NPDES Compliance Inspection Manual

Chapter 14

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CHAPTER 14 – INSPECTING GREEN INFRASTRUCTURE CONTROLS

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A. INTRODUCTION

In addition to materials in this chapter, inspectors must be familiar with Chapter 1, "Introduction," and Chapter 2, "Inspection Procedures."

An increasing number of National Pollutant Discharge Elimination System (NPDES) permittees are implementing green infrastructure practices that mimic natural processes to infiltrate, evapotranspirate, or use stormwater on or close to where it falls. This document is designed for United States Environmental Protection Agency (EPA), state, and local NPDES inspectors and provides background and suggested procedures for inspecting green infrastructure practices for proper installation, operation, and maintenance.

SCIENCE OF GREEN INFRASTRUCTURE

Green infrastructure systems are often designed using soil, vegetation and natural infiltration to more effectively manage urban stormwater and reduce impacts to receiving water. The hydraulic cycle is altered by the land use practices associated with human development, resulting in increased erosion and stream flooding during storms, reduced surface water base flow and interflow (shallow infiltration), groundwater recharge, and degraded water quality. Green infrastructure mimics pre-developed conditions by restoring the natural hydrology and enabling water to infiltrate instead of run off. This effects the timing of water release to rivers and streams, resulting in less flooding, and minimizing the quantity of water released into municipal separate storm sewer systems (MS4s) or combined sewer systems (CSSs). In the same way, green infrastructure can help reduce stormwater flow into combined sewer systems, thereby reducing combined sewer overflows and treatment requirements, which may result in fewer discharges of pollutants.

Green infrastructure can provide a wide variety of environmental, social, and economic benefits in addition to water quality improvements, including improved air quality, reduced urban heat island effect, reduced energy use, improved health, green jobs, recreational amenities, wildlife habitat, and increased property values. Green infrastructure is also an important tool for communities to increase their climate change resilience because it can help manage flooding, prepare for drought, and protect coasts by reducing coastal erosion and storm impacts.

Exhibit 14-1 depicts the impact of urbanization on water infiltration and evapotranspiration.

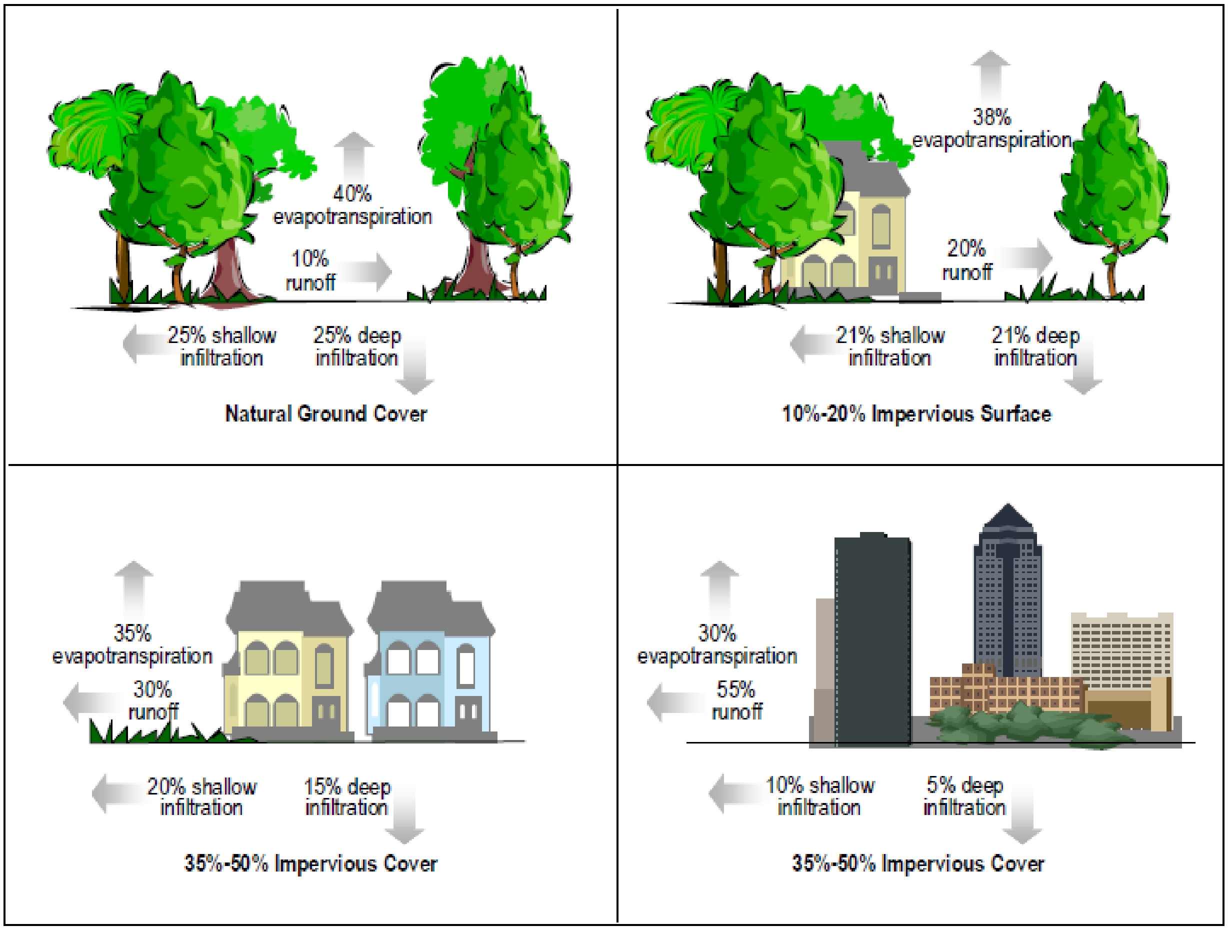


Exhibit 14-1. Impacts of Urbanization (as impervious surfaces are added, less and less precipitation is absorbed, resulting in more runoff) **(Source: EPA, 2005)**

Green infrastructure controls increase infiltration, filtration, storage, evaporation, transpiration, and rainwater capture and reuse. Green infrastructure can be used at varying landscape scales, including large regional treatment or watershed, as well as a neighborhood or small site in place of, or in addition to, more traditional stormwater controls. Small area stormwater infiltration practices (e.g., rain gardens, bioswales, infiltration planters, and tree plantings) can fit into individual site development or redevelopment sites, while larger area management strategies (e.g., riparian buffers, flood plain and wetland restoration, open space and forest preservation) systems are typically applied at the watershed level.

