United States Environmental Protection Agency

Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

Fact Sheet Series

Photo: Roadside bioretention facility

January 2014
EPA 800-R-14-005

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.

Contents

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Space Constraints

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The Challenge

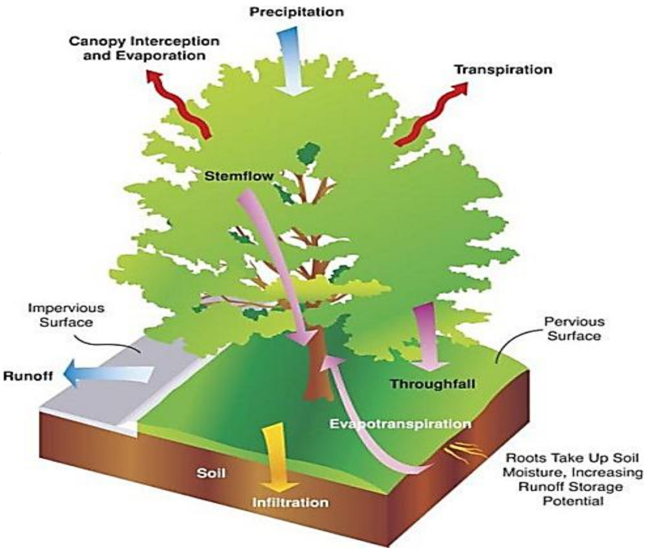
Future development in the Pittsburgh region is expected to require development of previously developed sites (*redevelopment*) or available sites nestled within urban areas (*infill*). Planned construction activities on redevelopment or infill sites and the road right-of-way present the opportunity to incorporate green infrastructure into urban areas. When incorporating green infrastructure into these areas however, limited space may pose a challenge because the existence of buried utilities, mature trees, basements, buildings, and roads pose obstacles.

Fortunately, designers have developed strategies for overcoming this challenge, for example, by using green features that serve multiple purposes or fit into small spaces. With care, the right green infrastructure practices can work well in the Pittsburgh region.

Opportunities

Green Infrastructure practices such as bioretention, permeable pavement, green roofs, and rain barrels are all practices that are successful in urban space-constrained sites.

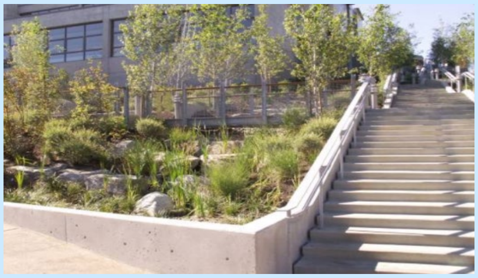
- Bioretention practices can be designed next to buildings and roads to absorb stormwater. Planted with trees, they become even more efficient at absorbing water.
- Permeable pavement can be substituted for traditional pavement, thereby not taking up additional space. Reducing the overall area of pavement also helps.
- Green roofs absorb rainfall while protecting the roof at the same time.
- Draining a roof to a rain barrel to water a garden helps reduce stormwater and saves drinking water.



This diagram shows the many natural routes rain water may take when it falls on a tree as opposed to merely running off of an impervious surface.
Source: Xiao, Q.; McPherson, E. G.; Ustin, S. L.; Grismer, M. E. 2000. A new approach to modeling tree rainfall interception. Journal of Geographical Research Atmospheres 105: 29173-29188.

Green Infrastructure Practices that Work in Constrained Spaces

This bioretention planter box was designed into a pedestrian corridor.
Source: Tetra Tech



Stormwater from a rooftop drains into this terraced bioretention facility.
Source: SvR Design Company Green Factor Workshop

This large parking lot helps to infiltrate stormwater through a permeable pavement system.
Source: Clean Water Services

Case Studies

Albert M. Greenfield Elementary School, built 2010, Philadelphia, PA

Albert M. Greenfield Elementary School is a pilot site for using green infrastructure to reduce the number and volume of combined sewer overflows within Philadelphia. The school is located within an urban corridor and is bordered on all sides by busy streets. As a collaborative effort, a plan was created to transform the existing impervious school yard into a green space complete with green infrastructure.

The installed green infrastructure includes a woodland garden and rain gardens, which are installed along the perimeter of the playground, and permeable pavement, which doubles as a forgiving play surface. Combined, these practices capture and infiltrate 97 percent of the annual runoff from the school yard.

