Field Survey of Permeable Pavement Surface Infiltration Rates

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Abstract: The surface infiltration rates of 40 permeable pavement sites were tested in North Carolina, Maryland, Virginia, and Delaware. Two surface infiltration tests (pre- and postmaintenance) were performed on 15 concrete grid paver lots filled with sand. Maintenance was simulated by removing the top layer of residual material (13–19 mm). Simulated maintenance significantly ($p < 0.007$) improved the surface infiltration rate. The median site surface infiltration rate increased from 4.9 cm/h for existing conditions to 8.6 cm/h after simulated maintenance. Fourteen permeable interlocking concrete pavers (PICP) and eleven porous concrete (PC) sites were also tested. PICP and PC sites built in close proximity to disturbed soil areas had surface infiltration rates significantly ($p < 0.0014$ and $p < 0.0074$, respectively) less than stable landscape sites. Median PICP surface infiltration rates of each condition were 80 cm/h and 2,000 cm/h, respectively. Median PC surface infiltration rates with and without fines were 13 cm/h and 4,000 cm/h, respectively. This study showed that: (1) the location of permeable pavements; and (2) maintenance of permeable pavements were critical to maintaining high surface infiltration rates.

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Introduction

Permeable pavement is an alternative to traditional impermeable asphalt and concrete surfaces. Permeable pavement allows stormwater to either infiltrate into an underground storage basin or exfiltrate to the soil and ultimately recharge the groundwater, while also potentially removing pollutants (Brattebo and Booth 2003; Sansalone and Buchberger 1995). Urbanization has a detrimental effect on surface waters. Increased runoff rates from impervious surface areas have increased peak flow through stream channels, causing erosion and stream bank instability (Leopold et al. 1964). Runoff from impervious surface areas carries pollutants, such as sediments, nutrients, and heavy metals, into surface waters. To reduce the effects of urbanization, state and local governments in North Carolina and throughout the United States have established regulations for stormwater management for new development and redevelopment (USEPA 2000). One stormwater management option is to minimize the amount of a project's impervious surface by utilizing permeable pavement (Bradley Bennett, personal communication, November 3, 2003). As a result, the use of permeable pavement is poised to grow.

Like many states, North Carolina has implemented a stormwater credit system for developed sites to manage on-site runoff (NC DENR 1997). Several best management practices (BMPs) were given credits for pollutant reduction, sediment reduction, and peak flow mitigation. Permeable pavement has not been given BMP credit because it is prone to clogging. However, regulators in North Carolina have not altogether prevented the use of permeable pavement. Permeable pavement is currently considered to be an "innovative BMP" (Bradley Bennett, personal communication, November 3, 2003), which requires monitoring on an individual basis to assess their performance (NC DENR 1995). Few landowners have been willing to assume the cost of the required monitoring, thus, limiting the number of state approved permeable pavement installations. Some recent studies have found that permeable pavement reduces runoff and improves water quality. The use of permeable pavement, in place of traditional asphalt, or concrete, has been shown to decrease surface runoff volumes and substantially lower peak discharge (Pratt et al. 1995; Booth et al. 1996; Rushton 2001; Hunt et al. 2002). Permeable pavement has also been shown to filter pollutants such as metals and automotive oil (Brattebo and Booth 2003; Pratt et al. 1995; Rushton 2001; Sansalone and Buchberger 1995).

Figs. 1(a–c) show examples of concrete grid pavers (CGP), permeable interlocking concrete pavers (PICP), and porous concrete (PC). A procedure, photoanalysis, used close-up photographs of surfaces to determine the percent of a permeable pavement surface area that was impermeable due to the pavement block itself. The remaining surface area was considered to be the open or void area. CGP paving systems are comprised of concrete blocks with internal voids and gaps between the blocks. Photoanalysis determined that CGP surface was approximately 30%

