STUDY ON THE SURFACE INFILTRATION RATE OF PERMEABLE PAVEMENTS

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Prepared for:
Interlocking Concrete Pavement Institute

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EXECUTIVE SUMMARY:

Asphalt surfaces have greatly increased the amount of runoff going into surface waters. To counteract this, permeable pavement can be installed to allow water to infiltrate, thus reducing runoff. This study tested the surface infiltration rate of 25 permeable pavement sites in North Carolina, Maryland and Delaware using variations of the double ring infiltrometer test. Five different classifications of surfaces were tested with pavement ages ranging from six months to 21 years. Two sets of tests were run on 12 concrete grid pavers lots with sand. The initial test was on the existing condition of the surface and second test was run after the removal the top layer of residue (0.5 - 0.8 in. or 1.3 - 1.9 cm) to simulate maintenance. Maintenance improved the surface infiltration rate on 11 of 12 sites. The tests showed that maintenance improved surface-permeability at a confidence level of 97%. The mean average surface infiltration rate increased from 2.1 cfs/ac (2.1 in./hr), for existing conditions, to 3.5 cfs/ac (3.5 in./hr) after maintenance. Ten permeable interlocking concrete pavements (PICP) sites were also tested. This study found that sites built in close proximity to loose fine particles had surface infiltration rates two orders of magnitude less than sites free of loose fines. Averages of each condition are 1.7 cfs/ac (1.7 in./hr) and 900 cfs/ac (900 in./hr) respectively. The report’s principal conclusions follow:

1. If sited in sandy soil environments, all the permeable pavement types tested, including CGP and PICP, had relatively high surface infiltration rates. Even the minimum rates were comparable to those of a grassed sandy loam soil.
2. Maintenance significantly improves the surface infiltration rates of CGP.
3. Locating permeable pavements away from disturbed soil areas is critical if exceedingly high (well over 500 cfs/ac) surface infiltration rates of PICP are to be preserved.
4. States which do not consider permeable pavement to actually be permeable, particularly in sandy soil applications, should reconsider this position, provided strict siting, design, construction, and maintenance guidelines are followed.

INTRODUCTION:

Permeable pavement is an alternative to traditional asphalt and concrete surfaces. Permeable pavement allows stormwater to infiltrate into either a storage basin below or exfiltrate to the soil and ultimately recharge the water table, while also potentially removing pollutants (EPA, 1999). Permeable pavement, or drainable pavers, use dates from the Roman Empire when large stones with spaces between the stones were used for drainage (Knapton, 2003). Europe is also where the current generation of permeable pavers’ implementation began. The earliest modern use of concrete pavers to limit stormwater runoff was in 1961 in Germany (ICPI, 1999).

Urbanization has a detrimental effect on our surface waters systems. Increased runoff rates from traditionally paved surfaces have increased peak flow through stream channels causing erosion and stream bank instability along with overland erosion (Leopold *et al.*, 1964). Runoff from parking lots also carry automotive fluids, (e.g. brake fluid, motor oil, antifreeze, etc.) into surface waters. In an effort to reduce these effects of urbanization, many municipalities in North Carolina established regulations that limit the amount of impervious surface a property can have (Bennett, 2003). Permeable pavement is a potential solution; in lieu of 100% impermeable lots, perhaps a fraction of runoff can be reduced. As a result, the use of permeable pavement is poised to grow.

In 1972, due to the degrading condition of many of our nation's waters, the Clean Water Act was passed. More recently urban non-point source pollution has been addressed by the North Carolina's regulatory agencies. North Carolina has implemented a stormwater credit system for developed sites to manage onsite runoff. Several best management practices (BMPs) were given credits for nutrient reduction, sediment reduction, and peak flow detention. Permeable pavement has not been included in BMPs receiving credit as a result of it being prone to clogging and poor site construction procedures. However, North Carolina has not altogether prevented the use of permeable pavement. Permeable pavement is allowed to be used as a BMP under the "innovative BMP" classification. Innovative BMPs however must be monitored on an individual basis to assess their performance (Bennett, 2003). Few landowners have been willing to assume the cost of this required monitoring, thus limiting the number of permeable pavement installations.

Recent studies have found positive results using permeable pavement with respect to both runoff reduction and water quality improvement. The use of permeable pavement, instead of traditional asphalt has been shown to decrease surface runoff and lower peak discharge significantly (Pratt 1995; Booth, 1996; Hunt *et al*., 2001). Permeable pavement has also been shown to act as a filter of such pollutants as lead and automotive oil (Brattebo and Booth, 2003; Pratt, 1995).

There are several types of permeable pavements that are used today. Figures 1-3 show examples of these. Permeable interlocking concrete pavements (PICP) are concrete block pavers that create voids on the corners of the pavers. Photo-analysis was used to determine that open, or void, space is at least nine percent (9%) of the surface area. Most research that has been conducted has examined these block pavers as test surfaces. Concrete grid pavers (CGP) systems are comprised of concrete blocks with voids inside the blocks which also create voids between blocks. Photo-analysis was used to determine that open, or void, space is approximately (30%) of the surface. In this study, the sites examined had voids either filled with sand or No. 78 stone (ASTM D 448). 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. In this study sandy-loam topsoil was used in at the PTRG site.

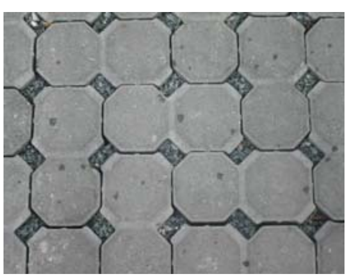


Figure 1

Figure 2

Figure 3

Figures 1-3: 1) PICP; 2) CGP; and 3) Placing PTRG

Though these three pavements are installed for similar purposes, they do not have the same durability. CGPs and PTRG are typically installed for areas intermittently used by vehicles.

These areas include overflow parking, median crossovers, building access and emergency fire lanes. Areas that have frequent use by vehicles experience added stressors such as: concentrated wheel traffic, constant shade from cars, sediment deposition, engine heat, and oil drippings. These factors can damage and kill the grass. Also, deicing salts should not be applied to these pavements since salts would kill the grass. PICPs are for areas regularly used by vehicles such as parking lots, residential and commercial driveways, and low-volume roads.

Pratt (1995) has found that clogging can be a result of 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). Many times this is aided by motor fluids, acting as coagulants, leaking from vehicles. However, clogging can be remedied by maintenance, either by vacuum truck, street sweeper or high pressure washing (Balades *et al.*, 1995). Removing the top 0.6 - 0.8 in. (15 - 20 mm) of void space material for low to medium traffic areas substantially regenerates infiltration capacity. Higher traffic areas improve somewhat when 0.8 - 1 in. (20 - 25 mm) of material is removed (Gerritts and James, 2002). This study compared surface infiltration rates before and after removal of void space material, using a removal depth of between 0.5 - 0.8 in. (1.3 – 1.9 cm).

North Carolina State University’s permeable pavement research was conducted in North Carolina, Maryland, and Delaware. A total of thirty (30) sites were used to collect surface infiltration rates with six different types of pavement surfaces. Table 1 displays the types and number of surfaces tested. A map showing all test sites is included in Appendix A. Each site was selected for its type of pavement, age, maintenance practice, and construction practice. Appendix B lists site specifics with pictures for each location tested.

The goals of this study were as follows: (1) determine surface infiltration rates of each pavement system; (2) compare and evaluate these rates among paver systems; (3) analyze the impact maintenance has on revitalizing surface infiltration rates; (4) offer basic siting guidelines based upon these results.

Table 1: Type and Number of Sites Tested**.**

Surface Type	Number Tested
Permeable Interlocking Concrete Pavements (PICP)	10
Concrete Grid Pavers w/ Sand Fill (CGP)	13
Concrete Grid Pavers w/ Pea Gravel (CGP)	1
Plastic Turf Reinforcing Grids (PTRG)	1

This permeable pavement study primarily focused on determining surface infiltration rates from CGP and PICP because the research was funded by Interlocking Concrete Pavement Institute.

PROCEDURE:

Fourteen CGP, 10 PICP and one PTRG sites were tested in this study to determine infiltration rates. Double- or single-ring infiltrometers were used at each site to measure surface infiltration rates. Two sets of tests were run at 12 of the 14 CGP sites, one set to measure existing conditions, and one set to measure "maintained" conditions.

Each set of tests included three infiltration tests to help counteract variability in the surface conditions and infiltration rates. Locations for these tests were representative of the entire surface.

This study used ASTM D 3385, the Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring Infiltrometer, as a basis to measure infiltration rates. This test measures infiltration rates for soils with a hydraulic conductivity between 10^{-6} cm/s to 10^{-2} cm/s. The test used during this study modified some of the methods and materials in ASTM D 3385 to operate more efficiently in this study's environments and resources. The double ring infiltrometers (Figure 4) used in this study consisted of two 16 gauge galvanized steel rings. The inner rings had a diameter between 11 in. (28 cm) and 12 in. (30.5 cm). The outer rings had diameters between 30 in. (76 cm) and 36 in. (91 cm), or approximately three times the diameter of the inner rings.

Figure 4. Surface infiltration rate test at site 13 (Nags Head).

Once locations were somewhat randomly selected for testing at each site, the infiltrometer rings were sealed to the surface using plumber's putty (Figure 5). Instead of driving the rings into the surface, the infiltrometer rings were sealed to the testing surface to preserve the surface integrity. If the rings had some how been driven through the top layer of the surface being tested, the surface would have been permanently damaged. It is possible that by not driving the rings through the pavement to return higher or lower initial surface infiltration rates if the tested surface does not have a uniform surface infiltration rate for the total area being covered by the rings. However, to counteract this, multiple tests were conducted at each site and data analysis compensated for any initial skewed data. Specifics about data analysis are detailed later in the Procedure section.

Figure 5. Plumber's putty seal.

The inner ring was then filled with water to a depth of approximately 2 in. (50 mm) above the testing surface to determine if there was any leakage to the outer ring. Once all leaks – if any - were plugged, both the inner and outer rings were filled to a depth between five and seven inches (125 mm and 175 mm). The initial level of water in the inner ring, outer ring, and current time (effectively time 0) were then recorded. Water was then allowed to infiltrate freely.