Green infrastructure is incorporated into this school yard as permeable play surface and garden areas.
Source: http://phillywatersheds.org/category/blog-tags/stream-restoration

Results

- This project shows the ability of an urban site to infiltrate a significant amount of water.
- Innovative design features were used to protect the gardens, such as installing strategically placed nets/climbing structures (pictured) near the basketball courts; an idea courtesy of a student involved in the design process.
- The overall lesson learned is the importance of involving all interested parties in the design process to successfully share space in a constrained urban setting.

Source: Michele Adams, President, Meliora Design, LLC; American Society of Landscape Architects; Schuylkill Action Network

Market Street Bioretention, built 2010, Lemoyne, PA

The Lemoyne Borough in Cumberland County, PA has a downtown revitalization project underway. The overall multi-phase streetscape improvements project uses green infrastructure as part of the stormwater management system.

Bioretention and permeable pavers were used within the Market Street right-of-way to capture and infiltrate the “first flush” of rainfall. Stormwater runs off of the street and into the bioretention areas through cuts in the curb. The stormwater is treated through an engineered soil mixture before infiltrating through the underlying soil.

This roadside bioretention captures stormwater from the road. The paved shoulder and metal grates provide roadside parking access.
Source: Kairos Design Group, LLC

Results

- The green infrastructure practices provide green space as well as stormwater treatment and volume reduction.
- Because of the use of road salt in the winter and lack of rain in the summer, a variety of salt- and drought-tolerant native plant species were planted in the bioretention areas.
- The design accommodates typical roadside challenges including buried utilities, roadside parking, pedestrian traffic, and gutter flow for the larger storm events.

Source: Kairos Design Group, LLC

With innovation and collaboration, green infrastructure practices can be effectively incorporated into constrained urban areas

Steep Slopes

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The Challenge

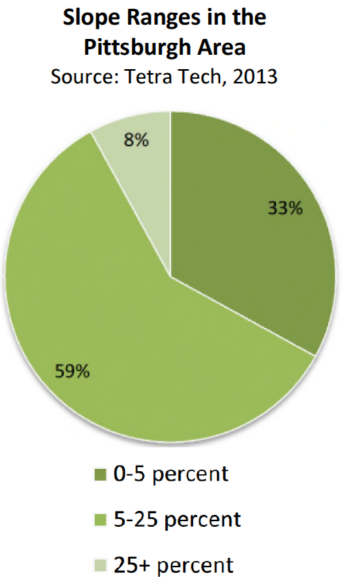
Soil erosion and landslides are concerns whenever construction occurs on or near slopes, but become even more of a concern when slopes are saturated with water. The Pittsburgh area has a dramatic landscape dominated by steep hills and valleys. Since many green infrastructure practices enhance infiltration of water into the soil, care must be taken when designing green infrastructure for the Pittsburgh area.

Fortunately, development is restricted on steep slopes, so this challenge is not as daunting as the landscape might suggest. Most ordinances state that a slope greater than 25 percent should be left undisturbed, while roads are typically built with slopes of less than 5 percent. Many strategies are available to manage stormwater at its source for slopes of up to 25 percent.

Opportunities

Green Infrastructure practices appropriate for steep slopes include slope protection, tree planting, use of diversion berms, and use of check dams within bioretention practices.

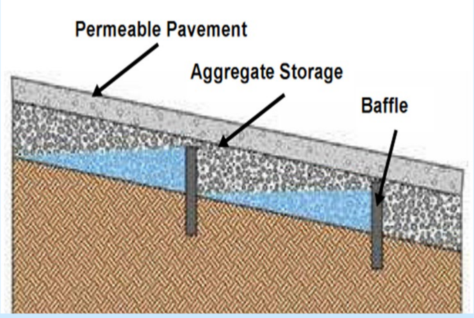
- Protecting natural slopes reduces erosion and enhances infiltration.
- Planting trees and other vegetation on a disturbed slope stabilizes soil and absorbs water.
- Diversion berms are constructed across slopes to reduce erosion caused by rapidly flowing water and to promote plant growth.
- Check dams can be incorporated into bioretention practices on slopes to encourage infiltration and reduce erosion.