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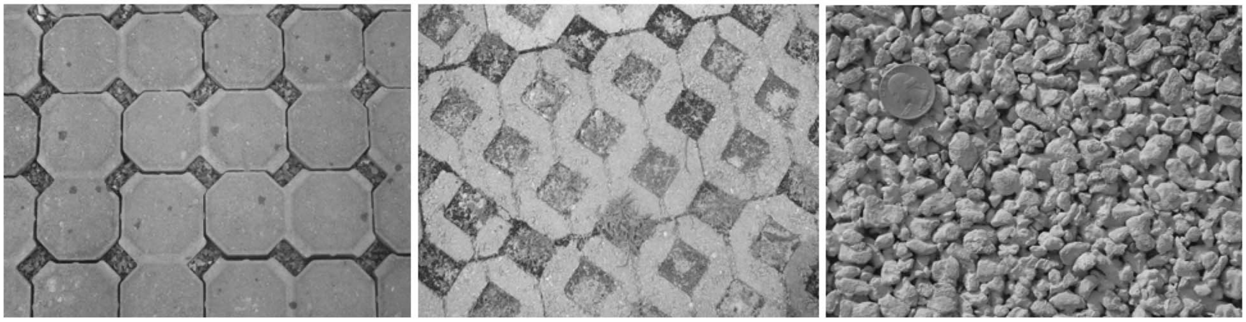

(a) (b) (c)

Fig. 1. (a) PICP; (b) CGP; and (c) PC

open, or void. In this study, the sites examined had voids either filled with sand or No. 78 stone; a gradation is listed in ASTM D 448-03a (ASTM 2003b). PICP are concrete block pavers that, when placed, have voids located at the corners and midpoints of the pavers. Photoanalysis determined that PICP surface was at least 9% open, or void. Most recent research that has been conducted on permeable pavements has examined PICP (Balades et al. 1995; Pratt et al. 1995; Gerrits and James 2002). PC is different from standard concrete, in that fine aggregate has been removed from the mix, allowing interconnected void spaces to form during curing.

Pratt et al. (1995) found that clogging can result from fine particles accumulating in void spaces of permeable pavements. Smaller particles trap larger particles; therefore, the rate of clogging increases as more fines are trapped (Balades et al. 1995). However, clogging can be limited by regular maintenance, either by a vacuum sweeper or pressure washing (Balades et al. 1995). Removing the top 15–20 mm (0.6–0.8 in.) of void space material for low to medium traffic areas substantially regenerates infiltration capacity. Permeable pavements in higher traffic areas improve when 20–25 mm (0.8–1.0 in.) of material is removed (Gerrits and James 2002). The goals of this study were to: (1) determine surface infiltration rates of each pavement type; (2) compare and evaluate infiltration rates by pavement type; (3) analyze whether maintenance restores surface infiltration rates on CGP; (4) determine if pavement location impacts surface infiltration rates for PICP and PC; and (5) offer basic siting guidelines based upon these results.

Procedure

Fifteen CGP, 14 PICP, and 11 PC sites were tested to determine the surface infiltration rates. Either double-ring infiltrometers, single-ring infiltrometers, or combinations were used to measure the surface infiltration rates at each site. At most CGP sites, two series of tests were conducted: The first measured the surface infiltration rate of existing pavement conditions, and the second measured these rates after simulated maintenance had been performed. Each test included three surface infiltration tests conducted at different locations on the pavement to address variability of surface conditions and associated surface infiltration rates of the permeable pavement. By visually evaluating a site, locations for these tests were chosen to be representative of the entire surface (i.e., potentially low, medium, and high surface infiltration areas were selected for testing).

ASTM D 3385 (ASTM 2003b), the "Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring Infiltrometer," was the procedural basis for measuring surface infiltration rates. This test measures infiltration rates for soils with a hydraulic conductivity between 10^{-6} cm/s and 10^{-2} cm/s. The test used for this study modified some of the methods and materials in ASTM D 3385 (ASTM 2003a) to operate on the unique pavement environment (hard pavement) and with a limited supply of water. The double-ring infiltrometers utilized consisted of two 16 gauge "thickness" galvanized steel rings. The inner rings have diameters between 280 mm (11 in.) and 305 mm (12 in.). The outer rings have diameters between 760 mm (30 in.) and 910 mm (36 in.), or approximately three times the diameter of the inner rings. The single-ring infiltrometer method utilized only the inner rings.