DESIGN AND INSPECTION PREPARATION

Design requirements for green infrastructure can vary by state and even by locality. Green infrastructure designs are based on a number of detailed design calculations and data (including geographic information system (GIS) data, modeling, soil tests, and other information). Also, many green infrastructure designs include significant components that are not easily visible to inspectors (e.g., soil media depth, underdrains). If as-built drawings are available, they can be used to assess whether an inspected control still meets the approved design.

Inspection Preparation

To prepare for an inspection, inspectors should be familiar with the local requirements and design standards. Inspectors can review permits, legal agreements (e.g., consent agreements), state/local manuals for design specifications, operations and maintenance manuals, previous inspection reports, and enforcement orders. Though consent decrees and NPDES permits typically authorize the permit authority to access the subject facility, inspectors need to follow the entry procedures in this inspection manual.

On the day of the inspection, inspectors should bring inspection forms or checklists, site plans, maps, and a camera. In some cases, a soil probe to check soil compaction and composition may be useful. Document observations through photographs and using the appropriate inspection form or checklist. Additional information may be obtained from interviews of local residents and/or business owners (who may have observed how the green infrastructure control functions under various weather conditions).

The University of Minnesota has developed an online guidance ("Developing an Assessment Program," a chapter in *Stormwater Treatment: Assessment and Maintenance*) to help inspectors assess the performance of and schedule maintenance for stormwater controls (Gulliver et al., 2010). This online manual can be found at http://stormwaterbook.safl.umn.edu/.

CONSIDERATIONS ON INSPECTION TIMING

When possible, inspectors should schedule green infrastructure inspections during the following timeframes to better observe performance:

During or immediately after a rain event. Conducting inspections during or right after a rain event (within 24 hours) will allow the inspector to view the green infrastructure control in operation, and make it easier to see if the control is functioning as designed. For example, inspections during a rain event allow an inspector to see where the stormwater flows and whether stormwater is bypassing controls. Most controls are designed to drain all stormwater within 24–72 hours, so standing water that has not drained three days after a rain event could indicate that maintenance is required for that infiltration control.

During spring, summer and fall. Spring, summer, and fall are probably the best times to inspect green infrastructure practices in most regions. Winter conditions can impact the vegetation in a green infrastructure control, which can look significantly different than during spring/summer. Also, snow cover in winter months in some areas can make inspecting green infrastructure controls very difficult.

After construction. Inspectors should be aware that vegetation in certain green infrastructure controls can take several years to become fully established. An inspection soon after installation is complete can allow an inspector to more easily see inlets, outlets and other aspects of the control, but vegetation may be sparse while it becomes established. Therefore, depending on the control, it may be best to inspect green infrastructure practices multiple times, both soon after installation and once vegetation is well-established to get a full picture of how practices are performing.

TYPES OF GREEN INFRASTRUCTURE MANAGEMENT PRACTICES

This chapter details infiltration controls, permeable pavement controls, rainwater harvesting systems and green roofs, as these are the most common types of green infrastructure controls that an inspector would investigate. There are many other types of stormwater and green infrastructure controls that an inspector may see in the field, and the inspection techniques described in this chapter may be applied to many of these controls as well.

Many times, multiple controls are integrated into a site and designed synergistically. Exhibit 14-2 depicts a typical site plan with green infrastructure controls annotated.

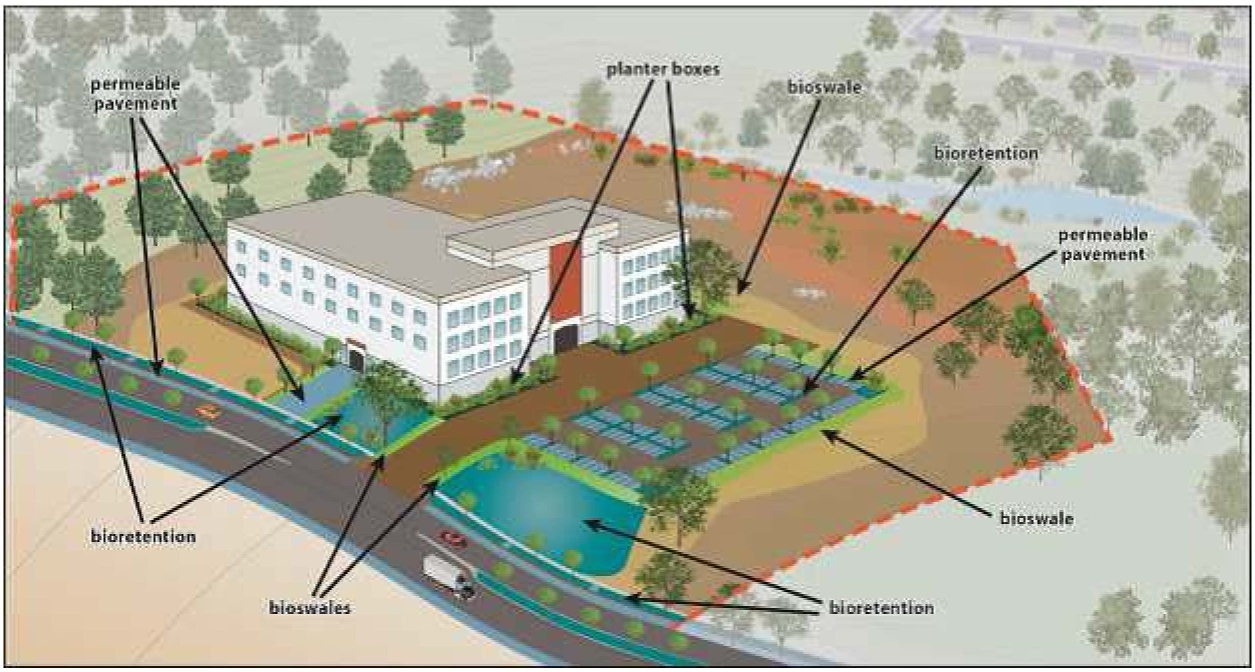


Exhibit 14-2. Multiple Green Infrastructure Controls on a Developed Site
(Source: Dorman et al., 2013)

To help educate inspectors on typical green infrastructure control performance, Table 14-1 provides a site selection matrix based on the desired function of the green infrastructure practice. It also includes pollutant reduction estimates and comparative costs.

