URBAN Waterways

Maintaining Permeable Pavements

INTENDED FUNCTION AND BENEFITS OF MAINTENANCE

Research studies and anecdotal case studies from across the USA and the world have shown that permeable pavements substantially and significantly reduce runoff volumes, limit peak flows, and sequester (trap) many types of pollutants. Many permeable pavements further improve ground water recharge, have high albedo (light reflectivity), reduce runoff temperature, and improve aesthetics. Permeable pavements are able to achieve this by allowing water to pass through the surface layer and temporarily collect in underlying aggregate storage layers. This water then either is released back to the storm drain system through underdrains or infiltrates into the underlying soil, or a combination of both. A small fraction of runoff will evaporate or evapotranspire. To enable permeable pavements to function as intended, however, inspection and consequent maintenance are imperative.

TYPES OF PERMEABLE PAVEMENTS

For the purposes of this bulletin, any pavement that is intended to let water pass through its surface and temporarily collect in an underlying aggregate storage zone is termed permeable pavement. However, among this broad definition of pavement, there are several specific types. Several of these types are pictured in Figure 1 below. For specific details of each pavement type, please see AG-588-14W (Permeable Pavement: Research Update and Design Implications).

Permeable concrete (PC) is a mixture of Portland cement, fly ash, washed gravel, and water. **Permeable asphalt** (PA) consists of fine and course aggregate stone bound by a bituminous-based binder. Water

Figure 1. Types of permeable pavement. Top L-R: Permeable concrete (PC), permeable asphalt (PA), permeable interlocking concrete pavers (PICP). Bottom L-R: concrete grid pavers (CGP), plastic reinforcing grids (PG) filled with gravel, and PG with grass.

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passes through interconnected pores in both PC and PA. **Permeable interlocking concrete pavements** (PICP) are available in many different shapes and sizes. When laid, the blocks form patterns that create openings through which rainfall can infiltrate. **Concrete Grid Pavers** (CGP) are an "older cousin" to PICP and have relatively larger open areas that are filled with gravel, sand, or even a loamy sand top soil. **Plastic reinforcement grid pavers** (PG), also called geocells, consist of flexible plastic interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turfgrass. A sand bedding layer and (more frequently) gravel base course are often added to increase infiltration and storage for many of these paver systems.

All permeable pavement types must be inspected and *maintained*. There are certain elements of maintenance that are common among permeable pavements and other elements that are specific to one or two pavement types.

DESIGNING AND CONSTRUCTING WITH MAINTENANCE IN MIND

Proper design can help avoid future maintenance problems. Typically, the most common permeable pavement performance concern is clogging. Pavements must allow water to pass through their surface to be permeable. Designers can minimize the likelihood of clogging by considering the two most likely clogging sources: vegetative litter and sediment.

Parking lots with overhanging trees provide many benefits: shading to cool pavement temperature and improved aesthetics are obvious reasons to landscape parking lots with trees and shrubs. Designers must be aware, however, of unintended consequences associated with a leaf canopy overhanging a permeable application. Vegetation debris and detritus collect in permeable pavement water pathways, rendering them much less permeable. This has been anecdotally observed at several permeable pavement applications across the U.S. (Figures 2 and 3). After the tree detritus falls on to the permeable pavement, it risks being ground into the pavement by passing vehicle tires. Large parking lots that are fringed by trees have had their perimeters clog, but the middle portions did not clog (Figure 2). While the purpose of this chapter/bulletin is not to dissuade designers from incorporating vegetation in the parking lot, designers do need to be mindful that any pavement underneath a tree canopy is at a much higher risk of clogging than pavement free and clear of vegetation.

Sediment accumulation from disturbed areas surrounding the permeable pavement is the most frequent cause of permeable pavement failure. Designers must take special care to inform contractors to minimize exposure of permeable pavement to sediment during construction. Permeable pavements in residential areas are particularly at risk. As one home is completed, an adjoining property may remain under construction. In these cases, the likelihood of sediment deposition from wind, water, and tires is very high (Figure 3).

