United States Environmental Protection Agency

2012 GREEN INFRASTRUCTURE TECHNICAL ASSISTANCE PROGRAM
Pittsburgh UNITED
Pittsburgh, Pennsylvania

Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

Steep Slopes

Photo: The Millvale TreeVitalize Project
Source: Western Pennsylvania Conservancy

January 2014
EPA 800-R-14-002

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.

Acknowledgements

Principal EPA Staff
Kenneth Hendrickson, USEPA Region 3
Dominique Lueckenhoff, USEPA Region 3
Christopher Kloss, USEPA
Tamara Mittman, USEPA

Community Team
Jennifer Rafanan Kennedy, Clean Rivers Campaign
Sara Powell, Nine Mile Run Watershed Association

Consultant Team
Dan Christian, Tetra Tech
Valerie Novaes, Tetra Tech
Anne Thomas, Tetra Tech

Technical Review Team
Beth Dutton, 3 Rivers Wet Weather
Kari Mackenbach, URS Corporation
Jim Pillsbury, Westmoreland Conservation District

This report was developed under EPA Contract No. EP-C-11-009 as part of the 2012 EPA Green Infrastructure Technical Assistance Program.

Contents

Introduction 1
Steep Slopes and Stormwater Management Overview 1
Steep Slopes in the Greater Pittsburgh Area 3
Topography 3
Soil and Vegetation 3
Swelling Soils 3
Landslides 4
Zoning Code 4
Methods to Address Steep Slopes 5
Site Planning for Protecting or Revegetating Steep Slopes 5
Green Infrastructure Design to Divert Sheet Flow from Steep Slopes 8
Green Infrastructure Design on Steep Slopes 9
Examples of Implemented Projects 12
NW 110th Street Natural Drainage System Project, Seattle, WA 12
1. Design Summary 12
2. Results Summary 14
3. Lessons Learned 15
Permeable Pavement Road Test Site, Auckland, New Zealand (Fassman and Blackbourn, 2010) 16
1. Design Summary 16
2. Results Summary 16
3. Lessons Learned 16
References 17
Manuals, Articles, and Books 17
Websites 18

Tables

Table 1. Pittsburgh Area Landslide Information 4

Table 2. Green Infrastructure Slope Information 9

Figures

Figure 1. Slopes within the Allegheny County Sanitary Authority (ALCOSAN) Service Area 2

Figure 2. Live Fascines (U.S. EPA Office of Solid Waste and Emergency Response, 2009) 6

Figure 3. Bioengineering Protection 7

Figure 4. Biotechnical Stabilization with Geogrid and Brush Layers 7

Figure 5. Proposed Green Infrastructure for "Waterfront" in Allentown, PA 8

Figure 6. Diversion Berm 10

Figure 7. Infiltration Trench 10

Figure 8. Slope Application of Permeable Pavement with Baffles 11

Figure 9. Seattle 110th Street Cascade Project 12

Figure 10. Plan of the Bioretention Cell and Weir 13

Figure 11. Section B-B of the Bioretention Cell 13

Figure 12. Section C-C of the Bioretention Cell 14

Figure 13. Permeable Concrete Paver Block Test Site 16

Introduction

Green infrastructure can successfully be implemented on steep slopes to manage urban stormwater. Although the use of green infrastructure practices on steep slopes must be considered early in the planning and design phases, design approaches are available to customize green infrastructure practices that are appropriate for use on a range of land slopes.

Green infrastructure is an important design strategy for protecting water quality while also providing multiple community benefits. EPA defines green infrastructure as structural or non-structural practices that mimic or restore natural hydrologic processes within the built environment. Common green infrastructure practices include permeable pavement, bioretention facilities, and green 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 will address the concern that green infrastructure is not appropriate for the steep slopes common in the Pittsburgh area. The paper will define the extent and nature of steep slopes in and around Pittsburgh; describe methods for applying green infrastructure on steep slopes; and provide examples of projects on or near steep slopes. The goal of this paper is to provide recommendations for design that are based on facts, research, and engineering in order to help practitioners make informed decisions regarding the use of green infrastructure on slopes of 5 to 40 percent grade.

Steep Slopes and Stormwater Management Overview

Steep slopes are defined differently for development sites than for roads. For development sites, steep slopes are typically defined as slopes greater than 25 percent. Most ordinances and design manuals suggest that these slopes be protected or restored. Within the road right-of-way, allowable slopes are typically defined as slopes less than 5 percent. The PennDOT Guidelines for the Design of Local Roads and Streets states that grades should not exceed 4 percent due to drainage design concerns (PennDOT, December 2009). AASHTO states that maximum grades are generally in the range of 7 to 12 percent for a road design speed of 30 mph, depending on terrain, (AASHTO, 2004).

One of the barriers to the use of green infrastructure in the greater Pittsburgh area is the perception that green infrastructure is incompatible with the area's steep slopes. This perception is based on the concern that green infrastructure will increase the incidence of soil erosion and slope failure on or near steep slopes. Experience demonstrates, however, that green infrastructure can effectively be integrated into development sites with steep slopes. Different strategies are available for different slope ranges – from slope protection to terracing. The following sections provide a more detailed discussion of the extent of steep slopes in the Pittsburgh area, regulatory measures intended to protect steep slopes, and methods to design green infrastructure to address steep slopes.

