URBAN Waterways

Permeable Pavements, Green Roofs, and Cisterns

Stormwater Treatment Practices for Low-Impact Development

Stormwater runoff continues to be a concern in communities large and small across North Carolina and the United States. State regulations targeting pollutants such as nitrogen, phosphorus, and total suspended solids have been in place since the 1990s. In 2003, federally mandated stormwater programs were established in more than 100 municipalities in North Carolina. These communities must reduce flooding and improve the water quality of runoff from new residential and commercial developments by using stormwater treatment practices.

In 1999, North Carolina State University Cooperative Extension published its first Urban Waterways fact sheet, an *Overview of Structural Stormwater Best Management Practices*. It described several stormwater practices, including wet ponds, stormwater wetlands, bioretention areas, sand filters, level spreader-riparian buffer systems, and grassy swales. Since then, additional structural practices have become commonplace throughout North Carolina, including the use of *permeable pavements, green roofs,* and water harvesting systems or *cisterns*. This new fact sheet in the Urban Waterways series describes these three stormwater practices and supplements the original overview.

These practices are incorporated within low-impact development (LID). LID uses site planning and engineering to reduce or prevent the adverse impacts of stormwater runoff from both residential and commercial developments. LID relies on both structural and nonstructural practices to conserve the site's natural or *predeveloped hydrologic response* to rainfall – the way rainfall is distributed among runoff, infiltration, and evapotranspiration.

Examples of nonstructural practices include minimizing site disturbance, preserving important site features, reducing and disconnecting *impervious cover* (sufaces that do not allow water to filter through them, such as asphalt and concrete), flattening slopes, utilizing native vegetation, minimizing grass lawns, and maintaining natural drainage features. Structural best management practices (BMPs), such as bioretention (see AGW-588-05 for more information), permeable pavements, green roofs, and cisterns, are used in LID to provide further runoff control and treatment close to the runoff's source.

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PERMEABLE PAVEMENTS

WHAT ARE THEY? Permeable pavements provide alternatives to standard asphalt and concrete, which are completely impervious surfaces. Permeable pavements allow water to infiltrate or pass through them. Several types of permeable pavements are available, including pervious concrete, pervious asphalt, permeable interlocking concrete pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavement (Figure 1).

These pavements are all similar in several ways. They usually contain a gravel storage layer underneath the surface pavement, which often doubles for structural support. Permeable pavements are typically targeted for paved areas with low traffic volumes. Some examples of appropriate uses for permeable pavements include patios, residential parking pads, driveways, fire lanes, overflow parking areas, and some daily parking areas. For runoff reduction, a permeable pavement on flat slopes tends to work better. Deeper gravel layers under the pavement allow for more storage of rainwater.

Permeable pavements are least expensive and work best when located on sandy soils (such as those on coastal barrier islands, the coastal plain, and in the sandhills), but they have been used throughout North Carolina. Constructing them over clay soils is possible but more expensive. Clay soils tend to shrink and swell and are rather impermeable. The properties of clay make permeable pavements less stable structurally and limit the rate at which water can infiltrate the paving material. However, when permeable pavements are constructed in watersheds with very limited or no construction, they can function over clay soils, such as those found in the piedmont.