Once locations were selected for testing at each site, the inner ring was sealed to the test surface. A thin ribbon of plumber's putty, about 40 mm (1.5 in.) wide, was molded along the bottom edge of the inner ring. The ring was then placed on the putty and pressed to the surface. The putty was depressed to form a tight seal between the surface and the ring. The inner ring was then filled with water to a depth of approximately 50 mm (2 in.) above the testing surface to determine if there was any leakage to the outer ring, and whether the hydraulic head would be maintainable during a double-ring infiltrometer test (DRIT). A hydraulic head was determined to be maintained if the water level rose while dispersing water into the rings using a submersible pump with a maximum flow of 25 gpm. If the hydraulic head was maintained during the trial, then a DRIT was conducted on the surface. The outer infiltrometer ring was sealed to the surface using plumber's putty in the same manner as the inner ring. The outer ring was then filled to a depth of approximately 50 mm (2 in.) above the testing surface to determine if there was any leakage from the outer ring that could not be maintained. Fig. 2 shows three simultaneous DRITs being conducted.

Once all leaks, if any, were plugged or, for outer ring leaks, slowed enough to maintain a head equal to the inner ring, both the inner and outer rings were filled to a depth between 125 mm (5 in.) and 175 mm (7 in.). The initial level of the water in the inner ring, outer ring, and current time (effectively time 0) were recorded. All three parameters were measured and then recorded approximately every five minutes. Each water level measurement (inner and outer) was taken from the top of the inner ring to the water level from the same location along the rim. A test was complete when enough time, typically between 30 and 45 minutes, had elapsed to determine the surface infiltration rate. Tests were preceded by at least a 24 h dry period at all sites.

One goal of this study was to compare existing condition surface infiltration rates to simulated maintained condition surface

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Fig. 2. Double-ring infiltrometer test

Fig. 4. SRIT test

infiltration rates for CGP. At each CGP site, three tests were conducted under existing conditions. After the simulated maintenance, three more tests were conducted in different locations. An "existing" test was defined to be a surface infiltration test where the paver surface remained unaltered prior to the surface infiltration test. A "simulated maintenance" test was a surface infiltration test conducted when void material was removed to a depth between 13 mm (0.5 in.) and 19 mm (0.8 in.) to simulate maintenance by a street sweeper (Stevens Personal Communication, 2001). Fig. 3 displays a maintained CGP location. If the measured existing surface infiltration rates of a site were lower than 25 cm/h (10 in./h), a simulated maintenance test was run.

Many sites had surface infiltration rates greater than the filling rate for the DRIT [>150 cm/h (60 in./h)]. A modified version of the DRIT, single-ring infiltrometer test (SRIT), was performed at the sites. When conducting the SRIT, an inner ring of the double-ring infiltrometer was sealed to the test surface, and a scale was vertically taped inside the ring (Fig. 4). Using a 19 L (5 gal) bucket, water was quickly poured into the inner ring; recording time from the moment water started pouring in. The time was also recorded when all the water was emptied into the single ring (along with the peak level of water inside the ring), and again every 30–60 s until the water completely infiltrated the pavement. If complete infiltration occurred in less than 30 s, the time to empty the ring was recorded. The test was then repeated at the same location and the two rates were averaged. The mean for that location was then averaged with the surface infiltration rates of the other two locations tested at the paver site to determine an overall surface infiltration rate. The SRIT is neither as accurate nor as precise as the DRIT, because the SRIT does not prevent horizontal migration of the water once it enters the media as well as the DRIT (Bouwer et al. 1999). However, it provided a method for quantifying the surface infiltration rate on highly permeable applications.

Fig. 3. Simulated maintenance on CGP surface

While performing SRITs on PICP, horizontal flow occurred through joints between pavers. In these situations, putty was applied to the joints to prevent water from flowing through these channels. However, this typically did not change the surface infiltration rate. In addition, the flow rates through these channels were not large enough to substantially increase the surface infiltration rate. Another behavior was observed, while performing SRITs on both the PICP and PC. Water infiltrated vertically through the PICP or PC surface and then, due to a lower infiltration rate of storage basin media, migrated horizontally and percolated vertically up through the surface outside of the single ring. Under this scenario, the surface infiltration rate was limited by the subsurface storage media, rather than the surface conditions. Thus, under these conditions, the calculated surface infiltration rate underpredicted the actual surface infiltration rate.

The only obvious method to prevent these behaviors would have involved removing vertical sections of pavement and the storage basin gravel, creating a barrier around the sections to prevent horizontal flow and to run the test. Otherwise, the entire surface would be tested. Both of these methods were impractical during this study. It should be noted that these typical behaviors did not affect the overall findings of this study.