The initial level of 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. Measurements were taken from a fixed point on the top of the ring down to the water level. A test was considered complete when either the inner ring ran dry or enough time had elapsed to determine the surface infiltration rate. Initially, the time needed to determine the surface infiltration rate was designated to be one hour. But, after reviewing initial data, that time was shortened to 45 minutes, because the surface infiltration rate remained stable after 45 minutes.

To be able to measure only vertical infiltration rates, two rings must be used. Typically, when water infiltrates into the soil, it does so three-dimensionally; vertically and along the two horizontal planes. In this case if a single ring were used to measure surface infiltration rates, vertical infiltration and horizontal migration would both account for the water level drop within the ring. To isolate infiltration inside a ring to only reflect vertical infiltration, a second ring is placed outside the first and filled with water to the same level (Figure 6).

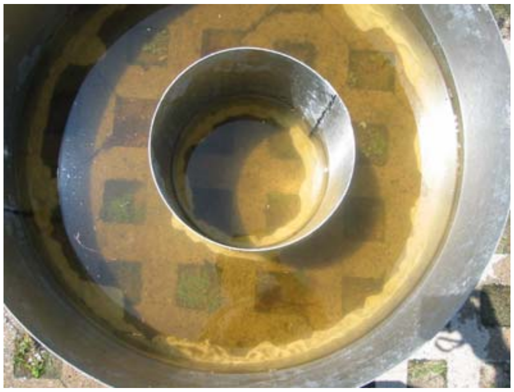


Figure 6. Water in both rings.

It is assumed that the infiltration rates of the outer and inner surface areas are equal. Therefore, water from both rings should infiltrate to the same depth after a given time, given that the hydraulic heads are equal at the surface. As water in the outer ring infiltrates, it creates a barrier within the soil that prevents horizontal migration of water infiltrating from the inner ring. To maintain equal hydraulic heads at the surface, the water levels in the inner and outer rings need to be maintained at equal levels. By preventing the horizontal migration, the water level inside the inner ring reflects only vertical surface infiltration. Figure 7 shows measurement of inner water level.

Figure 7. Measurement of inner ring water level.

Instead of using Mariotte tubes to compensate for infiltrated volume, water was either pumped through a hose or poured into the rings. Additionally, in lieu of maintaining uniform constant hydraulic heads inside the rings, water was added only to the outer ring as the test proceeded. As a test was run, the outer ring had a higher infiltration rate than the inner ring due to horizontal migration outward from the rings. Water was added to the outer ring to equalize the hydraulic heads whenever the hydraulic head, or water level, of the outer ring was recorded to be more than 0.4 in. (10 mm) below the level of the inner ring.

A goal of this study was to compare existing condition infiltration rates to maintained condition infiltration rates for CGP pavements. At each site three existing tests were conducted and then three maintenance tests were conducted in different locations. An existing test was an infiltration test where the surface remained unaltered prior to the infiltration test. A “maintenance" test is an infiltration test where the void material is removed (Figure 8) to a depth between 0.5 in. (1.3 cm) and 0.8 in. (1.9 cm) to simulate maintenance by a street sweeper. For CGP sites, if the measured existing infiltration rates of a site were lower than 10 cfs/ac (0.47 m^3/s-ha), a set of maintenance tests was run.

Figure 8. Maintained site at site 16. Note the depth of soil removed from the gaps.

Many PICP sites had infiltration rates too high to maintain a hydraulic head using the double-ring infiltrometer test. A modified test, known as a "surface inundation test" (Figure 9) was run at these sites. For the surface inundation test, an inner ring of the double ring infiltrometer was sealed to the test surface and a scale was taped inside the ring. Using a five gallon bucket, water was quickly poured into the inner ring. Time was recorded from when the water started pouring in. The time was then recorded when the bucket emptied (along with the peak level of water inside the ring), and then every 30-60 seconds until the ring emptied. If the ring emptied in less than 30 seconds, then the time that the ring emptied was recorded. This test is neither as accurate nor as precise as the double-ring-infiltrometer test (ASTM D 3385-03); because the surface inundation test does not prevent horizontal migration of the water once it enters the soil media. . However, this was a means of obtaining a rough estimate of the surface infiltration rate.

Figure 9. "Surface inundation test" at site.5.

After the data was collected, the water levels were plotted as functions of time for each test (Figure 10). The slope of the least squares line for each test was determined to be the surface infiltration rate of the permeable surface in mm/day. Units were then converted into in./hr, cfs/ac and m^3/s-ha. If it was determined that removing the initial two or three data points from a test was more representative of the surface infiltration rate (improved R^2 value), then those initial data points were omitted from the calculation of the least squares line. The infiltration rate stated for each site was determined for each set of infiltration tests by averaging the three results.

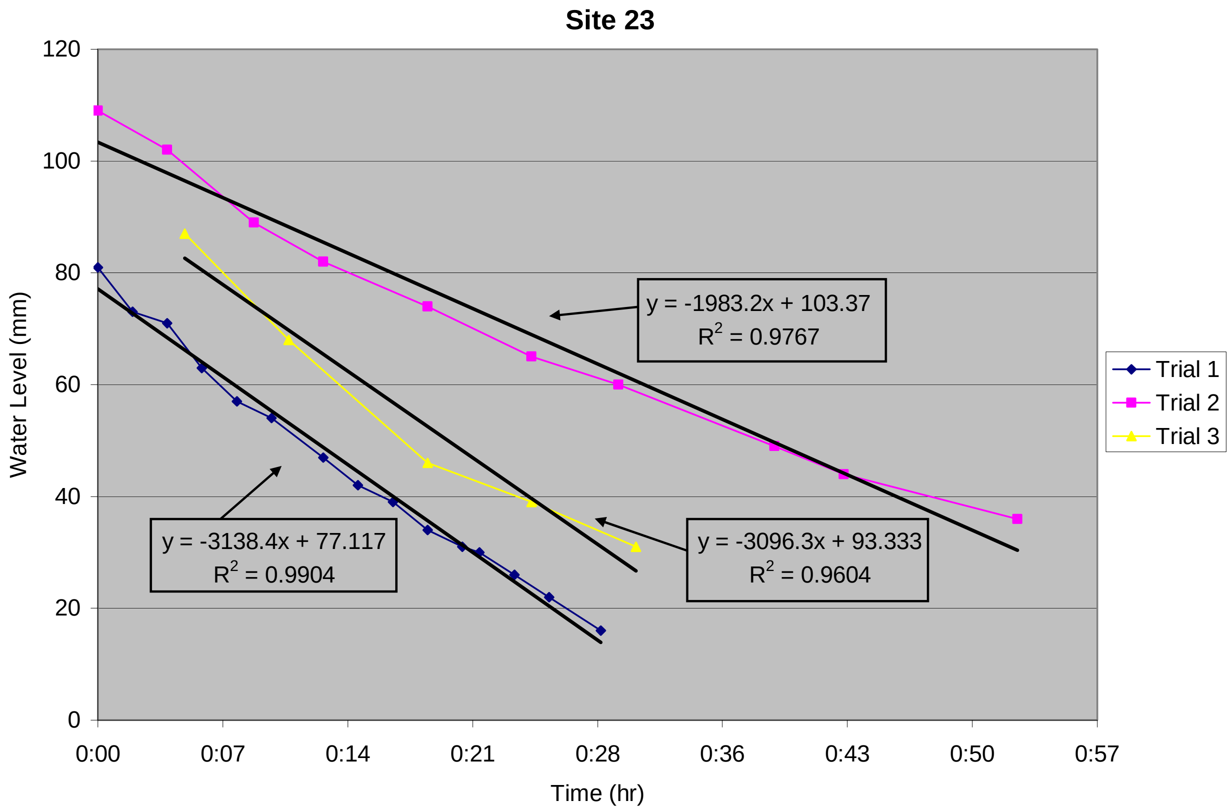


Figure 10. Graphical Data from site 23.

PAVERS TESTED:

Permeable Interlocking Concrete Pavements (PICP):

Eight PICP sites were tested in Maryland and Delaware, located either near the Atlantic Coast or adjacent to waters of the Chesapeake Bay or its tributaries. Each of these sites was selected by the Interlocking Concrete Pavement Institute (ICPI). Additionally, two PICP installations in North Carolina were tested.

Ocean City – Four sites (1, 2, 3, and 9) were located in Ocean City, MD. Ocean City (pop. 7,173) is a coastal town that, like Nags Head, Wilmington, and Wrightsville Beach in North Carolina, relies on summer tourism as a larger part of their economy (USCB, 2003). Site 1 was an area under construction of condos, but the contractor has set up hay bails to prevent sediment from flowing into the PICP lot. When the site was tested, hay bails appeared to be effective at preventing fines from entering the permeable areas due to the sediment line opposite of the permeable area. Both sites 2 and 3 (Figure 11) were used for customer parking. Site 9 is a main walkway for beach foot traffic onto the shore, with only maintenance vehicles being allowed to drive over. Sand was present in almost all void spaces at this site.

Figure 11. PICP at site 3 in Ocean City, MD. This pea gravel is visually free of fines.

Annapolis – Site 4 is an assisted living center in Annapolis, Maryland's capital, which uses PICP for all its open driving surfaces. Annapolis is located on the Chesapeake Bay and has a population of 35,838. Small pieces of assorted trash were noticed in some of the void spaces at this site.

Goldsboro – Goldsboro is a city in eastern North Carolina with a population of 39,043 (USCB, 2003). Site 5 is a bakery that installed a lot comprised of PICP with pea gravel designed by NCSU in 2002.

Rehoboth Beach – Site 6 has a PICP lot for overflow parking in Rehoboth Beach, DE, a town of 1,495 (USCB, 2003). Like Nags Head, Rehoboth Beach's permanent population is less than its summer population. When the site was inspected and tested in July 2003, the lot appeared to be rarely used.

Havre de Grace – Site 7 is located in Havre de Grace, population of 11,331, is a town at the head of the Chesapeake Bay. The site was used for street side parking composed of PICP in the marina district (USCB, 2003).