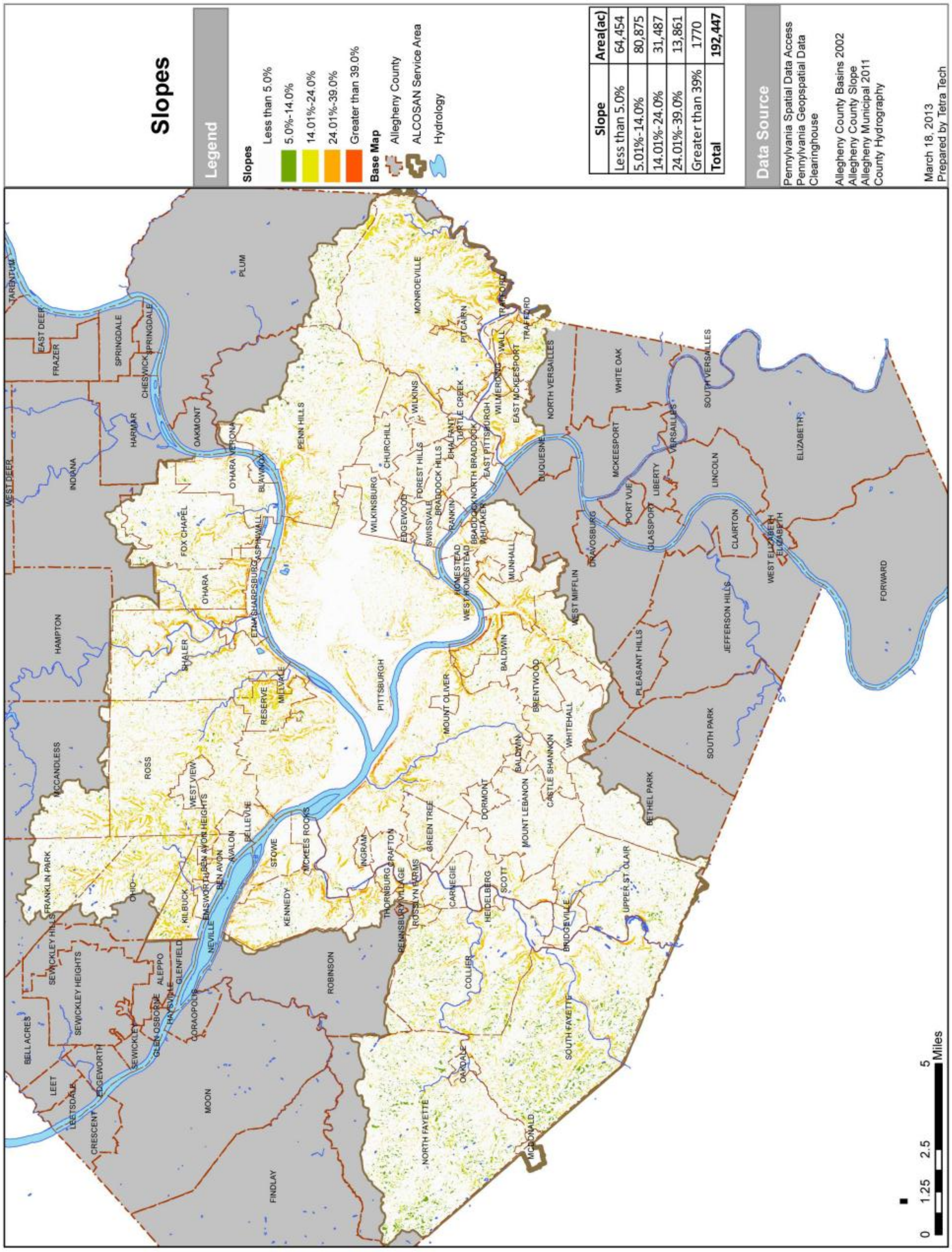


Figure 1. Slopes within the Allegheny County Sanitary Authority (ALCOSAN) Service Area

Steep Slopes in the Greater Pittsburgh Area

Steep slopes constitute a relatively small proportion of Pittsburgh's land area. This section characterizes the extent and nature of steep slopes in the Pittsburgh area, discusses the risk of landsliding, and reviews codes and ordinances intended to protect steep slopes and minimize this risk.

Topography

Topography in the greater Pittsburgh area is defined by the floodplains and bottomlands of the river valleys, the uplands between the rivers and hilltops, the high land at the top of the plateau, and the slopes in between (Aurand, 2006). Elevations in the Pittsburgh area range from 710 feet at the confluence of the Monongahela and Allegheny rivers to 1,200 to 1,300 feet at the plateau. Figure 1 shows slope ranges within the Allegheny County Sanitary Authority (ALCOSAN) Service Area, which approximates the greater Pittsburgh area. Steep slopes are found throughout the Pittsburgh area, but are relatively limited in their extent. Approximately 33 percent of the Pittsburgh area has slopes of 5 percent or less, and approximately 75 percent has slopes of 14 percent or less. Only 8 percent of the ALCOSAN service area has slopes greater than 24 percent.

Soil and Vegetation

According to the USDA Soil Survey of Allegheny County, Pennsylvania, the soil associations in the Pittsburgh area can be divided into "Areas dominantly unaltered by urban development and strip mines" and "Areas dominantly altered by urban development and strip mines." Generally, the steep slope areas located north of the Ohio and Allegheny rivers and along the creeks are unaltered, while the steep slopes areas located in the City of Pittsburgh and south of the Ohio and Allegheny rivers are considered altered. For the areas that are unaltered, the predominant soil texture is silt loam with some silty clay loam. The silt loam in the Pittsburgh area is about 25% sand, 50% silt, and 25% clay. Soils in these areas are therefore typically well drained and slowly permeable. Vegetation in these areas generally consists of forests with mixed hardwood.

The areas that are dominantly altered are characterized by urban soils underlain by the in situ silt loam. This describes slopes that have been disturbed. 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 locations for structural green infrastructure practices during design.

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.

Landslides

Landslides are the result of natural geologic processes involving movement of earth materials down a slope. Landslides can cause damage to property and loss of life, and are a real concern for areas with steep slopes in the Pittsburgh area. The risk of landslides is largely determined by environmental characteristics including slope, soil, and land cover. Fortunately, many federal and local agencies have conducted analyses to characterize the risk of landslides in the Pittsburgh area (Table 1). These risk assessments, coupled with the regulatory measures described below, help to identify areas that are appropriate for development and protect residents from the risk of landslides.

Table 1. Pittsburgh Area Landslide Information

Landslide References	URL
Pomeroy, J. S., and Davies, W. E., 1975, Map of susceptibility to landsliding, Allegheny County, Pennsylvania: U.S. Geological Survey Miscellaneous Field Studies Map MF–685–B, 2 sheets, scale 1:50,000.	http://www.dcnr.state.pa.us/topogeo/hazards/landslides/slidepubs/index.htm
USDA, Soil Conservation Service. 1981. Soil Survey of Allegheny County, Pennsylvania. National Cooperative Soil Survey.	http://www.alleghenycounty.us/dcs/gis/soils.aspx
Pomeroy, J.S., 1982, Landslides in the Greater Pittsburgh region, Pennsylvania: I.S. Geological Survey Professional Paper 1229, 48p.	http://pubs.usgs.gov/pp/1229/report.pdf
Allegheny County Landslide Prone Areas Map – This map is part of the Allegheny County Comprehensive Plan showing landslide prone areas.	http://www.alleghenyplaces.com/comprehensive_plan/maps.aspx
Delano, H. L., and Wilshusen, J. P., 2001, Landslides in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Educational Series 9, 2nd ed., 34 p.	http://www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_014592.pdf
The Pittsburgh Geological Society. Landsliding in Western Pennsylvania	http://www.pittsburghgeologicalsociety.org/landslide.pdf

Zoning Code

Both the City of Pittsburgh and Allegheny County have adopted codes and ordinances to protect steep slopes. These codes serve both to reduce the risk of landsliding, and to preserve natural areas located on steep slopes. The Allegheny County Subdivision and Land Development Ordinance applies to municipalities in the County without a municipal ordinance of their own. Per §780-504 of the County ordinance, Protection of Moderately Steep and Steep Slopes, the County allows limited development on slopes between 25 and 40 percent, no development on slopes between 15 and 40 percent located within GREENPRINT conservation areas, and no development on slopes exceeding 40 percent. The Allegheny Land Trust developed the GREENPRINT of Allegheny County to promote strategic conservation of natural areas, including large tracts of woodlands on steep slopes along the rivers. Refer to the Allegheny County Comprehensive Plan for GREENPRINT locations shown on the Greenways map.