After data were collected, the water levels were plotted as functions of time for each surface infiltration test (Fig. 5). The infiltration rate is equivalent to the maximum-steady state or average incremental infiltration velocity (ASTM 2003a,b). Therefore, the slope of the least squares line for each test was the surface infiltration rate of the permeable surface. Furthermore, if it was determined that removing the initial two or three data points from a test's dataset caused the least squares line to be more representative of the surface infiltration rate, then those ini-

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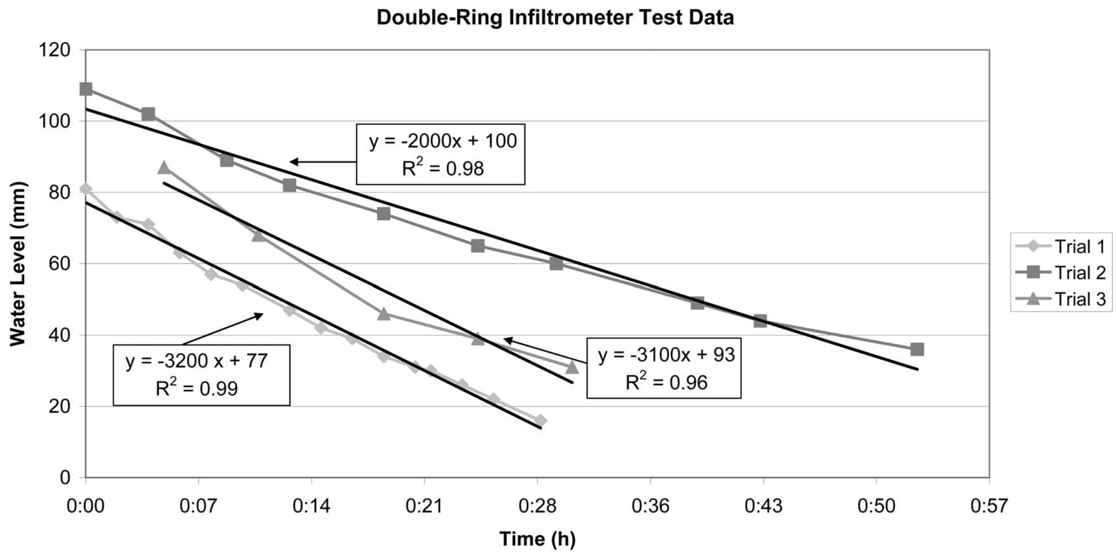

Fig. 5. Graph of DRIT data and regression lines from a CGP test in coastal North Carolina

tial data points were omitted from the calculation of the least squares line. The stated surface infiltration rate for each site was determined by averaging the results from the three test locations. Finally, ASTM D 3385 states that the hydraulic conductivity and infiltration rate "cannot be directly related unless the hydraulic boundary conditions are known or can be reliably estimated" (ASTM 2003a,b). Therefore, since these characteristics are unknown, the hydraulic conductivities cannot be determined from the data collected in this study.

Two major limitations differentiated the procedure followed in this study from ASTM D 3385. In principal, the ASTM method, applied to "field measurement of the rate of infiltration of liquid into soils using double-ring infiltrometer" (ASTM 2003a). The media tested in this study was not soil, but various types of permeable pavement and corresponding coarse grained fill material. Although the testing media differed, the hydraulic conductivities of all tests were within ASTM testing limitations. Surface infiltration rates were surrogates for the hydraulic conductivity. Since permeable pavements were tested rather than soil media, infiltrometer rings were not driven into the pavement, so surface infiltration occurred below the bottom of the rings instead of above. Pavement surfaces would have been damaged and a substantial amount of additional time, resources, and effort would be needed to drive the infiltrometer rings into the surfaces. This was not practical.

Rather than employ a constant head, this procedure used a falling head to determine the infiltration rate. This resulted from a water resource constraint. A limit of 1,100 L (300 gal) was transported at a given time, requiring additional time for refilling and transporting for a constant head study to be maintained. By using a falling head procedure, the volume of water needed for all studies was significantly reduced from what would have been necessary to maintain a constant head. Surface infiltration rates were occasionally variable during a test as a result of variable hydraulic heads, as seen in Fig. 5. However, R^2 values for water depth versus time relationships were nearly all greater than 0.9 and the majority met or exceeded 0.99, indicating minimal variability of the infiltration rates. The variation of the surface infiltration rate compared to the average surface infiltration rate was minimal; therefore, the data here were comparable to a constant head surface infiltration test.