Patuxent River –Site 8 is a boat ramp located on the Patuxent River off of MD 25 near Prince Frederick, MD. The boat ramp is a regional access for the Patuxent River. Sand was noted to be present in the voids. Sediments were also evident on the pavement surface, most likely due to deposition during high river levels and or from boat trailer traffic coming out of the river carrying sediments.

River Bend – River Bend is a small community just outside of New Bern, NC, with a population of 2,923 (USCB, 2003). Site 10 is a parking lot for public traffic at the town's police station and was constructed in 2000. The site is adjacent to a disturbed area of crush and run gravel. Small particles were present in the void spaces along with on the surface (Figure 12). The soil in the surrounding area is predominantly sand.

Figure 12. Site 10 PICP parking area with fines visible in the lower left hand corner.

Concrete Grid Pavers (CGP):

Cary – Cary is a suburban city located just southwest of Raleigh, NC, with a population of 94,536 (USCB, 2003). Site 11 is used as a traffic area for Cary's public works vehicles. The pavers have not been maintained. The typical in-situ soil is clayey, but the area is mostly undisturbed.

Nags Head – Nags Head is a coastal town in Northeastern North Carolina with a population of 2,700, but has over 4,000 residential houses due to the number of vacation homes (USCB, 2003). Ten sites (sites 12--21) in Nags Head were used for this study. Nine of the sites were parking lots adjacent to the beach. The other site was a parking lot for beach traffic and the town's public library, which was located on the opposite side of a thoroughfare from beach access. Each site used CGP with sand filled voids and was constructed between 1983 and 1987. Marginal site plans were found through the Nags Head City Public Works Office. Most plans only offered a list of materials and rarely had sand and gravel depths, but all had approximately the same notes regarding layers and make up of the lots. A representative from the Town of Nags Head noted the sites were maintained with a street sweeper on an as needed basis, usually after storms to remove residual sand on top of the CGP blocks (Clark, 2003). All the surrounding soil, which often was disturbed, was sand.

Wilmington – Wilmington is a coastal city with a population of 75,838 and is where site 22 is located (USCB, 2003). Site 13 is a restaurant located just off I-40, and this CGP lot is used for overflow parking by a cluster of several restaurants.

Kinston – Kinston is a town in eastern North Carolina with a population of 23,688 (USCB, 2003). Site 23 was designed by NCSU and is used for public works vehicle parking. The soil is sandy and there is very limited disturbed area around the parking lot. The city of Kinston maintains the lot by running a street sweeper over it on an annual basis.

Wrightsville Beach – Wrightsville Beach is a coastal community located just outside of Wilmington and has a population of 2,593 (USCB, 2003). Site 24 serves as a parking area for beach traffic. This site is the only CGP site in this study that uses choker stone instead of sand for void fill. The design of Wynn Plaza was reviewed by NCSU.

Plastic Turf Reinforcing Grids (PTRG):

Kinston – This site is located within the same parking lot and constructed at the same time as site 23 mentioned above. A PTRG system was used. The internal gaps in the plastic were filled with a local sandy loam soil to facilitate grass growth.

DATA & ANALYSIS

Surface infiltration averages for all 25 sites are listed in Appendix B. Sites are grouped by surface type and condition, as well as by estimated traffic volume. Infiltration rates were rounded to two significant figures for double-ring infiltrometer tests, while surface inundation test results are reported with one significant digit due reduced accuracy of the test. Traffic volumes were primarily estimated based on observations and location, while estimated values were based on the number of wheel passes per day (wpd). The three divisions and their ranges were: high (H), >10 wpd; medium (M), 4-10 wpd; and low (L), <4 wpd.

Permeable Interlocking Concrete Pavements:

Ten PICP sites were tested; seven in Maryland, two in North Carolina and one in Delaware. Six of these sites were tested using the surface inundation test, due to their high surface infiltration rates (>60 cfs/ac, >2.8 m^3/s-ha). Site 7 maintained hydraulic head just enough to fill the double ring infiltrometer rings for testing, but had a surface infiltration rate average of 40 cfs/ac (2 m^3/s-ha). The three remaining PICP sites had surface infiltration rates low enough so that a double-ring infiltrometer test was performed. These same three PICP sites were located in close proximity to areas containing exposed fine soil particles, i.e. gravel drive, a river bed, and a beach. It should be noted that maintenance was preliminarily performed on site 10 with anticipation of obtaining enough sites in the future to be able to compare maintained and unmaintained conditions for PICP sites. However, not enough sites were found to be able to test for maintenance and therefore other lower infiltrating sites were not tested. Figure 13 shows estimated surface infiltration rates for permeable pavement applications using PICP or similar products. The last three surface infiltration rates are the three PICP sites located in close proximity to exposed fine soil particles.

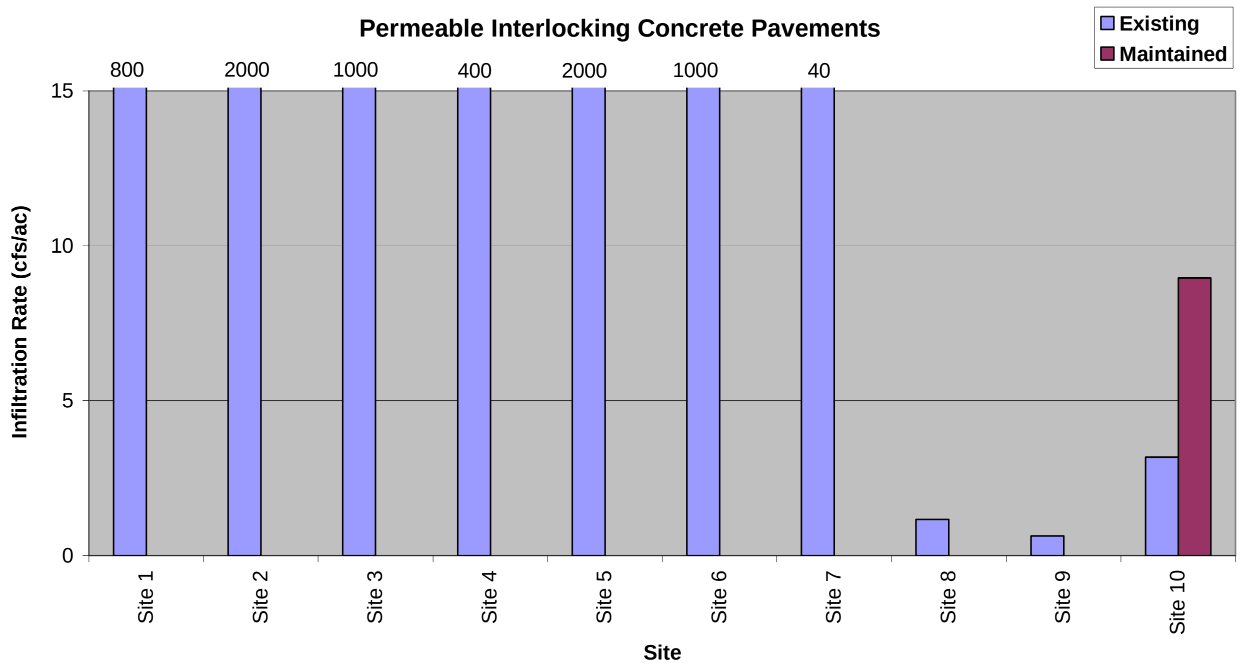


Figure 13. Surface infiltration rates for PICP or similar applications.

Surface infiltration rates of PICP filled with gravel are not limited by their surface infiltration capacity, provided they are sited in areas free of soil disturbances. The average PICP surface infiltration rate was 900 cfs/ac (40 m^3/s-ha), while the PICP sites near disturbed soils with fines was 1.6 cfs/ac (0.078 m^3/s-ha), a decrease of over 99%.

The average surface infiltration rate for PICP free of fines from this study is comparable to the range listed by ICPI (2001) for open graded-base material in the manual, Permeable Interlocking Concrete Pavements: Selection, Design, Construction, and Maintenance, rather than new pavements. ICPI states that open-graded base material has an infiltration rate of between 500 and 2000 in./hr which is comparable to the average surface infiltration rate of PICP sites free of fines (900 in./hr) listed above in Table 3. However, 900 in./hr is much higher than the average infiltration rates for PICP (up to 9 in./hr) pavements listed by ICPI (2001).

Figure 14 shows surface infiltration rates grouped by age for all PICP sites. Over time, permeable pavements are expected to have reduced infiltration rates (ICPI, 2000). It is possible that Firgure 13 shows this trend with pavements greater than 2 years old. However these sites were also located near free fines. More sites would have to be tested in order to make any definite conclusions to this effect.

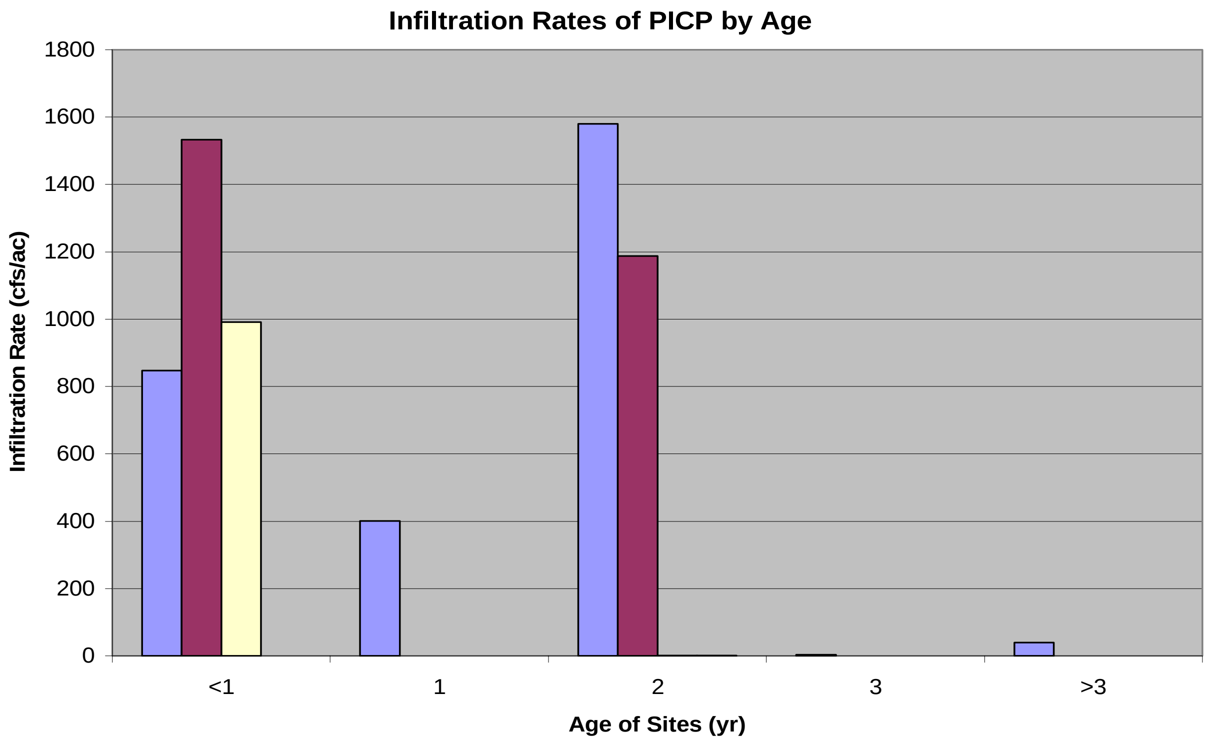


Figure 14. Infiltration rates of PICP sites grouped by age.