Table 14-1. Sample Design Management Practice Selection Matrix According to Site Characteristics (Source: Modified from Dorman et al., 2013)

Attribute		Infiltration Control	Permeable Pavement	Rainwater Harvesting	Green Roof
Typical contributing drainage area (acres)		<5	varies	Rooftop	Rooftop
Practice slope		<2%	<2%	N/A	N/A
Pollutant Removal	Sediments	High	High	Pollutant removal provided by downstream BMP	Typically, water quality is not improved by green roofs (although volume reduction can reduce total loads).
	Nutrients	Medium	Low		
	Trash	High	High		
	Metals	High	High		
	Bacteria	High	Medium		
	Oil and Grease	High	Medium		
	Organics	High	Low		
Runoff volume reduction		High	High	Varies based on cistern size and water demand	High
Peak flow control		Medium	Medium		Medium
Construction costs		Low to medium	Medium to high	Low to medium	High
O&M costs		Low to medium	Medium	Low to medium	Low to medium

B. INFILTRATION CONTROLS

DESCRIPTION

Infiltration controls are engineered systems designed to use temporary surface and underground storage to capture and hold stormwater on-site for enough time to allow a designed stormwater volume to evapotranspire, percolate, and filter into the ground, reducing or eliminating surface runoff depending on the regulatory requirements at the site. Infiltration utilizing landscaped areas, including bioretention, rain gardens and bioswales, typically consists of a combination of some or all of the following elements: a flow-regulating structure (such as a level spreader that slows and spreads the flow out into a control), a pretreatment element (such as a vegetated filter strip), an engineered soil mix planting bed, vegetation, and an outflow-regulating structure. In some places, bioretention (Exhibit 14-3 and Exhibit 14-4) is defined as an engineered structure while rain gardens are simpler structures with no formal engineering and designed/installed by a homeowner. Infiltration controls are designed to hold water for a specific amount of time and remove many of the pollutants through a variety of chemical, physical and biological processes, in a manner similar to natural ecosystems.

Infiltration can occur at both large and small sites. In addition to providing temporary storage that delays the timing of stormwater to waterways, infiltration provides effective treatment/capture for such pollutants as sediments, nutrients, trash, metals, bacteria, oil and grease, and organics. Infiltration practices that include trees have the added benefits of greater evapotranspiration and water uptake and reduction of energy demand by providing summer shade to buildings.

Infiltration systems are versatile stormwater management practices that can be readily adapted to parking lot islands; street medians; residential, commercial and industrial campus landscaping; and urban and suburban green spaces and corridors.

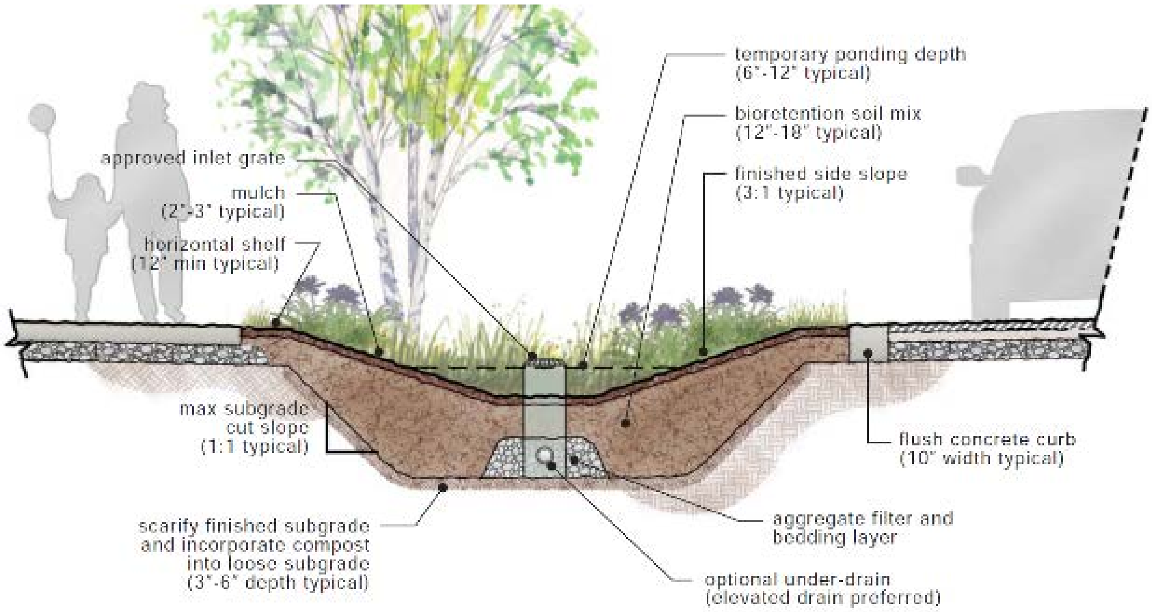


Exhibit 14-3. Example Cross-section of Bioretention with Primary Design Elements (under-drain is optional) **(Source: AHBL, 2012)**