Clay soil permeable pavements are designed dif-

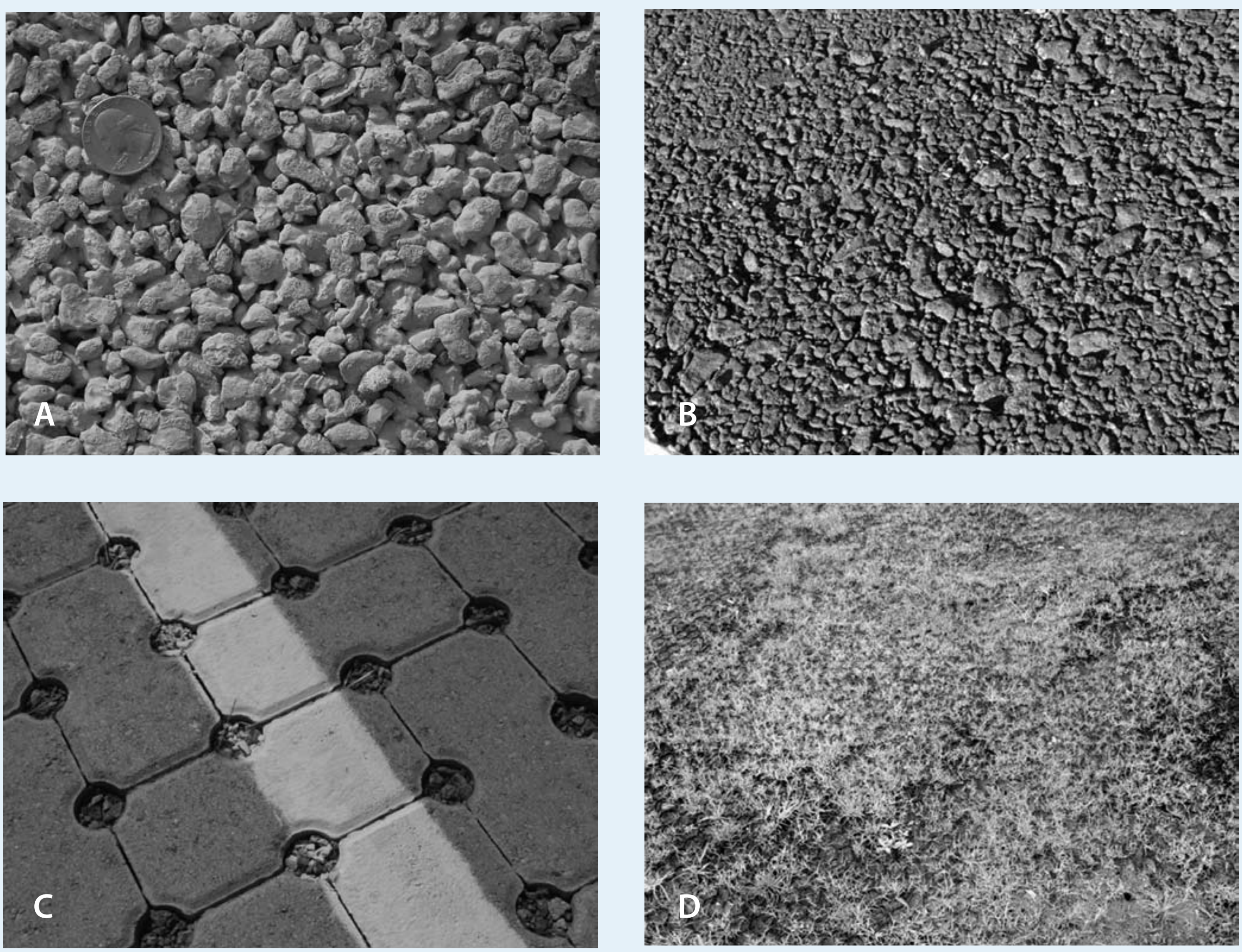

FIGURE 1. Four types of permeable pavement: (A) pervious concrete, (B) pervious asphalt, (C) permeable interlocking concrete pavers (PICPs), (D) plastic grid reinforced grass pavement. *(BAE, N.C. State University)*

ferently from their sandy soil counterparts. They tend to be deeper, with a thicker gravel storage layer. They usually have an impermeable liner between the bottom of the gravel storage layer and the existing clay soil on site, and they employ an underdrain system to slowly release water to the storm drain network. If sited, designed, and installed correctly, permeable pavement can be very effective at reducing peak runoff rates and consequently reducing local downstream flooding. Permeable pavements also reduce the pollution load to streams and water bodies, the likelihood of soil erosion along streams and waterways, and pavement temperature.

