United States Environmental Protection Agency

2012 GREEN INFRASTRUCTURE TECHNICAL ASSISTANCE PROGRAM
Pittsburgh UNITED
Pittsburgh, Pennsylvania

Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

Clay Soils

Photo: Rain Garden at Edgewood Train Station
Source: Nine Mile Run Watershed Association

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About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, the water is absorbed and filtered by soil and plants. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby waterbodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

EPA encourages the use of green infrastructure to help manage stormwater runoff. In April 2011, EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure.

In February 2012, EPA announced the availability of $950,000 in technical assistance to communities working to overcome common barriers to green infrastructure. EPA received letters of interest from over 150 communities across the country, and selected 17 of these communities to receive technical assistance. Selected communities received assistance with a range of projects aimed at addressing common barriers to green infrastructure, including code review, green infrastructure design, and cost-benefit assessments. Pittsburgh UNITED was selected to receive assistance developing fact sheets and technical papers to provide solutions for site conditions that are perceived to limit green infrastructure applicability.

For more information, visit http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm.

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Introduction

Green infrastructure is often entirely compatible with clay or slowly infiltrating soils for managing stormwater in urban areas. Although the design of green infrastructure practices in clay or low permeability soils must be considered early in the planning and design process, many effective design practices are available, both nonstructural and structural, for this soil type. Many cities throughout the United States have demonstrated the ability of green infrastructure to help treat, slow, and reduce stormwater even in low permeability soils.

Green infrastructure is an important design strategy for protecting water quality while also providing multiple community benefits. EPA defines green infrastructure as structural or nonstructural practices that mimic or restore natural hydrologic processes within the built environment. Common green infrastructure practices include permeable pavement, bioretention facilities, and vegetated roofs. These practices complement conventional stormwater management practices by enhancing infiltration, storage, and evapotranspiration throughout the built environment and managing runoff at its source.

This paper examines the applicability of green infrastructure practices on clay soils in the Pittsburgh area. The first section discusses the challenges to stormwater management posed by clay soils; the second section defines the extent and nature of clay soils in and around Pittsburgh; the third section describes methods for selecting and designing green infrastructure for sites with clayey or compacted soils including infiltration-based practices and noninfiltration-based practices; and the fourth section provides examples of monitored projects on clay soils. The goal of this paper is to provide recommendations for design that are based on observation, research, and engineering in order to help practitioners make informed decisions regarding the use of green infrastructure on sites with clay soils.

Clay Soil and Stormwater Management Overview

Clay soil is often thought of as a challenge to green infrastructure in that infiltration rates are minimal and therefore complete on-site retention is not likely. On the contrary, clay soil has been shown to provide almost as much runoff retention as sandy soil (see Section 'Examples of Implemented Projects'). Green infrastructure can enhance evapotranspiration, attenuate peak flows, and enhance infiltration, depending on the system design (see Section 'Methods to Address Clay Soils'). Note that in some cases, compacted soil is misconstrued as clay soil because of observed surface ponding and low infiltration rates. Compacted soil and clay soil are not the same and must be handled differently, as described in Section 'Methods to Address Clay Soils'. Often times, compacted soil can be restored through subsoiling and soil amendment.

To better understand clay soil, the remainder of this section presents hydrologic characteristics of clay as well as characteristics of silt and sand.

Soil Textural Classes

A normal uncompacted unit of soil is made up of about 45 percent sand, silt, or clay; 5 percent organic matter; 25 percent air; and 25 percent water. Different mixtures of sand, silt, and clay produce different soil textural classes with different material properties (Figure 1). Sand increases the permeability of the soil, silt increases the capillarity of the soil to help pull water upward toward plant roots, and clay further increases soil water-holding capacity as well as cation exchange capacity. Cation exchange capacity governs the ability of the soil to hold nutrients that are crucial to plant health. Organic matter is also essential to soil. Organic matter provides nitrogen; pH buffering; air space; food for worms, insects, and other life; and rainfall absorption (USGS, 2011). Grain size for soil particles decreases from sand to silt to clay, with sand having the largest grain size and clay the smallest (Table 1).

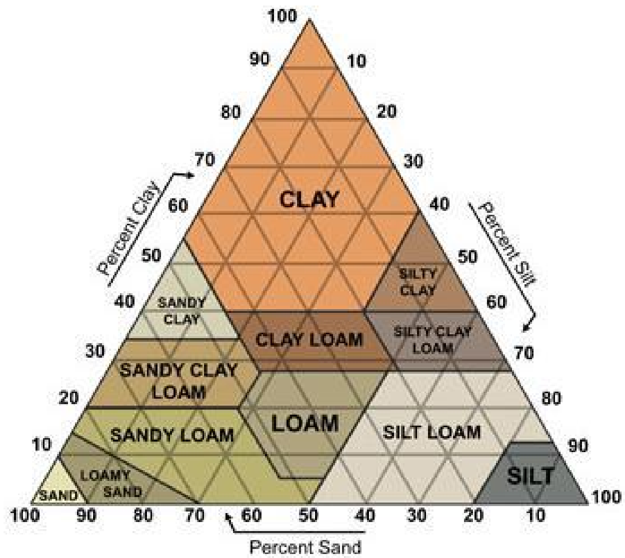


Figure 1. Soil Textural Classes

Source: http://www.stevenswater.com/articles/soiltypes.aspx

Soil Definitions

The following are important definitions related to soil hydrology. Table 1 includes values of these parameters for sand, silt, and clay.

Total Porosity – The total porosity of a porous medium, such as clay or sand, describes the ratio of pore volume to the total volume of the medium. This pore volume includes both the volume of 1) immobile pores containing adsorbed water and 2) mobile pores containing water that is free to move through the saturated system. Coarse-textured soils such as sand or gravel tend to have a lower total porosity than fine-textured soils such as clay. Particularly in clay soils, the total porosity is not constant because the soil swells, shrinks, compacts, and cracks with varying moisture levels.

Effective Porosity – The effective porosity is the ratio of the volume of mobile pores containing water that is free to move through the saturated system to the total volume of the medium.

