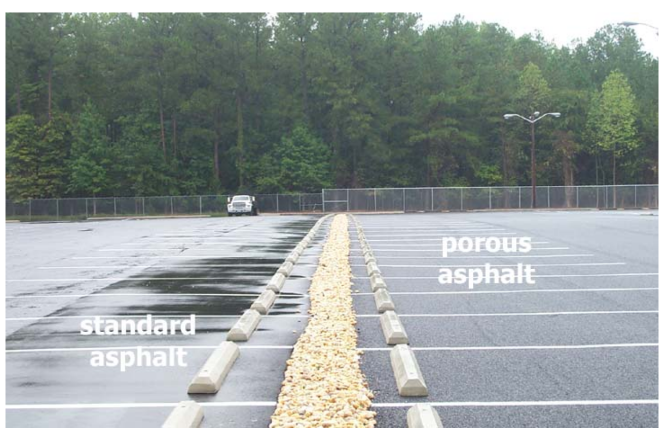


Figure 6.1-3 Standard pavement and porous pavement look very similar

Variations

Porous Bituminous Asphalt

Porous asphalt pavement was first developed in the early 1970's by the Franklin Institute in Philadelphia and consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through very small voids. Porous asphalt is placed directly on the stone subbase in a single 3 ½ inch lift that is lightly rolled to a finish depth of 2 ½ inches.

Because porous asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. Recent research in open-graded mixes for highway application has led to additional improvements in porous asphalt through the use of additives and binders. Porous asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 6.1-4 Porous asphalt parking lot at the Hockessin Library, Delaware (CA, 1991)

Figure 6.1-5 Porous asphalt parking lot at the University of North Carolina, Chapel Hill (CA, 2001)

Porous Concrete

Porous Portland Cement Concrete, or porous concrete, was developed by the Florida Concrete Association and has seen the most widespread application in Florida and southern areas. Like porous asphalt, porous concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. In northern and mid-Atlantic climates such as Pennsylvania, porous concrete should always be underlain by a stone subbase designed for stormwater management and should never be placed directly onto a soil subbase.

While porous asphalt is very similar in appearance to standard asphalt, porous concrete has a coarser appearance than its conventional counterpart. Care must be taken during placement to avoid working the surface and creating an impervious layer. Porous concrete has been proven to be an effective stormwater management BMP. Additional information pertaining to porous concrete, including specifications, is available from the Florida Concrete Association.

Figure 6.1-6 Porous concrete parking lot (www.chargerconcrete.com/perviousconcrete.htm)

Figure 6.1-7 Porous concrete parking lot at the University of North Carolina, Chapel Hill (CA, 2002)

Figure 6.1-8 The edge of this plaza at Villanova University is porous concrete (R. Traver).

Porous Paver Blocks

Figure 6.1-9 Porous paver block

Porous Paver Blocks consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. There are also products available that provide a fully permeable surface through the used of plastic rings grids filled with gravel. A number of manufactured products are available, including (but not limited to):

- Turfstone; UNI Eco-stone; Checkerblock; GravelPave

As products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application. Many paver products recommend compaction of the soil and do not include a drainage/storage area, and therefore, they do not provide optimal stormwater management benefits. A system with a compacted subgrade will not provide infiltration.

Reinforced Turf

Reinforced Turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management.

Reinforced Turf applications are excellent for applications such as Fire Access Roads, overflow parking, occasional use parking (such as at religious facilities and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. A number of products are available and the designer is encouraged to evaluate and select a product suitable to the design in question.

- Grasspave; Geoblock; Grassy Pave; Geoweb

Figure 6.1-10 Seven-acre parking area at Reliant Stadium in Houston,Texas paved with Grasspave. (www.invisiblestructures.com)

Figure 6.1-11 Standard asphalt pathway with 2ft. reinforced turf edges at Pennsylvania State University, Berks Campus, (CA, 2003)

Applications

Parking

Figure 6.1-12 Porous AC Pavement at Pennsylvania State University, Berks Campus, (CA, 2003)

Figure 6.1-13 Porous AC Pavement in Radnor Township, Delaware County (CA, 2003)

Walkways

Porous Pavement Walkways (Concrete and Asphalt)

Porous pavement, both as asphalt and concrete, has also been used in walkways and sidewalks. These installations typically consist of a shallow (12 in. minimum) aggregate trench that is sloped to follow the surface slope of the path. In the case of relatively mild surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize the infiltration capacity, at the expense of additional aggregate.

Figure 6.1-14 This pathway at Swarthmore College is made of porous asphalt, with subsurface infiltration bed beneath, 2002

Figure 6.1-15 The Visitor Center at Pennsylvania State University Main Campus used porous concrete to construct the sidewalks, 2000

Playgrounds

Figure 6.1-16 Porous asphalt playground at the Alexander-Penn-Partnership School in West Philadelphia, (CA, 2003)

Alleys

Roof drainage; Direct connection of roof leaders and/or inlets

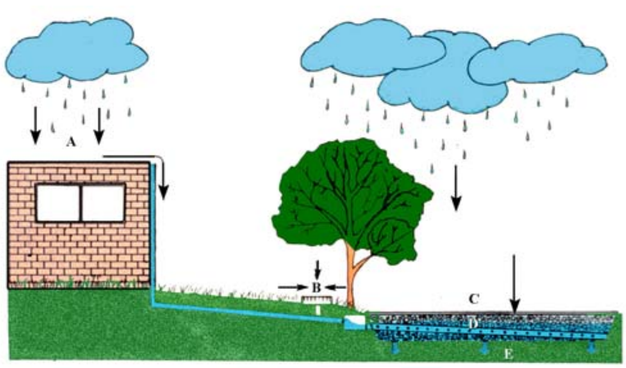


Figure 6.1-17 Conceptual schematic showing roof drains tied directly into infiltration bed below porous pavement, (CA, 2000)

Figure 6.1-18 Roof drains tie directly into the infiltration beds at the DuPont parking lot, (CA, 1985)

Limited use for roads and highways

Figure 6.1-19 Porous asphalt pavement on this road in Chandler, Arizona, (CA, 2004)

Figure 6.1-20 Porous asphalt highway (standard asphalt shoulder) in Japan, courtesy of Infrastructure Development Institute of Japan.

Design Considerations

1. Soil Investigation and Infiltration Testing Required (See Section 6.8)

2. Guidelines for Infiltration Systems must be met (i.e., depth to water table, setbacks, Loading Rates, etc.).

3. The overall site shall be evaluated for potential porous pavement / infiltration areas early in the design process, as effective porous pavement design requires consideration of grading.

4. Orientation of the parking bays along the existing contours will significantly reduce the need for cut and fill.

5. Porous Pavement and Infiltration Beds **shall not be placed on areas of recent fill** or compacted fill. Any grade adjust requiring fill shall be done using the stone subbase material. Areas of historical fill (>5 years) may be considered for porous pavement.

6. The bed bottom is not compacted, however the stone subbase is placed in lifts and lightly rolled according to the specifications.

7. During construction, the excavated bed may serve as a Temporary Sediment Basin or Trap. This will reduce overall site disturbance. The bed shall be excavated to within six (6) inches of the final bed bottom elevation for use as a sediment trap or basin. Following construction and site stabilization, sediment shall be removed and final grades established.

8. **Bed Bottoms must be level**. Sloping bed bottoms will lead to areas of ponding and reduced distribution.

9. **All systems shall be designed with an overflow system**. Water within the subsurface stone bed should never rise to the level of the pavement surface. Inlet boxes can be used for cost-effective overflow structures. All beds shall infiltrate within 72 hours.

10. While infiltration beds are typically sized to handle the increased volume from a 2-yr design storm, they must also be able to convey and mitigate the peak of the less-frequent, more intense storms (such as the 100-yr). Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal concrete weir and low-flow orifice is a common type of control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system.

11. The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the detention basin may be eliminated or significantly reduced in size.

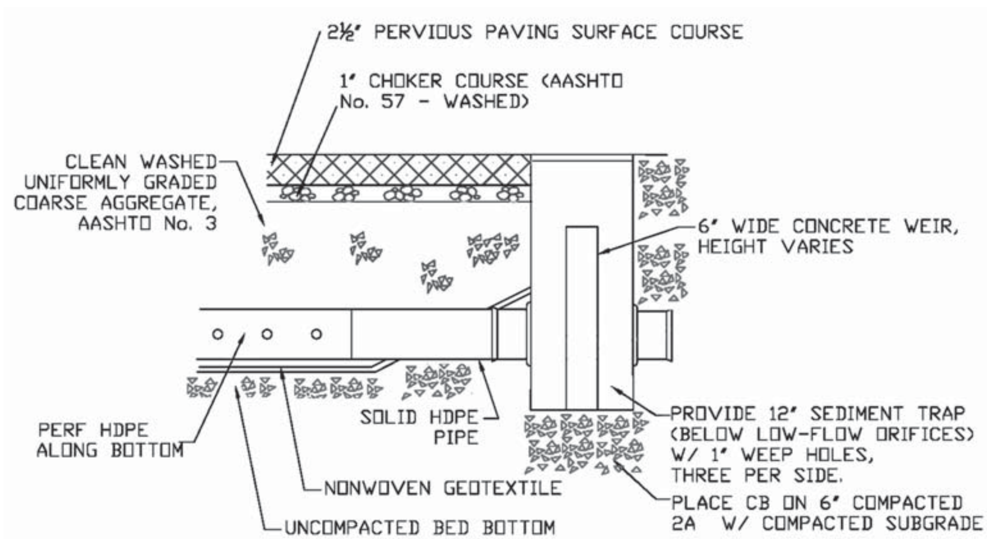


Figure 6.1-23 Detail showing typical outlet control structure

12. A weir plate or weir within an inlet or overflow control structure may be used to maximize the water level in the stone bed while providing sufficient cover for overflow pipes.

13. Perforated pipes along the bottom of the bed may be used to evenly distribute runoff over the entire bed bottom. Continuously perforated pipes shall connect structures (such as cleanouts and inlet boxes). Pipes shall lay flat along the bed bottom and provide for uniform distribution of water. Depending on size, these pipes may provide additional storage volume.

14. Roof leaders and area inlets may be connected to convey runoff water to the bed. Water Quality Inserts or Sump Inlets shall be used to prevent the conveyance of sediment and debris into the bed.

15. Infiltration areas should be located within the immediate project area in order to control

runoff at its source. Expected use and traffic demands shall also be considered in porous pavement placement.

16. **Control of Sediment is critical**. Rigorous installation and maintenance of erosion and sediment control measures is required to prevent sediment deposition on the pavement surface or within the stone bed. Nonwoven geotextile may be folded over the edge of the pavement until the site is stabilized. The Designer should consider the placement of Porous Pavement to reduce the likelihood of sediment deposition. **Surface sediment shall be removed by a vacuum sweeper and shall not be power-washed into the bed.**

17. **Infiltration Beds may be place on a slope by benching or terracing parking bays.** Orienting parking bays along existing contours will reduce site disturbance and cut/fill requirements.

Figure 6.1-21 Terraced infiltration beds below porous pavement at a steep site

18. The underlying infiltration bed is typically 12-36 in deep and comprised of clean, uniformly-graded aggregate with approximately 40% void space. AASHTO No.3, which ranges 1.5-2.5in in gradation, is often used. Depending on local aggregate availability, both larger and smaller size aggregate has been used. The critical requirements are that the aggregate be **uniformly-graded**, **clean washed**, and contain **40% void space**. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, and site grading. Infiltration beds are typically sized to mitigate the increased runoff volume from a 2-yr design storm.

19. While most porous pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate, at an increased cost.

20. All Porous Pavement installations must have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved 2 ft wide stone edge drain connected directly to the bed between the wheel stop. In curbed lots, inlets with 12 in sediment traps may be required at low spots. Backup drainage elements will ensure the functionality of the infiltration system if the porous pavement is compromised.

Figure 6.1-22 Porous parking lot w/ stone edge drain at the SmithKline Beecham Site

21. In areas with poorly-draining soils, infiltration beds below porous pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. Only in extreme cases (i.e. industrial sites with contaminated soils) may the aggregate bed be lined to prevent infiltration.

22. In those areas where the threat of spills and groundwater contamination is quite likely, pretreatment systems, such as filters and wetlands, may be required before any infiltration occurs. In Hot Spot areas, such as truck stops, and fueling stations, the appropriateness of Porous Pavement must be carefully considered. A stone Infiltration Bed located beneath standard pavement, preceded by spill control and water quality treatment, may be more appropriate.

23. The use of porous pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. An example would include an infiltration system constructed under a conventional driveway. Educational signage at porous pavement installations may guarantee its prolonged use in some areas.

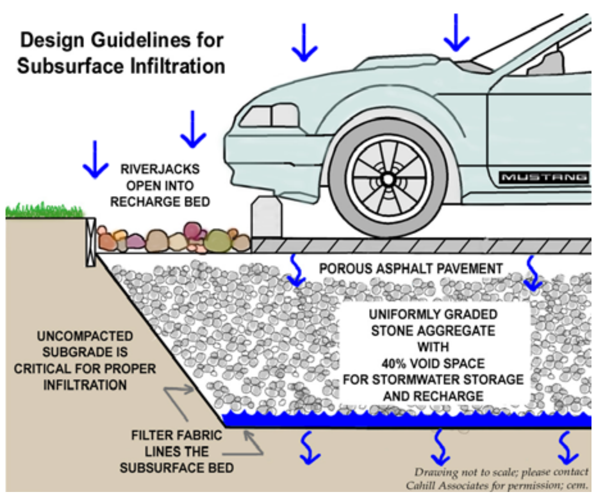


Figure 6.1-24 Design guidelines for porous pavement with subsurface infiltration, (CA 2004)

Detailed Stormwater Functions

Infiltration Area

For non-carbonate geologic areas, the minimum infiltration area shall be based on the following equation:

Minimum Infiltration Area =
Contributing Impervious Area (including infiltration area under porous pavement) / 6 ; depending on soil infiltration capacity.

For carbonate geologic areas, the minimum infiltration area shall be based on the following equation:

Minimum Infiltration Area =
Contributing Impervious Area (including infiltration area under porous pavement) / 4; where conditions warrant, the infiltration area can be increased as necessary

Volume Reduction Calculations

Volume = Depth* (ft) x Area (sf) x Void Space

*Depth is the depth of the water surface during a storm event, depending on the drainage area and conveyance to the bed.

Infiltration Volume = Bed Bottom Area (sf) x Infiltration design rate (in/hr) x Infiltration period* (hr) x (1/12)

*Infiltration Period is the time when bed is receiving runoff and capable of infiltration. Not to exceed 72 hours.

Peak Rate Mitigation

See in Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement

See in Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Due to the nature of construction sites, porous pavement and other infiltration measures should by installed toward the end of the construction period, if possible. Infiltration beds under porous pavement may be used as temporary sediment basins or traps provided they are excavated to within 6-12 in. of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to the its final grade and the porous pavement system is installed.

2. The existing subgrade under the bed areas shall NOT be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement.

3. Where erosion of subgrade has caused accumulation of fine materials and/or surface

ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake (or equivalent) and light tractor. All fine grading shall be done by hand. All bed bottoms are level grade.

4. Earthen berms (if used) between infiltration beds shall be left in place during excavation. These berms do not require compaction if proven stable during construction.

Figure 6.1-25 Unexcavated earthen berms between terraced bed bottoms

5. Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer's standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of 16 in. It shall also be secured at least 4 ft. outside of bed in order to prevent any runoff or sediment from entering the storage bed. This edge strip shall remain in place until all bare soils contiguous to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile along bed edges can be cut back to gravel edge.