Permeable interlocking concrete pavers and concrete grid pavers consist of concrete blocks with gaps between them filled with a permeable material like pea gravel or sand. The blocks rest on a bedding layer of fine gravel, which overlays a layer of coarse gravel. Pervious concrete and pervious asphalt both allow more air in the mix (air entrainment) and omit finer aggregates (sand) than conventional concrete and asphalt. Each also has a rougher look, slightly resembling a rice cake. The rough look is the result of small waterways connecting the surface of the permeable pavement to the gravel bedding layer underneath.

All permeable pavements are more expensive to construct than traditional asphalt. Due to peak runoff reduction, however, the system cost (which includes pavement plus other stormwater features like pipes, another structural BMP, or both) may be lower for the permeable pavement *system*.

How do they work? Unlike traditional surfaces, permeable pavements allow water to pass through their surfaces. After water migrates through the surface, it temporarily collects in the gravel storage layer (Figure 2). Depending upon the rainfall intensity, rainfall volume, and existing soil infiltration rate, rainwater either exits the bottom of the permeable pavement (via soil infiltration or drain pipes beneath the pavement), or it builds up inside the pavement until runoff occurs. Very intense rainfalls can produce runoff from permeable pavement, particularly on concrete grid paver systems filled with sand. But when water passes through a permeable pavement, many pollutants can be trapped inside of it or removed as the water passes out of the pavement into the surrounding soil.

How well do they work? N.C. State University researchers have tested several permeable lots in eastern North Carolina. Each reduced annual runoff volume – measured for several years at a few sites – by at least 60 percent. Most of this water infiltrated into shallow groundwater, which helped replicate predevelopment hydrology. This makes permeable pavement an excellent tool for low-impact development. One parking lot, albeit a special case tested in Swansboro for 10 months, never produced any runoff; all rainfall infiltrated the lot. Permeable pavement applications tested for water quality benefits in Goldsboro and Cary show that these pavements can reduce concentrations of zinc and copper. There were mixed results for phosphorus and no improvement in nitrogen. In all cases, however, nutrient and pollutant loads entering the storm drain network were decreased because much less water ran off the pavement.

Permeable pavements will function for up to 20 years if they are constructed in areas free of disturbed soil and regularly maintained. A survey of 48 permeable pavement sites in North Carolina and other Mid-Atlantic states found that permeable pavements built adjacent to active construction zones were far more likely to clog. The study also verified that standard maintenance, such as street sweeping, increased infiltration rates of the permeable pavements tested.

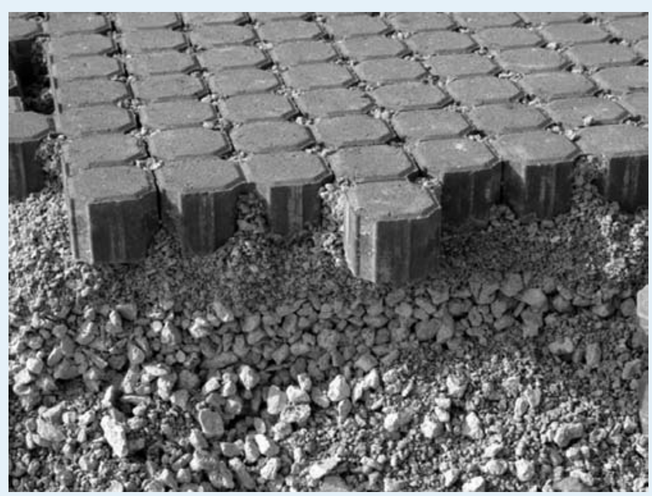

FIGURE 2. Permeable interlocking concrete pavers rest on fine gravel, which in turn overlies a coarse gravel stone. The gravel storage layer shown in this picture can hold up to 5 inches of rainfall. *(BAE, N.C. State University)*