Volumetric Water Content – Volumetric water content is the quantity of water contained in a given volume of soil and will differ at saturation, field capacity, and permanent wilting point.

Saturation – Saturation is when soil is at its maximum retentive capacity, i.e. when all pores are filled with water.

Field Capacity (F.C.) – Field capacity (a.k.a. specific retention, residual water content) is the ratio of the volume of water contained in the soil sample after all downward gravity drainage has ceased (the volume of immobile pores containing adsorbed water) to the total volume of the sample. Field capacity is reached about one to two days after a heavy rainfall. Refer to Figure 2 for a depiction of field capacity for different soil textural classes.

Permanent Wilting Point (P.W.P.) – Permanent wilting point is the minimum soil moisture at which a plant wilts and can no longer recover its turgidity. Refer to Figure 2 for a depiction of permanent wilting point for different soil textural classes.

Available Water Content (A.W.C.) – Available water content is the amount of water in the soil that is available to plants. It is the difference between field capacity and permanent wilting point.

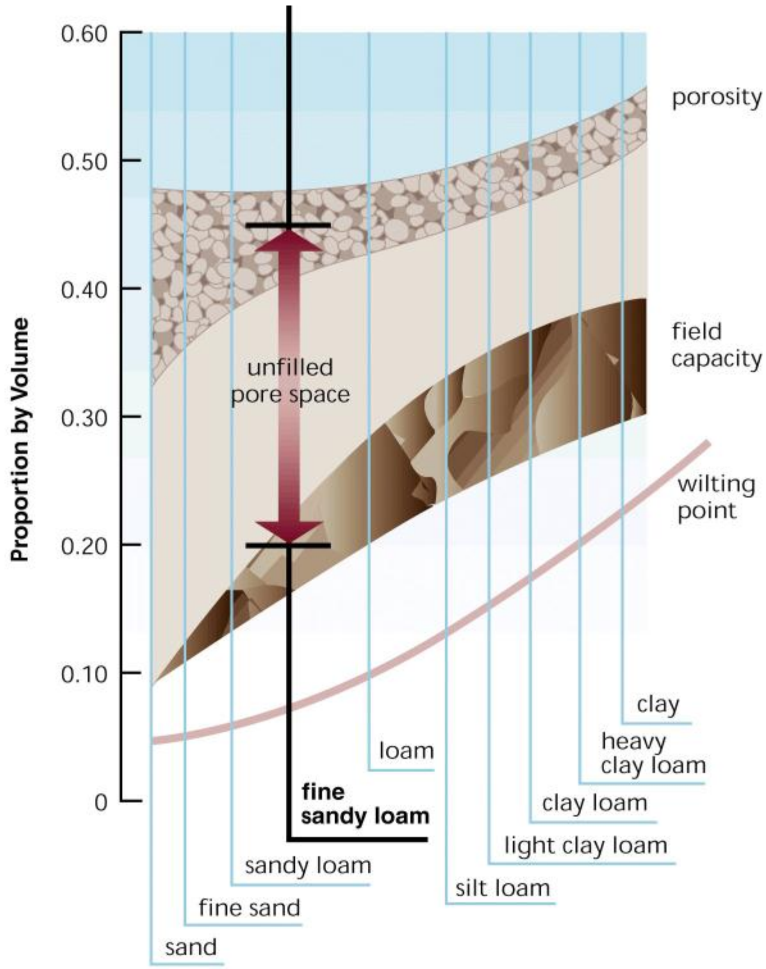
Infiltration Rate – The measure of the rate at which soil is able to absorb rainfall. The rate decreases as the soil becomes saturated.

Saturated Hydraulic Conductivity –The ease with which pores of a saturated soil permit water movement. Also the infiltration rate when the soil is saturated.

Permeability – The measure of how well a porous media transmits a fluid.

Table 1. Soil Properties

Soil Properties	Clay	Silt	Sand	Reference
Grain Size	<0.002 mm	0.002–0.05 mm	0.05–2.0 mm	USDA sand classifications
Total Porosity	0.34–0.57	0.34–0.51	0.25–0.46	http://web.ead.anl.gov/resrad/datacoll/porosity.htm
Effective Porosity	0.01–0.18	0.01–0.39	0.01–0.43	http://web.ead.anl.gov/resrad/datacoll/porosity.htm
Volumetric Water Content at F.C.	0.32–0.40	0.28–0.36	0.07–0.17	http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html
Volumetric Water Content at P.W.P.	0.20–0.24	0.12–0.22	0.02–0.07	http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html
Volumetric Water Content at A.W.C.	0.12–0.16	0.14–0.14	0.05–0.10	http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html
Saturated Hydraulic Conductivity, K_{sat}	0.02 in/hr	0.27 in/hr	8 in/hr	http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-saturated_water_flow.html
Permeability	10^{-10}– 10^{-15} cm^2	10^{-8}–10^{-11} cm^2	10^{-5}– 10^{-9} cm^2	http://en.wikipedia.org/wiki/Permeability_(earth_sciences)