LANDSCAPE MAINTENANCE ACTIVITIES: AVOIDING PROBLEMS

Property owners often incorporate landscape maintenance as part their property upkeep. Common activities include re-mulching and lawn mowing with discharge of clippings. An uninformed landscaper may deposit his mulch pile on the pavement immediately adjacent to the landscape bed he is beautifying or may discharge grass clippings onto the pavement. If that pavement is permeable, a clogging source has just been introduced. An easy way to avoid this issue is either to bag clippings or place the mulch pile on a tarp that can be carefully removed to prevent clippings or mulch from falling onto the permeable pavement.

In locations with snowfall, plowing is a necessary maintenance activity that can have an impact on permeable pavement function. When non-spec (unscreened and unwashed) sand (meant for vehicle traction, not permeable pavement infiltration) is

Figure 2. Leaf and tree detritus collects in pathways intended for water in PICP located underneath a tree line outside Chicago, IL.

Figure 3. Residential construction increases the likelihood of sediment accumulation in permeable pavements (left). A pervious asphalt pavement near Philadelphia, PA, is clogged due to runoff from an adjoining area that was not stabilized (right).

placed upon snow and ice and is later plowed to a location that drains to or on top of permeable pavement, a clogging source is introduced to the pavement. Either (1) preventing the stockpiling of snow on permeable pavement or (2) requiring post-event street sweeper maintenance (discussed later) are two options of limiting winter weather induced clogging.

PRIMARY INSPECTION AND MAINTENANCE TASKS

Permeable pavement maintenance is rather straightforward when compared to other stormwater management practices (such as bioretention, wet ponds, and stormwater wetlands). The common inspection and maintenance tasks are: (1) verifying that clogging has not occurred, (2) preventive street sweeping, (3) weeding, and (4) stain removal. Additionally, some pavement type-specific tasks include: (1) restorative street sweeping and (2) mowing.

Each of those inspection and maintenance activities is discussed in more detail.

Inspection

Regular inspection is an essential part of permeable pavement maintenance. During the visit the pavement's surface can be examined for accumulated dust, sediment, and debris (Figure 4). A simple test to verify whether the pavement is infiltrating properly is to empty a bucket or large bottle of water on the pavement and examine how long it takes for water to soak through the pavement and the "water mark" that is left. Pavements that require from several seconds to min-

Figure 4. Visual inspection of a pervious concrete lot in Georgia shows accumulation of both sediment and leaf debris (left). The fact that the lot is clogged is confirmed by emptying approximately 1 gallon of water on the lot, which subsequently runs off rather than infiltrating (right).

utes for the water to stop flowing are clogged to some degree (Figure 4).

During the site visit, the inspector can scout for weed growth and trash deposition. If the permeable pavement is underdrained, the underdrain outlet should be checked to verify it is not blocked. If the visit occurs after a storm, a trickle of water would be expected from the underdrain.

STREET SWEEPING

Street sweeping is the most important maintenance task associated with permeable pavement. Street sweeping can serve one of two purposes: preventive maintenance and restorative maintenance. Preventive street sweeping is preferred. Preventive sweeping is regular, scheduled passes by a street sweeper during a calendar year. While the exact frequency has yet to be determined, it appears two to four visits per year for most permeable pavement applications is sufficient. If the permeable pavement has been neglected for several years, however, preventive maintenance will not be sufficient, so restorative street sweeping will be required to restore a pavement's ability to infiltrate water. The type of equipment needed to achieve either preventative maintenance or restorative maintenance is not the same.

Types of Street Sweepers

There are three main classes of street sweepers: (1) mechanical, (2) regenerative air, and (3) vacuum. Examples of mechanical and vacuum sweepers are shown in Figure 5.

Mechanical street sweepers are the most common street sweeper on the market. By some accounts, approximately 70 percent of street sweepers in the U.S. are mechanical street sweepers (Mark Kinter[1]). Mechanical sweepers employ a multiple brush approach to first move sediment and trash to the middle and then lift the deposits onto a conveyor belt for temporary storage. The brush bristles can penetrate some types of permeable pavements, but not most.