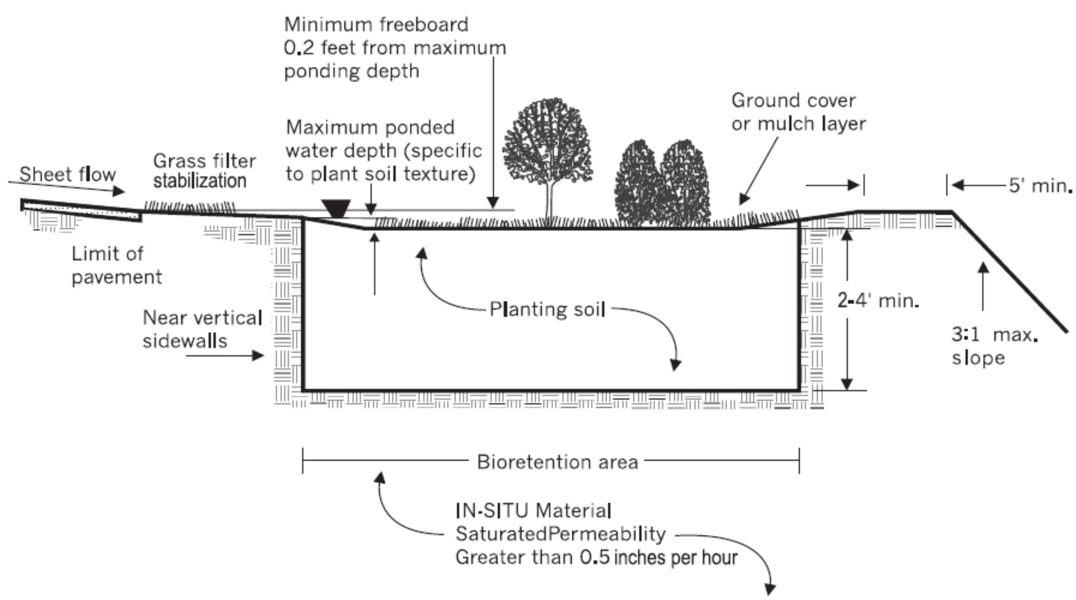


Exhibit 14-4. Example Primary Design Elements of a Bioretention Facility **(Source: PGDER, 1999)**

DESIGN OF INFILTRATION CONTROLS

Infiltration controls are designed to collect stormwater flows that temporarily collect on the surface in a ponding area. The stormwater then infiltrates or filters through a media layer where it either enters the subsurface soil over 24–72 hours, or is collected by an underdrain (perforated pipe below the media layer) for discharge to a storm drain or waterbody. Typical components of an infiltration control include:

Site applicability—Infiltration controls should generally be at least 10 feet away from any structure (e.g., buildings and parking lots), with a slope away from the structure.

Inlets—An inlet can consist of a curb cut, a flow spreading device such as a stone or gravel diaphragm that distributes stormwater runoff across the length of the control, a grass filter strip, or a similar device.

Outlet—An outlet can take many different forms, such as a riser structure or a curb cut/inlet that discharges stormwater once it exceeds the maximum ponding depth of the control. Controls can also be designed as a bypass system where flow does not enter the system once the maximum ponding depth is exceeded. It is important to review the site plans to determine if the controls are designed as a flow through or bypass system.

Pretreatment—To minimize clogging of the control device, infiltration controls need pretreatment, especially in drainage areas with excessive sediment (such as construction areas or unstabilized slopes). Pretreatment measures, if needed, can include sediment forebays, grass channels, level spreaders, or gravel diaphragms.

Soil media—Soil media mixes vary but generally include a mixture of largely course sand (~85 percent), fines (silt and clay ~10 percent), and organic media (~5 percent).

Vegetation—Infiltration controls can include a wide variety of suitable vegetation, from turf grass to shrubs or trees and should be based on the geographic location. Many jurisdictions recommend using hearty, drought-tolerant native plants to increase survival rates.

Underdrain—Consisting of perforated pipe beneath the media layer, underdrains convey excess stormwater that cannot be infiltrated into the soil within 24–72 hours, generally to the storm or combined sewer system or to a swale, stream or other surface water.

Mulch—Infiltration control designs often include specification for 1–2 inches of mulch to help retain soil moisture, provide a slow release of nutrients to plants, and shade out weed growth. Over mulching can “burn” vegetation and limit storage capacity.

Typical maintenance—The primary maintenance requirement for vegetated infiltration controls is regular plant, soil, and mulch layer maintenance to ensure a healthy vegetation system that promotes infiltration, storage, and pollutant removal. A healthy and densely vegetated system should be free of excess sediment and trash, and a typical system should drain within 72 hours after a storm event.

INSPECTING INFILTRATION CONTROLS

There are several issues that inspectors should look for when inspecting infiltration controls. These include:

Inlet—Improper grading at the inlet could impede flow to the control.

Vegetation/media/mulch—Controls that lack vegetation may indicate poor maintenance practices. Lack of mulch could allow erosion and too much mulch could inhibit plant growth.

Outlet—An outlet that is too low may allow the water to short-circuit the control and reduce its effectiveness.

Appendix Z, "Infiltration Control Inspection Form," is a sample post-construction inspection form that could be used when inspecting infiltration controls. Inspections should include a review of any available operation logs and maintenance plans.

COMMON INFILTRATION CONTROL ISSUES

Common issues and challenges associated with infiltration controls include:

Poor design or placement of outlet

Photo 14-1. An infiltration basin may be poorly sited or poorly designed to the extent that it is unable to retain and infiltrate stormwater. In the photo above, the outlet is too low as evidenced by the scour path from the curb cut to the grate. This could indicate that sediment is being carried into the drain and that little water is being retained and absorbed. Possible solution: consider adding diffuser along scour path and/or raising the level of the grate. (Credit: EPA Region 5)

Management practice impeding function of infiltration control

Photo 14-2. Bioswale treated with herbicide accidentally. Vegetation is sparse, which may allow erosion. Consider reseeding or replanting and providing adequate signage in English and Spanish to ensure the practice is not continually treated with herbicide. (Credit: EPA Region 5)

Improper grading towards infiltration control

Photo 14-3. Inappropriate grading is another common design flaw in infiltration-based control practices. If a parking lot, street or other impervious surface is not properly graded *towards* the control or is *bypassing* the control, the BMP is not serving its intended purpose. In the photo above, the wet spot on the pavement indicates either poor grading in the installation or poor drainage by the control. Consider adjusting the grade. (Credit: EPA Region 5)

Outlet set too low

Photo 14-4. If the outlet is set too low, then stormwater will not pond and very little water will infiltrate, as it is designed to do. (Credit: John Kosco, Tetra Tech)

The City of Seattle has developed a *Green Stormwater Operations and Maintenance Manual* (Seattle, 2009) that provides photographs and level of service categories for different maintenance levels. These photographs and maintenance levels can educate inspectors on different infiltration control issues. Illustrated examples of problems associated with flow control structures can be found at https://www.seattle.gov/util/cs/groups/public/@spu/@usm/documents/webcontent/spu02_020023.pdf.