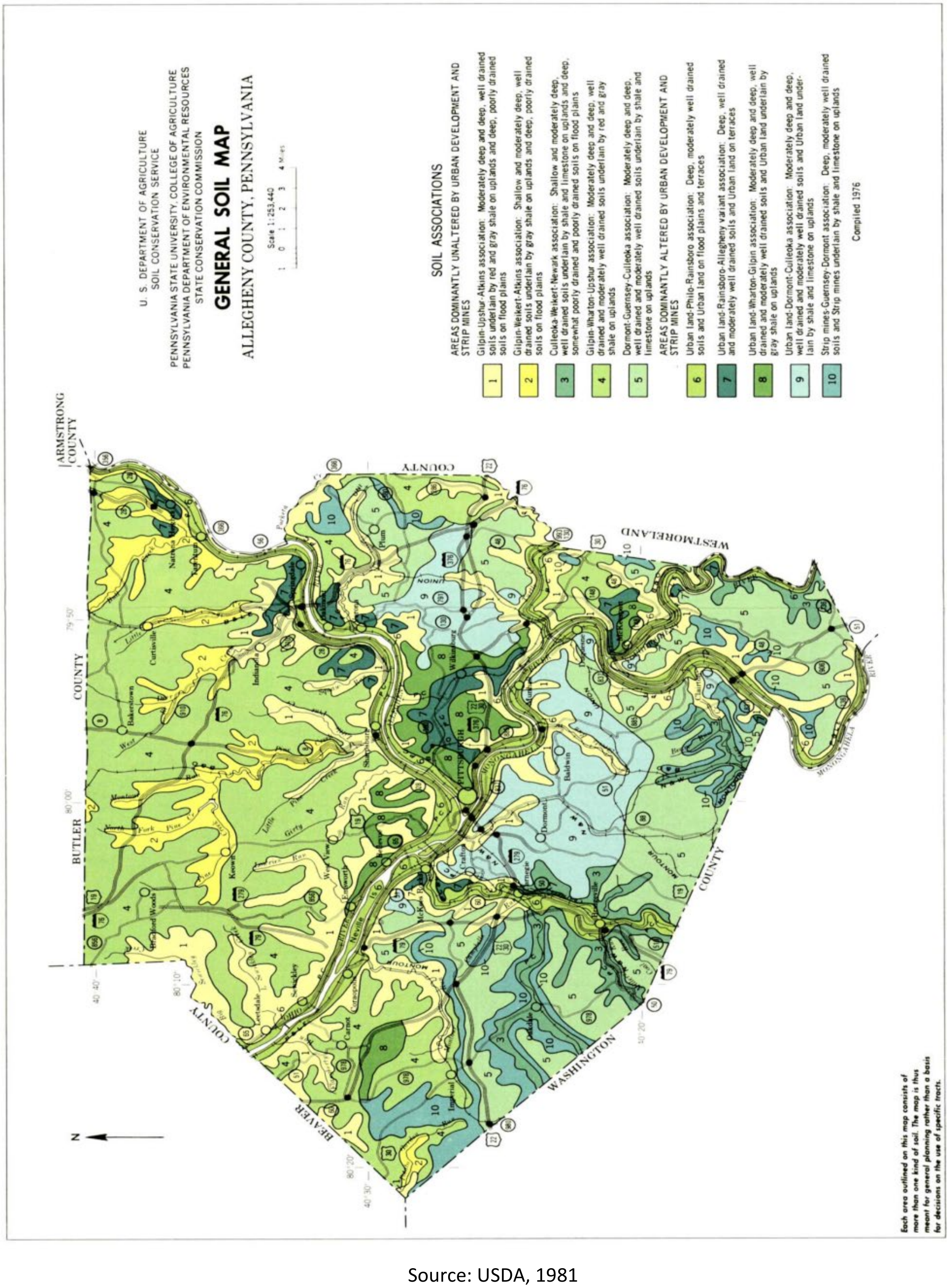


Source: FISRWG, 10/1998, Figure 2.7

Figure 2. Water-Holding Properties of Various Soils

Soils in the Greater Pittsburgh Area

On any given site within the greater Pittsburgh area there is a likelihood that the soil will contain clay, but this does not necessarily mean the soil drains poorly or is unsuitable for green infrastructure. This is why infiltration testing in and around the proposed location of a green infrastructure practice is so important during design (see Section 'Methods to Address Clay Soils'). Even if a particular location is deemed unsuitable for infiltration, another location on the same site may be suitable. According to the USDA Soil Survey of Allegheny County, Pennsylvania, the soil associations in this area can be divided into "Areas dominantly unaltered by urban development and strip mines" and "Areas dominantly altered by urban development and strip mines" (Figure 3).



Source: USDA, 1981

Figure 3. General Soil Map of Allegheny County, PA

Unaltered Soils

For the areas dominantly unaltered, the predominant soil texture is silt loam with some silty clay loam (Figure 1). The silt loam in the Pittsburgh area is about 25% sand, 50% silt, and 25% clay. These unaltered areas tend to be on the north side of the Ohio River and Allegheny River and along the creeks such as Squaw Run near Fox Chapel, Girty Run near Millvale, and Streets Run near Baldwin. Hydrologic characteristics of the soils in the area typically range from well drained and slowly permeable to poorly drained, all of which can be accommodated in green infrastructure design. Generally, the soils on gentler slopes are greater than 5 feet deep.

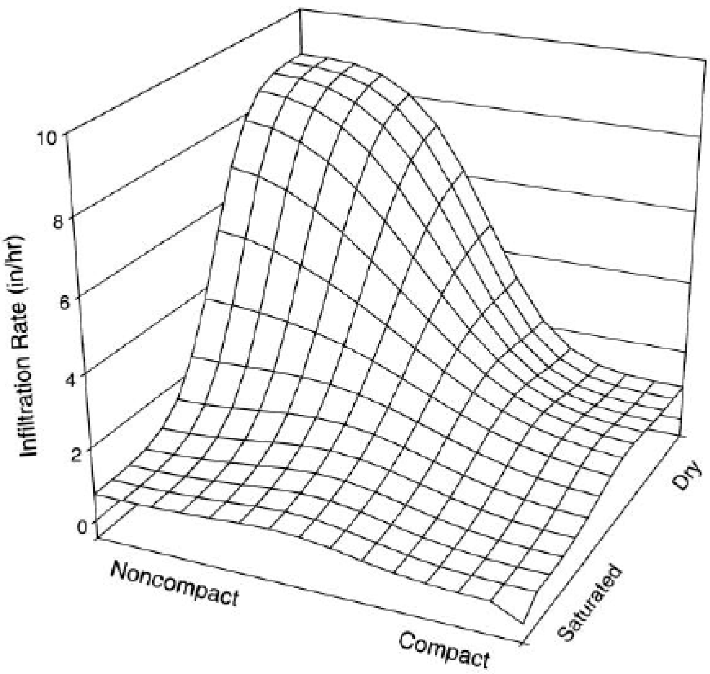
Swelling Soils

In the greater Pittsburgh area, outcrops of swelling clay (i.e. clay that is susceptible to large volume changes due to its moisture retaining capability) are generally sparse (USGS, 1989). If swelling clay is suspected on a site, a geotechnical investigation would be required to verify swelling clay. Where swelling clay occurs near building foundations or pavements, siting green infrastructure away from these structures may prevent any damage. Alternatively, the practice could be lined to keep the water away from foundations. Lining a system with an impermeable high density polyethylene (HDPE) geomembrane or a concrete box is a common technique used in locations where infiltration would be detrimental to adjacent structures or to groundwater. Groundwater contamination is a concern in locations with contaminated soils and in karst topography. Although there is zero infiltration, lined systems still have many advantages including pollutant removal through an engineered soil, peak flow attenuation, and evapotranspiration.