Slope Ranges in the Pittsburgh Area
Source: Tetra Tech, 2013

Green Infrastructure Practices that Work on Steep Slopes


This diversion berm is constructed across a steep slope (max. 25% slope) to slow stormwater.
Source: Tetra Tech


The rock check dams placed along this grassy swale help slow stormwater and prevent erosion in the swale (max. 6% slope).
Source: Pennsylvania SW BMP Manual - BMP 6.4.8



When permeable pavement is installed on a slope (max. 5% slope), baffles can be constructed beneath the pavement to increase water storage and promote infiltration.
Source: Adapted from http://perviouspavement.org/design/hydrologicaldesign.html

Case Studies

110th Street Cascade, built 2002, Seattle, WA

In Seattle, a series of cascading bioretention cells was installed on a sloped (6% grade), residential road to reduce the flow rate and volume of stormwater and to help reduce sediment and pollutant loads from a 2-acre drainage area. The design uses concrete walls, vegetation, and rock to slow down and infiltrate the water.

Results

- Monitoring results showed that the system was able to completely absorb 186 (79 percent) of the 235 precipitation events recorded from 2004 to 2006.
- In very dry conditions, storms with rainfall depths of up to 1 inch were completely absorbed by the system.
- Sediment, a pollutant harmful to aquatic life, was reduced by approximately 86 percent.
- Pollutant reductions occurred for sediment, lead and motor oil, nitrogen, phosphorus, copper, and zinc.

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

Cascading bioretention cells in Seattle help treat and infiltrate stormwater from roads.
Source: Seattle Public Utilities; www.seattle.gov

Permeable Pavement Road, built 2006, Auckland, New Zealand

A 2,100 square foot permeable pavement test site was constructed on an active roadway with a slope of 6-7.4% and underlying existing clay soils. Flow monitoring was conducted to assess the effectiveness of the site in reducing stormwater volume and peak flow rate. The peak flow rate of a storm is the maximum measured volume of water that moves past a point in a given amount of time.

This monitoring site in Auckland, New Zealand tested the effectiveness of permeable pavement on slopes.
Source: Fassman and Blackbourn, 2010

Results

- Monitoring results showed that the stormwater volume and peak flow rate passing through the permeable pavement was reduced.
- The permeable pavement was able to slow the flow of stormwater so that it resembled the flow from a natural area.
- The permeable pavement was able to effectively handle stormwater from frequent storms and large storms even on steep slopes.
- Typical of sites in the Pittsburgh area, the Auckland project site was challenged with a moderate slope, soil allowing little infiltration, and frequent rainfall.

Source: 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.

A variety of green infrastructure designs are suitable for handling stormwater on moderate to steep slopes including berms, swales, permeable pavement, and cascading bioretention cells.

Abundant and Frequent Rainfall

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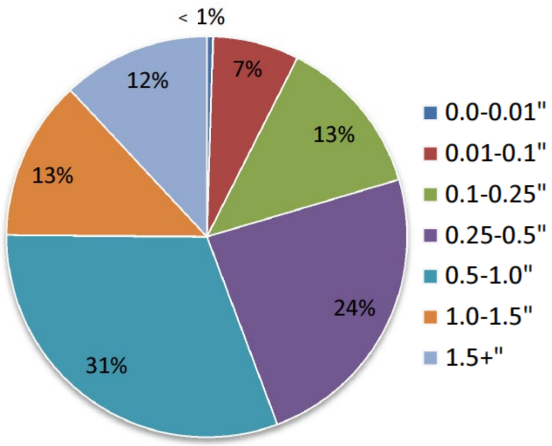
The Challenge

The Pittsburgh area receives 37 to 45 inches of rainfall per year, which is typical for the region. With the area's humid climate and frequent rain events, some practitioners may view green infrastructure as inappropriate for the Pittsburgh area.



Southwest Pennsylvania Annual Rainfall Grouped by Storm Depth

Source: Westmoreland Conservation District www.wcdpa.com

Analyzing the area's rainfall pattern, however, shows that green infrastructure works very well with Pittsburgh's climate. As shown in the figure above, the Pittsburgh area receives most of its annual precipitation as small rain events of one inch or less. Green infrastructure can effectively manage these small events.

Opportunities

Green Infrastructure practices such as rain gardens, permeable pavement, and green roofs are all practices that can succeed in Pittsburgh's climate.

- Rain gardens capture stormwater draining from roofs. When the garden is full of water, extra water is channeled downhill away from the building.
- Permeable pavement is used for sidewalks, parking lots, and roads. It allows water to drain through it to a stone storage reservoir and then infiltrate into the soil. Underdrains laid in the storage reservoir help the practice drain between rainfall events.
- Green roofs introduce vegetation and soil onto roofs to absorb and filter rainfall. When the soil is saturated, the extra water overflows through a roof drain to a vegetated area, such as a rain garden.

Green Infrastructure Practices that Work with Frequent Rainfall

A storm inlet is used in this bioretention area to drain overflowing stormwater.