GREEN ROOFS

WHAT ARE THEY? Green roofs or vegetated rooftops have been extensively used in northern Europe since the 1970s and are now gaining popularity in North America. Also called *landscaped roofs, roof gardens*, and *eco-roofs*, green roofs consist of waterproofing and drainage mats, a special growing media, and plants able to withstand extreme climates. They offer several real and potential benefits, including reduced runoff, increased evapotranspiration, prolonged roof life, reduced roof temperature, decreased energy costs, and reduction of the *urban heat island* – the area of higher temperatures that exists around intensely developed and densely paved urban areas. Green roofs also help to meet aesthetic and landscaping requirements, and they can create additional living space if constructed to bear the weight of people and their outdoor activities. The possibilities of so many benefits – particularly in urban, high-density environments, such as uptown Charlotte and downtown Raleigh – have triggered the use of green roofs.

Figure 3. Extensive (A) and Intensive (B) green roofs. The plant growing on the extensive green roof (A) is a sedum, a type of succulent. The intensive green roof (B) is the North Carolina State Government Plaza between the Archdale Building and the Legislative Building in downtown Raleigh. Hundreds of people walk across this green roof, which is on top of a parking deck, every weekday. *(BAE, N.C. State University)*

The main drawback to green roofs is their construction cost, which ranges from $12 to $25 per square foot more than conventional roofs. Costs are high for green roofs because the materials used are expensive and difficult to transport onto the building, and they require more structural reinforcement than other roofing materials.

There are two general types of green roofs: extensive and intensive (Figure 3). An *extensive green* roof can be thought of as a vegetated carpet. This roof type is covered in engineered soil (media),typically 3 to 5 inches thick, with low-lying vegetation growing across it. An extensive green roof is generally much less expensive to construct and maintain than an intensive green roof. It requires only a little maintenance, and it is not constructed to hold and support large groups of people.

Intensive green roofs are garden-like. They can be designed to grow trees and shrubs because of their deep soil layer, and they can carry pedestrian traffic. They are typically very expensive to construct and require more intense maintenance, such as irrigation and fertilization. Intensive green roofs often cover underground parking decks.

The most common type of green roof used in North Carolina is extensive. One concern with extensive roofs, however, is the type of plant that is able to survive on it. A rooftop is usually a dry and barren environment, making it very difficult for native N.C. plants to survive without supplemental irrigation. Succulents, relatives of the cactus family, can thrive on nonirrigated green roofs. But because the vast majority of these species are not native to North Carolina, many potential users are wary of introducing non-native plants that might migrate to the ground and invade native vegetation. Those fears, however, should be minimized when considering whether to use a green roof. On the ground, where most soils are wetter and denser than on a roof, native N.C. plants can out-compete the succulents that survive on a desert-like rooftop.

How do they work? An extensive green roof contains a mat underlying a 3- to 4-inch soil-like media composed of some natural soil and any of several lightweight ingredients, such as expanded (superheated) clay, shale, or slate. The media temporarily stores water between storm events (Figure 4). As rain falls, the soil media captures some of the water and later releases it back to the atmosphere through *evapotranspiration* – loss of water from the soil through evaporation and from plants through transpiration. Plastic cups underlying the media catch additional rain for later uptake by the vegetation.

FIGURE 4. A cross-section of an extensive green roof shows storage "cups" in a drainage mat, 3 to 4 inches of an engineered soil media, and green roof vegetation overlying an impermeable membrane. *(BAE, N.C. State University)*

Once the media is saturated, rainwater flows to the roof surface via a drainage network that takes it through gutters to the ground. In addition to reducing stormwater runoff quantity, the media and plants can filter and capture particulates deposited from the air, thus potentially improving the quality of runoff.