Altered Soils

The City of Pittsburgh and much of the area south of the Ohio and Allegheny rivers have soils which are considered altered. These are mostly urban soils underlain by the in situ silt loam. Typically these soils are compacted and it is difficult to predict what levels of infiltration can be expected. This unknown supports conducting infiltration tests at the proposed green infrastructure locations during design. Ideally infiltration tests should be conducted under saturated conditions. This is because infiltration rates for clay soils can decline as much with soil saturation as with compaction (Figure 4; Pitt et al*.*, 1999).

Based on studies of compacted sandy and clayey urban soils (Pitt et al., 1999), average infiltration rates for urban soils in the Pittsburgh area may range from 0.7 inches per hour to 2.5 inches per hour. Other published infiltration rate data indicate saturated hydraulic conductivity values of 0.27 inches per hour for silt loam and 0.06 inches per hour for silty clay loam (Ferguson and Debo, 1990). **Because of the wide range of reported values, these numbers can only be used as an initial estimate until site-specific infiltration testing is conducted.**



Source: Pitt et al., 1999, Figure 3-2

Figure 4. Three-Dimensional Plot of Infiltration Rates for Clayey Soil Conditions

Methods to Address Clay Soils

Soils need to be evaluated early in the design process. Only after addressing the question "What type of infiltration rate can be expected through the site's soils?" can practices be selected and sized to meet design storm criteria. Practices include infiltration- and noninfiltration-based practices.

The remainder of this section provides potential procedures for evaluating soils on a site and selecting and designing green infrastructure practices on sites with low permeability soils.

Site Evaluation and Soil Infiltration Testing

Site evaluation and soil infiltration testing should be completed early in the site planning and design process. Prescreening may be conducted to identify preliminary sites for green infrastructure practices. Once preliminary sites are proposed, further investigation at the location of each proposed practice is recommended. Even if the soil is expected to have a low capacity for infiltration, accounting for the removal of runoff through infiltration may decrease the required size of the practice.

In evaluating site soils, it is important to differentiate between compacted soil and clay soil. Soils that have previously been disturbed by development should be considered compacted. Note that for disturbed compacted soils, typically the compaction only persists about 18 inches below the surface (PADEP, 2006). Infiltration testing below this depth is important in understanding the true infiltration rate of the soil.

During site evaluation, the depths to the seasonal high groundwater table and to bedrock should be measured. These depths will also affect the design and siting of the practice. The PA BMP Manual recommends at least 2 feet of separation to bedrock and to seasonal high groundwater. In the greater Pittsburgh area it is also essential to prevent infiltration altogether in landslide-prone areas. Refer to the Allegheny County Comprehensive Plan maps for locations of landslide-prone areas (http://www.alleghenyplaces.com/comprehensive_plan/maps.aspx). Refer to Appendix C, Site Evaluation and Soil Testing, of the Pennsylvania Best Management Practices Manual for detailed procedures for site background evaluation, test pit observation, infiltration and permeability tests.

Selecting Green Infrastructure Practices

Once site soils are characterized and infiltration rates for the surface and subsurface are known, appropriate green infrastructure practices may be selected and sized. There are many green infrastructure practices that are appropriate on sites with low permeability soils including noninfiltration-based practices and infiltration-based practices. The final selection of practices will depend on many other factors including space availability, site topography, aesthetics, cost, maintenance, pollutant removal goals, and stormwater design criteria.

Noninfiltration-based practices include vegetated roofs, water harvesting (runoff capture and reuse), vegetated filter strips, contained sand/media filters, and constructed wetlands. Infiltration-based practices include bioretention systems, infiltration basins, permeable pavement, and vegetated swales.

In addition, a designer should consider the importance of *detaining* the water where it may be difficult to *retain* the water due to low permeability soils. This consideration may be important if a greater goal is to lessen the peak flow burden on the combined sewer system.

Noninfiltration-Based Practices

Noninfiltration-based practices include vegetated roofs, water harvesting (runoff capture and reuse), vegetated filter strips, contained sand/media filters, and constructed wetlands. Vegetated roofs do well at removing stormwater through evapotranspiration for small rain events. Water harvesting systems include rain barrels and cisterns, which are used for water reuse in addition to runoff reduction. Vegetated filter strips are typically used as a pretreatment mechanism taking on sheet flow from a paved surface. Contained sand and media filters are used as flow-through treatment practices that are contained within a lined system. More information about these practices can be found in the Pennsylvania Best Management Practices Manual.

A familiar noninfiltration-based practice in the Pittsburgh area is a constructed wetland system. Constructed wetlands are shallow marsh systems that treat stormwater. To support their wetland vegetation, they require either a high groundwater table or large drainage area. Pittsburgh's frequent rainfall is particularly supportive of wetlands. Wetland systems should be designed as part of a 'treatment train' to protect them from sediment and debris. A sediment forebay is commonly used as well as a flow splitter to divert heavy flows away so as to not harm the sensitive soil and plants.

Detention – The stormwater management practice of temporarily detaining runoff before releasing it downstream at a controlled rate.

Retention – The stormwater management practice of preventing stormwater from leaving a developed or developing site through interception, infiltration, or evapotranspiration.

Infiltration-Based Practices

Infiltration-based practices include bioretention systems, infiltration basins, permeable pavement, and vegetated swales. This section discusses the various techniques available for designing infiltration-based practices in low permeability soils. Specifically, soil amendments, practices to protect the existing soil from clogging, and important design components for conveying stormwater are discussed.