6. Clean (washed) uniformly-graded aggregate is placed in the bed in maximum 8in lifts. Each layer shall be lightly compacted, with the construction equipment kept off the bed bottom as much as possible. Once bed aggregate is installed to the desired grade, a 1 in. layer of choker base course (AASHTO #57) aggregate shall be installed uniformly over the surface in order to provide an even surface for paving.

Figure 6.1-26 Aggregate being placed in the infiltration bed

Figure 6.1-27 The uniformly-graded stone must be washed and clean.

7. The porous bituminous asphalt is installed just like standard bituminous asphalt. Porous pavement shall be laid in one lift directly over the storage bed and stone base course to a 2.5 in. thickness. It shall not be installed on wet surfaces or when the ambient temperature is 60 degrees Fahrenheit or lower. Compaction of the surface course shall take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction. More rolling could cause a reduction in the surface course porosity.

Prior to installation, the porous pavement mix shall not be stored in excess of 90 minutes. Transporting of the mix to the site shall be in vehicles with smooth, clean dump beds that have been sprayed with a non-petroleum release agent. The mix shall be covered during transport to control cooling.

After final rolling, no vehicular traffic of any kind shall be permitted on the surface until cooling and hardening has taken place, and in no case within the first 48 hours.

The full permeability of the pavement surface shall be tested by application of clean water at the rate of at least 5 gpm over the surface, using a hose or other distribution devise. All applied water shall infiltrate directly without puddle formation or surface runoff.

Maintenance Issues

The primary goal of porous pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from being clogged with fine sediments. To keep the system clean throughout the year and prolong its life-span, the pavement surface should be vacuumed biannually with a commercial cleaning unit**. Pavement washing systems or compressed air units are not recommended.** All inlet structures within or draining to the infiltration beds should also be cleaned out on a biannual basis.

Planted areas adjacent to porous pavement should be well maintained to prevent soil washout onto the pavement. If any washout does occur it should be cleaned off the pavement immediately to prevent further clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected on a semiannual basis. All trash and other litter that is observed during these inspections should be removed.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking or spilling dirt onto the pavement. Furthermore, all construction or hazardous materials carriers should be prohibited from entering a porous pavement lot.

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
  - Porous pavement systems generally perform better and require less treatment than standard pavements
  - Do not apply abrasives such as sand or cinders on or adjacent to porous pavement
  - Snow plowing is fine but should be done carefully (i.e. set the blade slightly higher than usual)
  - Salt application is acceptable, although more environmentally-benign deicers are preferable

- Repairs
  - Surface should never be seal-coated
  - Damaged areas less than 50 sq. ft. can be patched with porous or standard asphalt
  - Larger areas should be patched with an approved porous asphalt

Winter Maintenance

Winter maintenance for a porous parking lot may be necessary but is usually less intensive than that required for a standard asphalt lot. By its very nature, a porous pavement system with 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 porous 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 porous pavement. Snow plowing is fine, 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 porous pavement, though nontoxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferable.

Repairs

Potholes in the porous pavement are extremely unlikely; though 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 porous mix. If an area greater than 50 sq. ft. is in need of repair, approval of patch type must be sought from either the engineer or 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.

Cost Issues

- Porous Asphalt, with additives, is generally 10% to 20% higher in cost than standard asphalt on a unit area basis.

- Porous Concrete as a material is generally more expensive than asphalt and requires more labor and experience for installation due to specific material constraints.

- Porous Paver Blocks vary in cost depending on type and manufacturer.

The added cost of a porous pavement/infiltration system lies in the underlying stone bed, which is generally deeper than a conventional subbase and wrapped in geotextile. However, this additional cost is often offset by the significant reduction in the required number of inlets and pipes. Also, since porous pavement areas are often incorporated into the natural topography of a site, there generally is less earthwork and/or deep excavations involved. Furthermore, porous pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space, etc.) for detention basins. When all of these factors are considered, porous pavement with infiltration has proven itself less expensive than the traditional approach. Recent installations have averaged between $2000 and $2500 per parking space, for the pavement and stormwater management.

Specifications

The following specifications are provided for informational purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Stone** for infiltration beds shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29. Choker base course aggregate for beds shall be 3/8 inch to 3/4 inch uniformly graded coarse aggregate AASHTO size number 57 per Table 4, AASHTO Specifications, Part I, 13th Ed., 1998 (p. 47).

2. **Non-Woven Geotextile** shall consist of needled nonwoven polypropylene fibers and meet the following properties:
   a. Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
   b. Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
   c. Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft^2
   d. UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
   e. Heat-set or heat-calendared fabrics are not permitted.

   Acceptable types include Mirafi 140N, Amoco 4547, Geotex 451, or approved others.

3. **Pipe** shall be continuously perforated, smooth interior, with a minimum inside diameter of 8-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

4. **Storm Drain Inlets and Structures**
   a. Concrete Construction: Concrete construction shall be in accordance with Section 1001, PennDOT Specifications, 1990 or latest edition.

b. Precast Concrete Inlets and Manholes: Precast concrete inlets may be substituted for cast-in-place structures and shall be constructed as specified for cast-in-place. Precast structures may be used in only those areas where there is no conflict with existing underground structures which may necessitate revision of inverts. Precast structures shall be placed on a 6-inch bed of compacted coarse aggregate Size No. 2A. Reinforcement steel, if required for handling, shall have a minimum of 2-inch cover. Handling devices, if used, shall be removable and the holes filled with concrete. Type M standard PennDOT inlet boxes will be modified to provide minimum 12" sump storage and bottom leaching basins, open to gravel sumps in sub-grade, when situated in the recharge bed.

c. All PVC Catch Basins/Cleanouts/Inline Drains shall have H-10 or H-20 rated grates, depending on their placement (H-20 if vehicular loading).

d. Steel reinforcing bars over the top of the outlet structure shall conform to ASTM A615, grades 60 and 40.

e. HDPE Flared End Section shall be installed according to manufacturers' specifications.

f. Permanent turf reinforcement matting shall be installed according to manufacturers' specifications.

5. **Porous Bituminous Asphalt**

Bituminous surface course for **porous paving** shall be two and one-half (2.5) inches thick with a bituminous mix of 5.75% to 6% by weight dry aggregate. In accordance with ASTM D6390, drain down of the binder shall be no greater than 0.3%. If more absorptive aggregates, such as limestone, are used in the mix, then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Porous Asphalt Pavements" (2003) or PennDOT equivalent.

Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22 as specified in AASHTO MP-1. The elastomer polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by weight of the total binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.

Aggregate shall be minimum 90% crushed material and have a gradation of:

U.S. Standard Sieve Size	Percent Passing
½ (12.5 mm)	100
3/8 (9.5 mm)	92-98
4 (4.75 mm)	34-40
8 (2.36 mm)	14-20
16 (1.18 mm)	7-13
30 (0.60 mm)	0-4
200 (0.075mm)	0-2

Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix when tested in accordance with AASHTO T 283. The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-1664. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

Porous pavement shall not be installed on wet surfaces or when the ambient air temperature is 50 degrees Fahrenheit or lower. The temperature of the bituminous mix shall be between 300 degrees Fahrenheit and 350 degrees Fahrenheit (based on the recommendations of the asphalt supplier).

6. **Porous Concrete**

GENERAL

Weather Limitations: Do not place Portland cement pervious pavement mixtures when the ambient temperature is 40 degrees Fahrenheit or lower, unless otherwise permitted in writing by the Engineer.

Test Panels: Regardless of qualification, Contractor is to place, joint and cure two test panels, each to be a minimum of 225 sq. ft. at the required project thickness to demonstrate to the Engineer's satisfaction that in-place unit weights can be achieved and a satisfactory pavement can be installed at the site location.

Test panels may be placed at any of the specified Portland Cement pervious locations. Test panels shall be tested for thickness in accordance with ASTM C 42; void structure in accordance with ASTM C 138; and for core unit weight in accordance with ASTM C 140, paragraph 6.3.

Satisfactory performance of the test panels will be determined by:
Compacted thickness no less than ¼" of specified thickness.

Void Structure: 12% minimum; 21% maximum. Unit weight plus or minus 5 pcf of the design unit weight.

If measured void structure falls below 15% or if measured thickness is greater than ¼" less than the specified thickness of if measured weight falls less than 5 pcf below unit weight, the test panel shall be removed at the contractor's expense and disposed of in an approved landfill.

If the test panel meets the above-mentioned requirements, it can be left in-place and included in the completed work.

CONCRETE MIX DESIGN

Contractor shall furnish a proposed mix design with proportions of materials to the Engineer prior to commencement of work. The data shall include unit weights determined in accordance with ASTM C29 paragraph 11, jigging procedure.

MATERIALS

Cement: Portland Cement Type I or II conforming to ASTM C 150 or Portland Cement Type IP or IS conforming to ASTM C 595.

Aggregate: Use No 8 coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448. If other gradation of aggregate is to be used, submit data on proposed material to owner for approval.

Air Entraining Agent: Shall comply with ASTM C 260 and shall be used to improve resistance to freeze/thaw cycles.

Admixtures: The following admixtures shall be used:

Type D Water Reducing/Retarding – ASTM C 494.

A hydration stabilizer that also meets the requirements of ASTM C 494 Type B Retarding or Type D Water Reducing/Retarding admixtures. This stabilizer suspends cement hydration by forming a protective barrier around the cementitious particles, which delays the particles from achieving initial set.

Water: Potable shall be used.

Proportions:
Cement Content: For pavements subjected to vehicular traffic loading, the total cementitious material shall not be less than 600 lbs. Per cy.
Aggregate Content: the volume of aggregate per cu. yd. shall be equal to 27 cu.ft. when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure. Fine aggregate, if used, should not exceed 3 cu. ft. and shall be included in the total aggregate volume.

Admixtures: Shall be used in accordance with the manufacturer's instructions and recommendations.

Mix Water: Mix water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water yielding a cement paste with a dull-dry appearance has insufficient water for hydration).

- Insufficient water results in inconsistency in the mix and poor bond strength.
- High water content results in the paste sealing the void system primarily at the bottom and poor surface bond.

An aggregate/cement (A/C) ratio range of 4:1 to 4.5:1 and a water/cement (W/C) ratio range of 0.34 to 0.40 should produce pervious pavement of satisfactory properties in regard to permeability, load carrying capacity, and durability characteristics.

INSTALLATION
Portland Cement Pervious Pavement Concrete Mixing, Hauling and Placing:
Mix Time: Truck mixers shall be operated at the speed designated as mixing speed by the manufacturer for 75 to 100 revolutions of the drum.

Transportation: The Portland Cement aggregate mixture may be transported or mixed on site and should be used within one (1) hour of the introduction of mix water, unless otherwise approved by an engineer. This time can be increased to 90 minutes when utilizing the hydration stabilizer specified in Section 2.2.C.4. Each truck should not haul more than two (2) loads before being cycled to another type concrete. Prior to placing concrete, the subbase shall be moistened and in a wet condition. Failure to provide a moist subbase will result in a reduction in strength of the pavement.

<u>Discharge</u>: Each mixer truck will be inspected for appearance of concrete uniformity according to Section 2.2.C.6.d. Water may be added to obtain the required mix consistency. A minimum of 20 revolutions at the manufacturer's designated mixing speed shall be required following any addition of water to the mix. Discharge shall be a continuous operation and shall be completed as quickly as possible. Concrete shall be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete. The practice of discharging onto subgrade and pulling or shoveling to final placement is not allowed.

<u>Placing and Finishing Equipment</u>: Unless otherwise approved by the Owner or Engineer in writing, the Contractor shall provide mechanical equipment of either slipform or form riding with a following compactive unit that will provide a minimum of 10 psi vertical force. The pervious concrete pavement will be placed to the required cross section and shall not deviate more than +/- 3/8 inch in 10 feet from profile grade. If placing equipment does not provide the minimum specified vertical force, a full width roller or other full width compaction device that provides sufficient compactive effort shall be used immediately following the strike-off operation. After mechanical or other approved strike-off and compaction operation, no other finishing operation will be allowed. If vibration, internal or surface applied, is used, it shall be shut off immediately when forward progress is halted for any reason. The Contractor will be restricted to pavement placement widths of a maximum of fifteen (15') feet unless the Contractor can demonstrate competence to provide pavement placement widths greater than the maximum specified to the satisfaction of the Engineer.

<u>Curing</u>: Curing procedures shall begin within 20 minutes after the final placement operations. The pavement surface shall be covered with a minimum six-(6) mil thick polyethylene sheet or other approved covering material. Prior to covering, a fog or light mist shall be sprayed above the surface when required due to ambient conditions (high temperature, high wind, and low humidity). The cover shall overlap all exposed edges and shall be secured (without using dirt or stone) to prevent dislocation due to winds or adjacent traffic conditions.

<u>Cure Time</u>:

1. Portland Cement Type I, II, or IS – 7 days minimum.
2. No truck traffic shall be allowed for 10 days (no passenger car/light trucks for 7 days).

<u>Jointing</u>: Control (contraction) joints shall be installed at 20-foot intervals. They shall be installed at a depth of the 1/ 4 the thickness of the pavement. These joints can be installed in the plastic concrete or saw cut. If saw cut, the procedure should begin as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking (normally after curing). Transverse constructions joints shall be installed whenever placing is suspended a sufficient length of time that concrete may begin to harden. In order to assure aggregate bond at construction joints, a bonding agent suitable for bonding fresh concrete shall be brushed, tolled, or sprayed on the existing pavement surface edge. Isolation (expansion) joints will not be used except when pavement is abutting slabs or other adjoining structures.

TESTING, INSPECTION, AND ACCEPTANCE

Laboratory Testing:

The owner will retain an independent testing laboratory. The testing laboratory shall conform to the applicable requirements of ASTM E 329 "Standard Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction" and ASTM C 1077 "Standard Practice for Testing Concrete and Concrete Aggregates for use in Construction, and Criteria for Laboratory Evaluation" and shall be inspected and accredited by the Construction Materials Engineering Council, Inc. or by an equivalent recognized national authority.

The Agent of the testing laboratory performing field sampling and testing of concrete shall be certified by the American Concrete Institute as a Concrete Field Testing Technician Grade I, or by a recognized state or national authority for an equivalent level of competence.

Testing and Acceptance:

A minimum of 1 gradation test of the subgrade is required every 5000 square feet to determine percent passing the No. 200 sieve per ASTM C 117.

A minimum of one test for each day's placement of pervious concrete in accordance with ASTM C 172 and ASTM C 29 to verify unit weight shall be conducted. Delivered unit weights are to be determined in accordance with ASTM C 29 using a 0.25 cubic foot cylindrical metal measure. The measure is to be filled and compacted in accordance with ASTM C 29 paragraph 11, jigging procedure. The unit weight of the delivered concrete shall be +/- 5 pcf of the design unit weight.

Test panels shall have two cores taken from each panel in accordance with ASTM 42 at a minimum of seven (7) days after placement of the pervious concrete. The cores shall be measured for thickness, void structure, and unit weight. Untrimmed, hardened core samples shall be used to determine placement thickness. The average of all production cores shall not be less than the specified thickness with no individual core being more than ½ inch less than the specified thickness. After thickness determination, the cores shall be trimmed and measured for unit weight in the saturated condition as described in paragraph 6.3.1 of 'Saturation' of ASTM C 140 "Standard Methods of Sampling and Testing Concrete Masonry Units." The trimmed cores shall be immersed in water for 24 hours, allowed to drain for one (1) minute, surface water removed with a damp cloth, then weighed immediately. Range of satisfactory unit weight values are +/- 5 pcf of the design unit weight.

After a minimum of 7 days following each placement, three cores shall be taken in accordance with ASTM C 42. The cores shall be measured for thickness and unit weight determined as described above for test panels. Core holes shall be filled with concrete meeting the pervious mix design.