Results

The findings for all three paver types were reviewed. The CGP tests examined if simulated maintenance had a significant impact on surface infiltration. Tests run on PICP and PC sites determined whether siting permeable pavements adjacent to disturbed soil, a potential source of fines, had a significant effect on surface infiltration.

Concrete Grid Pavers

Surface infiltration rates were measured from 15 CGP sites (Table 1). Each of the 15 sites had both existing and postsimulated maintenance tests run on them. Of the 15 sites that had postsimulated maintenance tested, 14 had higher infiltration rates than those of the existing, nonmaintained, pavers. The only site where the surface infiltration rate did not increase was Blackman. This anomaly was likely due to a high surface infiltration rate of 22 cm/h (8.8 in./h) for one of the existing tests, while the other tests at Blackman Beach Access, existing and maintained, had surface infiltration rates less than 10 cm/h (3.9 in./h). Simulated maintained surface infiltration rates were significantly ($p < 0.007$) higher than rates for existing surface conditions (SAS 2003). The mean and median existing surface infiltration rates were 6.9 cm/h (2.7 in./h) and 4.9 cm/h (1.9 in./h), respectively; the mean and median maintained surface infiltration rates were 13 cm/h (5.1 in./h) and 8.6 cm/h (3.4 in./h), respectively. The mean surface infiltration rate after simulated maintenance was 89% greater than the mean surface infiltration rate before simulated maintenance.

The lowest surface infiltration rate, measured at the Town of Cary Public Works [1.0 cm/h (0.38 in./h)], could have been the result of several factors including no maintenance, frequent heavy traffic, and/or a clay soils watershed.

Permeable Interlocking Concrete Pavers

Fourteen PICP sites were tested, including: seven in Maryland, four in North Carolina, two in Virginia, and one in Delaware. Eight of these sites were tested using only the SRIT, due to high surface infiltration rates [>150 cm/h (60 in./h)]. A hydraulic

Table 1. CGP Average Site Surface Infiltration Rates and *R*-Squared Values

Site name	Existing SIR (cm/h)	Existing Avg. *R* squared	Maintained SIR (cm/h)	Maintained Avg. *R* squared
Atlantic station (high)	19	0.99	32	0.99
Indian Beach access	16	1.00	27	0.99
Blackman	13	0.99	6.7	0.99
Conch	9.2	0.99	10	0.97
Municipal Building	7.9	0.99	27	0.99
Gull	5.1	0.97	7.3	0.99
Glidden	5.0	0.99	7.5	0.99
Carrabba's	4.9	0.98	7.5	0.99
Govenor	4.6	0.97	8.6	0.97
Atlantic Station (low)	4.4	1.00	31	0.98
Epstein	4.2	0.92	9.7	0.99
Bainbridge	4.2	0.99	4.6	0.99
Loggerhead	3.6	0.99	9.3	0.98
Hargrove	1.7	0.97	6.5	0.95
Cary Public Works	1.0	0.88	1.6	0.93
Average	6.9[a]		13[a]	

Note: SIR=surface infiltration rates.

[a]The differences in surface infiltration rate, pre- and postmaintenance, were significant. ($p=0.0070$, $df=1$.)

head was maintained at Havre de Grace when filling the DRITs for testing, but the average surface infiltration rate was 100 cm/h (39 in./h). One of the three tests run at the Penny Road site was an SRIT; however, the other two were DRITs. The Penny Road site was also determined to be affected by fines as clay accumulation (a result of on going construction) could be seen in the voids. Surface infiltration rates at the four remaining PICP sites were low enough to maintain a hydraulic head so that DRITs could be performed. These four sites were located in close proximity to areas containing exposed and transportable soil particles, e.g., a gravel drive, a river bed, or a beach. Table 2 shows measured infiltration rates for permeable pavement applications using PICP. The last five infiltration rates in Table 2 are the PICP sites whose surfaces were partially filled by fine soil particles. Surface infiltration rates of sites located adjacent to disturbed soil, or that had fines deposited on them, were significantly ($p<0.002$) lower than those rates from sites free from fines. The median surface infiltration rate for sites affected by fines was 8.0 cm/h (3.1 in./h); the median surface infiltration rate for sites away from fines was 2,000 cm/h (900 in./h). There were three orders of magnitude difference and an overall decrease of more than 99% when comparing the median surface infiltration rates of stable sites to the median for those sites affected by fine soil particulates. The surface infiltration rates of sites impacted by fines (sand) were very comparable to those of CGP filled with sand reviewed earlier.