General design guidance on each infiltration-based practice can be found in the Pennsylvania Best Management Practices Manual. The Westmoreland Conservation District also provides design guidance for bioretention in clay soils (Westmoreland Conservation District, 2013).

1. Soil Amendment

The soil discussion in this section is divided into the near surface soil and the subsurface soil. The near surface soil is what is termed the planting soil or growing layer. For clayey or compacted soil, it is typical to either excavate to the depth of the planting soil and replace with an engineered soil, having suitable properties for drainage and plant growth, or amend the native soil with 2.5 inches of compost over the surface of the site (King County, 2005). When amending the native soil, the soil and compost are tilled with a subsoiler or ripper attached to a tow vehicle (Kees, 2008). The engineered soil is typically a mixture of loamy soil, sand, and compost, the details of which depend on the needs of the plants selected and the hydraulic properties desired. It is helpful for a professional with knowledge in plants and soils to formulate the soil mix.

Note that for disturbed or compacted soils, typically the compaction only goes about 18 inches below the surface (PADEP, 2006). Infiltration testing below this depth is important in understanding the true infiltration rate of the soil.

For clayey or compacted subsurface soil, it may also be beneficial to amend the existing subsurface soil with compost to enhance the infiltration rate. This practice increases infiltration rates and also helps reduce cations and toxicants in the water. The disadvantage is that nutrient leaching occurs for a period of time (Pitt et al., 1999). Establishing native plants with extensive root systems will also help provide channels to promote infiltration in the subsurface soil.

2. Protecting the Existing Soils

Regardless of the particular practice selected, underlying soils should be protected for all practices relying on the infiltration rate of existing soils. Efforts to protect the soils from clogging and compaction should occur during design, construction, and post-construction.

Design: Pretreatment to provide removal of sediment from runoff should be considered during design. Pretreatment designs vary depending on the siting and properties of the green infrastructure practice, but common options include vegetated swales, vegetated filter strips, catch basin sumps, and water quality inlets. The Pennsylvania Best Management Practices Manual includes design guidance on vegetated filter strips and vegetated swales.

In the Pennsylvania Best Management Practices Manual, the inclusion of catch basin sumps and water quality inlets is a design recommendation for roof runoff draining to subsurface infiltration practices such as a dry well or seepage pit. These pretreatment designs are also recommended for any surface drains. Water quality inlets consist of one or more chambers that promote sedimentation of coarse materials and separation of free oil. Some are designed to drop directly into existing catch basins, while others may require retrofit construction. Their primary function is to remove sediment, oils and grease, floatables, and pollutants, which are common constituents of parking lot and road runoff (PADEP, 2006).

Note that for permeable pavement, which typically does not have an upgradient drainage area, the primary design consideration is ensuring that there is no potential for sediment-laden stormwater to drain onto the permeable pavement.

The design phase is also the time to address soil erosion and sedimentation control (SESC). SESC practices should be located on the construction drawings to protect the green infrastructure practices. If sediment-laden runoff is allowed to drain to a green infrastructure practice, the integrity of the practice is diminished. For more information on erosion and sediment control, refer to the PA DEP Erosion and Sediment Pollution Control Program Manual.

Construction: Construction documents must address protection of the green infrastructure practices during construction. Specifications must include language prohibiting all heavy equipment and minimizing all other traffic, including foot traffic, from entering the sites for the green infrastructure practices. If planting soil is used for a practice, it should only be compacted by water droplets. Construction documents should also include language instructing the contactor to install a temporary construction fence around the protected areas.

During construction of the green infrastructure practices, careful adherence to the construction documents related to exclusion of traffic and sediment from the green infrastructure practice sites is imperative.

Post-Construction: Maintenance of the green infrastructure practice will help sustain the existing soil infiltration rate. In particular, maintenance of the pretreatment practices is necessary for periodic removal of sediment. Maintenance intervals vary depending on typical sediment concentrations in the drainage area runoff, and frequent inspections initially should help determine a proper maintenance schedule. In many situations, annual sediment removal from forebays and sumps is sufficient. Sediment transport through filter strips and swales may be more difficult to track.

3. Design Components

This section describes the essential overflow and underdrain system for low permeability soils. Overflow systems convey excess water safely away from buildings and areas where it could cause a hazard. Underdrains convey the subsurface water in a green infrastructure practice to help meet required dewatering times when infiltration rates are too slow. Two common formulas used to account for the volume of water lost to infiltration include the Horton and Green-Ampt equations.

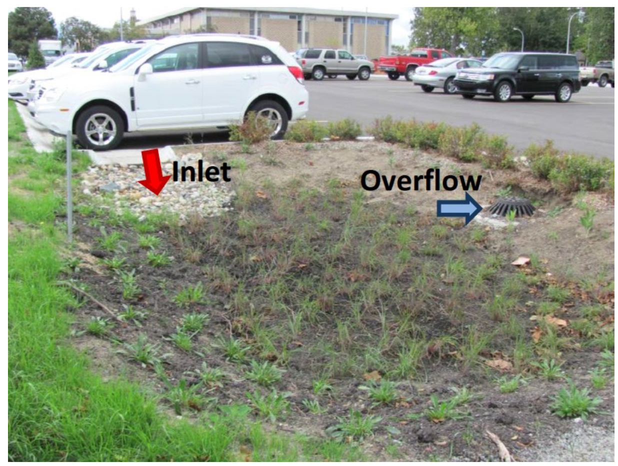
Overflow Systems: Green infrastructure practices should always be designed with an overflow system regardless of the existing soil properties. The overflow system is designed to convey the peak flow from storm events with a greater recurrence interval than the design storm used for sizing the green infrastructure practice. For practices with an upgradient drainage area (e.g. bioretention, vegetated swales, wetlands) there are essentially two types of overflow systems: one for on-line systems, and one for off-line systems (Figure 5). When the green infrastructure practice is an on-line system, an overflow catch basin or weir is used to handle larger flows. When the green infrastructure practice is an off-line system, stormwater from the larger storm events bypasses the practice and continues down the conveyance network, e.g. curb and gutter, storm pipe, or swale. An off-line system is preferred as it has less exposure to the large storm events. For practices with no upgradient drainage area, such as permeable pavement or a vegetated roof, the overflow system is typically a downstream catch basin and conveyance network.