C. PERMEABLE PAVEMENT CONTROLS

DESCRIPTION

Permeable pavement combines stormwater infiltration, storage, and a structural pavement consisting of a permeable pavement layer underlain by a storage/infiltration bed. Permeable pavement has not been thoroughly tested on high speed roads in extreme weather conditions, although it has been successfully applied for low speed residential streets, parking lots, parking lanes and roadway shoulders (DDOE, 2013). The permeable pavement layer can consist of pervious concrete, porous asphalt, or various types of interlocking pavers, which are each summarized below (EPA, 2009):

Pervious concrete—Achieves porosity by reducing the number of fines in the mix, giving the concrete surface a much coarser appearance compared to standard impervious concrete.

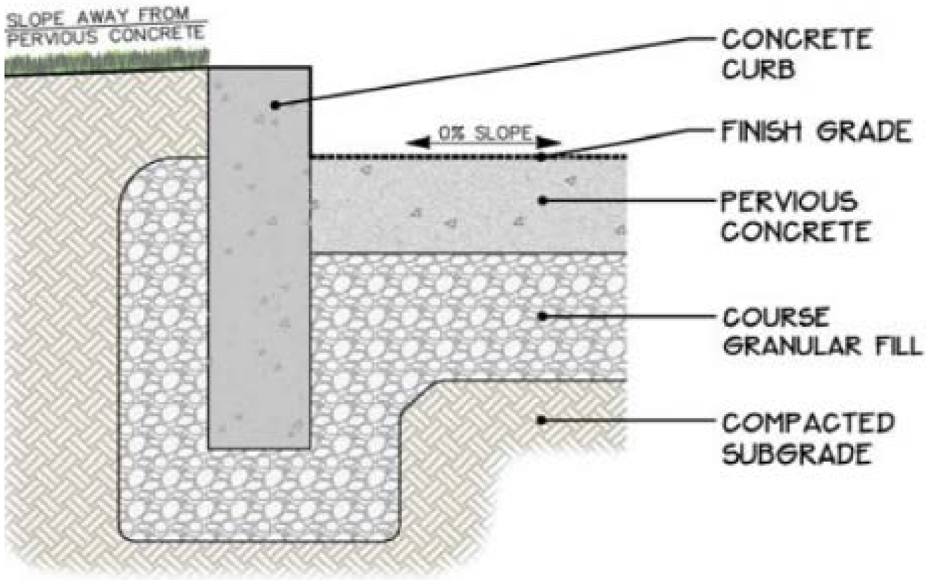


Exhibit 14-5. Example Pervious Concrete Cross-section (Source: EPA, 2009)

Porous asphalt—Like pervious concrete, achieves its porosity by eliminating the fine particles from its mix specification, allowing water to flow through it rather than over it.

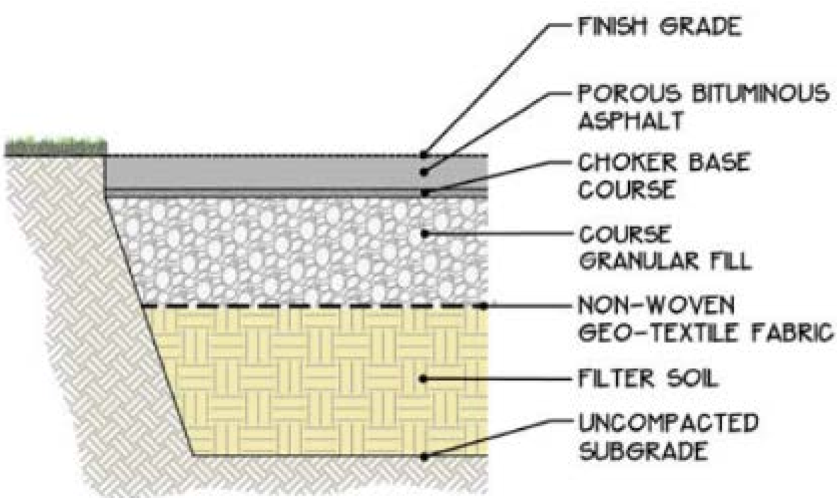


Exhibit 14-6. Example Porous Asphalt Cross-section (Source: EPA, 2009)

Permeable paver blocks—Manufactured units that interlock to create a durable pavement. Void spaces between units are filled with permeable materials such as pea gravel or sand to allow surface water to infiltrate.

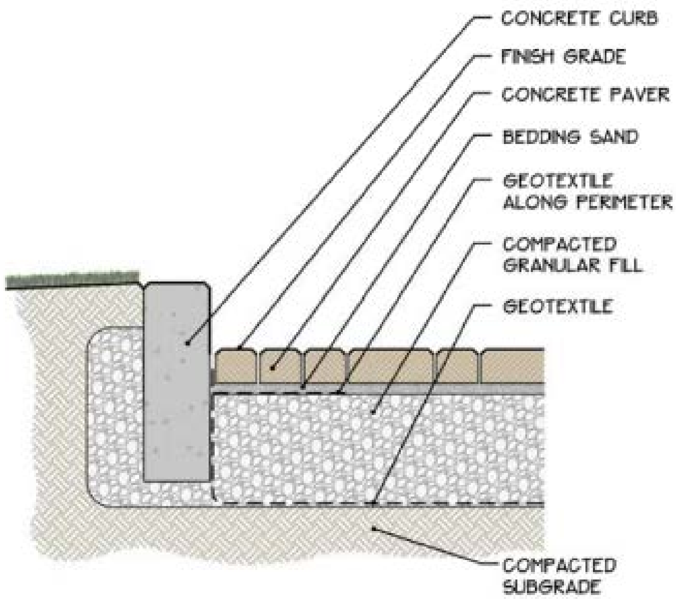


Exhibit 14-7. Example Permeable Paver Blocks Cross-section **(Source: EPA, 2009)**

Grid pavers—Concrete grid paver (CGP) systems are composed of concrete blocks made porous by eliminating finer particles in the concrete that creates voids inside the blocks; additionally, the blocks are arranged to create voids between blocks. Plastic turf reinforcing grids (PTRG) are plastic grids that add structural support to the topsoil and reduce compaction to maintain permeability. Grass is encouraged to grow in PTRG, so the roots will help improve permeability due to their root channels. Grid pavements provide a cool, green surface solution for vehicular access lanes, emergency access areas, and overflow parking areas, and even residential driveways.