Regenerative air street sweepers are the second most common street sweeper, accounting for roughly 20 percent of street sweepers in use in the U.S. They work by shooting air at an angle to the pavement, which effectively loosens dust and other fine particles at and near the surface of the pavement. Because air is blown across the carriage of the truck, a relatively minor vacuum is created, which then lifts the loosened particles into a hopper. This system removes surface-deposited sediments from all pavement types.

Vacuum street sweepers are the least common and most expensive type of sweepr, and account for 10 percent of street sweepers in the U.S. They function by applying a strong vacuum to a relatively narrow area that lifts particles both at and below the surface of the pavement. Vacuum sweepers have demonstrated their ability to suction 3 to 4 inches of gravel from PICP and have the ability to restore infiltration to some types of pavements that have been grossly neglected.

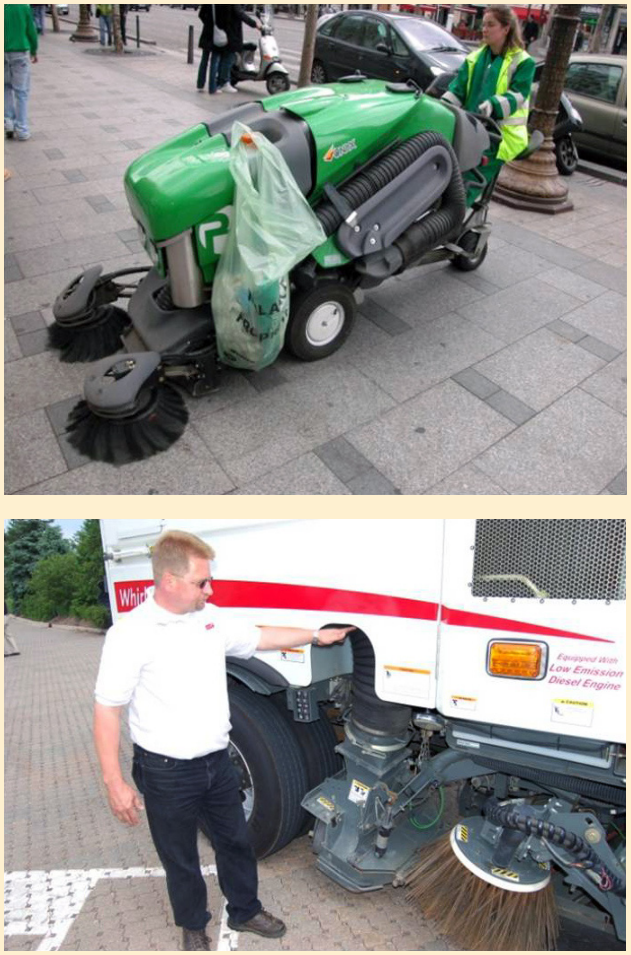

Figure 5. A small mechanical street sweeper (top) and the underpinnings of a vacuum sweeper (bottom).

Where do permeable pavements clog?

Permeable pavement systems clog at different locations in their cross-section. Because of this, not one type of street sweeper is recommended for all types of permeable pavements. Based upon anecdotal observation and research, here are the observed zones or depths of surface clogging.

Concrete grid pavers, because their gaps are filled with sand, act like a sand filter and trap most of the fine

[1]Mr. Kinter is an Elgin Street Sweeper marketing director. Conversation took place in May 2009.

Figure 6. Mechanical sweeper bristle penetration of larger gaps associated with CGP filled with sand (left) is possible, but pavement types with small gaps (such as PICP) is not (right, courtesy of Elgin Street Sweepers).

Figure 7. The clogged zone of PICP is evident toward the top portion of the interlocking paver. The depth of clogging at this location outside Chicago, IL, after 6 years of neglect was 1.5 inches (40mm).

sediment at their surface. The thin clogged zone is named "schmutzdecke" from the German word for dirt cover or ceiling. The thickness of the schmutzdecke for CGP ranges from 0.25 to 0.50 inches (James and Gerrits 2003, Bean et al. 2007). As the gaps associated with CGP are the largest of all permeable pavement types, CGP is the easiest to maintain with a mechanical sweeper. By basic geometry, the ability of bristles to penetrate a large gap to a deeper depth benefits CGP (Figure 6). Research has shown that a standard mechanical street sweeper can sufficiently penetrate the sand-filled gaps of CGP to break apart the schmutzdecke.