Underdrains: In addition to an overflow system, installation of an underdrain may be important to meeting acceptable dewatering times, particularly for slowly permeable soils. A perforated underdrain is placed at the bottom of the practice for lined practices and essentially at a higher elevation within the soil/aggregate matrix for un-lined practices to promote infiltration. The higher elevation can be governed by an upturned elbow configuration as shown in Figure 6. The elevation of the outlet is governed by the required dewatering time of the practice. According to the Pennsylvania Best Management Practices Manual, a maximum 72-hour dewatering time is recommended for surface ponding. The outlet configuration would be placed such that the water stored beneath it could infiltrate within 72 hours.

Source: Tetra Tech

Off-Line System

Water enters the bioretention area from a curb cut. Once the ponding area is full to the level of the gutter, stormwater will not enter the area but will be conveyed down the gutter to a catch basin.

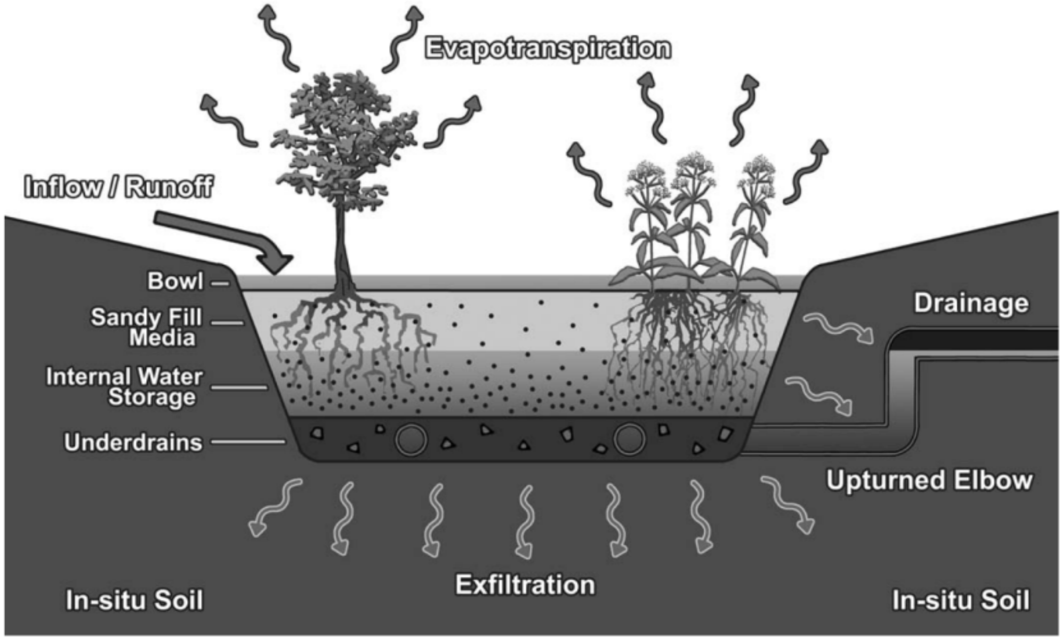


Source: Tetra Tech

On-Line System

Water enters the bioretention area from a curb cut. An overflow structure is placed within the bioretention area to convey flows in excess of the design flow.

Figure 5. Off-Line and On-Line Bioretention Systems



Source: Brown, et al., 2009

Figure 6. Example of an Upturned Elbow Outlet Configuration

Examples of Implemented Projects

Evaluation of Turf-Grass and Prairie-Vegetated Rain Gardens in a Clay and Sand Soil, Madison, WI, Water years 2004-2008 (Selbig and Balster, 2010)

A study was conducted in Madison, Wisconsin from 2004 to 2008 to compare the capability of rain gardens with different soil and vegetation types to infiltrate stormwater runoff. Two side-by-side rain gardens were installed on sandy soil, and two additional side-by-side rain gardens were installed on clay soil (Figure 7). For each soil type, one of the rain gardens was planted with turf grass and the other with a native prairie species (Figure 8). Results showed that the rain gardens with clay soils performed such that at least 99 percent of the inflow was able to be infiltrated after four years of operation. Underdrains were not used in this study.

1. Design Summary

Each side-by-side rain garden received approximately equal amounts of roof runoff and was sized to a ratio of approximately 5:1 contributing drainage area to receiving area. The parent soil was excavated to form berms around the rain gardens to exclude drainage from areas other than the roof. Approximately 4 to 6 inches of screened compost was then worked into the remaining parent soil with a rototiller. The surface was then leveled and planted leaving approximately 6 inches of ponding depth.

2. Results Summary

The results showed that regardless of soil type or vegetation, the rain gardens were capable of storing and infiltrating most of the runoff over the 4-year study period. Refer to Table 2 for influent and effluent data for each rain garden. Other significant observations included the following:

- Median infiltration rates for rain gardens in sand were greater than those in clay.
- Rain gardens with prairie vegetation had greater median infiltration rates than those with turf grass for each soil type.
- Infiltration was highest during spring and summer.
- Although infiltration rates were reduced during winter months, the hydraulic function of the rain gardens did not appear to be appreciably altered.
- Based on storage capacity alone, approximately 90 percent of all precipitation measured over the 4-year study was stored in the gardens. Taking into account infiltration rate and specific yield of subsurface soils, nearly 100 percent of precipitation was retained.
- Roots in the prairie-clay rain garden extended 4.7 feet deep compared with 0.46 feet in the turf-clay rain garden. This and greater earthworm activity in the prairie-clay garden may result in greater capacity of the prairie-clay garden to store and infiltrate stormwater than the turf-clay garden.