Exhibit 14-8. Grid Pavers—Concrete (left) and Plastic (right) **(Credit: Tetra Tech)**

DESIGN OF PERMEABLE PAVEMENTS AND PAVERS

The design components of a typical permeable pavement are described below. Note that the specific design components can change based on the type of permeable pavement installed and the local design standard requirements:

Inflow/Surface materials

As described above, there are several different types of surface materials for permeable pavements, from pervious concrete to porous asphalt to grid pavers or paver blocks. Porous asphalt and concrete mixes are similar to their impervious counterparts, but do not include the finer grade particles. Interlocking pavers have openings that are filled with stone to create a porous surface. Permeable pavements can accept runoff from adjacent impervious surfaces, but the impervious area should not exceed three-to-five times the pervious area (some states limit even more or prohibit the impervious area that can discharge to permeable pavements).

Storage

In addition to distributing mechanical loads, coarse aggregate laid beneath porous surfaces is designed to store stormwater prior to infiltration into soils or discharging to a stormwater BMP. The aggregate is wrapped in a non-woven geotextile to prevent migration of soil into the storage bed and resultant clogging. In porous asphalt and porous paver applications, the storage bed also has a choker course of smaller aggregate to separate the storage bed from the surface course.

Infiltration/Outflow

Most of the stormwater that enters a permeable pavement system is infiltrated, however, these systems are often designed with an outflow to prevent flooding or standing water from larger storms. The outflow can be a perforated pipe system, or a positive outflow that consists of a stone buffer that connects to the stone sub-based under the permeable pavement and allows a path for excess water to flow out of the system.

INSPECTING PERMEABLE PAVEMENTS

The primary issue with permeable pavements and pavers is clogging, which can slow infiltration rates or even result in surface ponding. Permeable pavements should not receive runoff from disturbed or vegetated areas—the sediment can quickly clog the system.

Spills can be significant problems on permeable pavements because of the potential for groundwater contamination and the difficult in cleaning up spills on permeable pavement (as opposed to cleaning up spills on impervious concrete or asphalt). Inspectors should always look for evidence of spills on or near permeable pavements.

Permeable pavements are designed to drain stormwater quickly—any standing water on a permeable pavement typically indicates a problem with the control. Also, permeable pavement should have signage (Exhibit 14-9) to ensure that maintenance staff do not spread chemicals and to help educate the public.

Exhibit 14-9. Porous Asphalt Signage **(Credit: Tetra Tech)**

Appendix AA provides a sample post-construction inspection form that could be used to inspect permeable pavement. Inspections should include a review of any available operation logs and maintenance plans.

COMMON PERMEABLE PAVEMENT ISSUES

Common issues and challenges associated with permeable pavements include:

Excess sediment on permeable pavement

Photo 14-5. Sediment from the impervious parking is entering the permeable pavement area. This photo also indicates improper grading, with the flow accumulating in one area. (Credit: Bill Hunt, NCSU)

Sediment accumulation between paver blocks

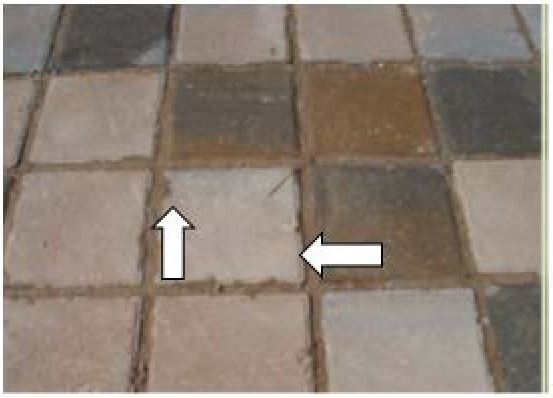


Photo 14-6.Fine mud and silt in between permeable pavers hindering rapid infiltration. (Credit: Bill Hunt, NCSU)

Excessive sediment on permeable pavement

Photo 14-7. Sediment on permeable pavement clogs void spaces thus slowing infiltration. Important to protect permeable pavement from construction stormwater run-off. (Credit: Bill Hunt, NCSU)

Sediment/poor grading

Photo 14-8. Visible silt on the permeable pavement surface, indicates that water is collecting before infiltrating. Maintenance, such as sweeping or vacuuming is needed. (Credit: EPA Region 5)

Vegetation between paver blocks

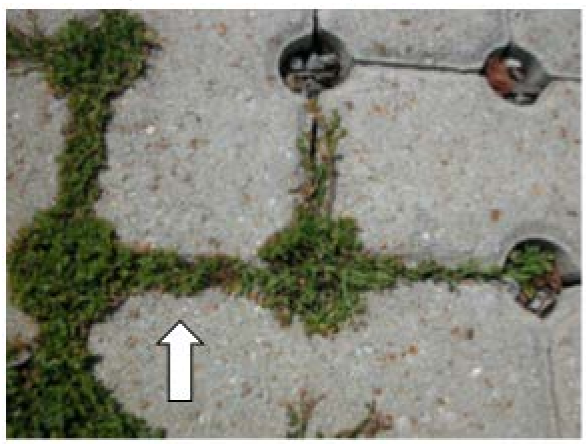


Photo 14-9. Weeds and moss between pavers may indicate a sediment problem. Herbicides should not be used on permeable pavement systems. (Credit: Bill Hunt, NCSU)

D. RAINWATER HARVESTING SYSTEMS

DESCRIPTION

Rainwater harvesting systems collect rainwater that falls on rooftops or other impervious surfaces and conveys it to above- or below-ground storage tanks, where it can be used between rain events as non-potable water for irrigation or other uses. This technology reduces potable water use while also reducing stormwater discharge off-site. Rain barrels are typically used in residential applications and connect to a rooftop downspout to collect rainwater for irrigation purposes. Cisterns are typically large containers or tanks that hold significantly more stormwater volume than a rain barrel. Cisterns are more commonly used in commercial applications and can store stormwater for irrigation or a variety of other uses, including re-use inside the building.