Porous Concrete

The surface infiltration rates were tested for 11 PC sites located in the Piedmont and Coastal Plain of North Carolina (Table 3). Surface infiltration rates were high enough at five sites so that only the SRIT could be performed [>150 cm/h (60 in./h)]. A combination of SRITs and DRITs was used to determine the site's surface infiltration rate at the Ready Mix Lab, and Bailey's Landing

Table 2. PICP Average Site Surface Infiltration Rates and Average *R*-Squared Values

Site name	SIR (cm/h)	*R* squared
Without fines		
Mickey's Pastries	4,000	NA
CVS Pharmacy	4,000	NA
Wal-Mart	3,000	NA
Dough Rollers	2,500	NA
Swansboro	2,000	0.96
Captiva Bay Condos	2,000	0.97
PNMC Walkway	1,000	0.98
Baywoods	1,000	0.97
Harve de' Grace	100	0.98
Average	2,000[a]	
With fines		
Penny Road PICP	200	0.99
PNMC parking lot	50	0.98
River Bend	8.0	0.97
Boat Ramp	2.9	0.90
Somerset Dr.	1.6	0.99
Average	53[a]	

[a]The difference in surface infiltration rate when PICP was sited in stable versus disturbed watersheds was significant. ($p=0.0014$, $df=1$.)

I sites. Surface infiltration rates were low enough to maintain a hydraulic head at the four other PC sites so that DRITs were used. The four sites where DRITs were used, like the PICP sites, were located in areas that accumulated fine soil particles, e.g., receiving wind blown particles near beaches or deposition of soil particles from vehicular traffic. The first seven sites in Table 3 were relatively free of fines, while the last four had visual evidence of sediment deposition on the surface. The infiltration rates of the last four sites (with fines) were significantly lower ($p<0.008$) than those of the first seven. The median surface infiltration rates for sites with fines was 16 cm/h (6.4 in./h); the median surface

Table 3. PC Average Site Surface Infiltration Rates and Average *R*-Squared Values

Site name	SIR (cm/h)	*R* squared
Without fines		
Catawba College	7,000	N/A
Loflin Concrete	6,000	0.94
Bailey's Landing II	6,000	0.97
Penny Rd. PC	4,000	0.96
FCPR PC	2,000	0.97
Ready Mix Lab	1,000	0.94
Bailey's Landing I	600	0.90
Average	4,000[a]	
With fines		
McCrary Park	27	0.98
Atlantic Beach PC	14	0.97
Bryarton I	13	0.60
WB Church	11	0.97
Average	16[a]	

[a]The difference in surface infiltration rate when PC was sited in stable versus disturbed watersheds was significant. ($p=0.0074$, $df=1$.)

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infiltration rates for sites free of fines was 4,000 cm/h (2,000 in./h). The median surface infiltration rates for stable watersheds was two orders of magnitude different and reduced by over 99% from the median infiltration rate for the unstable watersheds.

Analysis and Conclusions

There were several observations drawn from this field study: (1) maintenance was key to sustaining high surface infiltration rates for CGP; (2) the siting of permeable pavement applications, including PICP and PC, away from disturbed soil areas was a significant factor in preserving high surface infiltration rates; and (3) permeable pavement that was installed in sandy soil environments maintained relatively high surface infiltration rates, without regard to pavement age or type

Fourteen of 15 CGP sites had increased infiltration rates after removal of the top layer [13 mm (0.5 in.) typical depth] of accumulated void space material. Without maintenance, the median average infiltration rate was 4.9 cm/h (1.9 in./h); while with maintenance, the median infiltration rate was 8.6 cm/h (3.4 in./h). A mixed procedure (SAS 2003) analysis showed that there was a statistically significant difference between existing and maintained infiltration rates at a 99.3% confidence level. Simulated maintenance, therefore, significantly improved infiltration rates for the CGP sites filled with sand.