Table 2. Summary of Influent and Effluent Volumes over the Period of the Study (Selbig and Balster, 2010)

[—, data not available; values represent volumes into and out of rain garden from roof and direct precipitation; they include snowmelt for runoff but do not include water equivalent for snow falling directly on rain garden. Therefore, the volumes in this table and those presented in table 4 will be different because table 4 includes estimates of water equivalent for snow using available NOAA data.]

	Volume (cubic feet)									
	Influent					Effluent				
Rain Garden	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
Turf-sand	1,279	749	1,142	1,341	2,157[1]	0	0	0	0	11[1]
Prairie-sand	1,275	764	1,206	1,354	—	0	0	0	0	—
Percent difference	0	-2	-5	-1	—	0	0	0	0	—
Turf-clay	5,436	2,923	4,247	5,198	—	191	35	10	12	—
Prairie-clay	5,859	2,423	3,608	4,437	8,331[1]	0	0	0	0	138[1]
Percent difference	-7%	21%	18%	17%	—	100%	100%	100%	100%	—

[1] In water year 2008, all roof runoff was directed to the turf-sand and prairie-clay rain gardens. This doubled the ratio of contributing to receiving area to 10 to 1 and 8 to 1, respectively.

Figure 7. Side-by-Side Rain Garden Configuration

Figure 8. Planting Native Prairie Plugs

Maywood Avenue Combined Sewer Overflow (CSO) Bioswales Project, Toledo, OH

The Maywood CSO project in Toledo, Ohio is an example of a neighborhood-scale green infrastructure project constructed on clay soils (Figure 9). Maywood Avenue is a single 1,300-foot long street in a neighborhood located on the north side of Toledo. The neighborhood demographics and physical components are typical of other well-established, older urban neighborhoods in the city. Results showed that despite the clay soils, the system was able to retain about 64 percent of annual runoff volume. Peak flows were reduced by 60–70 percent.

Figure 9. Before and After Bioswales on Maywood Avenue

1. Design Summary

The design accounted for a capture of approximately 0.35 inches of runoff primarily through the use of bioswales and pervious pavement sidewalks and driveway approaches, but based on subsequent flow monitoring and modeling, the actual capture was greater than this. The post-construction analysis showed a significant amount of water being retained through infiltration, which was not anticipated in the design. An underdrain was installed due to the existence of clay soils, but was later closed with a valve to promote infiltration. The project goal was to determine the effectiveness of using green infrastructure to reduce stormwater runoff, improve water quality, and assess impacts on stormwater and CSO management. Refer to Figure 10 for a design detail of the bioswale.

2. Results Summary

Flow monitoring was conducted before and after construction of the green infrastructure practices to assess effectiveness. Despite being constructed on clayey soils, the new system has shown a decrease in peak flows and runoff volumes as indicated in Figure 11 and Figure 12. The figures show pre-construction monitoring in 2010, post-construction monitoring with the valve at the underdrain outlet open in 2011, and post-construction monitoring with the valve at the underdrain outlet closed in 2011. With the valve closed, which is normal operation, the water is left to infiltrate below the bioswales.

Long-term simulations using US-EPA SWMM indicate an annual average reduction of runoff volume of approximately 64 percent. Peak flows are reduced by 60 percent to 70 percent at equivalent rainfall intensities.

3. Lessons Learned

Construction of the Maywood Avenue bioswale was simplified by the presence of clay soils, which eliminated the need for trench shoring (Figure 13). Overall the bioswale provided much more stormwater volume reduction than expected. These results indicate that the infiltration rate of clay soils can contribute significantly to green infrastructure performance.