The City of Pittsburgh also has zoning requirements related to steep slopes greater than 25 percent. While development on slopes greater than 25 percent is not prohibited, it is discouraged. Chapter 906.08 SS-O of the Pittsburgh zoning code, Steep Slope Overlay District, requires that impervious surfaces be minimized, and that "natural landforms shall be maintained to the maximum extent practicable." Additional regulations on steep slopes in Pittsburgh are located in Chapter 905.02 (H, Hillside District) and Chapter 915 (Environmental Performance Standards).

Methods to Address Steep Slopes

While it is important to consider site slopes in the design of any stormwater management system, it is particularly important in the design of green infrastructure systems for sites with steep slopes. Soil erosion and landslides are concerns whenever construction occurs on or near slopes, but become even more of a concern when slopes are saturated with water. Since many green infrastructure practices enhance infiltration of water into the soil, care must be taken when designing green infrastructure for the Pittsburgh area.

Many strategies are available to manage stormwater at its source for slopes of up to 25 percent. Depending on the orientation of the planned earth-disturbance (i.e. Is the development upgradient of the slope, downgradient of the slope, or on the slope?) and the steepness of the slope, one or more of the design approaches described below may be considered. The approaches include protection or revegetation of the slope, design of green infrastructure practices to divert runoff away from the slope, and design of green infrastructure practices on the slope.

Site Planning for Protecting or Revegetating Steep Slopes

One effective approach to minimizing the risk of erosion on steep slopes is simply to protect the slope from development. When reviewing a site during the site planning process, steep slopes may be identified and set aside for preservation (if undisturbed) or revegetation (if already disturbed or if disturbance is unavoidable during construction). Preservation and revegetation are examples of "non-structural" green infrastructure practices that use site planning to maintain or restore the natural hydrologic function of a site. Within the greater Pittsburgh area there are many opportunities for slope protection and revegetation along the region's waterways.

Preservation: In many areas around the country, including Pennsylvania, steep slopes are considered an environmental resource because of their biodiversity, recreational potential, and viewsheds. To protect this resource, some regulatory and watershed manuals set thresholds for preservation of steep slopes. Some areas set the threshold for preservation at 15 percent (for example, the Turtle Creek Watershed in Allegheny County and the Georgia Coastal Region), while other areas set the threshold at 25 percent (for example Allegheny County, PA; Vermont; and Seattle, WA). Local ordinances regarding steep slope preservation may vary.

The primary concerns with disturbing steep slopes include 1) an increase in soil erosion and runoff affecting water quality, water quantity, and aquatic animals downstream, 2) public safety concerns because of landslide potential and emergency vehicle access, and 3) loss of forestland, natural areas, and wildlife habitat (Land of Sky Regional Council, 2008).

Once a slope is identified for preservation during the planning process, it will need to be fenced off and left untouched during construction.

Revegetation: Methods used to revegetate a disturbed steep slope include typical seeding and planting techniques in areas with stable soil conditions, or bioengineering and biotechnical stabilization in areas with unstable soil conditions. A plant specialist should be consulted to determine the most suitable plants for the soil conditions of the slope. During and after construction, heavy vehicular traffic and foot traffic should be prohibited on slopes, first by clearly delineating protected areas on the plan set and then by installing a construction fence. It is important to note that vegetation will help stabilize soil but will not prevent landslides.

Bioengineering is the use of plant material, living or dead, to stabilize slopes. The selected plants act as a structural component as well as an aesthetic addition and are usually chosen for their resistance to the stressors of the application such as erosion or landsliding (U.S. EPA Office of Solid Waste and Emergency Response, 2009).

Bioengineering options can be employed after runoff diversion has been completed upgradient of the slope. A typical bioengineering method is berm planting. In this method a series of ditches is excavated 3 to 5 feet apart along the slope, and a berm is created on the downslope side of each ditch. The ditches are then planted with rooted cuttings including trees and shrubs (City of Seattle, 2007). Other bioengineering methods include sod walls on terraces, timber frame stabilization, woven willow whips, brush layers, and live fascines (City of Seattle, 2007 and U.S. EPA Office of Solid Waste and Emergency Response, 2009). Refer to Figure 2 and Figure 3 for schematics of these bioengineering practices.

Biotechnical stabilization is the integration of living plants and inert structural components, such as geotextiles or geogrids. It is similar to bioengineering, but is better suited for repair of slope failure or construction on steeper slopes. Figure 4 shows a detail of biotechnical stabilization with geogrids and brush layers. Maintenance of bioengineering and biotechnical stabilization includes conducting regular inspections to ensure the system is functioning correctly.