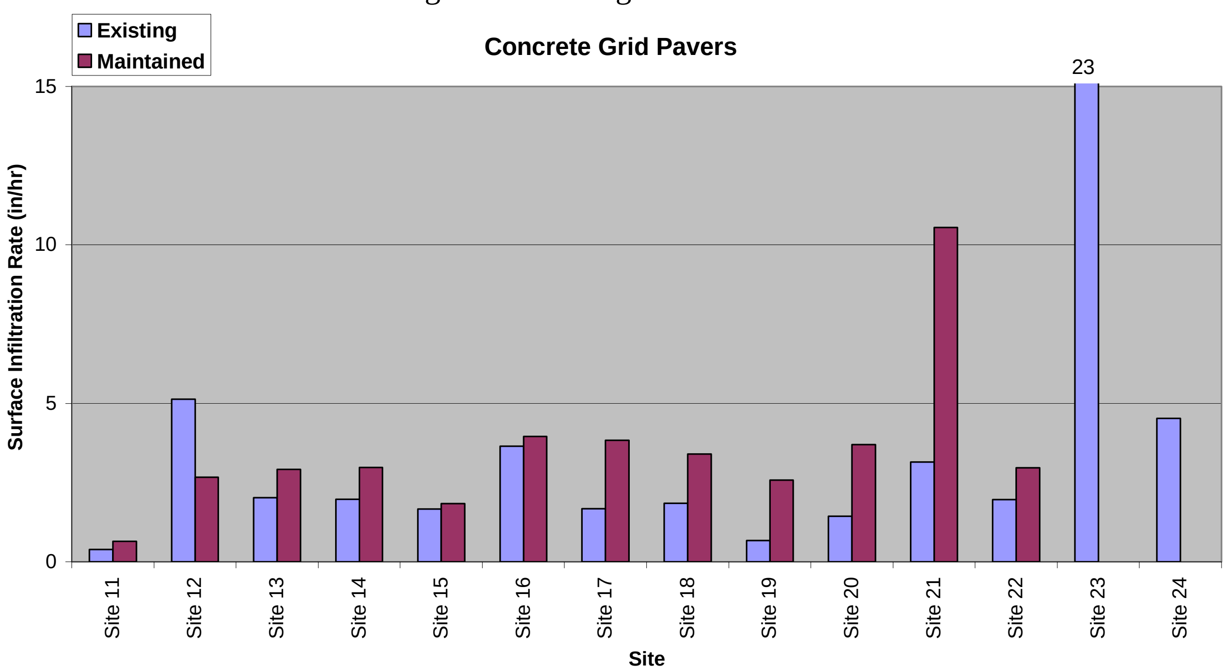
However, a statistical test was run to determine if there was a significant difference between the surface infiltration rates of PICP near fines and free of fines. To test whether the surface infiltration rates at sites without fines were significantly different from sites with fines a SAS™ (2003) ANOVA statistical analysis was run. The analysis showed a significant difference in surface infiltration rates at a confidence level of 98%. Thus, it can be said that PICP free of fines have significantly higher surface infiltration rates than PICP with sandy fines present. PICP shows a strong tendency to have highly decreased surface infiltration rates when they are either (1) substantially older and/or (2) located near exposed fines.

Concrete Grid Pavers:

Surface infiltration rates were measured from 14 sites with CGP (Figure 15). Of these, 12 sites were "maintained", and had their maintenance surface infiltration rate collected. (The terms "existing", "unmaintained", and "maintained" were defined earlier in the Procedure section.) Of the two sites that did not have maintenance performed, the measured surface infiltration rate at one site, site 23, was greater than 10 cfs/ac (0.47 m^3/s-ha), and the other site, site 24, had an existing surface infiltration rate of 4 cfs/ac (0.2 m^3/s-ha),. It was supposed that maintenance had either recently been performed or the site had yet to need maintenance. The site with the lowest surface infiltration rate, site 11, (0.4 cfs/ac, 0.02 m^3/s-ha), could be the result of a combination of factors (i.e. no maintenance and frequent heavy traffic). This site also was constructed in a clayey soil area; however, since the surrounding area is relatively undisturbed, this may not be a significant factor.

Figure 15. Surface infiltration rates measured from concrete grid pavers sites.

Of the sites that were maintained, 11 had noticeably higher surface infiltration rates than the "unmaintained" pavers. The only site that did not increase its surface infiltration rate was site 12. This anomaly is potentially due to a high surface infiltration rate of 8.8 cfs/ac (0.41 m^3/s-ha) for one of the existing tests, while all other tests, existing and maintained, had surface infiltration rates less than 3.9 cfs/ac (0.19 m^3/s-ha). However, of the 10 sites in Nags Head, this site had the highest existing surface infiltration rate. Figure 15 is a graphic showing the surface infiltration rates of the 14 CGP lots tested throughout NC. The mean and median average pre-maintenance surface infiltration rate where both rates were recorded were 2.1 cfs/ac (0.10 m^3/s-ha) and 1.9 cfs/ac (0.90 m^3/s-ha) respectively; the mean and median average post-maintenance surface infiltration rate was 3.5 cfs/ac (0.16 m^3/s-ha) and 2.9 cfs/ac (0.14 m^3/s-ha), respectively. On average, the surface infiltration rate of CGP increased by 64% after maintenance was performed. Site 24, which used pea gravel rather than sand, was tested only for existing conditions and had a surface infiltration rate twice as high as the average for CGP filled with sand.



Figures 16 and 17, on the following page, show infiltration rates for CGP sites grouped by age for both existing and maintained conditions, respectively. As was the case for the PICP age analysis, it is unclear with a limited number of sites whether infiltration rates decrease over time.

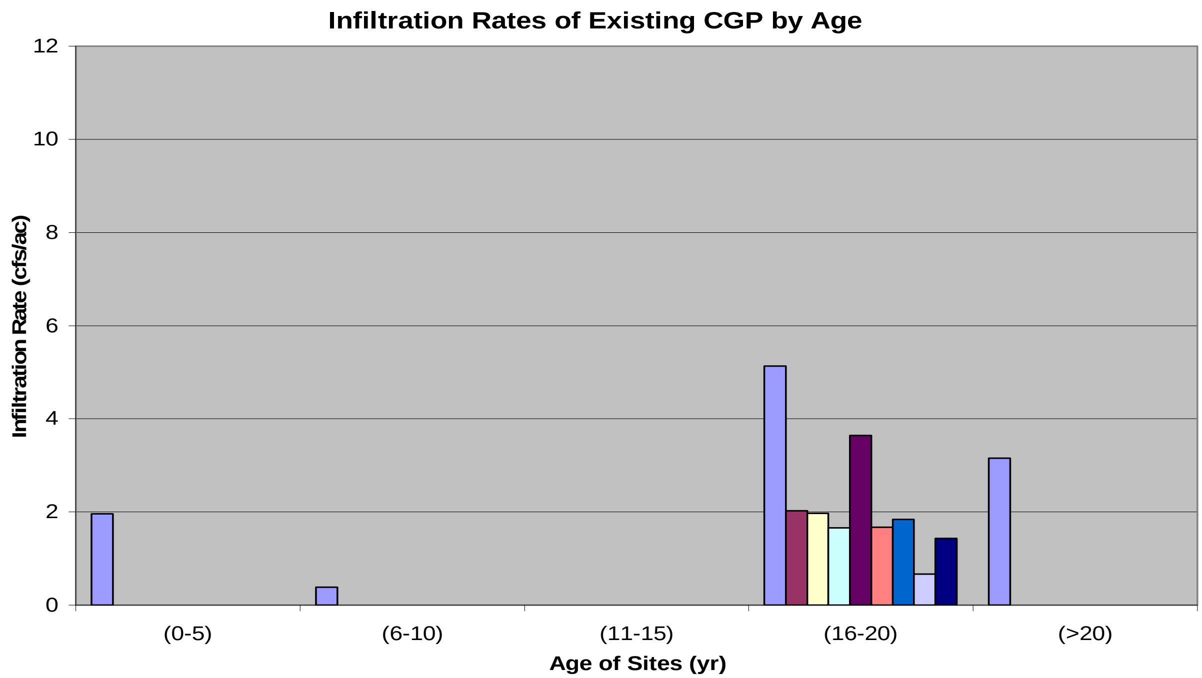


Figure 16. Infiltration rates of existing CGP sites grouped by age.