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.2: Infiltration Basin

An Infiltration Basin is a shallow impoundment that stores and infiltrates runoff over a level, subtle, uncompacted, (preferably undisturbed area) with permeable soils.

Key Design Elements

- Uncompacted sub-grade
- Infiltration Guidelines and Soil Testing Protocols apply
- Preserve existing vegetation, if possible
- Design to hold/infiltrate volume difference in 2-yr storm
- Provide positive stormwater overflow through engineered outlet structure.
- Do not install on recently placed fill (<5 years).
- Allow 3 ft buffer between bed bottom and seasonal high groundwater table and 2 ft buffer for rock.
- When possible, place on upland soils.

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**LIMITED**
Industrial:	**YES***
Retrofit:	**YES**
Highway/Road:	**LIMITED**

**Applicable with specific considerations to design*

Stormwater Functions

Volume Reduction:	**High**
Recharge:	**High**
Peak Rate Control:	**High**
Water Quality:	**Med./High**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

Infiltration Basins are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. The size and shape can vary from one large basin to multiple, smaller basins throughout a site. Ideally, the basin should avoid disturbance of existing vegetation. If disturbance is unavoidable, replanting and landscaping may be necessary and should integrate the existing landscape as subtly as possible and compaction of the soil must be prevented (see Infiltration Guidelines). Infiltration Basins use the existing soil mantle to reduce the volume of stormwater runoff by infiltration and evapotranspiration. The quality of the runoff is also improved by the natural cleansing processes of the existing soil mantle and also by the vegetation planted in the basins. The key to promoting infiltration is to provide enough surface area for the volume of runoff to be absorbed within a given time (22 hours or less). An engineered overflow structure must be provided for the larger storms.

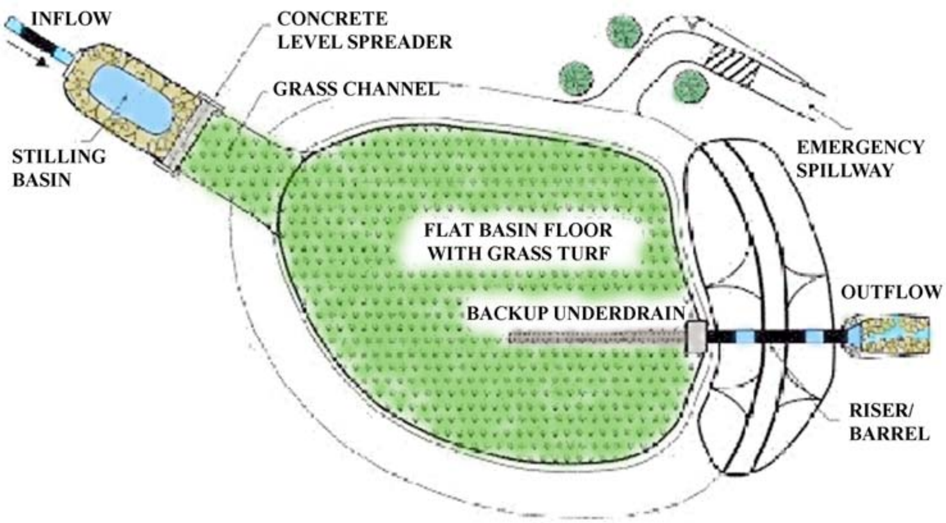


Figure 6.2-1. Schematic design of constructed infiltration basin with concrete level spreader (Schueler)

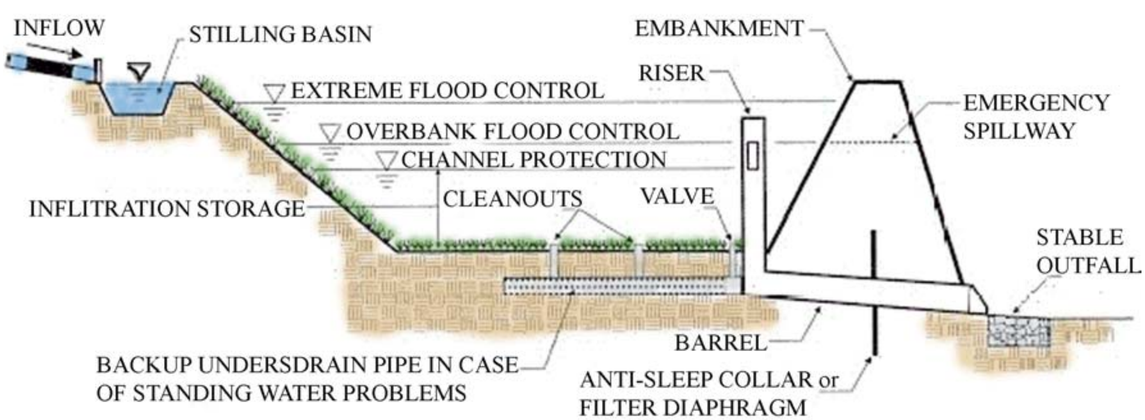


Figure 6.2-2. Cross section schematic of infiltration basin (Schueler)

Variations

- Re-Vegetation
  For existing unvegetated areas or for infiltration basins that require excavation, vegetation may be added. Planting in the infiltration area will improve water quality, encourage infiltration, and promote evapotranspiration. This vegetation may range from a meadow mix to more substantial woodland species. The planting plan should be sensitive to hydrologic variability anticipated in the basin, as well as to larger issues of native plants and habitat, aesthetics, and other planting objectives. The use of turf grass, which requires frequent mowing is discouraged due to soil compaction.

- Usable Surface
  A grassed Infiltration Basin can be used for recreation (usually informal) in dry periods. Heavy machinery and/or vehicular traffic of any type should be avoided so as not to compact the infiltration area.

- Soils with Poor Infiltration Rates
  A layer of sand (6") or gravel can be placed on the bottom of the Infiltration Basin, or the soil can be amended to increase the permeability of the basin. (See Soil Amendment & Restoration BMP 6.19 for details.)

Applications

- New Development
  Infiltration Basins can be incorporated into new development. Ideally, existing vegetation can be preserved and utilized as the infiltration area. Runoff from adjacent buildings and impervious surfaces can be directed into this area, which will "feed" the vegetation, thereby increasing evapotranspiration in addition to encouraging infiltration.

- Retrofitting existing "lawns," "open space"
  Existing grassed areas can be converted to an infiltration basin. If the soil and infiltration capacity is determined to be sufficient, the area can be enclosed through creation of a berm and runoff can be directed to it without excavation. Otherwise, excavation can be performed as described below.

- Other Applications
  Other applications of Infiltration Basins may be determined by the Design Professional as appropriate.

Design Considerations

1. Soil Investigation and Infiltration Testing is required (see Section 6) Appropriate soil for infiltration is important; site selection for this BMP should take soil and infiltration capacity into consideration.

2. Guidelines for Infiltration Systems must be met (i.e., depth to water table, setbacks, Loading Rates, etc.) Infiltration capacity is crucial for this BMP, as infiltration is the main mechanism used for volume control and the condition of the basin bottom will dictate this effectiveness.

3. Basin designs that do not remove existing soil and/or vegetation are preferred.

4. The slope of the Infiltration Basin bottom should be level or with a slope no greater than 1%. A level bottom assures even water distribution and infiltration.

5. Basins may be constructed where impermeable soils on the surface are removed and where more permeable underlying soils then are used for the base of the bed; care must be taken in the excavation process to make sure that soil compaction does not occur.

6. The discharge or overflow from the Infiltration Basin must be properly designed for anticipated flows. Large infiltration basins may require multiple outlet control devices to effectively overflow water during the larger storms. Emergency overflow systems can be constructed to direct large storm overflows.

7. The berms surrounding the basin should be compacted earth with a slope of not less than 3:1, and a top width of at least 2 feet.

8. There should be at least 2 feet of freeboard between the invert out and the top of the berms, or maintaining one foot of freeboard above the 100-year storm elevation.

9. Infiltration basins can be planted with natural grasses, meadow mix, or other “woody” mixes. These plants have longer roots than traditional grass and increase soil permeability, improving the growth of these plantings and increasing evapotranspiration. Native plants should be used.

10. Use of fertilizer should be avoided.

11. The surface should be compacted as little as possible to allow for surface percolation through the soil layer.

12. When directing runoff from roadway areas into the basin, measures to reduce sediment should be used.

13. The inlets into the basin should have erosion protection. (See the Level Spreader BMP 6.20 for design guidelines.)

14. Contributing inlets (up gradient) should have a sediment trap or proprietary water quality insert to prevent large particles from clogging the system.

15. Note: the presence of soluble contaminants should be avoided as much as possible, as this will risk groundwater contamination.

16. Use of a backup underdrain or low-flow orifice may be considered in the event that the water in the basin does not drain in 72 hours. This underdrain valve should remain in the shut position unless the basin does not drain.

Detailed Stormwater Functions

Infiltration Area

The Infiltration Area is the bottom area of the bed.

This is the area to be considered when evaluating the Loading Rate to the Infiltration basin.

Volume Reduction Calculations

Volume = Depth* (ft) x Area (sf) x Void Space

*Depth is the depth of the water surface during a storm event, depending on the drainage area and conveyance to the bed.

Infiltration Volume = Bed Bottom Area (sf) x Infiltration design rate (in/hr) x Infiltration period* (hr) x (1/12)

*Infiltration Period is the time when bed is receiving runoff and capable of infiltration. Not to exceed 72 hours.

Peak Rate Mitigation Calculations: See Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement: See Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Protect Infiltration basin area from compaction prior to installation.
2. If possible, install Infiltration basin during later phases of site construction to prevent sedimentation and/or damage from construction activity. After installation, protect sediment-laden water from entering inlets and pipes.
3. Install and maintain proper Erosion and Sediment Control Measures during construction.
4. If necessary, excavate Infiltration basin bottom to an uncompacted subgrade free from rocks and debris. Do NOT compact subgrade.
5. Install Outlet Control Structures.
6. Seed and stabilize topsoil. (Vegetate if appropriate with native plantings.)
7. Do not remove Inlet Protection or other Erosion and Sediment Control measures until site is fully stabilized.
8. Any sediment that enters inlets during construction is to be removed within 24 hours.

Maintenance and Inspection Issues

- Catch Basins and Inlets (upgradient of infiltration basin) should be inspected and cleaned on an annual basis.
- The vegetation along the surface of the Infiltration basin should be maintained in good condition, and any bare spots immediately revegetated.
- Vehicles should not be parked or driven on an Infiltration Basin, and care should be taken to avoid excessive compaction by mowers.
- Inspect the completed basin and make sure that runoff drains down within 72 hours.
- Also inspect for accumulation of sediment, damage to outlet control structures, erosion control measures, signs of water contamination/spills, and slope stability in the berms.
- Mosquito's should not be a problem if the water drains in 72 hours. Mosquitoes require a considerably long breeding period with relatively static water levels.
- Mow only as appropriate for vegetative cover species.
- Remove sediment from basin accumulations. Restore original cross section and infiltration rate. Properly dispose of sediment.

Cost Issues

The construction cost of Infiltration Basins can vary greatly depending on the configuration, location, site-specific conditions, etc.

Excavation (if necessary) - varies
Plantings - to Meadow mix $2500 - $3500 / acre
Pipe Configuration – varies with stormwater configuration, may need to redirect pipes into the infiltration basin.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. Topsoil amend with compost if necessary or desired. (See Soil Amendment & Restoration BMP 6.19)

2. Vegetation See Native Plant List available locally, and/or see Appendix B.

References

Michigan Department of Environmental Quality. *Index of Individual BMPs*. 2004. State of Michigan. < http://www.michigan.gov/deq/1,1607,7-135-3313_3682_3714-13186—,00.html>

FHWA

California Stormwater Quality Association. *California Stormwater Best Management Practices Handbook: New Development and Redevelopment*. 2003.

Minnesota BMP manual

New Jersey Department of Environmental Protection. *New Jersey Stormwater Best Management Practices Manual*. 2004.

Volume/Peak Rate Reduction by Infiltration BMPs

BMP 6.3: Subsurface Infiltration Bed

Subsurface Infiltration is the temporary storage and infiltration of stormwater runoff accomplished by placing an infiltration bed of varying types beneath an engineered layer of soil and vegetation.

Key Design Elements

- Beds filled with stone (or alternative) as needed
- Uncompacted sub-grade
- Wrapped in nonwoven geotextile
- Level bed bottoms
- Provide positive stormwater overflow from beds
- Protect from sedimentation during construction
- Provide perforated pipe network along bed bottom for distribution
- Open-graded stone bed with minimum 40% void space
- Do not place bed bottom on compacted fill
- Allow 3 ft buffer between bed bottom and seasonal high groundwater table and 2 ft for bedrock.

Potential Applications

Residential: **YES**
Commercial: **YES**
Ultra Urban: **YES**
Industrial: **YES**
Retrofit: **YES**
Highway/Road: **LIMITED**

Stormwater Functions

Volume Reduction: **High**
Recharge: **High**
Peak Rate Control: **High**
Water Quality: **High**

Pollutant Removal

TSS: **85%**
TP: **85%**
NO_3: **30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

Subsurface Infiltration Beds consists of a vegetated, highly pervious soil media underlain by a uniformly graded aggregate (or alternative) bed for temporary storage and infiltration of stormwater runoff. Subsurface Infiltration beds are ideally suited for expansive, generally flat open spaces, such as lawns, meadows, and playfields, which are located downhill from nearby impervious areas. Subsurface Infiltration beds can be stepped or terraced down sloping terrain provided that the base of the bed remains level. Stormwater runoff from nearby impervious areas (including rooftops, parking lots, roads, walkways, etc.) can be directly conveyed to the subsurface storage media, where it is then distributed via a network of perforated piping.

The storage media for subsurface infiltration beds typically consists of clean washed, uniformly graded aggregate. However, other storage media alternatives are available. These alternatives are generally variations on plastic cells that more than double the storage capacity of aggregate beds, at a substantially increased cost. Storage media alternatives are ideally suited for sites where potential infiltration area is limited. They may encourage concentrated loading (as opposed to distributed) in some sites.

If designed, constructed, and maintained as per the following guidelines, Subsurface Infiltration features can stand-alone as significant stormwater runoff volume, rate, and quality control practices. These systems can also maintain aquifer recharge, while preserving or creating valuable open space and recreation areas. They have the added benefit of functioning year-round, given that the infiltration surface is typically below the frost line.

Variations

As its name suggests, Subsurface Infiltration is generally employed for temporary storage and infiltration of runoff in subsurface storage media. However, in some cases, runoff may be temporarily stored on the surface (to depths less than 6 inches) to enhance volume capacity of the system. The overall system design shall ensure that runoff detained on the surface will seep through the permeable soil layer (or drain through area drains) and into the infiltration bed in less than 48 hours. Subsurface Infiltration areas are often used for recreational purposes and therefore extended periods of standing water are not acceptable.

Applications

Direct Connection of Roof Leaders

Runoff from nearby roofs shall be directly conveyed to subsurface beds via roof leader connections to perforated piping. Roof runoff generally has relatively low sediment levels, making it ideally suited for direct discharge to an infiltration bed. However, cleanout(s) with a sediment sump are still recommended between the building and infiltration bed.

Direct Connection of Inlets

Catch Basins, inlets, and area drains may be directly connected to Subsurface Infiltration beds. However, sediment and debris removal must be provided. Storm structures should therefore include sediment trap areas below the inverts of discharge pipes to trap solids and debris. In areas of high traffic or excessive generation of sediment, litter, and other similar materials, a water quality insert may be required.