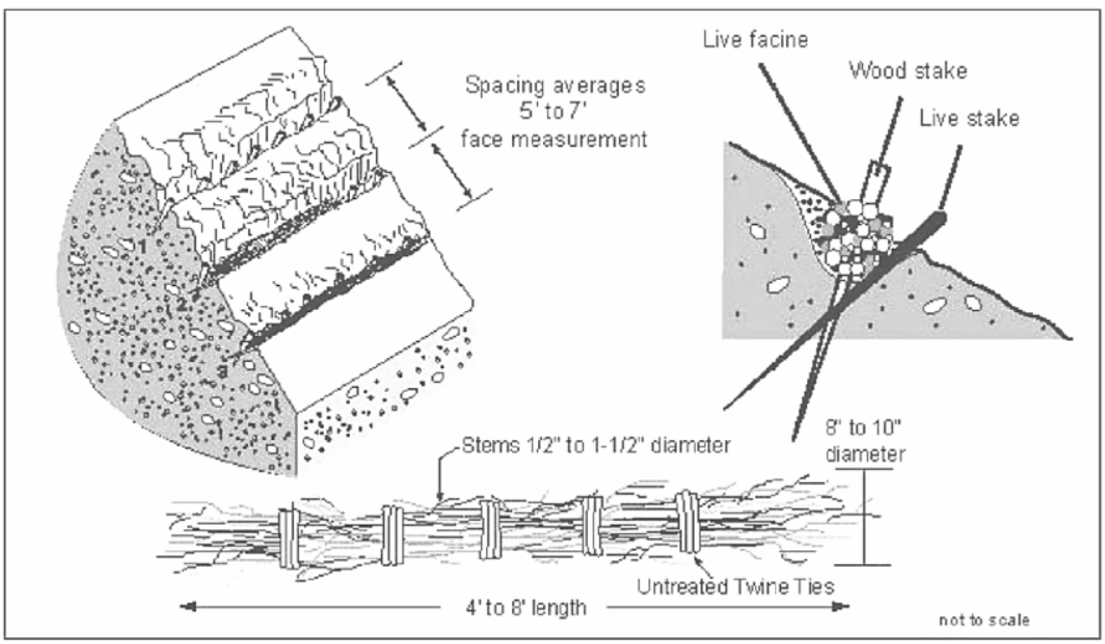
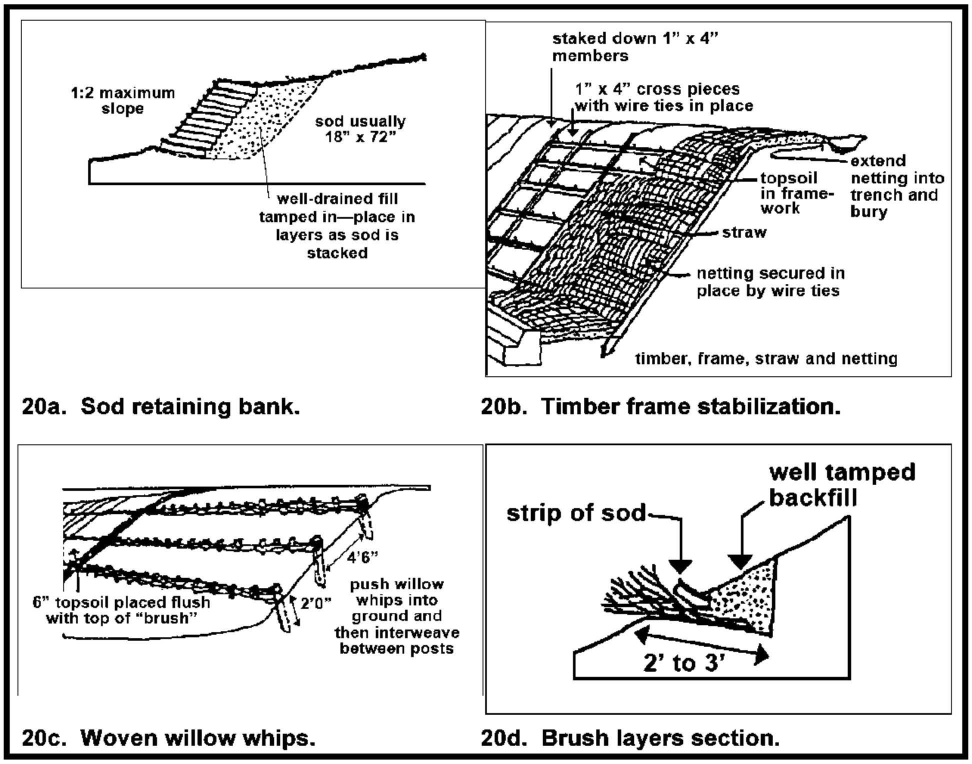
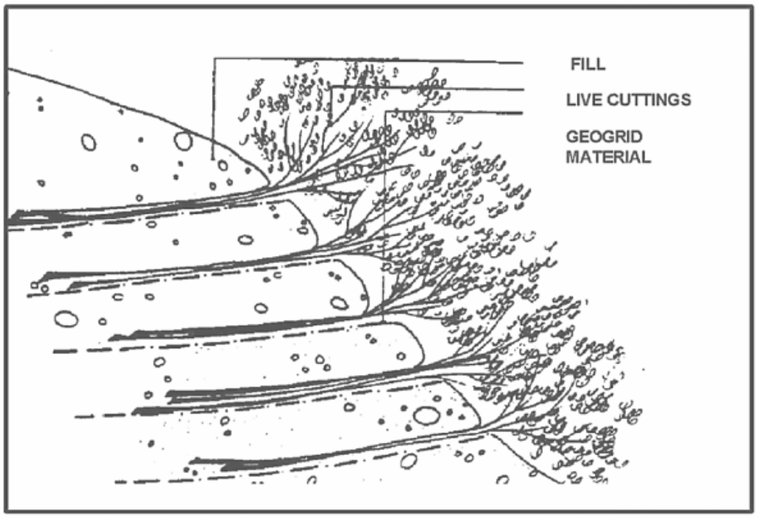


Figure 2. Live Fascines (U.S. EPA Office of Solid Waste and Emergency Response, 2009)



Source: City of Seattle, 2007, Figure 20

Figure 3. Bioengineering Protection



Source: U.S. EPA Office of Solid Waste and Emergency Response, 2009

Figure 4. Biotechnical Stabilization with Geogrid and Brush Layers

Green Infrastructure Design to Divert Sheet Flow from Steep Slopes

Where the earth-disturbing activity is located upgradient of a slope, green infrastructure can help protect steep slopes by managing runoff at its source. In this context, green infrastructure will be most effective when placed 1) at the top of the slope to intercept sheet flow or 2) close to the impervious source. Green infrastructure practices suitable for intercepting sheet flow include infiltration trenches, level-spreader/vegetated filter strips, diversion berms, pervious pavement, or vegetated swales. Closer to the source, vegetated roofs, cisterns, seepage pits, pervious pavement and bioretention practices may be appropriate. Design guidance, specifications, and maintenance practices for each of these practices can be found in the Pennsylvania Stormwater Best Management Practices Manual.

In Allentown, PA, "The Waterfront" redevelopment project along the Lehigh River demonstrates the use of a variety of green infrastructure practices to divert runoff from a steep slope. The bank of the river is narrow and very steep (at 45 degrees), making construction of green infrastructure practices within the bank undesirable. Widening the bank to achieve a flatter slope is also undesirable, as this would decrease the available development space (U.S. EPA Office of Solid Waste and Emergency Response, 2009). To manage runoff from the site and protect the river's steep banks, the project plans to install filter strips, infiltration trenches, bioretention, and pervious concrete to intercept sheet flow at the top of the slope. The project also will install pervious pavement, bioretention, a green roof, and a cistern closer to the impervious sources.

Figure 5 shows the strategy for placing green infrastructure on the site. The filter strip, infiltration trench, and pervious concrete riverwalk are located between the development and the river bank along the entire length of the project site. Rain gardens (bioretention) and pervious asphalt, pervious concrete, and paver blocks are located next to the proposed buildings.