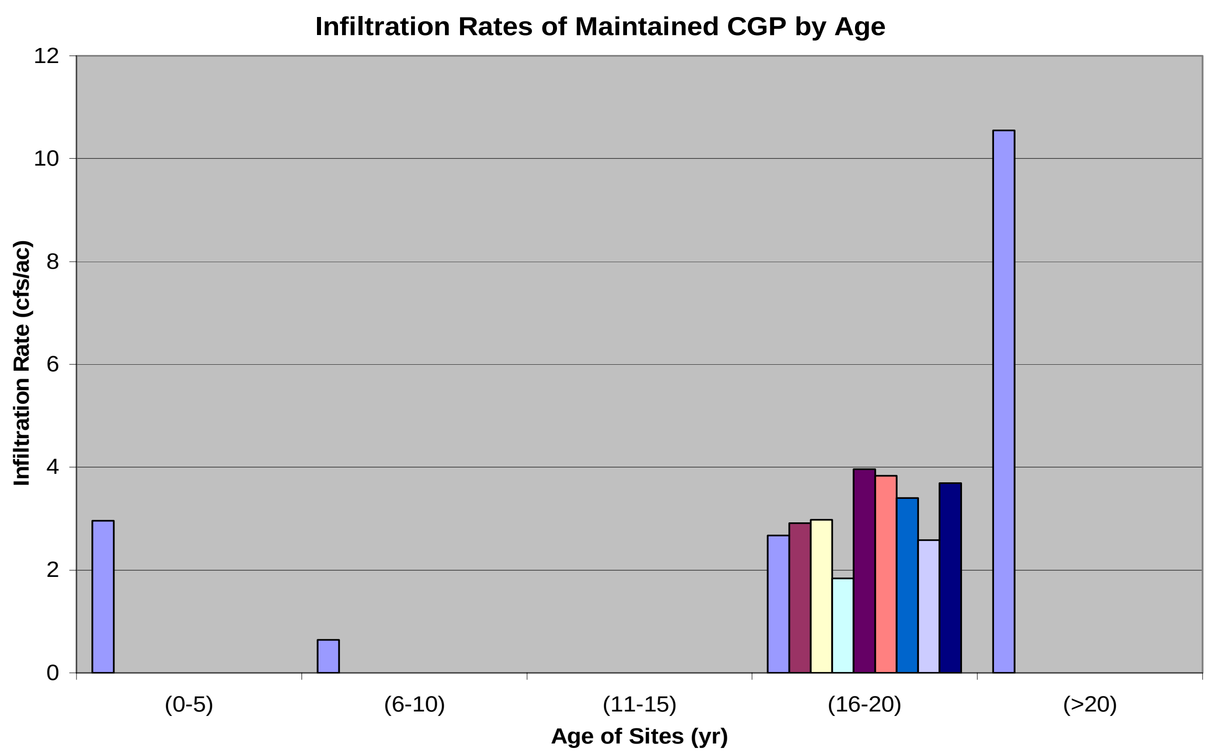


Figure 17. Infiltration rates of maintained CGP sites grouped by age.

To test whether the pre-maintained surface infiltration rates were significantly different from the maintained surface infiltration rates, a SAS™ (2003) ANOVA two-factor without replication statistical analysis was run. The analysis showed that there was a statistically significant difference between existing and maintained surface infiltration rates at a 97% confidence. As a result, it can be stated with high confidence that maintenance significantly improved surface infiltration rates for the CGP sites with sand in this study.

Concrete Grid Pavers vs. Plastic Turf Reinforcing Grids:

Sites 23 and 25, adjacent to each other, were designed and constructed by NCSU. Site 25 was constructed with PTRG, and filled with sandy loam topsoil, while site 23 was constructed with concrete grid pavers and back filled with concrete sand. Figure 18 shows the comparison of the two sites. For this study, site 25 was divided into areas with good cover (grassed) and without grass (bare). Both sites were designed and constructed at the same time and have experienced the exact same conditions with respect to weather, traffic, and age. This offers a unique comparison between concrete grid pavers and plastic turf reinforcing grids.

The areas without grass have most likely been compacted due to vehicle traffic, but still retain some infiltration due to the soil being sandy. Areas with grass have a much higher surface infiltration rate, almost three times than the barren areas; 10 cfs/ac, 0.47 m^3/s-ha compared to 3.6 cfs/ac, 0.17 m^3/s-ha. This shows, at least for this site, that grass is an important factor for maintaining surface infiltration rates. Grass could have prevented the compaction of the soil with its foliage along with its roots. By preventing compaction the grass would also preserve the loose state of the soil. Grass may also simply be indicative of areas that have not been compacted.

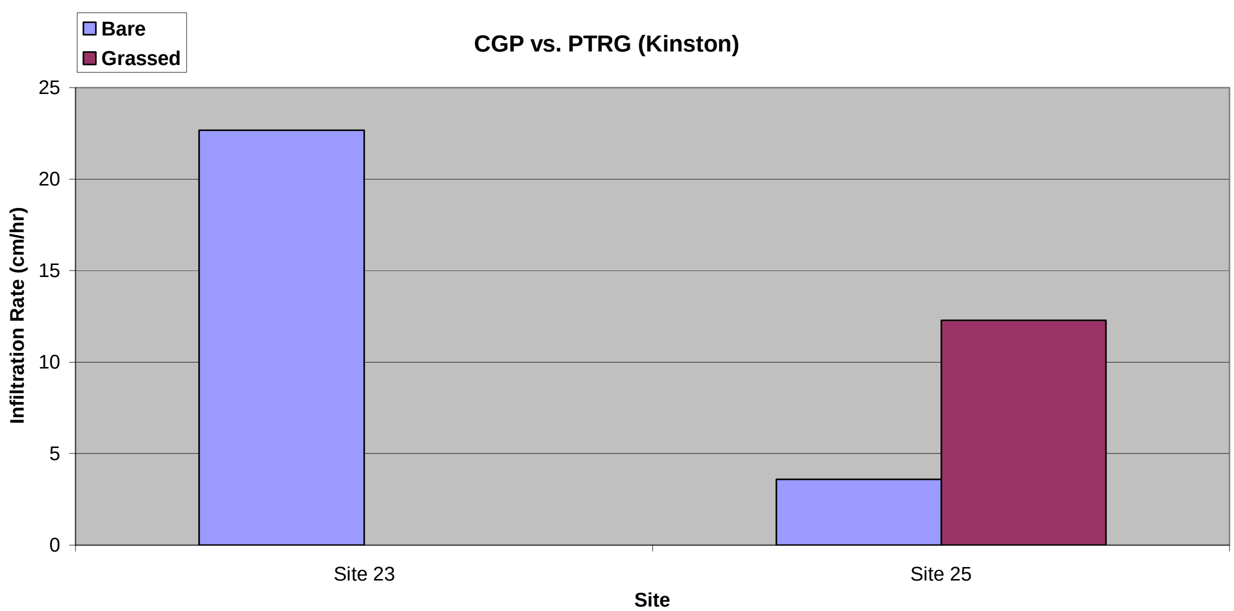


Figure 18. Surface infiltration rates for sites 23 and 25, comparing CGP and PTRG.

Comparison:

PICP sites near fines had surface infiltration rates that were comparably low to those found with CGP filled with sand, while PICP free of fines were the highest infiltrating surfaces. Table 2 below shows a comparison of infiltration rates for the main surfaces tested. PICP sites free of fines had surface infiltration rates three orders of magnitude greater than sites with fines, suggesting that this is a very significant factor in determining long term surface infiltration rates for PICP sites. Though only one PTRG site was tested in this study, it can be seen that the difference between grassed areas and barren areas was larger than between existing and maintenance for CGP. This study was unable to make any conclusions based on infiltration rates over time for permeable pavements.

Table 2 lists the average infiltration rates for each pavement surface type. CGP averages are only for the 12 sites that were tested to compare existing and maintained infiltration rates and do not include sites 23 and 24. Table 3 also converts infiltration rates to metric units as well as in./hr to assist in comparison to rainfall intensities. These values should not be used as design parameters, but rather should be used to compare the performance of selected sites found within in Mid-Atlantic region

Table 2: Average surface infiltration rates for permeable pavements tested.

Pavement Type	cfs/ac	m^3/s-ha	in./hr*
PICP (no fines)	900	66	900
PICP (near fines)	1.7	0.12	1.6
CGP (Existing)	2.1	0.15	2.1
CGP (Maintained)	3.5	0.21	3.5

*One in./hr = 1.008 cfs/ac

Infiltration rates for new pavements were calculated using infiltration rates of sub-grade and percent open area on pavements. Through digital photo-analysis, CGP was determined to be 30% void space while PICP pavements were found to be 9% void space. The median surface infiltration rates found during this study were then compared to new pavement infiltration rates. The maintained CGP site median surface infiltration rate (3.0 cfs/ac, in./hr) was comparable to the value calculated (3.2 cfs/ac, in./hr) for 30% void space over a sand sub-grade (ICPI, 2000). The calculated value for new PICP (180 cfs/ac, in./hr) was determined for 9% void space over open-graded base material. This infiltration rate is accurate for PICP, however the median tested surface infiltration rate from this study for PICP sites away from fines was much higher (1000 cfs/ac, in./hr). Although, the surface infiltration rate can be much lower than the calculated value for sites where fines are disturbed and able to clog the surface (1.2 cfs/ac, in./hr).

During the design process for a permeable pavement surface it is important to consider expected rainfall intensities for the area to predict the runoff expected from the surface. Tables 3 and 4 below compare average infiltration rates for the four main conditions of pavements tested to with their expected percent runoff for Raleigh and Wilmington, NC. The 2-, 5-, and 10-yr return period 5 minute rainfall depths for Raleigh are 0.48 in., 0.55 in., and 0.60 in., respectively. For Wilmington they are 0.49 in., 0.55 in., and 0.60 in., respectively. It is important to note that the ratio of infiltration to runoff is not only contingent upon surface infiltration rate, but also, for example, length of storm, sub-grade volume capacity, and sub-grade infiltration rate, to name a few.

Table 3: Infiltration rates and potential runoff amounts from 2-, 5-, and 10-year peak rainfall intensities (5 min) for Raleigh, NC.

Pavement Type	Infiltration Rate (cfs/ac)	2 yr (cfs/ac)	5 yr (cfs/ac)	10 yr (cfs/ac)
PICP (no fines)	78	0	0	0
PICP (near fines)	0.14	0.34	0.42	0.47
CGP (existing)	0.18	0.30	0.38	0.42
CGP (maintained)	0.29	0.22	0.26	0.31

Table 4: Infiltration rates and potential runoff amounts from 2-, 5-, and 10-year peak rainfall intensities (5 min) for Wilmington, NC.