Source: Pennsylvania Stormwater BMP Manual

A stone channel is used in this residential rain garden to direct overflowing stormwater to the street.

Source: Stewardship Partners/Flickr

When this bioretention planter box is full of stormwater, the extra water "backs up" into the street to drain into a storm inlet.

Source: ASLA HQs, Washington, DC

This underdrain pipe system will help to drain the bioretention area above it.

Source: Brisbane City Hall, San Mateo County

Case Studies

Michigan Avenue Bioretention Planter Boxes, built 2006, Lansing, MI

In 2006, bioretention planter boxes were installed along four blocks of Michigan Avenue, a busy 5-lane street in Lansing, MI. The planters can treat the runoff from 1 to 4 inches of rain falling on the adjacent street and sidewalk.

If the planter reaches its maximum capacity, the extra stormwater "backs up" into the street and drains to a curb storm inlet. Water held in the soil is used by the plants, infiltrates to groundwater, or is released through an underdrain.

Results

- Flow meters were used to monitor the system, and model results show that about 90% of the total annual stormwater volume was treated by the planter box.
- While only 16% of the stormwater volume is kept within the planters, the peak flow rate of the water released through the underdrain is reduced by 87%.

Bioretention planter boxes in Lansing help treat stormwater from roads and sidewalk.
Source: Christian and Novaes, 2011

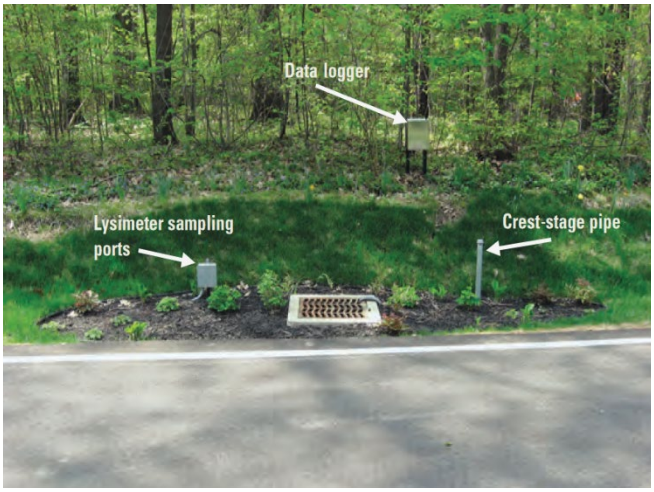
Source: Christian, D. and Novaes, V. 2011. Michigan Avenue Bioretention: Monitoring the Results Three Years Later. MWEA 86th Annual Conference.

Sterncrest Drive Bioswale and Rain Gardens, built 2007, Cuyahoga County, OH

In 2007, the Chagrin River Watershed Partners with a grant from the U.S. EPA replaced 1,400 feet of roadside ditch with grassed bioswale and nine rain gardens to conduct a study. The U. S. Geological Survey (USGS) then monitored the site from 2008-2010 to better define the effect of green infrastructure on stormwater runoff. The bioswales and rain gardens were designed to handle a 0.75-inch rainfall falling on the adjacent roadway. Rainfall and runoff data were collected along with overflow data to determine how well the system performed.

Results

- Numerous rainfall events greater than 0.75-inch were absorbed by the bioswales and rain gardens.
- Over the three years of monitoring, the system only overflowed 22 times.
- The bioswales and rain gardens performed better than expected in that there were more rainfall events greater than 0.75-inch that did not cause an overflow than events that caused an overflow.



Roadside rain garden in Cuyahoga County is monitored for its effectiveness in absorbing stormwater.
Source: USGS, 2011.

Source: Darner, R.A., and Dumouchelle, D. H. 2011. Hydraulic characteristics of low-impact development practices in northeastern Ohio, 2008-2010: U.S. Geological Survey Scientific Investigations Report 2011-5165, 19 p.

Green infrastructure practices can be designed to effectively manage the frequent small rainfall events in the Pittsburgh area.

Clay Soil

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The Challenge

The Pittsburgh region's clay soil is sometimes perceived as a challenge to green infrastructure practices. Clay soil is often thought to allow little to no infiltration of water to the groundwater table.