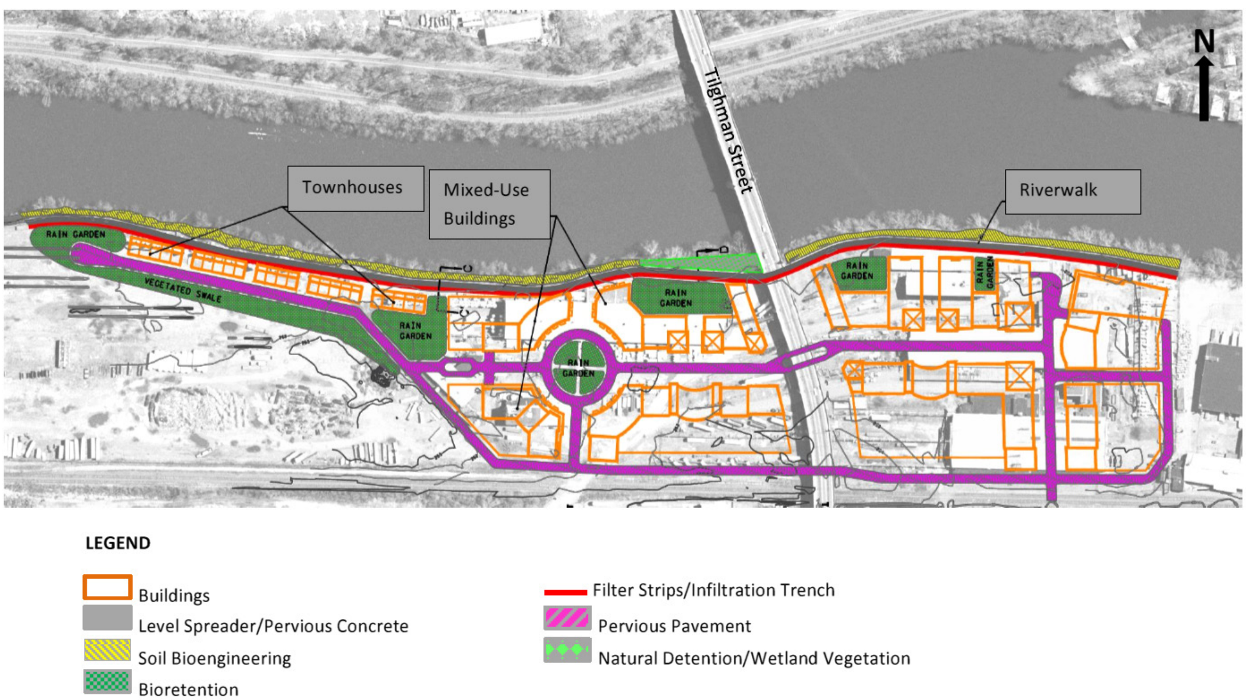


Figure 5. Proposed Green Infrastructure for "Waterfront" in Allentown, PA

Green Infrastructure Design on Steep Slopes

Where the planned earth disturbing activity is located on or very near a slope, it may not be possible to avoid placement of green infrastructure practices on the slope. In this context, different green infrastructure practices are appropriate for different maximum slopes. For example, terracing to slow water down and provide areas for vegetation to grow is suitable for slopes up to 25 percent. In contrast, pervious pavers to infiltrate runoff are only suitable for slopes up to 5 percent, due to their tendency to creep down the slope. Table 2 provides a list of various green infrastructure practices and the maximum slope application as recommended by various sources. The Pennsylvania Stormwater Best Management Practice Manual contains design, construction, and maintenance information on the practices in Table 2.

Table 2. Green Infrastructure Slope Information

Green Infrastructure Practice	Maximum Slope	Reference	Comments
Bioretention/Vegetated swale/ Planter box	6%	CWP, 2009; Penn. SW BMP Manual (BMP 6.4.5/BMP 6.4.8)	Use stepped pools and weirs to slow flows (e.g. Seattle Public Utilities stormwater cascade projects) (Horner and Chapman, 2007).
Dry well	6%	CWP, 2009; Penn. SW BMP Manual (BMP 6.4.6)	
Grass channel with check dams (vegetated swale)	5%	CWP, 2009; CED Engineering web site	
	6%	Penn. SW BMP Manual (BMP 6.4.8)	
Diversion/infiltration berm (terracing)	25%	Penn. SW BMP Manual (BMP 6.4.10)	Not to be used with shallow soils near bedrock or on landslide prone areas (Figure 6).
Infiltration trench	5%	Penn. SW BMP Manual (BMP 6.4.4)	Infiltration trenches may be stepped down a slope (Figure 7).
Permeable pavement	5%	Fassman and Blackbourn, 2010; CWP, 2009; Muench et al. 2011; Penn. SW BMP Manual (BMP 6.4.1)	Consider substorage baffles for more storage volume (Figure 8).
Vegetated filter strip	6%	CWP, 2009	Use terracing or level spreaders at 20-foot intervals along flow path for slopes >3%.
	8%	Penn. SW BMP Manual (BMP 6.4.9)	Slopes less than 5% are preferred.
	33%	Navickis-Brasch, 2011	Highway application: Where vegetation can be established, sand percentage is low in soil, and sheet flow is established off of pavement.

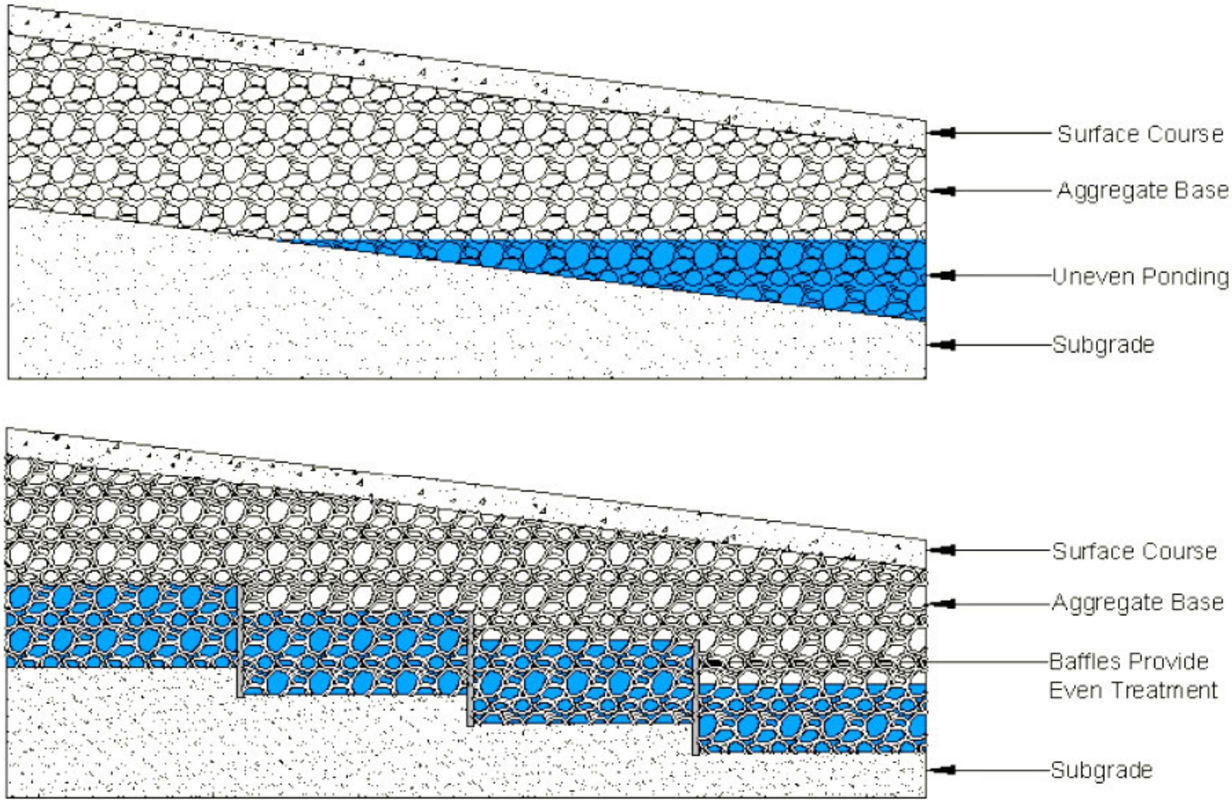
Diversion and infiltration berms are one of the few green infrastructure practices that are considered appropriate for construction on steep slopes. A diversion berm is a mound of compacted earth with sloping sides that is constructed along a contour (Figure 6). Diversion berms are often considered a slope protection practice or a method to revegetate the slope (Pennsylvania SW BMP Manual - BMP 6.4.10). In addition to these goals, berms can be used to promote infiltration in the ditch on the uphill side of the berm (infiltration berm). Care must be taken when infiltrating above structures. Many of the homes and buildings in the Pittsburgh area are structurally vulnerable to wet soil conditions.