Pavement Type	Infiltration Rate (cfs/ac)	2 yr (cfs/ac)	5 yr (cfs/ac)	10 yr (cfs/ac)
PICP (no fines)	78	0	0	0
PICP (near fines)	0.14	0.36	0.42	0.47
CGP (existing)	0.18	0.32	0.38	0.42
CGP (maintained)	0.29	0.20	0.26	0.31

Lastly, each site tested, with the exception of three (sites 9, 11, and 19) had surface infiltration rates greater than 1 cfs/ac (0.047 m3/s-ha). These rates are equal to or greater than surface infiltration rates expected for grassed sandy loam. Surface clogging in predominantly course grain soil environments, therefore, does not cause permeable pavements to have surface infiltration rates reduced below some naturally grassed areas.

KEY CONCLUSIONS

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

For PICP sites:

1) PICP lots installed for infiltration purposes should not be sited adjacent to areas with free fine particles. Fine particles have been shown to severely decrease surface infiltration rates.

2) Maintenance should include the use of a vacuum sweeper at least once per year. More frequent maintenance should be practiced if accumulation of fines is evident from foot traffic, automotive traffic, or any other means. 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 profile.

For CGP sites filled with sand:

3) Maintenance, using a street sweeper, should be performed on at least a yearly basis. Removing the top 0.5 in. (1.3 cm) of material accumulated within void spaces has been

significantly shown to improve surface infiltration rates. Sand should then be backfilled into the void spaces to prevent sealing at a lower depth.

For PTRG sites:

4) PTRG sites should be maintained so that grass cover can provide full coverage.

To conclude, there are several states, including North Carolina, which do not credit permeable pavement with reducing runoff. The data discussed in this report contradicts this belief, particularly in sandy soil (course grain soil) environments. Of 30 pavements tested only three sites had surface infiltration rates less than 1 cfs/ac, including the one site tested in a fine grain soil (clay soil) environment. This report's strong recommendation is for states to reconsider whether permeable pavements do in deed reduce runoff. Evidence suggests that, providing the following conditions are met, permeable pavements do reduce runoff to a significant extent: (1) the application is sited in a sandy or loamy sand soil, (2) is located in soils without seasonally high water tables, (3) the pavement is well-maintained, (4) proper construction materials and techniques are followed, (5) the pavement is essentially flat and away from disturbed clay soils, and (6) does not have overburdening structural loads.

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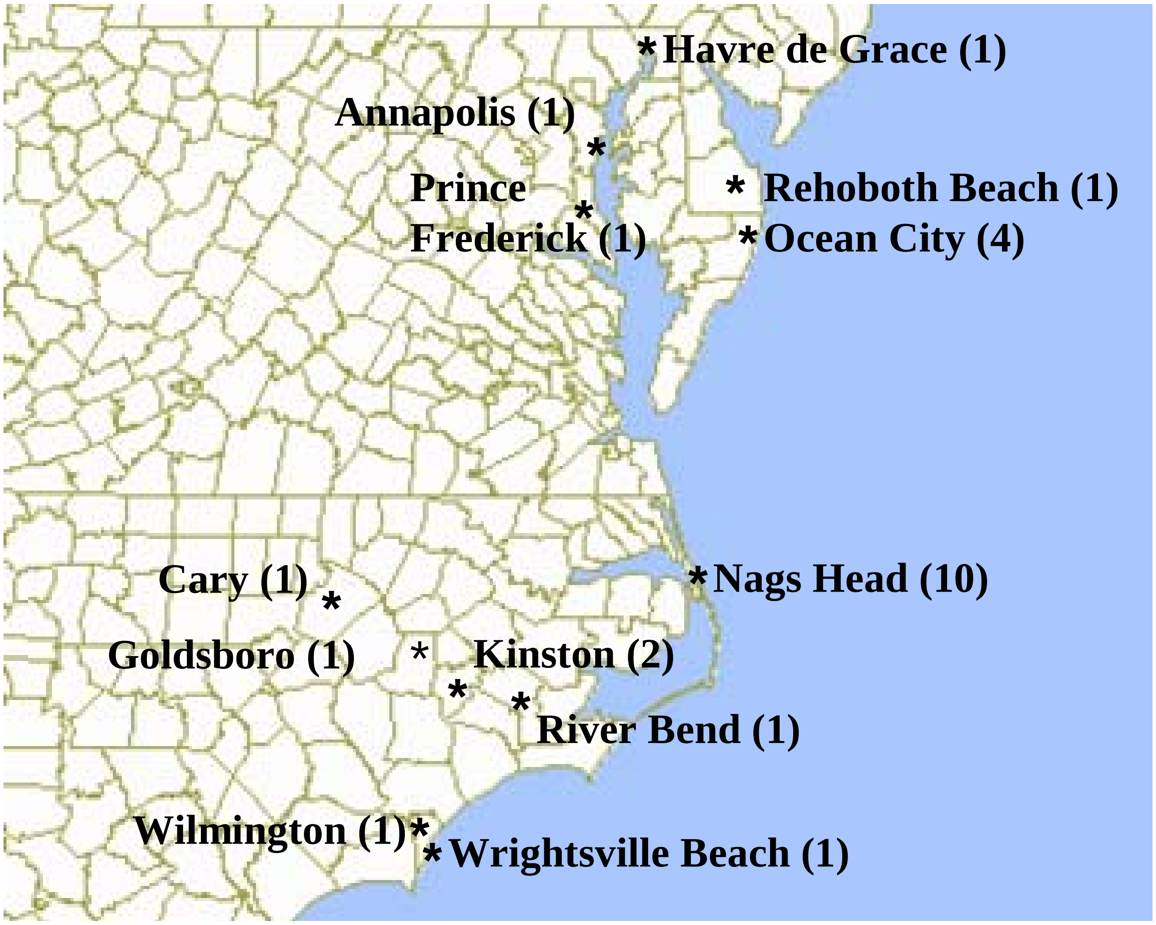
APPENDIX

Plastic Turf Reinforcing Grids

APPENDIX A



Appendix A Regional Map of Cities and Number of Sites.

APPENDIX B

Appendix B. Average surface infiltration rates for all

Site #	Surface Type	Traffic Volume	Age (yrs)	Existing (cfs/ac)	Maintained (cfs/ac)
Site 1	PICP (no fines)	M	0	900	
Site 2	PICP (no fines)	M	0	2000	
Site 3	PICP (no fines)	M	0	1000	
Site 4	PICP (no fines)	M	1	400	
Site 5	PICP (no fines)	M	2	2000	
Site 6	PICP (no fines)	L	2	1000	
Site 7	PICP (no fines)	L	6	40	
Site 8	PICP (with fines)	M	2	1.2	
Site 9	PICP (with fines)	L*	2	0.6	
Site 10	PICP (with fines)	L	3	3.2	9.0
Site 11	CGP	H	8	0.4	0.6
Site 12	CGP	M	18	5.1	2.7
Site 13	CGP	M	18	2.0	2.9
Site 14	CGP	M	18	2.0	3.0
Site 15	CGP	M	19	1.7	1.8
Site 16	CGP	M	19	3.6	4.0
Site 17	CGP	M	19	1.7	3.8
Site 18	CGP	M	19	1.8	3.4
Site 19	CGP	M	19	0.7	2.6
Site 20	CGP	M	19	1.4	3.7
Site 21	CGP	M	21	3.2	11
Site 22	CGP	L	4	2.0	3.0
Site 23	CGP	H	4	23	
Site 24	CGP (with pea gravel)	H	2	4.5	
Site 25	PTRG	H	4	3.6	12

Site 1: Captiva Bay Condos

Type of Surface: Permeable Interlocking Concrete Pavements

Use: Residential Parking

Size (stalls/sq. ft.): 3,360 sq. ft.

Approximate Drainage Area: Equal to permeable area

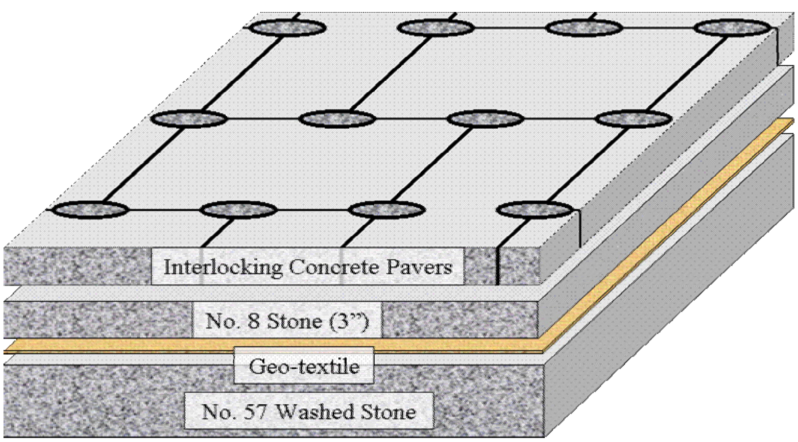
Construction Date: 2003

Address: 85th St., Ocean City, MD

Test Date: July 29, 2003

Visual Assessment: Condos under construction w/ hay bales around test site.

Maintenance Practice: New

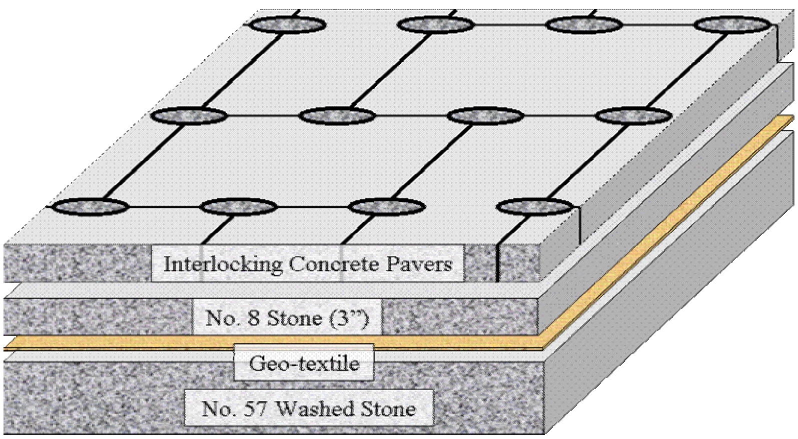


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
845	1359	338	847

Site 2:	CVS Pharmacy
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Fringe parking

Size (stalls/sq. ft.):	5,760 sq. ft.
Approximate Drainage Area:	Equal to permeable area.
Construction Date:	2003
Address:	12001 Ocean Highway, Ocean City, MD
Test Date:	July 29, 2003
Visual Assessment:	Looks clean working well.
Maintenance Practice:	New



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1429	1805	1364	1533

Site 3: Dough Roller's

Type of Surface: Permeable Interlocking Concrete Pavements

Use: Resteraunt parking

Size (stalls/sq. ft.): 6,000 sq. ft.