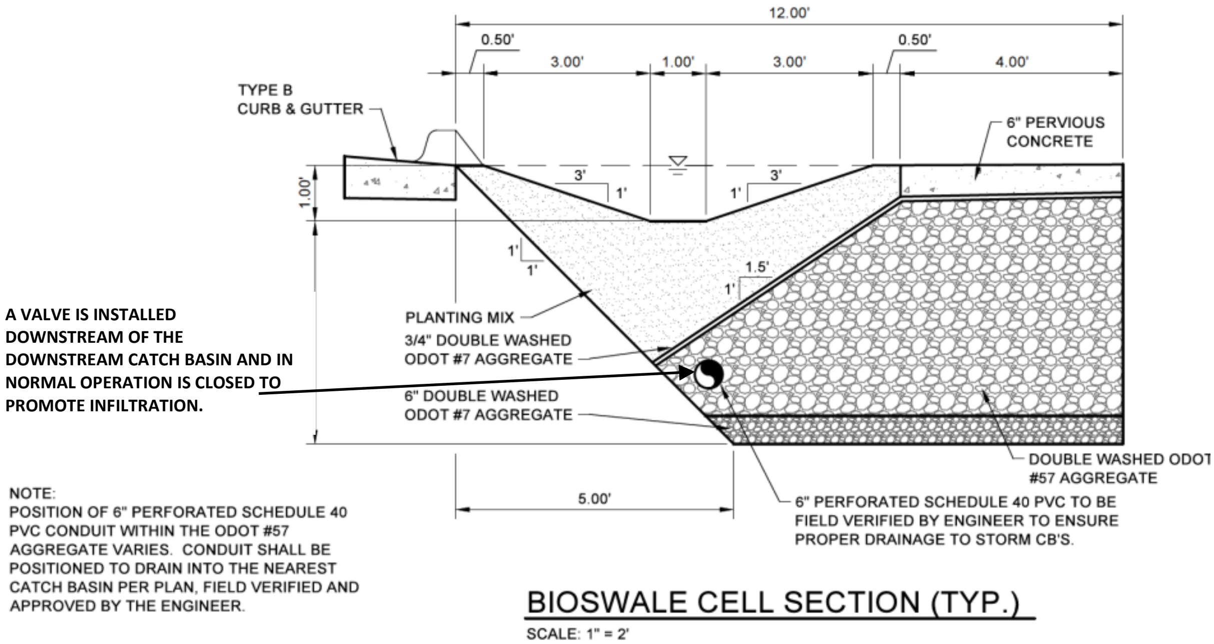


Figure 10. Maywood Avenue Bioswale and Pervious Concrete Section

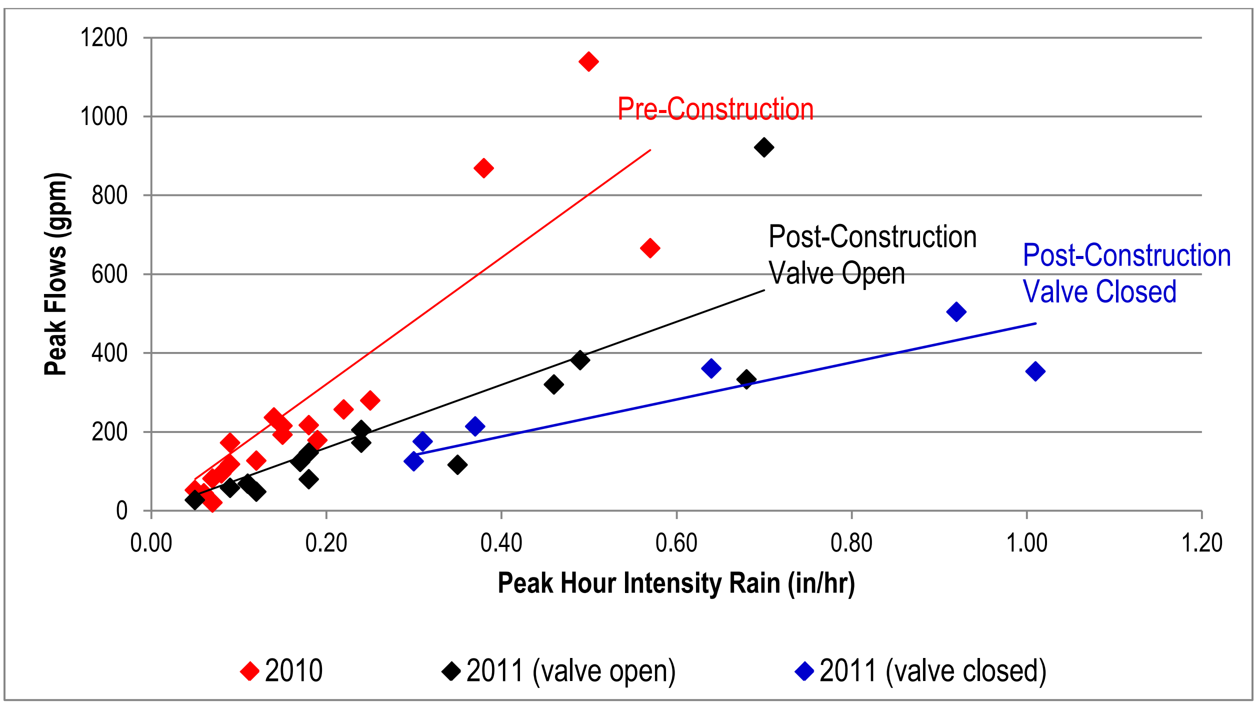


Figure 11. Stormwater Peak Flow Attenuation

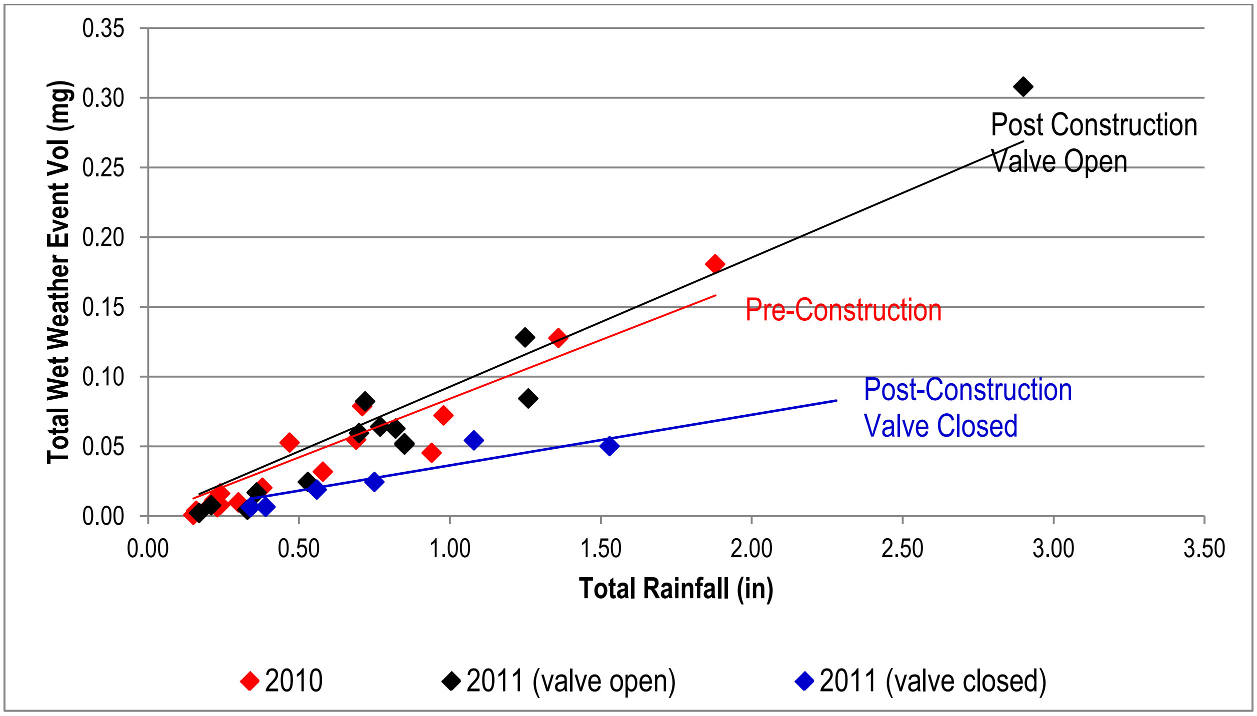


Figure 12. Stormwater Runoff Volume Reduction

Figure 13. Construction in Clay Soil

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