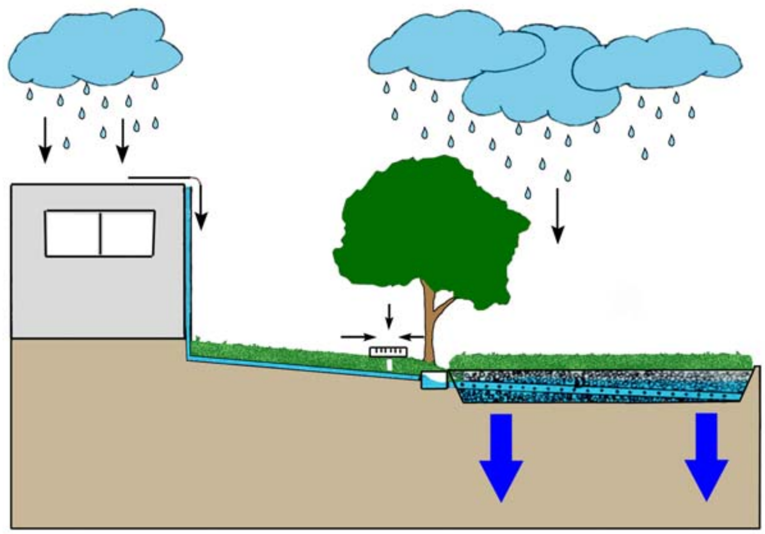


Figure 6.3-1. Roof leader connection to subsurface infiltration bed (CA, 2003)

Under Recreational Fields

Subsurface Infiltration is very well suited below playfields and other recreational areas. Special consideration should be given to the engineered soil mix in those cases.

Figure 6.3-2. Subsurface infiltration under athletic field

Under Open Space
Subsurface Infiltration is also appropriate in either existing or proposed open space areas. Ideally, these areas are vegetated with native grasses and/or vegetation to enhance site aesthetics and landscaping plans. Aside from occasional clean-outs or outlet structures, Subsurface Infiltration systems are essentially hidden stormwater management features, making them ideal for open space locations (deed restricted open space locations are especially desirable because such locations minimize the chance that Subsurface Infiltration systems will be disturbed or disrupted accidentally in the future.

Other Applications
Other applications of Subsurface Infiltration beds may be determined by the Design Professional as appropriate.

Design Considerations

1. Soil Investigation and Infiltration Testing is required (see Section 6.8).

2. Guidelines for Infiltration Systems must be met (see Section 6.8).

3. The overall site shall be evaluated for potential Subsurface Infiltration areas early in the design process, as effective design requires consideration of existing site characteristics (topography, natural features/drainage ways, soils, geology, etc.).

4. Control of Sediment is critical. Rigorous installation and maintenance of erosion and sediment control measures is required to prevent sediment deposition within the stone bed. Nonwoven geotextile may be folded over the edge of the bed until the site is stabilized.

5. The Infiltration bed must be wrapped in nonwoven geotextile filter fabric.

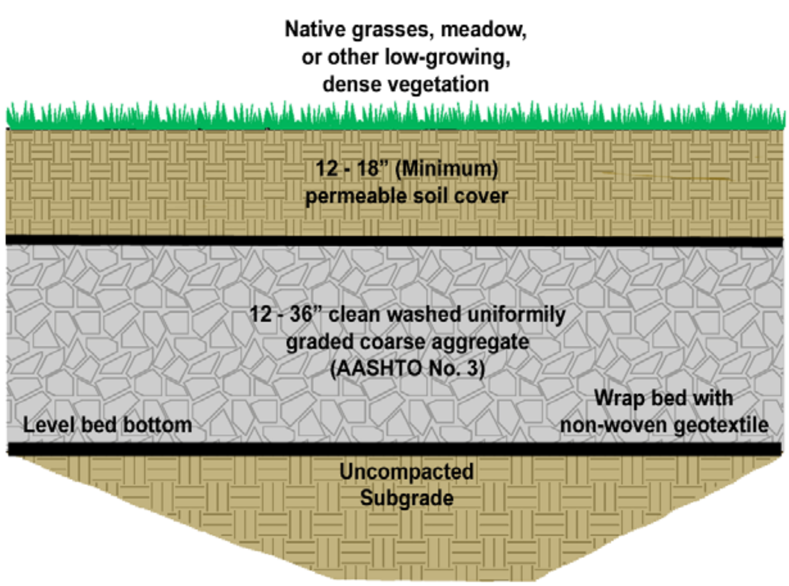


Figure 6.3-3. Cross Section detail of subsurface infiltration bed (CA, 2004)

6. Subsurface Infiltration areas shall not be placed on areas of recent fill or compacted fill. Any grade adjustments requiring fill shall be done using the stone subbase material, or alternative. Areas of historical fill (>5 years) may be considered if other criteria are met.

7. The subsurface infiltration bed is typically comprised of 12-36 inches of aggregate, such as AASHTO No.3, which ranges 1.5-2.5 inches in gradation. Depending on local aggregate availability, both larger and smaller size aggregate has been used. The critical requirements are that the aggregate be uniformly graded, clean washed, and contain at least 40% void space. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, and site grading. Infiltration beds are typically sized to mitigate the increased runoff volume from a 2-year design storm.

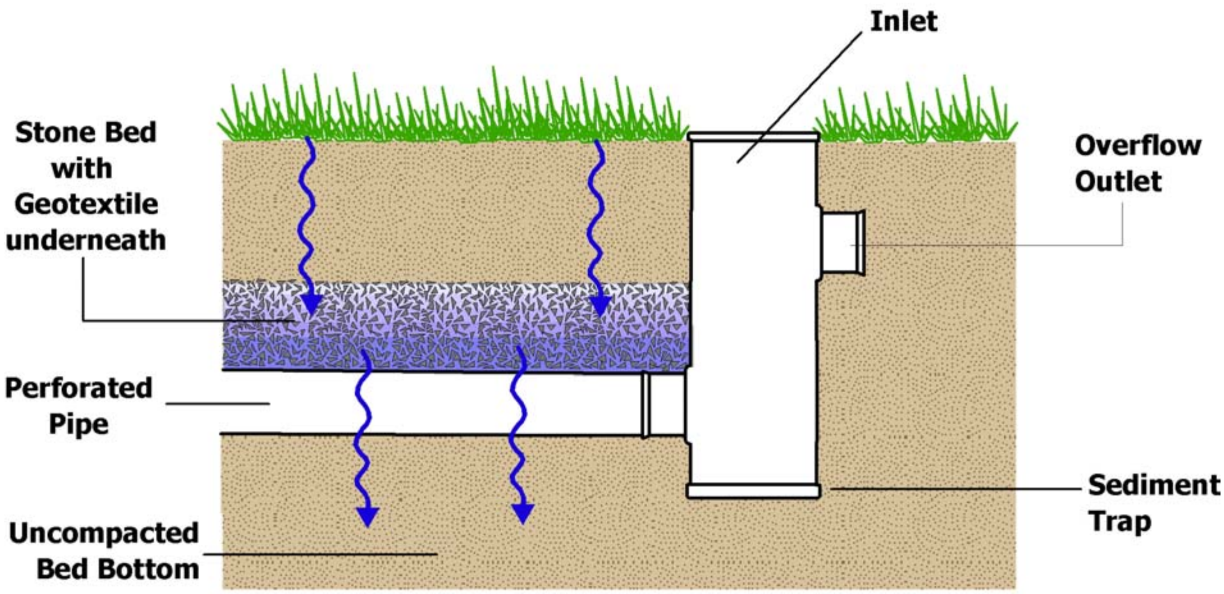


Figure 6.3-4. Cross-section showing subsurface infiltration bed detail, (CA, 2001)

8. Water Quality Inlet or Catch Basin with Sump required for all surface inlets, designed to avoid standing water for periods greater than 72 hours.

9. Infiltration beds may be placed on a slope by benching or terracing infiltration levels.

10. Perforated pipes along the bottom of the bed are necessary to evenly distribute runoff over the entire bed bottom. Continuously perforated pipes shall connect structures (such as cleanouts and inlet boxes). Pipes shall lay flat along the bed bottom and provide for uniform distribution of water. Depending on size, these pipes may provide additional storage volume. Perforated pipes shall have a positive flow connection designed to allow high flows to be conveyed through the bed.

11. The slope of the infiltration bed bottom should be level or with a slope no greater than 1%. The bed may be constructed as a series of “steps” if necessary. A level bottom assures even water distribution and infiltration.

12. Cleanouts or inlets should be installed at a few locations within the bed and at appropriate intervals to allow access to the perforated piping network.

13. Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal concrete weir (or weir plate) and low-flow orifice is a common type of control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it must always include positive overflow from the system. The overflow structure is used to maximize the water level in the stone bed, while providing sufficient cover for overflow pipes. Generally, the top of the outlet pipe shall be 4 inches below the top of the aggregate to prevent saturated soil conditions in remote areas of the bed. As with all infiltration practices, multiple discharge points are recommended.

14. Adequate soil cover (12 - 18” minimum) must be maintained above the infiltration bed to ensure structural stability and functional integrity. Soil cover shall be of an engineered and highly permeable nature, except when precluded by other design considerations.

15. Open space overlying infiltration beds can be vegetated with native grasses, meadow mix, or other low-growing, dense vegetation. These plants have longer roots than traditional grass and will likely benefit from the moisture in the infiltration bed, improving the growth of these plantings and increasing evapotranspiration.

16. Fertilizer shall never be required by a maintenance plan and should be minimized.

17. The surface (above the stone bed) should be compacted as minimally as possible to allow for surface percolation through the engineered soil layer and into the stone bed.

18. When directing runoff from roadway areas into the beds, measures to reduce sediment should be used.

19. Surface grading should be relatively flat, although a relatively mild slope between 1% and 3% is recommended to facilitate drainage.

20. In those areas where the threat of spills and groundwater contamination exists, pretreatment systems, such as filters and wetlands, may be required before any infiltration occurs. In Hot Spot areas, such as truck stops and fueling stations, the suitability of Subsurface Infiltration must be considered.

21. In areas with poorly-draining soils, Subsurface Infiltration areas may be designed to overflow to adjacent wetlands or bioretention areas.

22. While most Subsurface Infiltration areas consist of an aggregate storage bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate, at an increased cost.

23. The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, detention basins may be eliminated or significantly reduced in size.

24. During Construction, the excavated bed may serve as a Temporary Sediment Basin or Trap. This will reduce overall site disturbance. The bed shall be excavated to within 6 inches of the final bed bottom elevation for use as a sediment trap or basin. Following construction and site stabilization, sediment shall be removed and final grades established.

Detailed Stormwater Functions

Infiltration Area

The Infiltration Area is the bottom area of the bed, defined as:

Length of bed x Width of bed = Infiltration Area (if rectangular)
This is the area to be considered when evaluating the Loading Rate to the Infiltration bed.

Volume Reduction Calculations

Volume = Depth* (ft) x Area (sf) x Void Space

*Depth is the depth of the water surface during a storm event, depending on the drainage area and conveyance to the bed.

Infiltration Volume = Bed Bottom Area (sf) x Infiltration design rate (in/hr)
x Infiltration period* (hr) x (1/12)

*Infiltration Period is the time when bed is receiving runoff and capable of infiltration. Not to exceed 72 hours.

The overlying soil provides additional volume reduction as follows:

For planting beds: Volume = Area x Depth of Soil x 20%
For amended soils: Volume = Area x Depth of Soil x 20%
For lawn and playfields, additional volume credit is not given.

Peak Rate Mitigation Calculations

See in Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement: See in Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Due to the nature of construction sites, Subsurface Infiltration should be installed toward the end of the construction period, if possible. (Infiltration beds may be used as temporary sediment basins or traps provided they are excavated to within 6 to 12 inches of the designated final bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to its final grade and the infiltration bed is installed.)

2. Install and maintain adequate Erosion and Sediment Control Measures (as per the Pennsylvania Erosion and Sedimentation Control Program Manual) during construction.

3. The existing subgrade under the bed areas shall NOT be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement.

4. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake (or equivalent) and light tractor. All fine grading shall be done by hand. All bed bottoms are level grade.

5. Earthen berms (if used) between infiltration beds shall be left in place during excavation. These berms do not require compaction if proven stable during construction.

6. Install upstream and downstream control structures, cleanouts, perforated piping, and all other necessary stormwater structures.

7. Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation and installation of structures. Geotextile is to be placed in accordance with manufacturer's standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of 16 inches. It shall also be secured at least 4 feet outside of bed in order to prevent any runoff or sediment from entering the storage bed. This edge strip shall remain in place until all bare soils contiguous to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile along bed edges can be cut back to gravel edge.

8. Clean (washed), uniformly-graded aggregate is placed in the bed in maximum 8-inch lifts. Each layer shall be lightly compacted, with construction equipment kept off the bed bottom as much as possible.

9. Place approved soil media over infiltration bed in maximum 6-inch lifts.

10. Seed and stabilize topsoil.

11. Do not remove inlet protection or other Erosion and Sediment Control measures until site is fully stabilized.

Maintenance Issues

As with other BMP's combining vegetated and infiltration elements, Subsurface Infiltration systems require sustained maintenance efforts for continued functionality. Subsurface Infiltration is actually less maintenance intensive than other practices of its type. Generally speaking, vegetation associated with Subsurface Infiltration practices is less substantial than practices such as Recharge Gardens and Vegetated Swales and therefore requires less maintenance. Subsurface Infiltration areas surfaced with turf grass may actually require more frequent mowing. Maintenance activities required for the subsurface bed are similar to those of any infiltration system and focus on regular sediment and debris removal. The following represents the recommended maintenance efforts:

- All Catch Basins and Inlets should be inspected and cleaned on an annual basis.
- The overlying vegetation of Subsurface Infiltration features should be maintained in good condition, and any bare spots immediately revegetated.
- Vehicular access on Subsurface Infiltration areas should be prohibited, and care should be taken to avoid excessive compaction by mowers. If access is needed, use of permeable, turf reinforcement should be considered.

Cost Issues

The construction cost of Subsurface Infiltration can vary greatly depending on design variations, configuration, location, desired storage volume, and site-specific conditions, among other factors. Typical construction costs are about $5.70 per square-foot, which includes excavation, aggregate (2.0 feet assumed), nonwoven geotextile, pipes and plantings.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. __Stone__ for infiltration beds shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

2. __Non-Woven Geotextile__ shall consist of needled nonwoven polypropylene fibers and meet the following properties:

a. Grab Tensile Strength (ASTM-D4632) ³ 120 lbs
b. Mullen Burst Strength (ASTM-D3786) ³ 225 psi
c. Flow Rate (ASTM-D4491) ³ 95 gal/min/ft^2
d. UV Resistance after 500 hrs (ASTM-D4355) ³ 70%
e. Heat-set or heat-calendared fabrics are not permitted

Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

3. __Topsoil__ may be amended with compost (See soil restoration BMP 6.19)

4. __Pipe__ shall be continuously perforated, smooth interior, with a minimum inside diameter of 8-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

5. __**Storm Drain Inlets and Structures**__

a. Concrete Construction: Concrete construction shall be in accordance with Section 1001, PennDOT Specifications, 1990 or latest edition.
b. Precast Concrete Inlets and Manholes: Precast concrete inlets may be substituted for cast-in-place structures and shall be constructed as specified for cast-in-place.

Precast structures may be used in only those areas where there is no conflict with existing underground structures which may necessitate revision of inverts. Precast structures shall be placed on a 6 inch bed of compacted coarse aggregate Size No. 2A. Reinforcement steel, if required for handling, shall have a minimum of 2-inch cover. Handling devices, if used, shall be removable and the holes filled with concrete. Type M standard PennDOT inlet boxes will be modified to provide minimum 12 inch sump storage and bottom leaching basins, open to gravel sumps in sub-grade, when situated in the recharge bed.

c. All PVC Catch Basins/Cleanouts/Inline Drains shall have H-10 or H-20 rated grates, depending on their placement (H-20 if vehicular loading).
d. Steel reinforcing bars over the top of the outlet structure shall conform to ASTM A615, grades 60 and 40.
e. HDPE Flared End Section shall be installed according to manufacturers' specifications.
f. Permanent turf reinforcement matting shall be installed according to manufacturers' specifications.