Source: Pennsylvania SW BMP Manual - BMP 6.4.10

Figure 6. Diversion Berm

Source: Pennsylvania SW BMP Manual - BMP 6.4.4

Figure 7. Infiltration Trench



Source: http://www.aces.edu/waterquality/documents/9.PermPaveOverview.pdf

Figure 8. Slope Application of Permeable Pavement with Baffles

Examples of Implemented Projects

NW 110th Street Natural Drainage System Project, Seattle, WA

[Horner, R. R. and Chapman, C. (September 2007). NW 110th Street Natural Drainage System Performance Monitoring. Civil and Environmental Engineering, University of Washington]

NW 110th Street Natural Drainage System Project, is an example of constructing a bioretention practice on a moderately steep slope. Refer to row 1 of Table 2. Seattle Public Utilities built their second stormwater cascade during 2002 and 2003 along NW 110th Street between Greenwood Avenue N and 3rd Avenue NW. In Seattle, a cascade is a roadside bioswale using a series of stepped pools on a sloped road. Refer to Figure 9 showing the 110th Street cascade, which is on a residential street with a slope of nearly 6 percent over a 53-foot vertical drop.

The main goal was to improve performance of peak flow rate and volume reduction from the first cascade project, Viewlands Cascade, which was able to provide a 60 percent reduction in peak flow rate and an average of 75-80 percent reduction in runoff volume between the inlet and the outlet. In addition, water quality measurements were taken.

Figure 9. Seattle 110th Street Cascade Project

1. Design Summary

The 110th Street cascade drainage area is approximately 2 impervious acres with 1 acre coming from an upstream subcatchment and another 1 acre flowing as sheet flow from the adjacent street and intersecting streets. Because the latter subcatchment flow was immeasurable, the measured inflow from the first subcatchment was doubled to represent the entire drainage area.

The cascade utilizes a series of 12 stepped-pool bioretention cells separated by concrete V-notch weirs along one side of the street. The total length is 900 horizontal feet. The existing soil was somewhat sandy weathered till and was amended with compost to promote infiltration. Figure 10, Figure 11, and Figure 12 show design details for the project. The weirs, vegetation, and rock berms help decrease the velocity of the water. The complete construction plan can be found at the following web address: http://www.seattle.gov/util/MyServices/DrainageSewer/Projects/GreenStormwaterInfrastructure/CompletedGSIProjects/110thCascadeProject/index.htm