Dust and sediment will penetrate PICP filled with gravel to a much deeper level than that of CGP filled with sand. Field observation at a lot outside Chicago found that a 6-year-old PICP lot that had never been maintained had become clogged to a depth of 1.5 to 2.0 inches (Figure 7). Removing a schmutzdecke of this thickness is clearly beyond the ability of a standard mechanical sweeper. In fact, regenerative air street sweepers are considered insufficient for this restorative measure.

Clogging depth of pervious asphalt and pervious concrete depends upon the contributing sediment load. Research has shown that sand collected on a pervious concrete pavement will not penetrate the pavement more than an inch deep. Although pervious asphalt was not tested, it is assumed it would function similarly. However, when a fine fraction of soil (silts or clays) was a part of the clogging sediment, the clogged zone was much deeper, often at or near the bottom of the pervious concrete section (Mata 2008). Restorative maintenance of a PA or PC system clogged by fines has not yet been deemed possible. However, preventative maintenance, by way of a regenerative air street sweeper, has proven to be an adequate measure and keeps PA and PC surfaces infiltrating rainfall and run-on.

Table 1 summarizes the clogging depth of various types of permeable pavements and the appropriate vehicle for prevention or restoration. Obviously, the simplest pavement type to either maintain or restore is concrete grid pavers filled with sand. All pavement types can remain clog-free if preventive sweeper maintenance is reliably provided. If pavements are neglected and allowed to clog to sometimes substantial depths, it is uncertain whether all pavements' necessary surface infiltration rates can be restored. Also important to note, other than for CGP filled with sand, different street sweeper types are used for either preventive or restorative maintenance.

Importance of Underlying Soil Type

Bean et al. (2007) showed that even when maintenance (street sweeping) has been neglected for up to 20 years, permeable pavements can still be permeable, provided the underlying soils are permeable. Several tests of rela-

Table 1. Street sweeper assignment to various permeable pavements

Pavement Type	*Schmutzdecke* Depth	Preventive Sweeper	Restorative Sweeper
Concrete Grid Pavers filled with sand	0.5 inches	Mechanical	Mechanical
PICP filled with aggregate	1.5 to 2.0 inches	Regenerative Air	Vacuum
Pervious concrete	If Sand: < 1 inch	Regenerative Air	If Sand: Vacuum?
	If Silt/Clay: > 3 inches		If Silt/Clay: Not known
Pervious asphalt	If Sand: < 1 inch	Regenerative Air	If Sand: Vacuum?
	If Silt/Clay : > 3 inches		If Silt/Clay: Not known

tively old permeable pavements located along the North Carolina barrier islands and in the NC sandhills, both very sandy soil regions, demonstrated that despite being clogged, infiltration rates usually exceeded 1 in/hr. This is because the pavement was clogged by sand. Designers and regulators should consider whether an infiltration rate of 1 to 2 inches per hour is acceptable. If so, the frequency of required street sweeping in some (albeit limited) parts of the U.S. is reduced. A recent analysis of rainfall intensities in NC demonstrated that less than 2 percent of all rainfall intensities (as measured hourly) exceed 1 in/hr.

PICP related specifics

Street sweepers will remove fill aggregate that could then pose a tripping hazard (Figure 8). So every time PICP is machine swept, aggregate refill is mandatory (Figure 8). Be mindful that not every aggregate may be appropriate for the landowner and application. The aggregate's color or hue and that of the PICP block could be important to the landowner. Refilling gaps is a very easy process and is usually achieved by broom sweeping.

Vacuum sweepers are powerful and, if not carefully operated, can suction too much aggregate from the gaps and beneath the pavers. Care must be taken to verify that the amount of suction provided by the vacuum sweeper is not removing portions of the gravel base layer. This can be quickly checked by sticking a pencil down the vacuumed gap to verify the depth of gravel suctioned is less than the depth of the block.

Figure 8. PICP gaps must be filled with aggregate to prevent a tripping hazard (top). Gravel replacement is simple and done with a push broom (bottom).