6. <u>Alternative storage media</u> see information in Appendix E, and follow appropriate Manufacturers' specifications.

7. <u>Vegetation</u> see Local Native Plant List and Appendix B.

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.4: Infiltration Trench

An Infiltration Trench is a "leaky" pipe in a stone-filled trench with a level bottom. An Infiltration Trench may be used as part of a larger storm sewer system, such as a relatively flat section of storm sewer. Or it may serve as a stormwater system for a small area, such as a portion of a roof or a single catch basin. In all cases, an Infiltration Trench must be designed with a positive overflow.

Key Design Elements

- Continuously perforated pipe set at a minimum slope in a stone filled, level-bottomed trench
- Limited in width (3 to 8 feet) and depth of stone (6 feet max. recommended)
- Trench is wrapped in nonwoven geotextile (top, sides, and bottom)
- Placed on uncompacted soils
- Minimum cover over pipe is 12-inches
- A minimum of 6" of topsoil is placed over trench and vegetated
- Positive Overflow always provided

Potential Applications

Residential:	**YES**
Commercial:	**YES***
Ultra Urban:	**YES***
Industrial:	**YES***
Retrofit:	**YES**
Highway/Road:	**YES***

** With consideration of hotspots*

Stormwater Functions

Volume Reduction:	**Medium**
Recharge:	**High**
Peak Rate Control:	**Medium**
Water Quality:	**High**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

An Infiltration Trench is a linear stormwater BMP consisting of a continuously perforated pipe at a minimum slope in a stone-filled trench (Figure 1). Usually an Infiltration Trench is part of a **conveyance system** and is designed so that large storm events are conveyed through the pipe with some runoff volume reduction. During small storm events, volume reduction may be significant and there may be little discharge. All Infiltration Trenches are designed with a **positive overflow** (Figure 2).

An Infiltration Trench differs from an Infiltration Bed in that it may be constructed without heavy equipment entering the trench. It is also intended to convey some portion of runoff in many storm events.

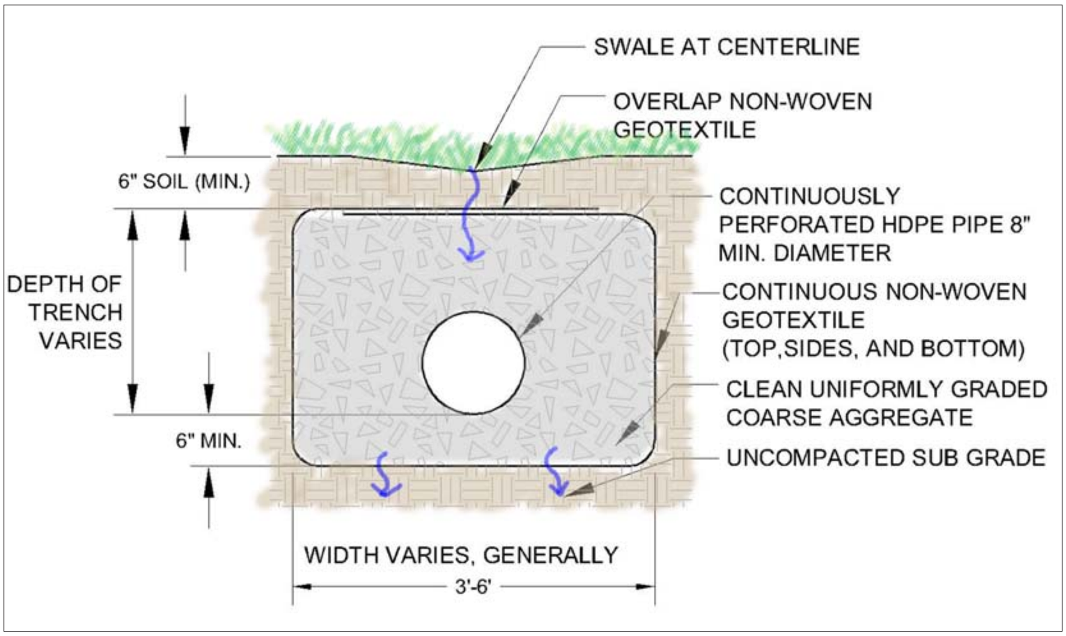


Figure 6.4-1. Cross section of an Infiltration Trench

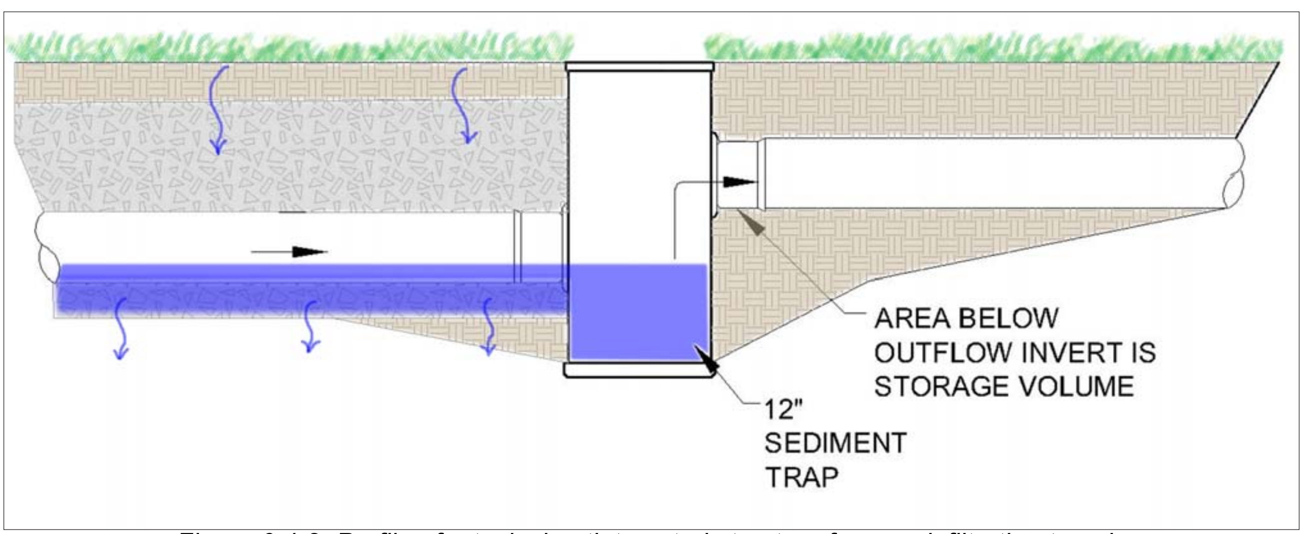


Figure 6.4-2. Profile of a typical outlet control structure from an infiltration trench.

All Infiltration Trenches must be designed in accordance with the Guidelines for Infiltration Systems. Although the width and depth can vary, it is recommended that Infiltration Trenches be limited in depth to not more than six (6) feet of stone. This is due to both construction issues and Loading Rate issues (as described in the Guidelines for Infiltration Systems). Appropriate depth should be considered by the designer.

Variations

Infiltration Trenches generally have a vegetated (grassed) or gravel surface. Infiltration Trenches also may be located beneath or within roadways or impervious paved areas with proper design. The subsurface drainage direction should be to the downhill side (away from subbase of pavement), or located lower than the impervious subbase layer. Proper measures must be taken to prevent water infiltrating into the subbase of impervious pavement.

Infiltration Trenches may also be located down a mild slope by "stepping" the sections between control structures as shown in Figure 3. A level or nearly level bottom is recommended for even distribution.

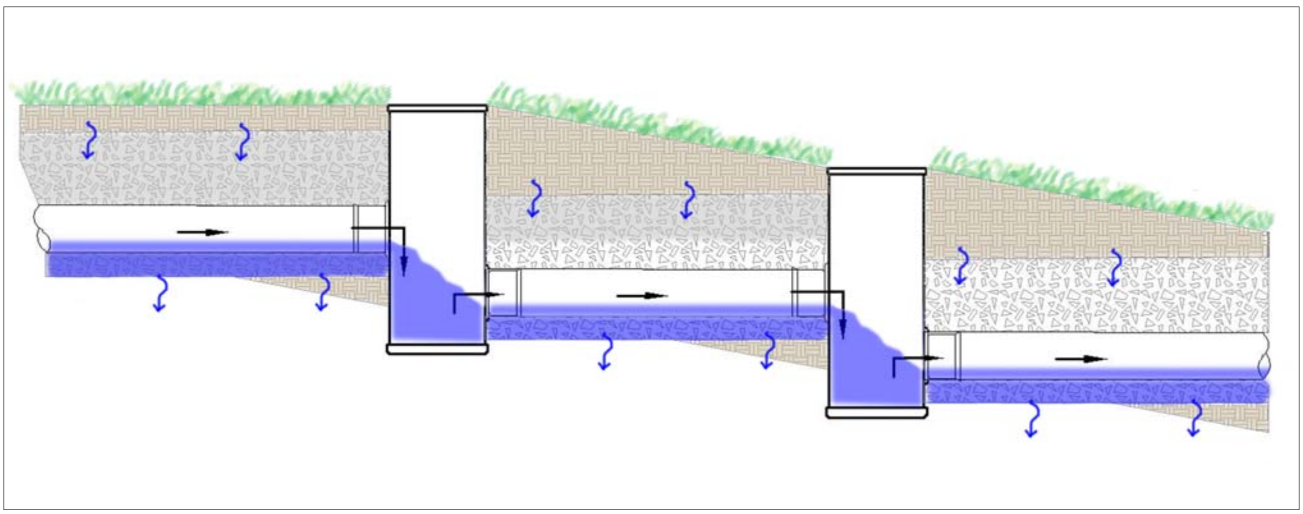


Figure 6.4-3. Profile of "stepping" down an infiltration trench.

Applications

- **Direct Connection of Roof Leaders**

Roof leaders may be directly connected to Infiltration Trenches (Figure 4). Roof runoff generally has lower sediment levels and often is ideally suited for discharge through and Infiltration Trench. A cleanout with sediment sump must be provided between the building and Infiltration Trench.

- **Direct Connection of Inlets**

Catch Basins, inlets, and area drains may be connected to Infiltration Trenches, however, sediment/ debris removal must be addressed. Structures should include a sediment trap area below the invert of the pipe for solids and debris. In areas of high traffic or areas where excessive sediment, litter, and other similar materials may be generated, a water quality insert is required.

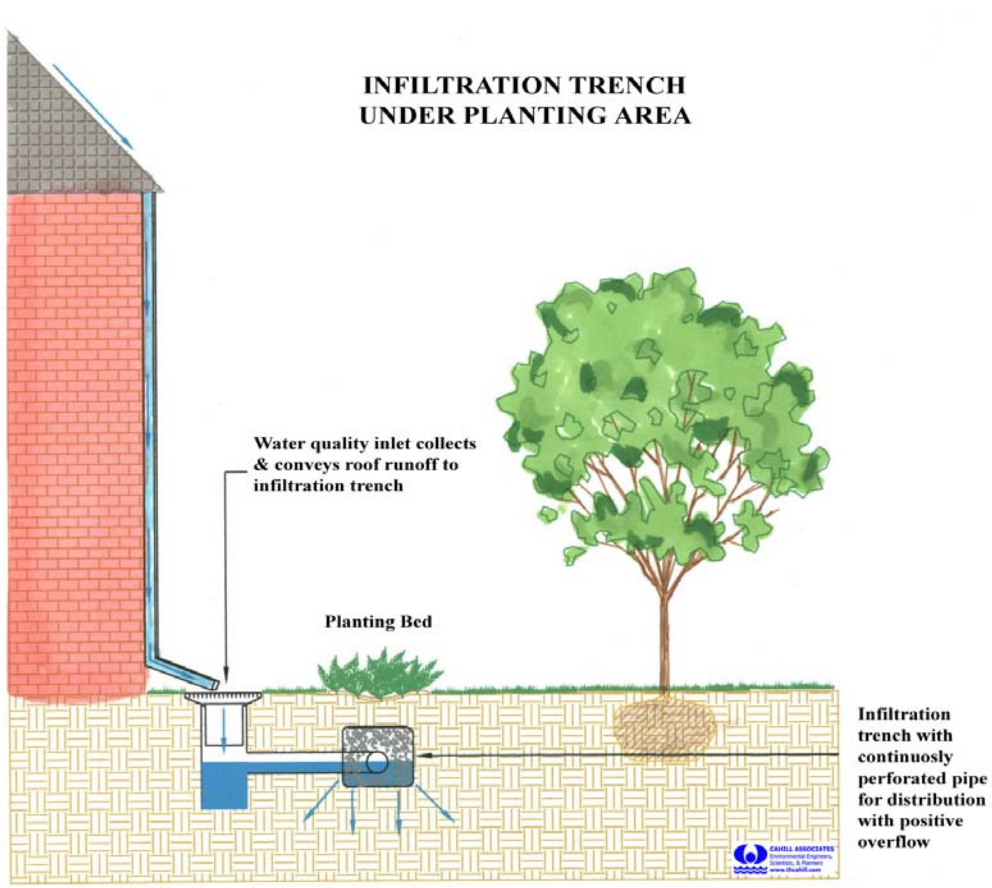


Figure 6.4-4. Roof leaders connect to infiltration trench under planting area.

- **In Combination with Vegetative Filters**

An Infiltration Trench may be preceded by or used in combination with a Vegetative Filter, Grassed Swale, or other vegetative element used to reduce sediment levels from areas such as high traffic roadways. Design must ensure proper functioning of vegetative system.

- **Other Applications**

Other applications of Infiltration Trenches may be determined by the Design Professional as appropriate.

Design Considerations

1. Soil Investigation and Percolation Testing is required (see Section 6.8, Protocol 2)
2. Guidelines for Infiltration Systems must be met (i.e., depth to water table, setbacks, Loading Rates, etc. See Section 6.8, Protocol 1)
3. Water Quality Inlet or Catch Basin with Sump (see Sections 6.16) required for all surface inlets, designed to avoid standing water for periods greater than 72 hours.
4. A continuously perforated pipe must extend the length of the trench and have a positive flow connection designed to allow high flows to be conveyed through the Infiltration Trench.
5. The slope of the Infiltration Trench bottom should be level or with a slope no greater than 1%. The Trench may be constructed as a series of "steps" if necessary. A level bottom assures even water distribution and infiltration.
6. Cleanouts or inlets must be installed at both ends of the Infiltration Trench and at appropriate intervals to allow access to the perforated pipe.
7. The discharge or overflow from the Infiltration Trench must be properly designed for anticipated flows.

Detailed Stormwater Functions

Infiltration Area

The Infiltration Area is the bottom area of the Trench, defined as:

Length of Trench x Width of Trench = Infiltration Area (Bottom Area)

This is the area to be considered when evaluating the Loading Rate to the Infiltration Trench.

Volume Reduction Calculations

Volume = Depth* (ft) x Area (sf) x Void Space

*Depth is the depth of the water surface during a storm event, depending on the drainage area and conveyance to the bed.

Infiltration Volume = Bed Bottom Area (sf) x Infiltration design rate (in/hr)
x Infiltration period* (hr) x (1/12)

*Infiltration Period is the time when bed is receiving runoff and capable of infiltration. Not to exceed 72 hours.

The void ratio in stone is 40% for AASTO No 3. If the conveyance pipe is within the Storage Volume area, the volume of the pipe may also be included. All Infiltration Trenches should be designed to infiltrate or empty within 72 hours.