Non-potable uses of harvested rainwater may include the following:

- Landscape irrigation
- Exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, and fire trucks)
- Flushing of toilets and urinals
- Fire suppression (i.e., sprinkler systems)
- Supply for cooling towers, evaporative coolers, fluid coolers, and chillers
- Supplemental water for closed loop systems and steam boilers
- Replenishment of water features and water fountains
- Distribution to a green wall or living wall system
- Laundry

DESIGN OF RAINWATER HARVESTING SYSTEMS

There are seven primary design components of a rainwater harvesting system:

1. Contributing drainage area (CDA) or CDA surface
2. Collection and conveyance system (i.e., gutter and downspouts)
3. Pretreatment, including prescreening and first flush diverters
4. Storage system (cisterns)
5. Water quality treatment
6. Distribution systems
7. Overflow, filter path or secondary stormwater retention practice

Contributing Drainage Area (CDA) or CDA Surface

When considering CDA surfaces, note that smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality. Some roofing materials such as tar and gravel, asbestos shingle and treated cedar shakes may leach toxic chemicals and are not suitable CDA surfaces. Cedar shake and other wooden roofs are the least efficient surfaces in regards to rainwater harvesting because they are porous while metal roofs are the most efficient.

Collection and Conveyance System

The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall into cisterns. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Gutters and downspouts should be kept clean and free of debris and rust.

Pretreatment

Pre-filtration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards are typically used for pre-filtration of small systems, although direct water filtration is preferred. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Diverted flows (i.e., first flush diversion and/or overflow from the filter, if applicable) should be directed to an appropriate best management practice (BMP) or to a settling tank to remove sediment and pollutants prior to discharge from the site.

Various pretreatment devices are described below:

- **First Flush Diverters** direct the initial pulse of rainfall away from the cistern. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces. First flush diverters are typically passive devices that retain a relatively small amount of stormwater that is first captured from the roof system before the remaining roof runoff is directed into the rainwater harvesting system.
- **Leaf screens** are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens should be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the cisterns.

Exhibit 14-10. First Flush Diverter (Credit: NCSU BAE)

- **Roof washers** are placed just ahead of cisterns and are used to filter small debris from harvested rainwater. Roof washers consist of a cistern, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30 microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers should be cleaned on a regular basis.
- **Hydrodynamic Separator** can be used to filter rainwater from larger CDAs.

Exhibit 14-11. Roof Washer (Credit: NCSU BAE)

Storage System (Cisterns)

The cistern provides the storage for a rainwater harvesting system. Rain barrels typically hold about 55 gallons, but cistern capacities generally range from 250 to 30,000 gallons, but can be as large as 100,000 gallons or more for larger projects. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the storage volume needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume retention objectives.

While the common cistern has a cylindrical shape, cisterns can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the cisterns will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site.

Water Quality Treatment

Depending upon the collection surface, method of dispersal and proposed use for the harvested rainwater, a water quality treatment device may be necessary to clean the harvested rainwater.

Distribution Systems

Rain barrel systems and small cisterns can use a gravity fed distribution system. Most distribution systems for larger cisterns need a pump to convey harvested rainwater from the cistern to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. The rainwater harvesting system should be equipped with an appropriately sized pump that produces sufficient pressure for all end-uses. A backflow preventer should be used to separate harvested rainwater from the main potable water distribution lines.

Overflow

An overflow mechanism is needed as a component of the rainwater harvesting system design to handle an individual storm event or multiple storms in succession that exceed the capacity of the cistern. Overflow pipe(s) should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe(s) should be screened to prevent access to the cistern by small mammals and birds. All overflows from the system should be directed to an acceptable flow path that will not cause erosion.

INSPECTING RAINWATER HARVESTING SYSTEMS

Inspectors should look for obvious defects with the rainwater harvesting system such as tanks that are leaking or cracked, inflow controls that are not working properly (such as downspouts not properly connected to the tank), and improper maintenance (including sediment in the tank or debris in the filters or screens).

If available, inspectors should also review maintenance and use records to determine if the rainwater harvesting system is being used properly. For example, is the system largely empty before large rain events? Is the water being used as soon as practical after rain events?

Appendix AB, “Rainwater Harvest Inspection Form,” provides a sample post-construction inspection form that could be used to inspect rainwater harvesting systems. Inspections should include a review of any available operation logs and maintenance plans.

COMMON RAINWATER HARVESTING ISSUES

Common issues and challenges associated with rainwater harvesting systems include:

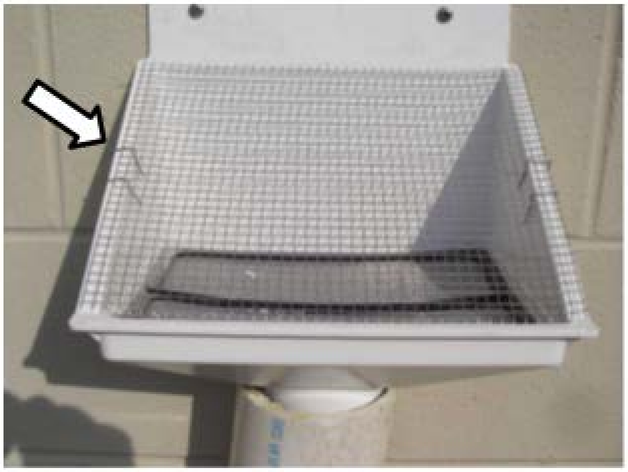
Overflowing rain barrel

Overflowing rain barrel. Consider larger capacity cistern or higher volume overflow pipe. The overflow pipe may also be clogged. Overflow could cause water problems inside the adjacent building. (Credit: Innovative Water Solutions)

Improper maintenance of gutters

Gutters, which drain to cistern, in need of cleaning
(Credit: Jason Wright, Tetra Tech)

Screen maintenance



This screen is clear, but inspectors should check filters to determine if they are clogged (Credit: Tetra Tech)

Overflow devices is clogged or in need of repair

Check overflow features to determine if they are working (Credit: Tetra Tech)

E. GREEN ROOFS

DESCRIPTION

Green, living, or vegetated, roofs are alternative roof surfaces that typically consist of a layer of soil/media and vegetation over waterproofing and drainage materials on a conventional flat or pitched roof to absorb and retain water, like vegetation and soil on the ground.