OTHER MAINTENANCE ISSUES: REMOVING UNWANTED VEGETATION

Vegetation is often a sign that too much sediment has accumulated, because the excess sediment provides an environment for vegetation to survive. Weeds should be removed using a systemic herbicide such as glyphosate and then returning within the week to pull the weeds. It is imperative to not let unwanted vegetation persist. As weeds mature, it becomes harder to remove the root structure, and its removal can be more destructive to the structure of the pavement.

One cautionary note: some permeable applications are meant to be grassed. Mowing may actually be the appropriate maintenance activity. If a parking lot is to be mowed, please remember to catch the grass clippings before they are deposited on the pavement. Accumulation of grass biomass (clippings) could further limit infiltration.

Figure 9. A stain remover applied to PICP (left) and subsequent pressure washing (right). Ideally, the stain remover is allowed to set overnight.

Table 2. Summary Table of PP Maintenance. Maintenance tasks deemed essential to the hydrologic performance of the device are in bold italics.

Task	Frequency	Notes and Drivers
Inspection	Two-three months	Avoid significant clogging by observation.
Street Sweeping (preventative)	2 to 4 times a year	Using a regenerative air street sweeper for most pavements is appropriate.
Stain Removal	Per client desires	Stains may be tolerated. If stain must be removed, consider a biodegradable detergent.
Weed removal	Do upon inspection	Use glyphosate.
Mowing	In high season 1-2 times per month	Some permeable pavement applications are meant to be mowed.

Do vegetated pavements have higher infiltration than non-vegetated permeable pavements?

There are two ways to answer this question. Permeable applications that are not intended to be vegetated (like PICP filled with gravel, pervious concrete, and pervious asphalt) and that are working as intended will have much higher infiltration rates than purposefully vegetated permeable lots. This is due to the lack of fines collected in the former. However, a lot that without vegetation and with sediment accumulated in pavement gaps probably has a lower infiltration rate than a lot with vegetation, because the grass roots facilitate water flow through the soil media. Were permeable applications to be ranked by permeability the following hierarchy would apply:

- Unclogged PICP with aggregate fill, PC, PA — **Highest**
- Pavement with sediment accumulation with vegetation — **Much Lower**
- Pavement with sediment accumulation without vegetation — **Lowest**

Designers should remember that when a grassed permeable pavement application is specified, the designer is sacrificing infiltration for aesthetics.

OIL AND GREASE STAINS

Can you live with them? Many permeable pavement applications are along parking lot perimeters, and the client may be comfortable with simply allowing the pavements to slowly stain. Clearly, pervious asphalt does not show stains as much as other pavement types. A designer has the option of selecting pavement types that camouflage stains better than others. However, the same pavement types that are good at hiding stains also have low albedo, which conflicts with another driver for the use of permeable pavement. (Designers choose high albedo pavements to comply with LEED™[2] light reflectivity goals.)

Can you remove stains? There are detergents, such as Pour-N-Restore™, that can be used to partially remove stains. They are applied to the stain and allowed to soak. The following day, the soap is pressure washed from the blocks (Figure 9). The majority of stain is removed, but inspection will show a watermark from where the stain had been.

SUMMARY

Designers choose permeable pavements because they reduce runoff volume, mitigate runoff peaks, and sequester many forms of pollution. They may also provide other benefits like groundwater recharge, minor evapotranspiration losses, light reflectivity (albedo), and visual improvement. For permeable pavements to remain permeable, their surface layer must be freely draining, making clogging prevention and street sweeping the most important tasks associated with inspection and maintenance. Although not necessarily inexpensive, permeable pavement maintenance is very straightforward. Other tasks that maintenance professionals should consider include stain removal, weed removal, and in some cases mowing. The exact maintenance tasks will vary by permeable pavement type and intended function.

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Related Bulletins in the Urban Waterways (AG-588) Series:

Hunt, W.F. and K.A. Collins. 2008. *Permeable Pavement: Research Update and Design Implications*. North Carolina Cooperative Extension, Raleigh, NC. AG-588-14W.

[2]Leadership in Energy and Environmental Design, an effort of the US Green Building Council.

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