Peak Rate Mitigation Calculations

See Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control..

Water Quality Improvement

See Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Protect Infiltration Trench area from compaction prior to installation.
2. If possible, install Infiltration Trench during later phases of site construction to prevent sedimentation and/or damage from construction activity. After installation, protect sediment laden water from entering inlets and pipes.
3. Install and maintain proper Erosion and Sediment Control Measures during construction.
4. Excavate Infiltration Trench bottom to a uniform, level uncompacted subgrade free from rocks and debris. Do NOT compact subgrade.
5. Place nonwoven geotextile along bottom and sides of trench. Nonwoven geotextile rolls should overlap by a minimum of 24 inches within the trench. Fold back and secure excess geotextile during stone placement.
6. Install upstream and downstream Control Structures, cleanouts, etc.
7. Place uniformly graded, clean-washed aggregate in 6-inch lifts, lightly compacting between lifts.
8. Install Continuously Perforated Pipe as indicated on plans. Backfill with uniformly graded, clean-washed aggregate in 6-inch lifts, lightly compacting between lifts.
9. Fold and secure nonwoven geotextile over Infiltration Trench, with minimum overlap of 12-inches.
10. Place 6-inch lift of approved Topsoil over Infiltration Trench, as indicated on plans.
11. Seed and stabilize topsoil.
12. Do not remove Inlet Protection or other Erosion and Sediment Control measures until site is fully stabilized.
13. Any sediment which enters inlets during construction is to be removed within 24 hours.

Figure 6.4-5. Installation of Infiltration Trench

Figure 6.4-6. (From left to right) Installation of Inlets and Control Sturcture; Non-woven Geotextile is folded over Infiltration Trench; Stabilized Site

Figure 6.4-7. (Clockwise from top left) Infiltration Trench is on downhill side of roadway; Infiltration Trench is Installed; Infiltration Trench is paved with standard pavement material

Maintenance and Inspection Issues

- Catch Basins and Inlets should be inspected and cleaned on an annual basis.
- The vegetation along the surface of the Infiltration Trench should be maintained in good condition, and any bare spots immediately revegetated.
- Vehicles should not be parked or driven on a vegetated Infiltration Trench, and care should be taken to avoid excessive compaction by mowers.

Cost Issues

The construction cost of infiltration trenches can vary greatly depending on the configuration, location, site-specific conditions, etc. Typical construction costs in 2003 dollars range from $4 - $9 per cubic foot of storage provided (SWRPC, 1991; Brown and Schueler, 1997). Annual maintenance costs have been reported to be approximately 5 to 10 percent of the capital costs (Schueler, 1987).

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. Stone for infiltration trenches shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

2. Non-Woven Geotextile shall consist of needled nonwoven polypropylene fibers and meet the following properties:

a. Grab Tensile Strength (ASTM-D4632)	^{3} 70%
b. Mullen Burst Strength (ASTM-D3786)	^{3} 120 lbs
c. Flow Rate (ASTM-D4491)	^{3} 225 psi
d. UV Resistance after 500 hrs (ASTM-D4355)	^{3} 95 gal/min/ft^2
e. Heat-set or heat-calendared fabrics are not permitted	

Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

3. Topsoil See Appendix C.

4. Pipe shall be continuously perforated, smooth interior, with a minimum inside diameter of 8-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

References

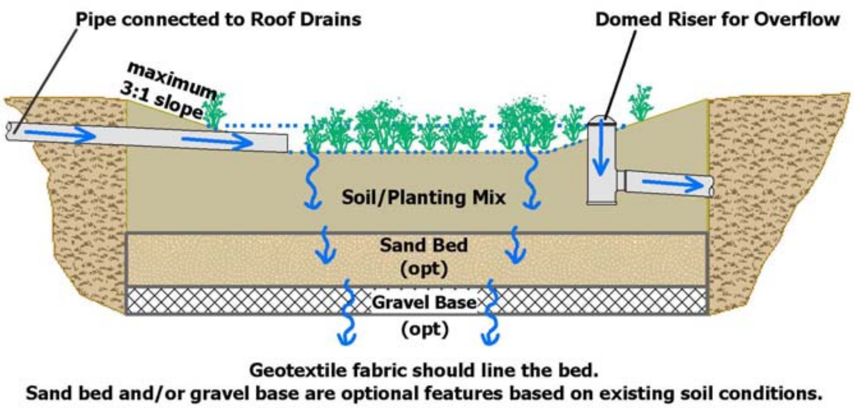
Brown and Schueler, 1997

Schueler, T., 1987. *Controlling urban runoff: a practical manual for planning and designing urban BMPs*, Metropolitan Washington Council of Governments, Washington, DC

SWRPC, 1991

Volume/Peak Rate Reduction by Infiltration BMPs

BMP 6.5: Rain Garden/Bioretention



A Rain Garden (also called Bioretention) is an excavated shallow surface depression planted with specially selected native vegetation to treat and capture runoff and underlain by a sand or if needed gravel infiltration bed.

Key Design Elements

- Flexible in terms of size and infiltration
- Ponding depths restricted to 6 inches or less for draw down within 72 hours.
- Deep rooted perennials and trees encouraged.
- Native vegetation that is tolerant of hydrologic variability and environmental stress
- Modify soil with compost if needed during construction.
- Maintenance required two times per year.
- Provide positive overflow

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**YES**

Stormwater Functions

Volume Reduction:	**Medium**
Recharge:	**High**
Peak Rate Control:	**Low/Med.**
Water Quality:	**Med./High**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

Bioretention is a method of treating stormwater by pooling water on the surface and allowing filtering and settling of suspended solids and sediment at the mulch layer, prior to entering the plant/soil/microbe complex media for infiltration and pollutant removal. Rain Gardens / bioretention techniques are used to accomplish water quality improvement and water quantity reduction. Prince George's County, Maryland, and Alexandria, Virginia have used this BMP since 1992 with success in many urban and suburban settings.

Rain Gardens can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems, including porous asphalt parking lots, infiltration trenches, as well as non-structural stormwater BMP's described in Section 5.

The Rain Garden vegetation serves to filter (water quality) and transpire (water quantity) runoff, and the root systems can enhance infiltration. The plants take up pollutants; the soil medium filters out pollutants and allows storage and infiltration of stormwater runoff; and the infiltration bed provides additional volume control. Properly designed bioretention techniques mimic natural forest ecosystems through species diversity, density and distribution of vegetation, and the use of native species, resulting in a system that is resistant to insects, disease, pollution, and climatic stresses.

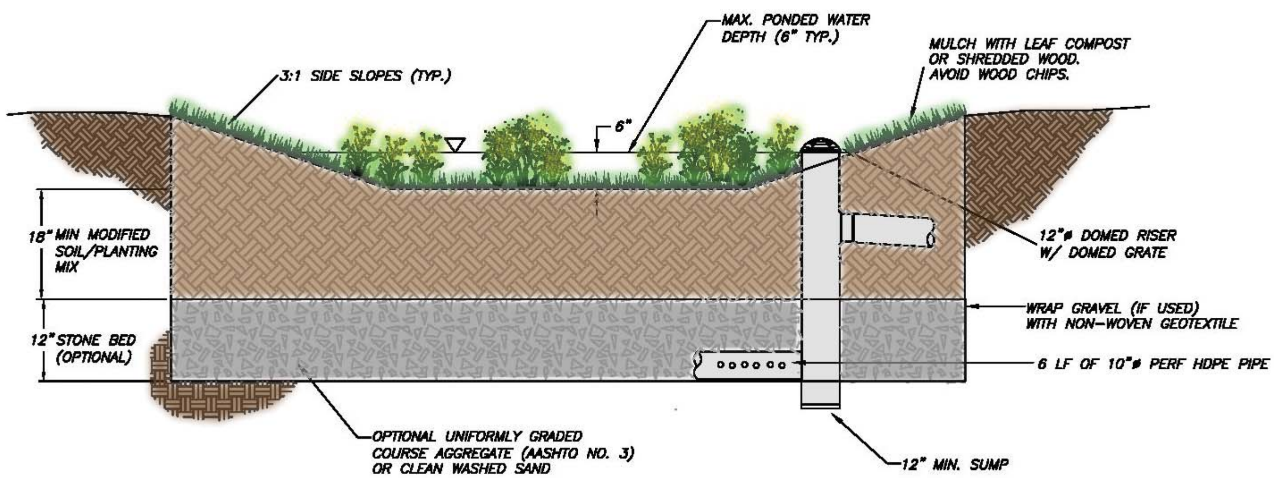


Figure 6.5-1 Cross section of a typical rain garden (stone bed is optional)

Bioretention with Rain Gardens function to:

- Reduce runoff volume
- Filter pollutants, through both soil particles (which trap pollutants) and plant material (which take up pollutants)
- Recharge groundwater
- Reduce stormwater temperature impacts
- Enhanced aesthetics
- Provide habitat

Primary Components of a Rain Garden/Bioretention System

The primary components (an subcomponents) of a rain garden/bioretention system are:

Pretreatment (optional)

- Sheet flow through a **vegetated buffer strip** prior to entry into the Rain Garden

Flow entrance

- Varies with site use (e.g.,parking island versus residential lot applications)
- Water may enter via an **inlet** (e.g., flared end section)
- Sheet flow into the facility over grassed areas
- Curb cuts with grading for sheet flow entrance
- Roof leaders with direct surface connection
- Trench drain
- Entering velocities must not be non-erosive.

Ponding area

- Provides temporary surface storage of runoff
- Provides evaporation for a portion of runoff
- Design depths allow sediment to settle
- Limited in depth to prevent mosquito/other problems

Plant material

- Evapotranspires stormwater
- Root development and rhizome community create pathways for infiltration
- Bacteria community resides within the root system creating healthy soil structure with water quality benefits
- Improves aesthetics for site
- Provides habitat for animals and insects
- Reinforces long-term performance of subsurface infiltration

Organic layer or mulch

- Acts as a filter for pollutants in runoff
- Protects underlying soil from drying and eroding
- Simulates leaf litter by providing environment for microorganisms to degrade organic material
- Provides a medium for biological growth, decomposition of organic material, adsorption and bonding of heavy metals
- Wood mulch must be shredded. Compost or leaf mulch preferred.

Planting soil and filter media

- Provides water/nutrients to plants
- Enhances biological activity and encourages root growth
- Provides storage of stormwater by the voids within the soil particles

Sand Bed / Gravel Base (Filter Fabric Wrapped)

- Sand Bed (optimal) and Gravel Base provide volume control
- Protect long-term infiltration performance of the BMP
- Optional depending on the design

Positive overflow

- Discharges runoff during large storm events when the subsurface/surface storage capacity is exceeded.
- Examples include domed riser, inlet, weir structure, etc.

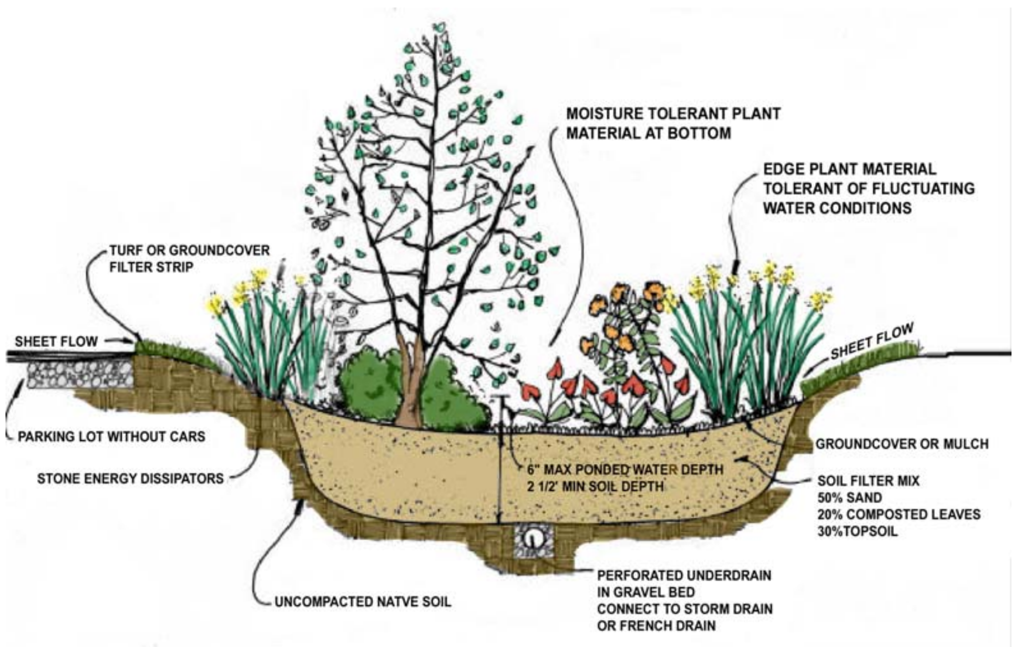


Figure 6.5-2. Components of a rain garden (PGDER)

Variations

Generally, a Rain Garden/Bioretention system is a vegetated surface depression that provides for the infiltration of relatively small volumes of stormwater runoff, often managing stormwater on a lot-by-lot basis (versus the total development site). If greater volumes of runoff need to be managed or stored, the system can be designed with an expanded subsurface infiltration bed or the Rain Garden can be increased in size.

The design of a Rain Garden can vary in complexity depending on the quantity of runoff volume to be managed, as well as the pollutant reduction objectives for the entire site. Variations exist both in the components of the systems, which are a function of the land use surrounding the Rain Garden system. Rain Gardens have been designed elsewhere without a Sand Bed or Gravel Base, if soil and infiltration conditions allow.

Flow Entrance: Curbs and Curb Cuts

Figure 6.5-3. Curb cut inlet for a rain garden in a parking island (PGDER, 2002)

Flow Entrance: Trench Drain

Figure 6.5-4. Trench drain inlet for rain garden in parking lot (LIDC)

Positive Overflow: Domed Riser

Figure 6.5-5. Domed riser provides positive overflow during extreme storm events

Positive Overflow: Inlet

Figure 6.5-6. The surface inlet shown in the lower left provides positive overflow during extreme storm events (LIDC)

Applications

Bioretention areas can be used in a variety of applications: from small areas in residential lawns to extensive systems in large parking lots (incorporated into parking islands and/or perimeter areas).