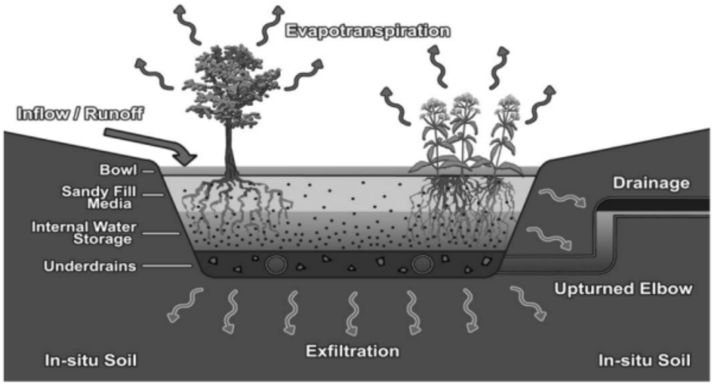
In actuality, undisturbed clay soil can infiltrate water quite well. The real challenge is when soil has been disturbed and compacted by construction. Compacted soil often results in very little infiltration and ponding is often observed.

While the design of green infrastructure practices for sites with clay soils may require greater care, the right green infrastructure practices can work well in Pittsburgh's clay soil.

Opportunities

Green Infrastructure practices such as rain gardens, permeable pavement, and bioretention are all practices that are successful in clay soils.

- Rain Gardens capture stormwater draining from roofs. Even in clay soils, infiltration can be expected if the soil is protected from compaction or restored through deep plowing.
- Permeable pavement is used for sidewalks, parking lots, and roads. It allows water to drain through it to a stone storage layer. Underdrains can be laid in the storage layer to help the practice drain in clay soils.
- Bioretention is similar to a rain garden but is typically more engineered. In clay soil, an underdrain is generally installed to ensure drainage.



This diagram shows a bioretention system. Underdrains drain the system in clay soils.
Source: Brown, R., Hunt, W. and Kennedy, S. 2009. Urban Waterways: Designing Bioretention with an Internal Water Storage Layer. NC Coop. Ext.

Green Infrastructure Practices that Work with Clay Soils

This rain garden collects roof water through a downspout.
Source: Tetra Tech

Stormwater drains through this permeable paver drive to a stone storage layer.
Source: Tetra Tech

This roadside bioretention collects and treats roadway stormwater.
Source: Tetra Tech

Case Studies

Rain Gardens, built 2004, Madison, WI

In 2003, the US Geological Survey installed four rain gardens next to municipal buildings in Madison, Wisconsin to test the effect of soil type and plant type on the rain garden's ability to absorb stormwater. Two rain gardens were installed in sandy soils and two rain gardens were installed in clay soils. For each soil type, one rain garden was planted with turf, and the other with native prairie grasses. The rain gardens were 100 to 400 square feet in area and 0.5 feet in depth, and were not equipped with underdrains. The USGS monitored the rain gardens for 4 years, observing inflows, outflows, rainfall amounts, and evapotranspiration amounts.

Roof stormwater drains to these monitored rain gardens in Madison, Wisconsin.
Source: Selbig and Balster, 2010.

Results

- The rain gardens were able to infiltrate nearly 100% of the stormwater they received over four years of operation in both clay soil and sandy soil!
- The rain garden planted with the prairie species infiltrated stormwater better than the rain garden planted with turf grass.
- Roots in the rain garden planted with native prairie grass species extended 4.7 feet deep compared with 0.46 feet in the rain garden planted with turf grass.

Source: Selbig, W.R., and Balster, Nicholas. 2010. Evaluation of turf-grass and prairie-vegetated rain gardens in a clay and sand soil, Madison, Wisconsin, water years 2004–08: U.S. Geological Survey Scientific Investigations

Roadside Bioretention, built 2009, Toledo, OH

Nearly 800 feet of residential roadside bioretention and permeable sidewalk were constructed in Toledo, Ohio to help reduce the occurrence of sewer overflows during heavy rainfall events. The project was constructed in clay soils and included underdrains to help drain the system if needed. Underground water storage was provided beneath the permeable sidewalk. Flow monitors were installed before and after construction to assess the effectiveness of the system at absorbing stormwater.

Results

- Long-term modeling shows an annual average stormwater volume reduction of about 64 percent.
- Peak flow rates are reduced by 60 percent to 70 percent. The peak flow rate of a storm is the maximum measured volume of water that moves past a point in a given amount of time.
- Reducing peak flow can help to reduce flooding.

Source: Tetra Tech. 2009. City of Toledo, OH, Maywood Avenue Storm Water Volume Reduction Project Construction Plan Set.

Roadway and sidewalk stormwater drains to this roadside bioretention system on Maywood Avenue in Toledo, Ohio.
Source: Tetra Tech, 2009.

Studies have shown that green infrastructure can be very effective when installed on clay soils.