How well do they work? N.C. State University has conducted research on four green roofs – in Asheville, Goldsboro, Kinston, and Raleigh. Each green roof retained well over 50 percent of rainfall annually, and it also reduced peak flows and large volumes of rainfall generated by storms. Releasing such a large fraction of water by evapotranspiration and reducing runoff volumes and peaks are both important ways green roofs help replicate predevelopment hydrology as required by low-impact development.

The outflow from green roofs has more nitrogen and phosphorus in it than rainfall, which is a problem for North Carolina's nutrient-sensitive waters. Researchers attribute this to the composition of the soil media, and they continue to examine how changes in the media will help decrease nitrogen and phosphorus loading. Typically, limiting organics in the media does reduce effluent nitrogen and phosphorus levels.

WATER HARVESTING SYSTEMS – CISTERNS

What are they? Perhaps the oldest stormwater treatment devices, cisterns have been used to collect rainfall and runoff for many different uses since the Bronze Age (2000 to 1200 B.C.). Now cisterns harvest rainwater from rooftops and temporarily store it for irrigation, washing vehicles, washing laundry, and flushing toilets. Cistern water is most easily used for nonpotable (nondrinkable) purposes. With special treatment, however, harvested rainwater can be consumed.

A water harvesting system consists of a cistern, a pipe network diverting rooftop runoff to the cistern, an overflow bypass for when the cistern is full, and a pump and distribution network to deliver water to its intended use (Figure 5). The size of tanks or cisterns can range from quite small, less than 100 gallons, to more than 10,000 gallons for a small commercial site. The cisterns may rest on the surface or be located entirely underground. Tanks are made of plastic, metal, or concrete, depending upon the cistern's size and location.

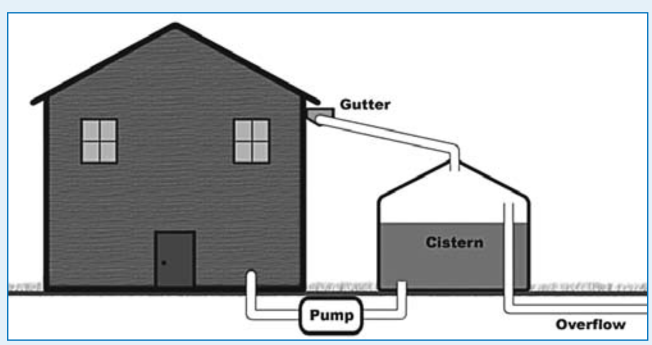

FIGURE 5. A water harvesting system consists of a cistern, which collects runoff from an adjoining rooftop, a gutter system to get the water to the cistern, and a pump to distribute the captured rainfall to uses in the home or on the landscape. Overflow water becomes runoff. *(Matthew Jones, BAE, N.C. State University)*

One common small-scale cistern is the rain barrel. Rain barrels are typically less than 100 gallons in size and can be used for limited water needs, such as watering a garden. Although rain barrels serve an excellent demonstration and awareness purpose, they rarely contribute significantly to runoff reduction due to their small size.

The pumps used to distribute water from cisterns tend to be low-head, high-flow pumps, like centrifugal pumps. The entire system cost for installation ranges from $0.75 per gallon for larger cisterns to nearly $2 per gallon for smaller cisterns. Economies of scale exist. Modeling shows that in certain instances, the payback period for cistern systems is less than 10 years.

The benefits of harvesting rainwater include a minor reduction in flooding and associated reduction of channel erosion, the capture of rain-borne nutrients and other pollutants deposited from the atmosphere, a water supply for which the owner does not need to pay potable water fees, and the chance to use nutrient-rich stormwater for irrigation.

Large-scale water harvesting is practiced frequently in Florida and in parts of North Carolina. Golf course ponds have long been used to capture stormwater runoff and re-use the runoff for greens and other course irrigation.

How do they work? Rainfall from rooftops is directed toward a tank or cistern. A mechanism called a *first flush diverter* allows the initial wash-off of particulates, such as pollen, to bypass the cistern. The comparatively clean water that does enter the tank is often relatively high in atmospheric nitrogen. Between storm events, water is taken from the cistern to supply various demands, including irrigation, toilet flushing, and vehicle washing (Figure 6).