- **Residential On-lot**

  Rain Garden (Prince George's County)
  Simple design that incorporates a planting bed in the low portion of the site

Figure 6.5-7. Example of residential on-lot rain garden (LIDC)

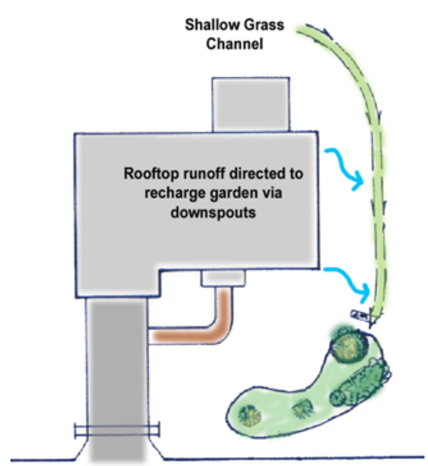


Figure 6.5-8. Recharge garden in residential application (Georgia Manual)

- **Tree and Shrub Pits**

Stormwater management technique that intercepts runoff and provides shallow ponding in a dished mulched area around the tree or shrub.
Extend the mulched area to the tree dripline

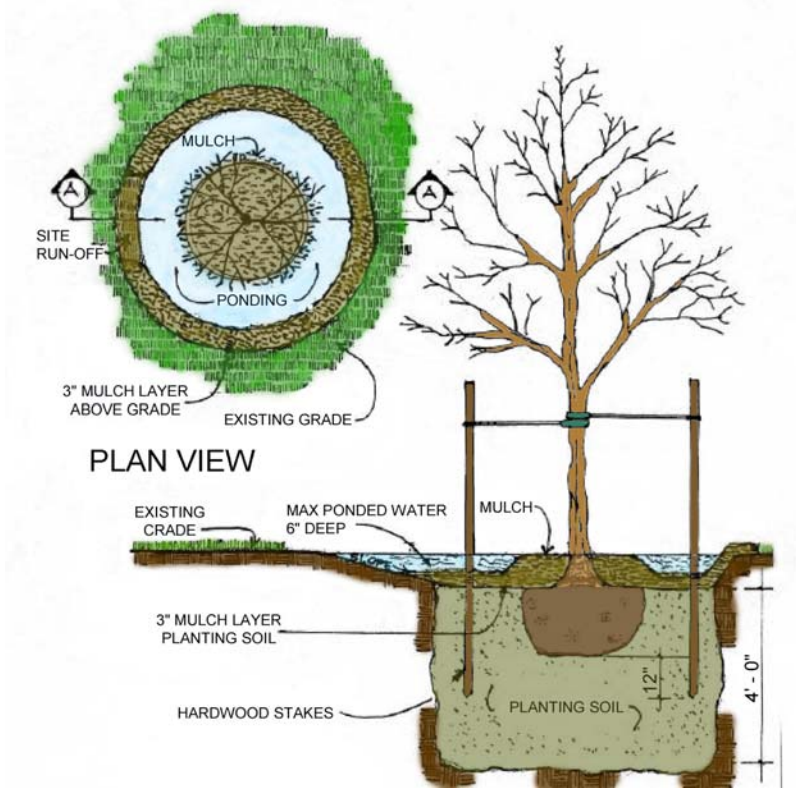


Figure 6.5-9. Tree Pit Bioretention (PGDER, 2002)

- **Roads and highways**

Figure 6.5-10. Example of rain garden treating highway runoff (LIDC)

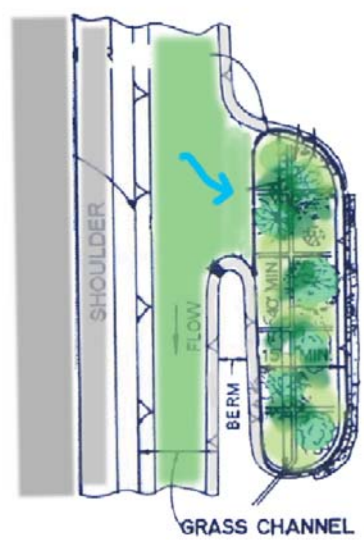


Figure 6.5-11. Schematic showing of highway drainage rain garden (modified figure, from Georgia Manual)

- **Parking Lots**

Figure 6.5-12. Parking island rain garden (LIDC)

- **Commercial/Industrial/Institutional**

In commercial, industrial, and institutional situations, stormwater management and greenspace areas are limited, and in these situations, Rain Gardens for stormwater management and landscaping provide multifunctional options.

- **Curbless Parking Lot Perimeter Bioretention**
  The Rain Garden is located adjacent to a parking area with no curb, allowing stormwater to sheet flow over the parking lot directly into the Rain Garden. Shallow grades must direct runoff at reasonable velocities; this design can be used in conjunction with depression storage for stormwater quantity control.

- **Curbed Parking Lot Perimeter Bioretention**

Figure 6.5-13. Curbed parking lot perimeter recharge garden (PGDER, 2002)

- **Parking Lot Island Bioretention**

Figure 6.5-14. Parking lot island with recharge bed (LIDC)

- **Roof leader connection from adjacent building**

Figure 6.5-15. Recharge garden along an office building in Alexandria, Virginia (LIDC)

Figure 6.5-16. Rain Garden in State College, PA.

Design Considerations

Rain Gardens are flexible in design and can vary in complexity according to water quality objectives and runoff volume requirements. Though Rain Gardens are a structural BMP, the initial siting of bioretention areas should respect the Comprehensive Stormwater Management Procedures described in Section 4 and integrated with the preventive non-structural BMP's.

It is important to note that bioretention areas are not to be confused with constructed wetlands or other BMP's which permanently pond water and store it to allow for infiltration and water quality benefits. Bioretention is best suited for areas with at least moderate permeability (more than ¼ inch per hour), and in extreme situations where permeability is less than ¼ inch per hour, special variants may apply, including underdrains, or even constructed wetlands.

Rain Gardens are often very useful in retrofit projects and can be integrated into already developed lots and sites. An important concern for all Rain Garden applications is their long-term protection and maintenance, especially if undertaken in multiple residential lots where individual homeowners provide maintenance. In such situations, it is important to provide some sort of management that insures their long-term functioning (deed restrictions, covenants, and so forth).

1. **Sizing criteria**

    a. **Surface area** is dependent upon storage volume requirements but should not exceed a maximum loading ratio of 5:1 (drainage area to infiltration area, where drainage area is assumed to be 100% impervious; to the extent that the drainage area is not 100% impervious, the loading ratio may be modified; see Site Guidelines for Infiltration Protocol for additional guidance or loading rates.)

    b. **Surface Side slopes** should be gradual. For most areas, 3:1 side slopes are recommended, however where space is limited, 2:1 side slopes may be acceptable.

    c. **Surface Ponding depth** should not exceed 6 inches and should empty within 72 hours.

    d. **Ponding area** should provide sufficient surface area to meet required storage volume without exceeding the maximum surface ponding depth. The subsurface storage/ infiltration bed is used to supplement surface storage where feasible.

    e. **Planting soil depth** shall not be less than 24” where only herbaceous plant species will be utilized. If trees and woody shrubs will be used, soil media depth map be increased, depending on plant species.

2. **Planting Soil** should be a loam, loam/sand mix, loamy sand or sandy loam capable of supporting a healthy vegetative cover. In-situ soils may be amended with a sand, organic material or a sand/organic mix. A typical sand/organic amended soil is combined with 20-30% organic material (compost), and 50% construction (coarse grained) sand. Planting soil should be approximately 4 inches deeper than the bottom of the largest root ball.

3. **Soils** should also have a pH of between 5.5 and 6.5 (better pollutant adsorption and microbial activity), a clay content less than 10% (a small amount of clay is beneficial to adsorb pollutants and retain water), be free of toxic substances and unwanted plant material.

4. Proper **plant selection** is essential for bioretention areas to be effective. Typically, native floodplain plant species are best suited to the extreme environmental conditions encountered in a Rain Garden. If shrubs and trees are included in a bioretention area (which is recommended), at least three species of shrub and tree should be planted at a rate of approximately 700 shrubs and 300 trees per acre (shrub to tree ratio should be 2:1 to 3:1). Plants should be placed at irregular intervals to replicate a natural forest. Use local landscape architect to design native planting layout.

5. **Planting periods** will vary, but in general trees and shrubs should be planted from mid-March through the end of June, or mid-September through mid-November

6. A maximum of 2 to 3 inches of shredded **mulch** or leaf compost (or other comparable product) should be uniformly applied immediately after shrubs and trees are planted to prevent erosion, enhance metal removals, and simulate leaf litter in a natural forest system. Wood chips should be avoided as they tend to float during inundation periods Trees and shrubs should generally only be planted from early April through the end of June or from early September through late October. Mulch layer should not exceed 3" in depth so as not to restrict oxygen flow to roots.

7. Must be designed carefully in areas with **steep slopes** and set along contours.

8. Underdrains should never be used except where in-situ soils fail to drain such that surface water within 72 hours.

Detailed Stormwater Functions

Infiltration Area

The Infiltration Area is the bottom area of a Rain Garden or the subsurface infiltration bed Gravel Base, defined as:

Length of bed x Width of bed (or bottom area of irregularly shaped bed) = Infiltration Area (Bottom Area)

This is the area to be considered when evaluating the Loading Rate to the Rain Garden.

Volume Reduction Calculations

The storage volume of a Rain Garden is defined as the sum total of the surface and subsurface void volumes beneath the level of the discharge invert. Inter-media void volumes may vary considerably based on design variations.

The volume of a Rain Garden has 3 components:

1. Surface Storage Volume (CF) =
   Bed Area (ft^2)   x   Max Water Depth (0.5ft)

2. Soil Storage Volume (CF) =
   Bed Area (ft^2) x   Depth of Amended Soil (ft)   x   20% Holding Capacity

3. Optional Stone Bed =
   Bed Area (ft^2)   x   Depth of Stone (ft)   x   40% Void Space*

* 20% Void Space for sand

Rain Garden Volume = Surface Storage Volume + Soil Storage Volume + Stone/Sand Volume

Peak Rate Mitigation

See in Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement

See in Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

The following is a typical construction sequence; however, alterations will be necessary depending on design variations.

1. Install temporary sediment control BMP's as shown on the plans.

2. Complete site grading. If applicable, construct curb cuts or other inflow entrance but provide protection so that drainage is prohibited from entering construction area.

3. Stabilize grading within the limit of disturbance except within the Rain Garden area. Rain garden bed areas may be used as temporary sediment traps provided that the proposed finish elevation of the bed is 6 inches lower than the bottom elevation of the sediment trap.

4. Excavate Rain Garden to proposed invert depth and scarify the existing soil surfaces. Do not compact in-situ soils.

5. Install subsurface infiltration/storage bed (if applicable), distribution pipes and stormwater structures, as specified. The top, sides, and bottom of the stone should be wrapped in nonwoven geotextile.

6. Backfill Rain Garden with amended soil as shown on plans and specifications. Overfilling is recommended to account for settlement. Light hand tamping is acceptable if necessary.

Figure 6.5-17. Newly constructed rain garden at Pennsylvania State University, State College, PA.

7. Presoak the planting soil prior to planting vegetation to aid in settlement.

8. Complete final grading to achieve proposed design elevations, leaving space for upper layer of compost, mulch or topsoil as specified on plans.

9. Plant vegetation according to planting plan.

10. Mulch and install erosion protect at surface flow entrances where necessary.

Maintenance Issues

Properly designed and installed Rain Gardens some annual maintenance.

- While vegetation is being established, pruning and weeding may be required. Weeds should be removed thereafter by hand.
- Detritus may also need to be removed approximately twice per year. Perennial plantings may be cut down at the end of the growing season.
- Mulch should be replaced when erosion is evident. Mulch should be replenished annually. Once every 2 to 3 years the entire area may require mulch replacement.
- Rain Gardens should be inspected annually for sediment buildup, erosion, vegetative conditions, etc.
- During periods of extended drought, Rain Gardens may require watering.
- Rain Gardens should not be mowed on a regular basis.
- Trees and shrubs should be inspected twice per year to evaluate health.

Cost Issues

Although Rain Gardens are relatively expensive to construct, they often replace areas that would have been landscaped and maintenance-intensive so that the net cost can be considerably less than the actual construction cost. In addition, the use of Rain Gardens can decrease the cost for stormwater conveyance systems at a site. Rain Gardens cost approximately $5 to $7 per cubic foot of storage to construct.

Specifications

The following specifications are provided for informational purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Topsoil Specifications** - See Appendix C
2. **Vegetation** - See Appendix B

2. Execution

a. Owner and Engineer shall be notified at least 24 hours prior to all work.

b. Subgrade preparation

1. Existing sub-grade in Rain Gardens shall NOT be compacted or subject to excessive construction equipment traffic.
2. Initial excavation can be performed during rough site grading but shall not be carried to within two feet of the final bottom elevation. Final excavation should not take place until all disturbed areas in the drainage area have been stabilized.
3. Where erosion of sub-grade has caused accumulation of fine materials and/or surface ponding in the graded bottom, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake or equivalent by light tractor.
4. Bring sub-grade of bioretention area to line, grade, and elevations indicated. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All bioretention areas shall be level grade on the bottom.
5. Halt excavation and notify engineer immediately if evidence of sinkhole activity or pinnacles of carbonate bedrock are encountered in the bioretention area.

c. Rain Garden Installation

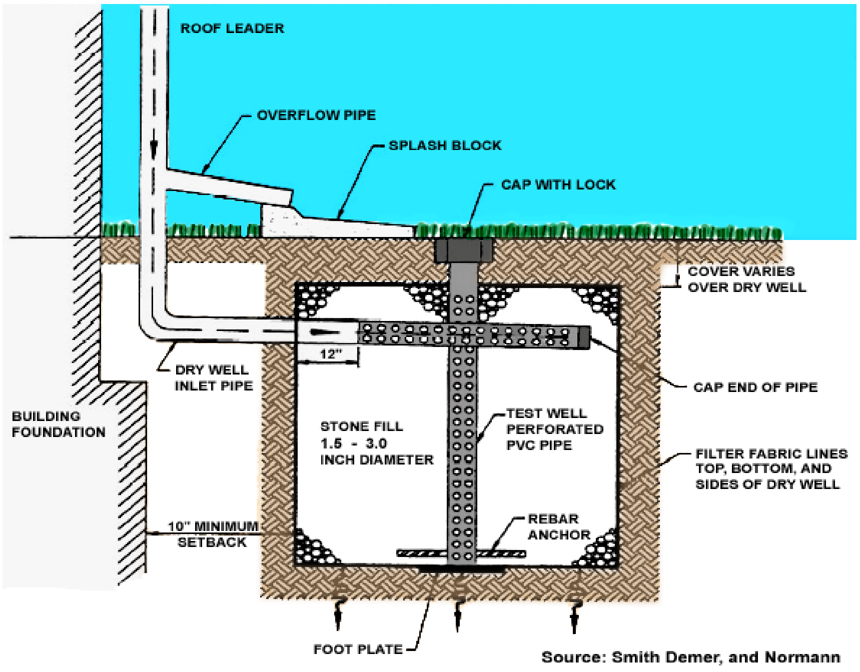
1. Upon completion of sub-grade work, the Engineer shall be notified and shall inspect at his/her discretion before proceeding with bioretention installation.
2. For the subsurface storage/infiltration bed installation (if applicable), geotextile shall be placed on the bottom and sides of excavated area with a minimum overlap of 12 inches and shall extend at least 4 feet beyond the bed area to protect bed from sedimentation.
3. Clean, washed, uniformly graded aggregate (AASHTO #3, #57 or approved substitute with at least 40% void space) shall be placed in the bed as per design depth. After placement of stone, geotextile should be folded over the top of the stone bed to prevent migration of fines into the stone bed.
4. Planting soil shall be placed immediately after approval of sub-grade preparation/ stone bed installation. Any accumulation of debris or sediment that takes place after approval of sub-grade shall be removed prior to installation of planting soil at no extra cost to the Owner.
5. Install planting soil (exceeding all criteria) in 18-inch maximum lifts and lightly compact (tamp with backhoe bucket or by hand). Do not allow equipment movement over planting soil to a minimum – **do not over compact**. Install planting soil to grades indicated on the drawings.
6. Plant trees and shrubs according to supplier's recommendations and only from early April through the end of June or from early September through late October.
7. Install 2-3" shredded hardwood mulch (minimum age 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.
8. Protect Rain Gardens from sediment at all times during construction. Hay bales, diversion berms and/or other appropriate measures shall be used at the toe of slopes that are adjacent to Rain Gardens to prevent sediment from washing into

these areas during site development.

9. When the site is fully vegetated and the soil mantle stabilized the Engineer shall be notified and shall inspect the Rain Garden drainage area at his/her discretion before the area is brought online and sediment control devices removed.
10. Water vegetation at the end of each day for two weeks after planting is completed.

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

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.6: Dry Well / Seepage Pit



(Source: Smith, Derner, and Normann)

A Dry Well, or Seepage Pit, is a variation on an Infiltration system that is designed to temporarily stores and infiltrate rooftop runoff.