Approximate Drainage Area: 8,500 sq. ft.

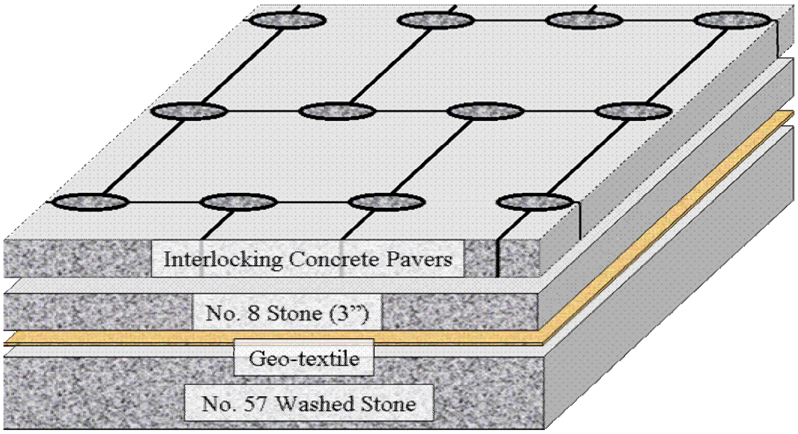
Construction Date: 2003

Address: 41st St. & Coastal Highway, Ocean City, MD

Test Date: July 29, 2003

Visual Assessment: Clean and open pores.

Maintenance Practice: New Site

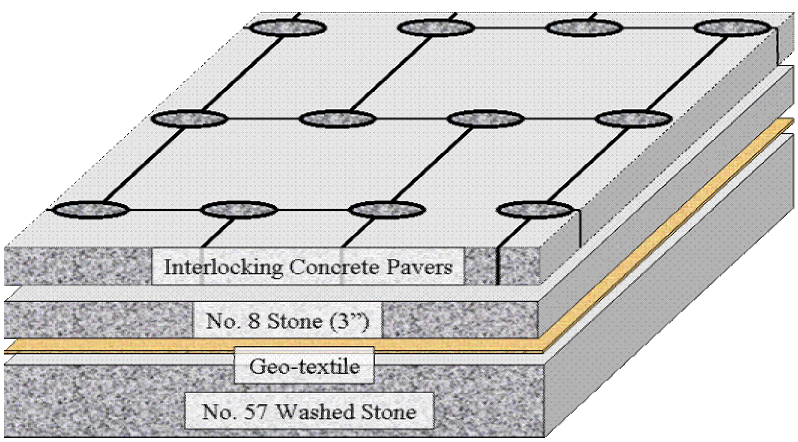


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1123	821	1032	992

Site 4:	Baywoods of Annapolis Assisted Living Center
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Parking and drive areas of assisted living center

Size (stalls/sq. ft.):	14,000 sf.
Approximate Drainage Area:	Permeable area
Construction Date:	2002
Address:	Bembe Beach Rd, Annapolis, MD
Test Date:	July 28, 2003
Visual Assessment:	Looks as though voids are permeable.
Maintenance Practice:	None



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
426	267	510	401

Site 5: Mickey's Pastry Shop

Type of Surface: Permeable Interlocking Concrete Pavements

Use: Public parking for bakery

Size (stalls/sq. ft.): 30

Approximate Drainage Area: Equal

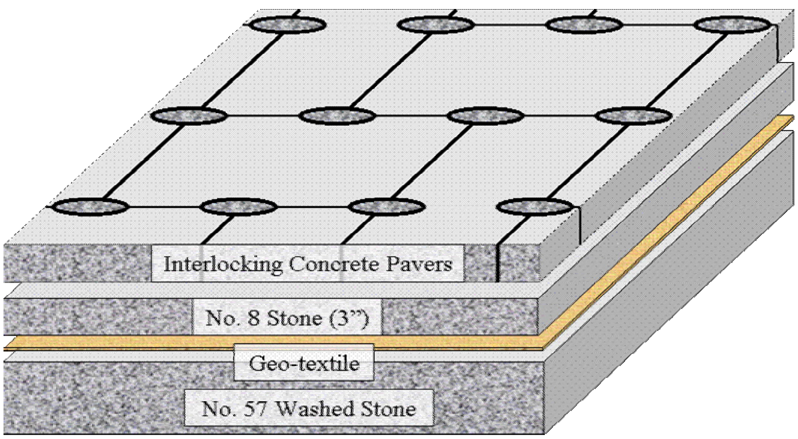
Construction Date: 2001

Address: 2704 Graves Dr., Goldsboro, NC

Test Date: July 22, 2003

Visual Assessment: Looks very clean with minimal debri in voids.

Maintenance Practice: None

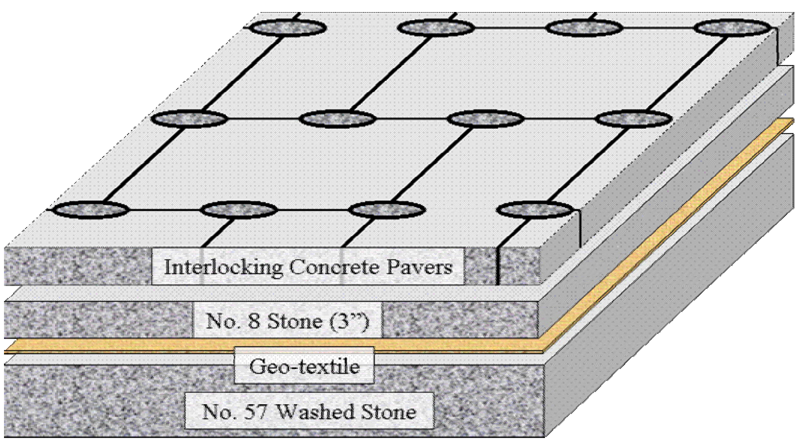


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1572	1553	1616	1580

Site 6:	Wal-Mart
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Overflow parking

Size (stalls/sq. ft.):	43,000 sq.ft.
Approximate Drainage Area:	Permeable area.
Construction Date:	Summer 2001
Address:	4493 Highway One, Rehoboth Beach, DE
Test Date:	July 29, 2003
Visual Assessment:	Lot is rarely used. May have underdrain.
Maintenance Practice:	New

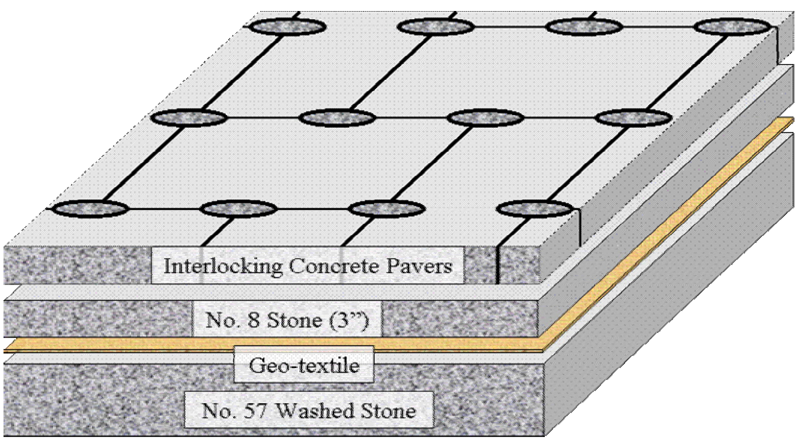


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1118	1200	1244	1188

Site 7:	Harve de Grace
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	City street parking

Size (stalls/sq. ft.):	12,000 sq. ft.
Approximate Drainage Area:	Equal to permeable area.
Construction Date:	1997
Address:	Concord Ave., Harve de' Grace, MD
Test Date:	July 28, 2003
Visual Assessment:	Needs maintenance and voids sealed by dirt, oil and debri.
Maintenance Practice:	Street sweeper every 1-2 weeks

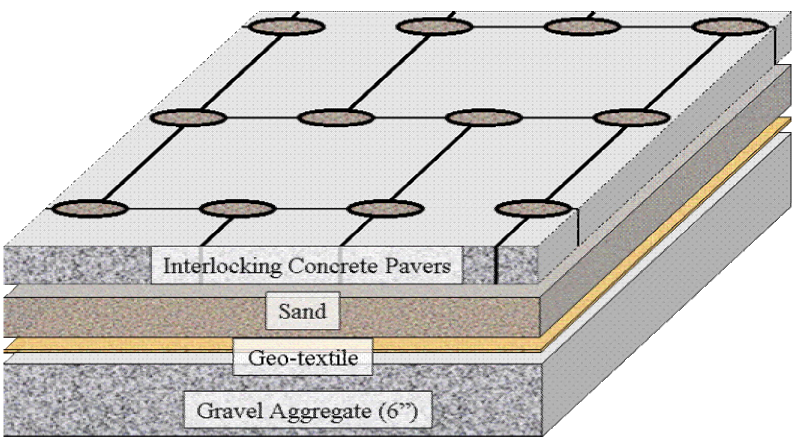


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
30.53	33.94	54.78	40

Site 8:	Boat Ramp
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Parking for boat launching.