Depending upon the intensity and frequency of

FIGURE 6. Three nonpotable uses for harvested rainfall: (A) irrigation, (B) washing vehicles, and (C) toilet flushing. Irrigation allows cistern-captured rainfall to infiltrate or evapotranspire. Commercial vehicle washing and toilet flushing take captured rainfall, use it, and transfer it to a wastewater treatment system. *(N.C. Cooperative Extension)*

the demand and the amount and incidence of contributing rainfall, the cistern will either be emptied, overflow, or remain in an active state (with a water level between empty and full). Harvested rainwater that is used for irrigation will infiltrate into the ground, allowing some of its nitrogen to be used by vegetation. The remaining nitrogen that enters shallow groundwater has a chance to be reduced by microbes. Commercial vehicle-washing wastewater and all water used to flush toilets goes to a wastewater treatment plant, where it receives very thorough treatment.

How well do they work?

Four cistern water-harvesting systems have been tested in North Carolina. To date, the tanks have typically been close to full, meaning that the rainfall supply far exceeded the demand and use of the captured water. Some rainfalls have been partially captured, but many storm events have bypassed the cisterns, thus receiving no treatment. One way to combat this is to employ a stricter water use regime, which would force more cistern water to be used, allowing for more rainwater to be captured. Another possible solution is to reduce the size of the cisterns, which would save on construction costs. A third option is to include tanks that have a slow leak to ensure that cisterns partially empty before the next rainfall. Modeling of cistern rainwater systems has shown that with dedicated and frequent use, between 30 and 70 percent of stormwater can be captured and used on the landscape or in the home.

Cisterns can also be integrated into low-impact development. When utilized for irrigation and infiltration, cisterns allow surface runoff to soak into the ground, enabling some water be taken up by vegetation.

CONCLUSION

Permeable pavements, green roofs, and cisterns can be used on both a small and a large scale. Homeowners can consider adding cisterns and permeable surfaces to their homes when constructing a new home or remodeling. Builders, developers (both commercial and residential), and engineers can rely on these practices to help their projects comply with stormwater management regulations, particularly in areas where large-scale practices, such as wet ponds and wetlands, are too costly due to high land cost. Those who are involved in low-impact development can use them to preserve the natural hydrologic cycle on their development sites. Additional information can be obtained through the resources listed below.

RESOURCES

Hunt, W. F. (1999). *Urban Waterways: Overview of Stormwater Structural Best Management Practices (BMPs).* N.C. Cooperative Extension publication no. AG-588-01. Raleigh: N.C. State University.

Hunt, W.F. and W.G. Lord. *Bioretention Research, Design, Construction and Maintenance*. N.C. Cooperative Extension publication no. AGW-588-05. Raleigh: N.C. State University.

The following online resources are available from the Department of Biological and Agricultural Engineering (BAE) at N.C. State University:

BAE Permeable Pavement Research Web page:
http://www.bae.ncsu.edu/topic/permeable-pavement

Information on N.C. State University's permeable pavement research locations, research publications, and links to permeable pavement resources.

BAE Green Roof Research Web page:
http://www.bae.ncsu.edu/greenroofs

Information on N.C. State University's green roof research locations, green roof research publications, and links to green roof resources.

BAE Water Harvesting Web page:
http://www.bae.ncsu.edu/topic/waterharvesting

Information on water harvesting research sites, a water harvesting model free to download, and cistern/water harvesting resources.

BAE Stormwater Extension & Research Web site:
http://www.bae.ncsu.edu/stormwater

An overview of stormwater extension and research efforts in BAE; all stormwater documents, images, and PowerPoint presentations for down load; upcoming workshops; and research-based BMP design specifications.

State of North Carolina Stormwater Web site:
http://www.ncstormwater.org

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