Key Design Elements

- Maintain minimum distance from building foundation (typically 10 feet)
- Provide adequate overflow outlet for large storms
- Depth of Dry Well aggregate should be between 18 and 48 inches deep
- At least one observation well; clean out is recommended
- Wrap aggregate with nonwoven geotextile
- Maximum drain-down time is 72 hours
- Provide pretreatment for some situations

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**LIMITED**
Retrofit:	**YES**
Highway/Road:	**NO**

Stormwater Functions

Volume Reduction:	**Medium**
Recharge:	**Medium**
Peak Rate Control:	**Medium**
Water Quality:	**Medium**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

A Dry Well, sometimes called a Seepage Pit, is a subsurface storage facility that temporarily stores and infiltrates stormwater runoff from the roofs of structures. Roof leaders connect directly into the Dry Well, which may be either an excavated pit filled with uniformly graded aggregate wrapped in geotextile or a prefabricated storage chamber or pipe segment. Dry Wells discharge the stored runoff via infiltration into the surrounding soils. In the event that the Dry Well is overwhelmed in an intense storm event, an overflow mechanism (surcharge pipe, connection to larger infiltration area, etc.) will ensure that additional runoff is safely and efficiently conveyed downstream.

By capturing runoff at the source, Dry Wells can dramatically reduce the increased volume of stormwater generated by the roofs of structures. Though roofs are generally not a significant source of runoff pollution, they are still one of the most important sources of new or increased runoff volume from developed areas. By decreasing the volume of stormwater runoff, Dry Wells can also reduce runoff rate and improve water quality. As with other infiltration practices though, Dry Wells may not be appropriate for "hot spots" or other areas where high pollutant or sediment loading is expected without additional design considerations. Dry Wells are not recommended within a specified distance to structures or subsurface sewage disposal systems. (see Section 6.8, Protocol 1)

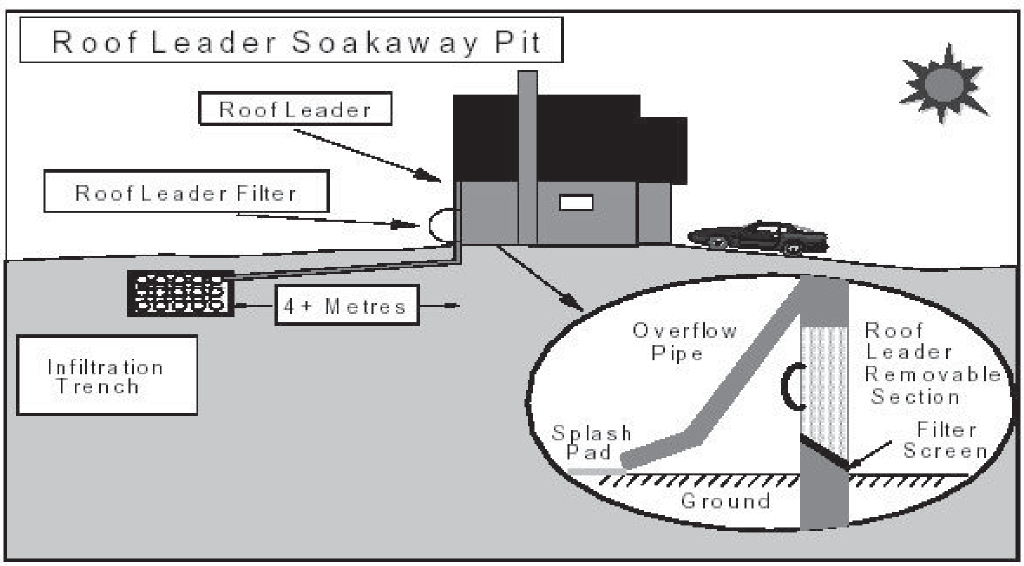


Figure 6.6-1. Roof Leader / Dry Well Schematic (Ontario Manual)

Variations

Intermediate "Sump" Box – Water can flow through an intermediate box with an outflow higher to allow the sediments to settle out. Water would then flow through a mesh screen and into the dry well.

Drain Without Gutters – For structures without gutters or downspouts, runoff is designed to sheetflow off a pitched roof surface and onto a stabilized ground cover (surface aggregate, concrete, or other means). Runoff is then directed toward a Dry Well via stormwater pipes or swales.

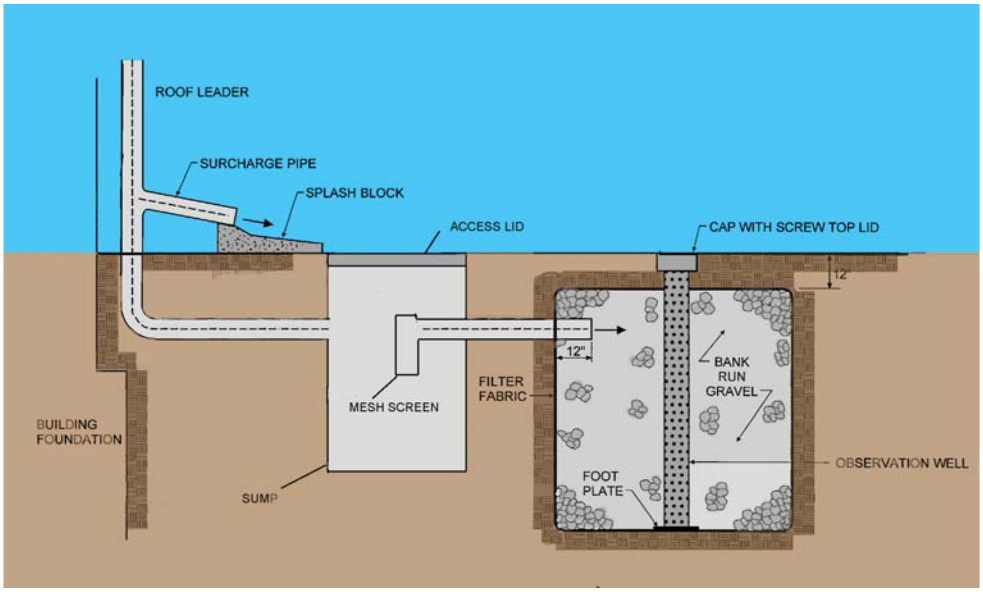


Figure 6.6-2. Intermediate Sump Box (New York Manual)

Prefabricated Dry Well – There are a variety of prefabricated, predominantly plastic subsurface storage chambers on the market today that can replace aggregate Dry Wells. Since these systems have significantly greater storage capacity than aggregate, space requirements are reduced and associated costs may be defrayed. Provided the following design guidelines are followed and infiltration is still encouraged, prefabricated chambers can prove just as effective as standard aggregate Dry Wells.

Figure 6.6-3. Example of pre-fabricated chamber (Infiltrator Systems, Inc.)

Applications
Any roof or impervious area with relatively low sediment loading

Design Considerations
1. Dry Wells are sized to temporarily retain and infiltrate stormwater runoff from roofs of structures. A dry well usually provides stormwater management for a limited roof area.

Care should be taken not to hydraulically overload a dry well based on bottom area and drainage area. (See Section 6.8, Protocol 1 for guidance)

2. Dry Wells should drain-down within 72 hours. Longer drain-down times reduce Dry Well efficiency and can lead to anaerobic conditions, odor and problems.

3. Dry Wells typically consist of 18 to 48 inches of clean washed, uniformly graded aggregate with 40% void capacity (AASHTO No. 3, or similar). Dry Well aggregate is wrapped in a nonwoven geotextile, which provides separation between the aggregate and the surrounding soil. At least 12 inches of soil is then placed over the Dry Well. An alternative form of Dry Well is a subsurface, prefabricated chamber. A variety of prefabricated Dry Wells are currently available on the market.

4. Dry Wells are not recommended when their installation would create a significant risk for basement seepage or flooding. In general, 10 feet of separation is recommended between Dry Wells and building foundations. However, this distance may be shortened at the discretion of a geotechnical or structural engineer. Shorter separation distances may warrant an impermeable liner to be installed on the building side of the Dry Well.

5. All Dry Wells must be able to convey system overflows to downstream drainage systems. System overflows can be incorporated either as surcharge (or overflow) pipes extending from roof leaders or via connections to more substantial infiltration areas.

6. The design depth of a Dry Well should take into account frost depth to prevent frost heave.

7. A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.

8. Adequate inspection and maintenance access to the Well should be provided. Observation wells not only provide the necessary access to the Well, but they also provide a conduit through which pumping of stored runoff can be accomplished in a failed system.

9. Though roofs are generally not a significant source of runoff pollution, they can still be a source of particulates and organic matter, as well as sediment and debris during construction. Measures such as roof gutter guards, roof leader clean-out with sump, or an intermediate sump box can provide pretreatment for Dry Wells by minimizing the amount of sediment and other particulates that may enter it.

Detailed Stormwater Functions

Volume Reduction Calculations

The storage volume of a Dry Well is defined as the volume beneath the discharge invert. The following equation can be used to determine the approximate storage volume of an aggregate Dry Well:

Dry Well Volume = Dry well area (sf) x Dry well water depth (ft) x 40% (if stone filled)

Infiltration Area: A dry well may consider both bottom and side (lateral) infiltration according to design.

Peak Rate Mitigation Calculations
See Section 9 for corresponding peak rate reduction.

Water Quality Improvement
See Section 9

Construction Sequence

1. Protect infiltration area from compaction prior to installation.

2. If possible, install Dry Wells during later phases of site construction to prevent sedimentation and/or damage from construction activity.

3. Install and maintain proper Erosion and Sediment Control Measures during construction as per the Pennsylvania Erosion and Sediment Pollution Control Program Manual (March 2000, or latest edition).

4. Excavate Dry Well bottom to a uniform, level uncompacted subgrade free from rocks and debris. Do NOT compact subgrade. To the greatest extent possible, excavation should be performed with the lightest practical equipment. Excavation equipment should be placed outside the limits of the Dry Well.

5. Completely wrap Dry Well with nonwoven geotextile. (If sediment and/or debris have accumulated in Dry Well bottom, remove prior to geotextile placement.) Geotextile rolls should overlap by a minimum of 24 inches within the trench. Fold back and secure excess geotextile during stone placement.

6. Install continuously perforated pipe, observation wells, and all other Dry Well structures. Connect roof leaders to structures as indicated on plans.

7. Place uniformly graded, clean-washed aggregate in 6-inch lifts, lightly compacting between lifts.

8. Fold and secure nonwoven geotextile over trench, with minimum overlap of 12-inches.

9. Place 12-inch lift of approved Topsoil over trench, as indicated on plans.

10. Seed and stabilize topsoil.

11. Connect surcharge pipe to roof leader and position over splashboard.

12. Do not remove Erosion and Sediment Control measures until site is fully stabilized.

Maintenance Issues

As with all infiltration practices, Dry Wells require regular and effective maintenance to ensure prolonged functioning. The following represent minimum maintenance requirements for Dry Wells:

- Inspect Dry Wells at least four times a year, as well as after every storm exceeding 1 inch.
- Dispose of sediment, debris/trash, and any other waste material removed from a Dry Well at suitable disposal/recycling sites and in compliance with local, state, and federal waste regulations.
- Routinely evaluate the drain-down time of the Dry Well to ensure the maximum time of 72 hours is not being exceeded. If drain-down times are exceeding the maximum, drain the Dry Well via pumping and clean out perforated piping, if included. If slow drainage persists, the system may need replacing.
- Regularly clean out gutters and ensure proper connections to facilitate the effectiveness of the dry well.
- Replace filter screen that intercepts roof runoff as necessary.
- If an intermediate sump box exists, clean it out at least once per year.

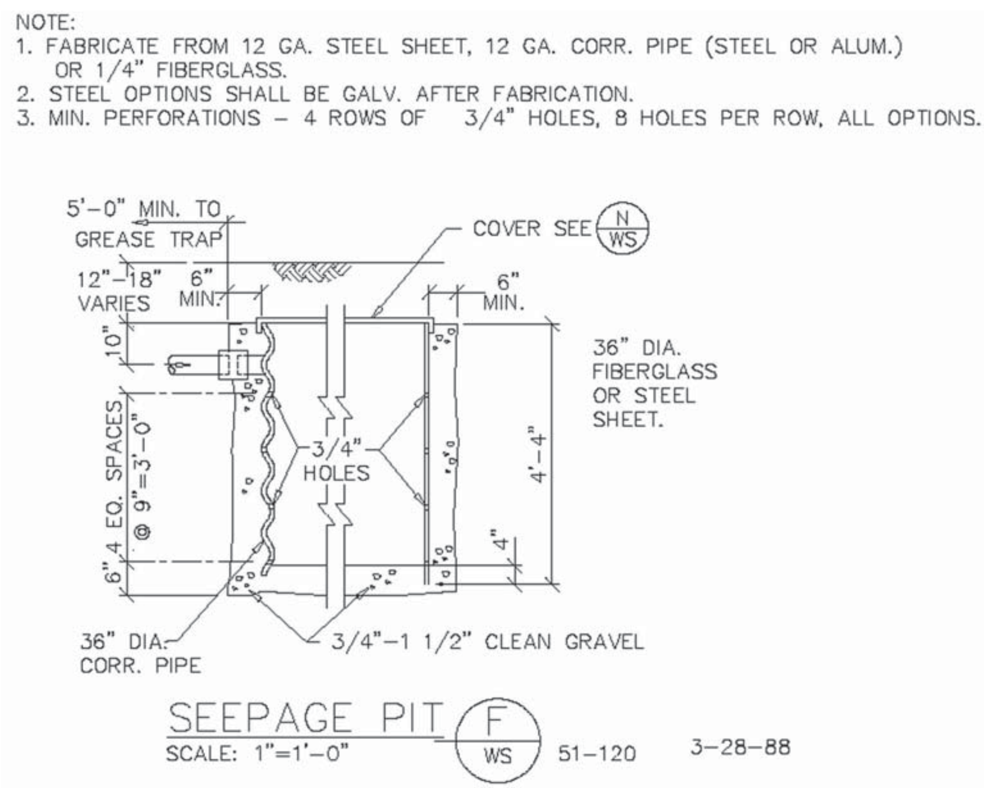


Figure 6.6-4. Seepage Pit detail (USDA, Pacific NW Forest Service)

Cost Issues

The construction cost of a Dry Well/Seepage Pit can vary greatly depending on design variability, configuration, location, site-specific conditions, etc. Typical construction costs in 2003 dollars range from $4 - $9 per cubic foot of storage volume provided (SWRPC, 1991; Brown and Schueler, 1997). Annual maintenance costs have been reported to be approximately 5 to 10 percent of the capital costs (Schueler, 1987). The cost of gutters is typically included in the total structure cost, as opposed

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Stone** for infiltration trenches shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size No. 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

2. **Nonwoven Geotextile** shall consist of needled nonwoven polypropylene fibers and meet the following properties:
    a. Grab Tensile Strength (ASTM-D4632) ^{3} 120 lbs
    b. Mullen Burst Strength (ASTM-D3786) ^{3} 225 psi
    c. Flow Rate (ASTM-D4491) ^{3} 95 $gal/min/ft^2$
    d. UV Resistance after 500 hrs (ASTM-D4355) ^{3} 70%
    e. Heat-set or heat-calendared fabrics are not permitted

Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

3. **Topsoil** See Appendix C

4. **Pipe** shall be continuously perforated, smooth interior, with a minimum inside diameter of 4-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S. 12 guage aluminum or corrugated steel pipe may be used in seepage pits.

5. **Gutters and splashboards** shall follow Manufacturer's specifications.

References

New Jersey Department of Environmental Protection. *New Jersey Stormwater Best Management Practices Manual*. 2004.

New York State Stormwater Management Design Manual

http://www.unexco.com/french.html

SWRPC, 1991

Brown and Schueler, 1997

Schueler, 1987