Infiltration rates of PICP filled with pea gravel were not limited by their surface infiltration capacity provided they were sited adjacent to areas free of soil disturbances. The median PICP infiltration rate was 2,000 cm/h (900 in./h), while the PICP sites near disturbed soils with fines was 8.0 cm/h (3.1 in./h), a decrease of 99.6%. A mixed procedure (SAS 2003) analysis was used to determine there was a significant difference between the surface infiltration rates of PICP near fines and free of fines, with a confidence level of 99.9%.

Eleven PC sites were measured for surface infiltration rates. Like PICP sites, infiltration rates of PC were not limited by their surface infiltration capacity as long as they were sited in areas unlikely to accumulate fines. The median surface infiltration rate for PC sites relatively free of small particle deposition was 4,000 cm/h (2,000 in./h); compared to 16 cm/h (6.4 in./h) for sites with deposition of fines. The difference was a 99.7% reduction of the median surface infiltration rate and a Mixed Procedure (SAS 2003) statistical analysis showed a significant difference in surface infiltration rates at a confidence level of 99.3%.

Even though test sites for PICP and PC were located in two different geographical and soil regions, there were not enough data to draw conclusions on permeable pavement use in clay soil regions. All piedmont (clay soil) PC sites were without fines, while all but one PC site in the coastal plain (sandy soil) were adjacent to a disturbed soil.

PICP and PC sites without fine sediment accumulation typically had surface infiltration rates two to three orders of magnitude greater than maintained CGP sites, while sites with fine sediment accumulation had surface infiltration rates either comparable to or within one order of magnitude of existing CGP surface infiltration rates. This likely resulted from the size of aggregate used to fill the void spaces of PICP (No. 78 stone) and CGP (sand). Drainage channels in sand are much smaller than for the larger aggregate and clog much easier. This is also shown by the comparable surface infiltration rates of PICP and PC sites with sediment accumulation and CGP sites. Therefore, CGP sites constructed with larger aggregate instead of sand may achieve similar performance to the PICP and PC sites. In addition, only two CGP sites were constructed after 1986 (1995 and 1999), while only one PICP site was constructed before 2001 (1997), and no PC sites were constructed before 2000. Thus, the age of a structure could affect the surface infiltration rates.

Lastly, 37 of 40 sites tested had surface infiltration rates greater than 2.5 cm/h (1.0 in./h). These rates were comparable to rates expected for some Hydrologic Group B soils (loamy sands, sandy loams) covered with grass (USDA 1986). Clogging at the permeable pavement surface in predominantly course grain (sandy) soil environments, therefore, does not cause permeable pavements to have surface infiltration rates reduced below some naturally grassed areas. This study, however, did not address clogging that sometimes occurs at lower depths within permeable pavement, nor did it address the impacts that poor siting and/or construction techniques have on flow rate below the pavement surface. A series of long term, multiple year studies of given sites would focus on the runoff reduction of such sites.

As a result of this study, suggested sitting and maintenance guidelines are as follows:

1. For CGP sites filled with sand:
   To sustain higher surface infiltration rates, maintenance, using a vacuum sweeper, should be performed at regular intervals (Balades et al. 1995; Hunt et al. 2002). Removal of the top 13–18 mm of material accumulated within void spaces has been shown to significantly improve infiltration rates. Sand should then be backfilled into the void spaces to prevent sealing at a lower depth.
2. For PICP/PC sites:
   PICP and PC sites installed for infiltration purposes should not be located adjacent to areas with disturbed soils as accumulations of fine particles have been shown to significantly and dramatically decrease surface infiltration rates. Maintenance should include regular use of a vacuum sweeper, or as needed, for sediment accumulation on the surface (Balades et al. 1995; Hunt et al. 2002). Problems with fines should be addressed before the fines are either compacted into void spaces or migrate to lower, harder to maintain depths within the pavement void profile. Construction sequencing is critical for maintaining high surface infiltration rates. Permeable pavements installed in stable watersheds will function substantially better than those constructed in unstable watersheds.

Data presented herein, and in other references (Balades et al. 1995; Pratt et al. 1995; Hunt et al. 2002) combined with anecdotal observation, suggest that permeable pavements do considerably reduce runoff, provided the following conditions are met: (1) the pavement is sited in a sandy or loamy sand soil, (2) it is located in soils without seasonally high water tables, (3) the pavement is well maintained, (4) proper construction materials and techniques are used, (5) the pavement is essentially flat and away from disturbed fine soils, and (6) does not have excessive structural loads beyond designed capacity.

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