Design variants include extensive and intensive green roofs. *Extensive* green roofs have a much shallower growing media layer that typically ranges from 3 to 6 inches thick. *Intensive* green roofs have a growing media layer that ranges from 6 to 48 inches thick. Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year) although some intensive green roof systems may be designed to meet these criteria. Green roof designs may be combined with other green infrastructure practices elsewhere on-site to control large storms.

DESIGN OF GREEN ROOFS

Standard specifications for North American green roofs continue to evolve, and no universal material specifications exist that cover the wide range of available roof types and system components. The American Society for Testing and Materials (ASTM) has issued several overarching green roof standards, which should be consulted when assessing the design of green roofs. Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules. Common components in a green roof are illustrated in Exhibit 14-12.

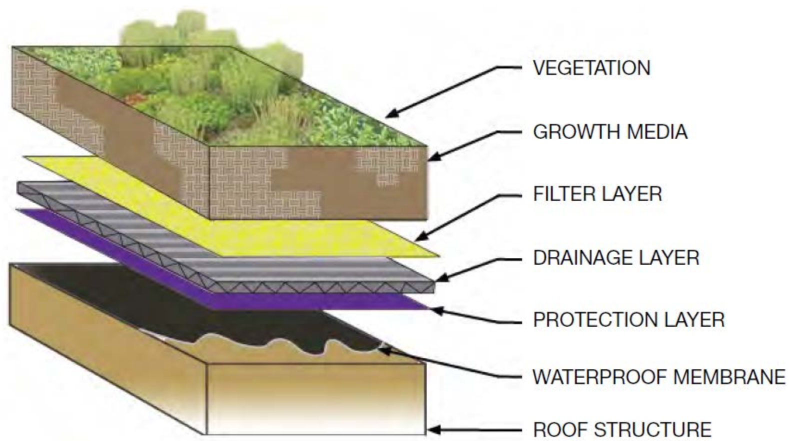


Exhibit 14-12. Extensive Green Roof Illustration (Source: SEMCOG, 2008)

Roof/Deck Layer

The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.

Leak Detection System

The leak detection system is an optional system used to detect and locate leaks in the waterproof membrane. Leak detection systems are often installed above the deck layer to identify leaks, minimize leak damage through timely detection, and locate leak locations.

Waterproof Membrane

All green roof systems should include an effective and reliable waterproofing layer to prevent water damage through the deck layer. The membrane should be designed to convey water horizontally across the roof surface to drains or gutter and may also act as a root barrier. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM). The waterproofing layer needs to be 100 percent waterproof and have an expected life span as long as any other element of the green roof system. The waterproofing material may be loose laid or bonded (recommended). If loose laid, overlapping and additional construction techniques should be used to avoid water migration.

Insulation Layer

Many green roofs contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to *Green Roof Plants: A Resource and Planting Guide* (Snodgrass et al., 2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. The designer should consider the use of open or closed cell insulation depending on whether the insulation layer is above or below the waterproofing layer (and thus exposed to wetness), with closed cell insulation recommended for use above the waterproofing layer.

Root Barrier

Another layer of a green roof system, which can be either above or below the insulation layer depending on the system, is a root barrier that protects the waterproofing membrane from root penetration. Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff, should be avoided in systems where the root barrier layer will contact water or allow water to pass through the barrier.

Drainage Layer

A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. The drainage layer usually consists of synthetic or inorganic materials (e.g., gravel, high density polyethylene (HDPE)) that can retain water and provide efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders.

Filter Fabric

A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric should not impede the downward migration of water into the drainage layer.

Growth Media

For an extensive green roof, the growing media is typically 3 to 6 inches deep (minimum 3 inches). The recommended growing media for extensive green roofs is typically composed of approximately 70 to 80 percent lightweight inorganic materials, such as expanded slates, shales or clays; pumice; scoria; or other similar materials. The remaining media should contain no more than 30 percent organic matter. The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. Media should also provide sufficient nutrients and water holding capacity to support the proposed plant materials. The growing media typically has a maximum water retention of approximately 30 percent.

The composition of growing media for intensive green roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the green roof planting plan, the growing media should be sufficient to provide enough soil volume for the root structure of mature trees.

Plant Materials

The top layer of an extensive green roof typically consists of plants that are non-native, slow-growing, shallow-rooted, perennial, and succulent. These plants are chosen for their ability to withstand harsh conditions at the roof surface. A mix of base ground covers (usually Sedum species) and accent plants can be used to enhance the visual amenity value of a green roof. The design should provide for temporary, manual, and/or permanent irrigation or watering systems, depending on the green roof system and types of plants. For most application, some type of watering system should be accessible for initial establishment or drought periods. The use of water efficient designs and/or use of non-potable sources are strongly encouraged.

INSPECTING GREEN ROOFS

Inspectors of green roofs should look for the following issues:

- Dead or dying vegetation
- Roof drains, scuppers, and gutters are overgrown or have organic matter deposits
- Evidence of erosion or loss of media
- Standing water

Other issues with green roofs can be more difficult to assess on a typical NPDES inspection. For example, improper installation, excessive dead loads that exceed what the building can handle, root penetration and leaks can be difficult to detect without extensive knowledge of the approved design and construction. However, inspectors can review maintenance records, which may identify some of these issues.

Caution should be taken when inspecting green roofs that are sloped or are at high elevations. Necessary safety measures should be taken at all times.

Appendix AC, “Green Roof Inspection Form,” provides a sample post-construction inspection form that could be used to inspect green roofs. Inspections should include a review of any available operation logs and maintenance plans.

COMMON GREEN ROOF ISSUES

Common issues and challenges associated with green roofs include:

Poor vegetation on green roof

Roof in Florida with poorly maintained plants
(Credit: Kevin Songer)

Green roof with adequate vegetation (Credit: EPA Region 5)

F. REFERENCES

The following is a list of resources providing additional information on green infrastructure.

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