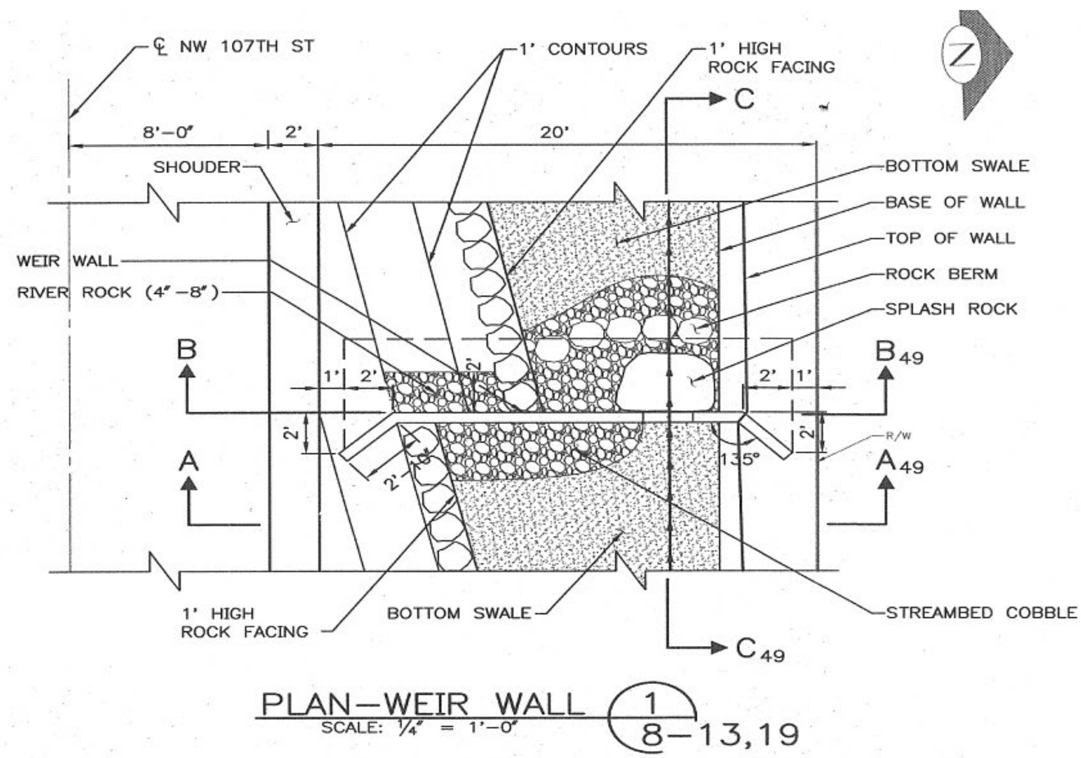


Figure 10. Plan of the Bioretention Cell and Weir

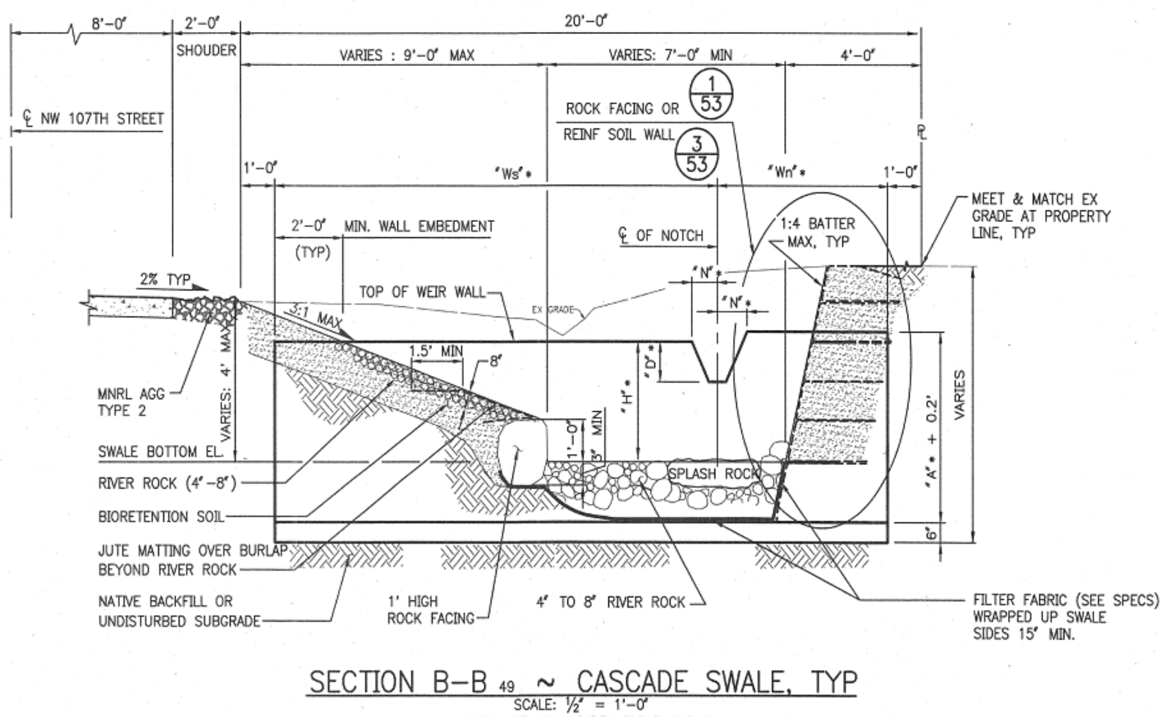


Figure 11. Section B-B of the Bioretention Cell

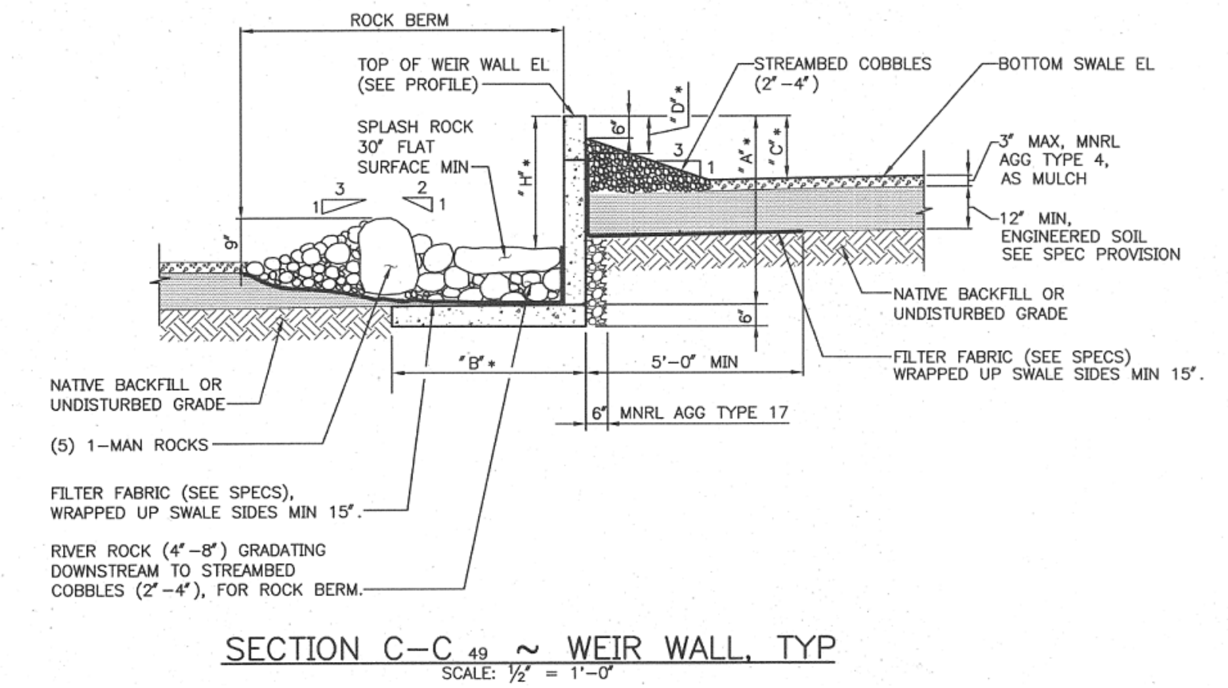


Figure 12. Section C-C of the Bioretention Cell

2. Results Summary

The 110th Street cascade was able to completely retain 186 (79 percent) of the 235 precipitation events recorded, and is able to completely attenuate surface runoff from about 0.3 inches of rain under any condition. These numbers are an improvement from the performance of the Viewlands cascade, which retained about 27 percent of precipitation events with no discharge and fully attenuated surface runoff from about 0.13 inches of rainfall. The main design enhancement likely contributing to the improvement was amending the soils in the 110th Street cascade. Other significant results include the following:

- In very dry conditions, storms up to one inch in 24 hours were completely retained by the system.
- Based on the results of storms producing at least 0.9 inches of rain, infiltration rates were 0.3 to 0.5 inch/hour.
- Over 90 percent of the 235 storms showed a peak flow rate reduction from the inlet to the outlet. The increase in peak flow rate shown in the remaining 10 percent of the events was likely due to the immeasurability of the subcatchment characterized by sheet flow to the cascade.
- For the 49 storm events which resulted in discharge from the outlet, the only contaminants not reduced in concentration between the inlet and outlet were dissolved zinc, for which there was no significant difference, and soluble phosphorus, which was significantly higher in concentration at the discharge. The increase in soluble phosphorus may be due to leaching from the bioretention soil.
- The best estimate of total suspended solids concentration reduction was 76 percent.

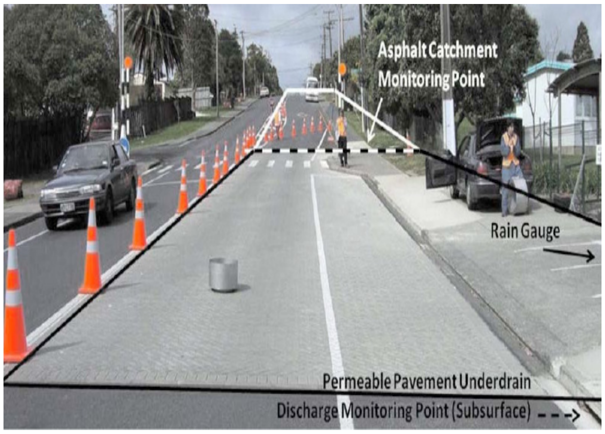
3. Lessons Learned

Bioretention with stepped pools situated along a roadside is very effective in reducing peak flow rates and volumes. It appears that providing an amended soil substantially increases the ability to retain the water within the cascade channel. This system could be considered along Pittsburgh's many streets as the opportunities arise, particularly streets with a slope of up to 6 percent.

The system should be monitored every 5-10 years to evaluate changes in performance over time. This additional water quality monitoring should be conducted to address emerging water quality concerns, such as commercial, industrial and vehicular-generated chemical compounds. Metals present in the channel bottom soils should also be tested.

Permeable Pavement Road Test Site, Auckland, New Zealand (Fassman and Blackbourn, 2010)

In 2006, a permeable modular concrete paver test site was constructed on an active roadway with an atypically high slope of 6-7.4%. The test site also included an adjacent conventional asphalt catchment for concurrent monitoring with the permeable modular pavement (PMP). Flow monitoring was conducted between 2006 and 2008 to assess the effectiveness of the site in reducing stormwater volume and peak flow rate.



Source: Fassman and Blackbourn, 2010

Figure 13. Permeable Concrete Paver Block Test Site

1. Design Summary

The 2,100-square foot PMP site is constructed of impermeable concrete paver blocks with enlarged joint spacing such that the peak flow from the 2-year 24-hr storm event can pass through the aggregate-filled joints. Beneath the paver blocks is a bedding layer. An approximate 18-inch base course thickness is installed below the bedding layer. The base course is made up of a layer of 0.5-inch aggregate over 1.5-inch aggregate. Water that percolates to the base course discharges through an underdrain at the downstream end of the test section or infiltrates to groundwater. Soil testing conducted before construction characterized the subgrade soils as silty clay and clayey silt with little to no permeability.

2. Results Summary

Over the monitoring period, the hydrologic performance of the PMP was better than expected and compared favorably to modeled predevelopment conditions. Predevelopment conditions were maintained for runoff lag time, peak flow, and duration of flow.

- The median runoff lag time in the PMP was 1 hour compared to 12 minutes for the asphalt catchment.
- The permeable pavement was able to slow the flow of stormwater so that it resembled the flow from a natural area.
- Despite the presumed impermeable subgrade soils, steep slope, and frequent rainfall, there was a substantial reduction in volume. The volume reduction is attributed to evaporation through the base course and infiltration through the subgrade.
- The permeable pavement was able to effectively handle stormwater from frequent storms and large storms events on steep slopes.

3. Lessons Learned

Typical of sites in the Pittsburgh area, the Auckland project site was challenged with a moderate slope, soil allowing little infiltration, and frequent rainfall. Despite these site conditions, there was a substantial reduction in volume. In Pittsburgh, volume reduction is important to reducing overflows from the combined sewer system. Use of permeable pavement on Pittsburgh's sloped roads should not be overlooked.

References

Manuals, Articles, and Books

American Association of State Highway and Transportation Officials (AASHTO). 2004. A Policy on Geometric Design of Highways and Streets.

Aurand, M. December 5, 2006. Chapter One of “The Spectator and the Topographical City.” Pittsburgh Post-Gazette.

Baker, M., Sarraf, R., and McAdoo, G. 2012. Allegheny County Subdivision and Land Development Ordinance, Allegheny County, Pennsylvania

Center for Watershed Protection. April 2009. Coastal Stormwater Supplement to the Georgia Stormwater Management Manual.

Clean Water Services. July 2009. Low Impact Development Approaches Handbook.

Delano, H. L., and Wilshusen, J. P., 2001, Landslides in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Educational Series 9, 2nd ed., 34 p

Fassman, E. A., and Blackbourn, S. June 2010. Urban Runoff Mitigation by a Permeable Pavement System over Impermeable Soils. *Journal of Hydrologic Engineering, ASCE.* 15:475-485.

Horner, R. R. and Chapman, C. September 2007. NW 110th Street Natural Drainage System Performance Monitoring. Civil and Environmental Engineering, University of Washington.

Land of Sky Regional Council. 2008. Mountain Ridge and Steep Slope Protection Strategies.

Muench, S. T., Anderson, J. L., Hatfield, J. P.,& Soderlund, M. et al. 2011. *Greenroads Manual v1.5.* (J.L. Anderson, C.D. Weiland, and S.T. Muench, Eds.). Seattle, WA: University of Washington.

Navickis-Brasch, A. May 2011. Eastern Washington Steep Slope Research for Management of Highway Stormwater.

Pennsylvania Department of Conservation and Natural Resources. April 2002. Volume 1: Turtle Creek Watershed River Conservation Plan.

Pennsylvania Department of Environmental Protection. 2006. Pennsylvania Stormwater Best Management Practices Manual.

Pennsylvania Department of Transportation Bureau of Design. December 2009. Guidelines for the Design of Local Roads and Streets. Pub 70M (12-09).

Seattle Public Utilities, Department of Planning and Development. February 2007, Draft. Director’s Rules for Seattle Municipal Code, Chapter 22.800, Stormwater and Drainage Control Code, Volume 1, Construction Stormwater Control Technical Requirements Manual Director’s Rule 17-2000.

USDA, Soil Conservation Service. 1973. Soil Survey of Allegheny County, Pennsylvania. National Cooperative Soil Survey.

U.S. EPA Office of Solid Waste and Emergency Response, Office of Brownfields and Land Revitalization. Prepared by Tetra Tech. June 2009. The Waterfront, Allentown, PA Conceptual Design using Low Impact Development.

Vermont League of Cities and Towns. May 2008. Municipal Assistance Center Technical Paper #5: Managing Stormwater through Low Impact Development (LID) Techniques.

Websites

Auburn SCM Workshop May 2, 2012
http://www.aces.edu/waterquality/documents/9.PermPaveOverview.pdf. Last accessed March 14, 2013.

CED Engineering. Construction Site Storm Water – Runoff Control
http://www.cedengineering.com/upload/Construction%20Site%20Storm%20Water%20-%20Erosion%20Control.pdf. Last accessed February 12, 2013.

Pennsylvania Department of Conservation and Natural Resources
http://www.dcnr.state.pa.us/topo geo/hazards/landslides/slidepubs/index.htm. Last accessed March 13, 2013.

The Pennystone Project
http://www.pennystone.com/soils/allegheny.php. Last accessed March 13, 2013.

The Pittsburgh Geological Society. Landsliding in Western Pennsylvania.
http://www.pittsburghgeologicalsociety.org/landslide.pdf. Last accessed March 13, 2013.