Size (stalls/sq. ft.):	22,000 sq. ft.
Approximate Drainage Area:	Equal to permeable area.
Construction Date:	2001
Address:	Route 231, Prince Frederick, MD
Test Date:	July 28, 2003
Visual Assessment:	Heavily used with lots of sand in void spaces.
Maintenance Practice:	none

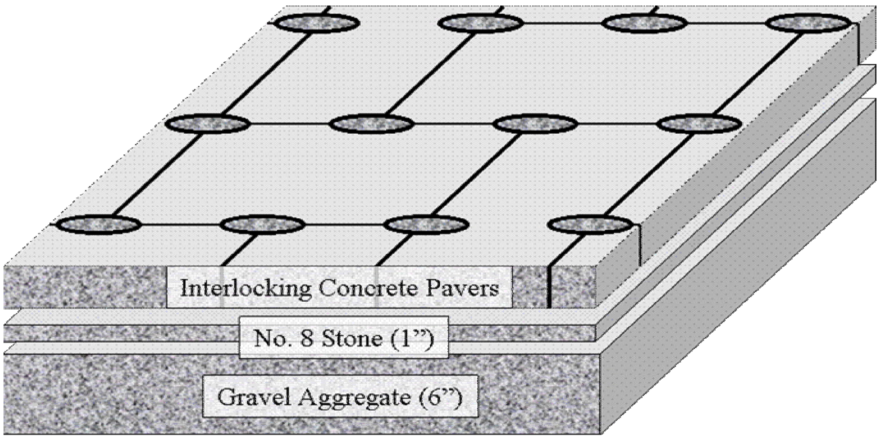


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.72	0.79	0.97	1.16

Site 9:	Somerset Drive, Ocean City, MD
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Walkway to beach.

Size (stalls/sq. ft.):	6,830 sq. ft.
Approximate Drainage Area:	Equal to permeable area.
Construction Date:	Winter 2001
Address:	Somerset St., Ocean City, MD
Test Date:	July 29, 2003
Visual Assessment:	Lots of sand in voids.
Maintenance Practice:	Street Sweeper twice per week from June-Sept.

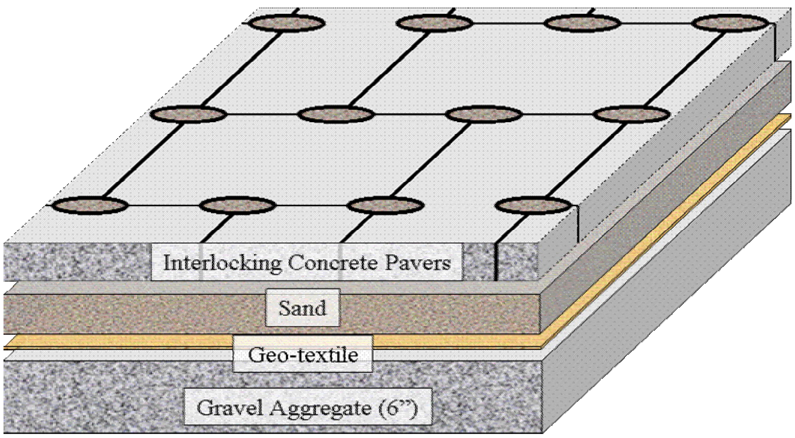


Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
0.00	0.72	1.19	0.64

Site 10:	River Bend
Type of Surface:	Permeable Interlocking Concrete Pavements
Use:	Parking for public works buildings

Size (stalls/sq. ft.):	8 stalls
Approximate Drainage Area:	Equal to permeable area.
Construction Date:	Dec. 2000
Address:	45 Shoreline Dr., River Bend, NC
Test Date:	July 22, 2003
Visual Assessment:	Compacted fines from gravel drive in voids.
Maintenance Practice:	None



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.38	1.32	6.82	3.18

Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
8.25	15.48	3.17	8.96

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 11: Cary Public Works

Type of Surface: Concrete Grid Pavers

Use: Parking and main traffic areas

Size (stalls/sq. ft.): 0.75 acre

Approximate Drainage Area: 1 acre

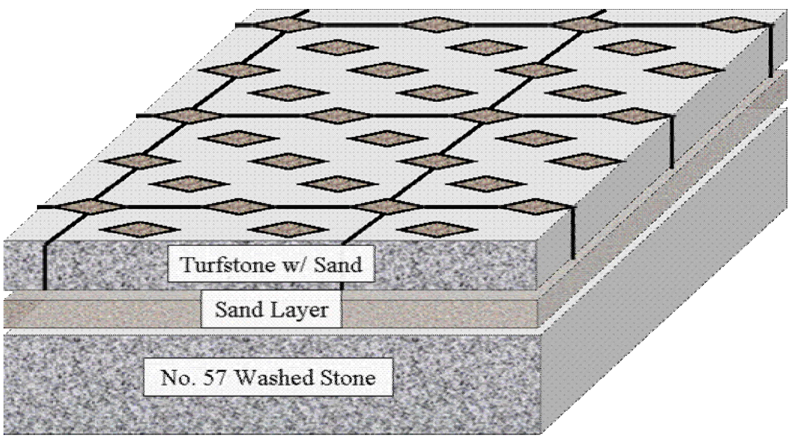
Construction Date: 1995

Address: 400 James Jackson Rd., Cary, NC

Test Date: August 7, 2003

Visual Assessment: Small plants, sand, and trash in void spaces, slightly sloped.

Maintenance Practice: None, only replaced broken blocks



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
0.30	0.27	0.60	0.39

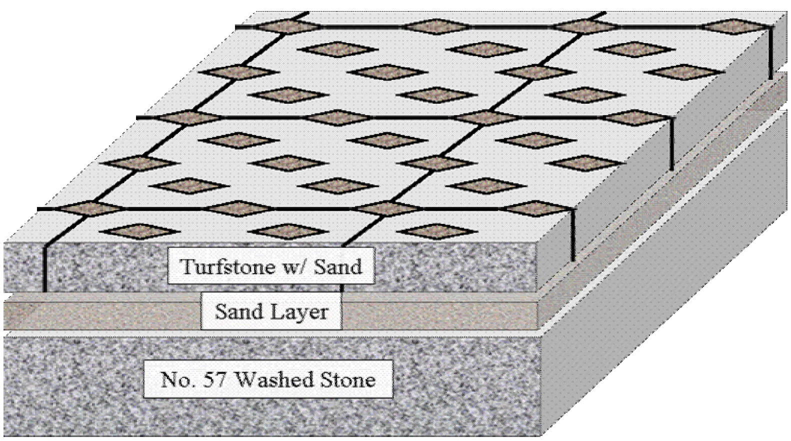
Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
0.60	0.75	0.56	0.64

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 12:	Blackman Beach Access
Type of Surface:	Concrete Grid Pavers
Use:	Beach Access Parking

Size (stalls/sq. ft.):	6700 sq. ft.
Approximate Drainage Area:	8700 sq. ft.
Construction Date:	1985
Address:	S. Virginia Dare Tr. & Blackman St., Nags Head, NC
Test Date:	July 17, 2003
Visual Assessment:	Grass in 30% of voids, very sandy and has pine trees.
Maintenance Practice:	As needed after large storms (a few times per year).



	Run #1	Run #2	Run #3	Average
Existing Conditions Test (cfs/ac):	3.06	3.50	8.83	5.13
Post-Maintenance Condition Test (cfs/ac):	2.80	3.15	2.06	2.67

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 13: Gull Beach Access

Type of Surface: Concrete Grid Pavers

Use: Beach Access Parking

Size (stalls/sq. ft.): 12 stalls

Approximate Drainage Area: Additional 50' towards the beach.

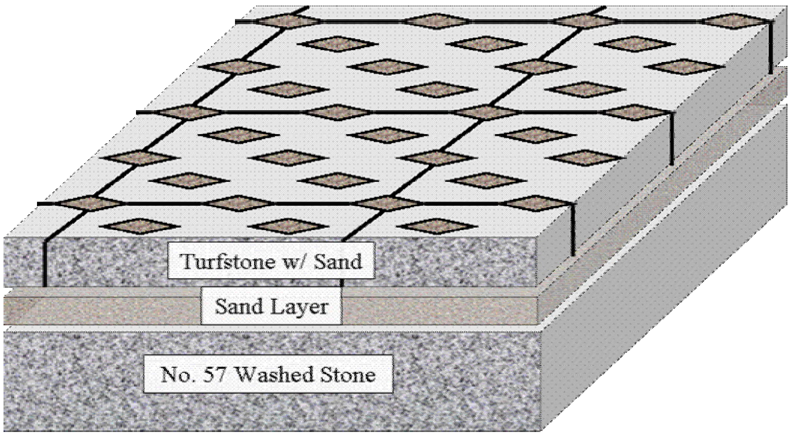
Construction Date: 1985

Address: S. Virginia Dare Trail and Gull St., Nags Head, NC

Test Date: July 15, 2003

Visual Assessment: Sand in voids and some grass.

Maintenance Practice: As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
0.97	1.58	3.52	2.02

Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.17	2.97	3.60	2.91

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 14: Glidden Beach Access

Type of Surface: Concrete Grid Pavers

Use: Beach Access Parking

Size (stalls/sq. ft.): 5100 sq. ft.

Approximate Drainage Area: 11000 sq. ft.

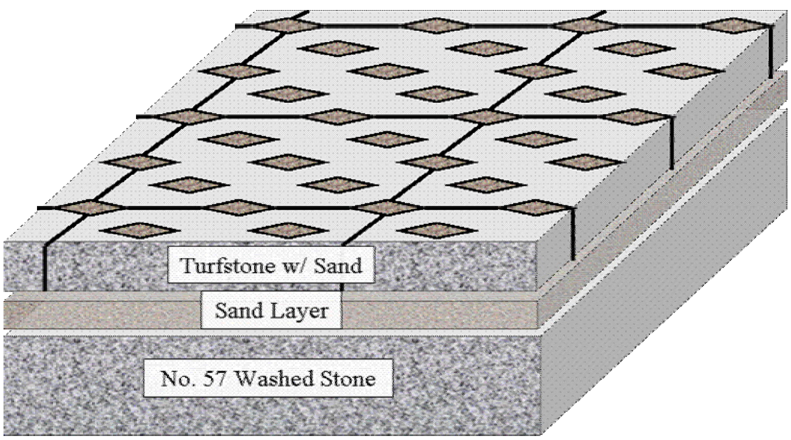
Construction Date: 1985

Address: S. Virginia Dare Tr. & Glidden St., Nags Head, NC

Test Date: July 16, 2003

Visual Assessment: Surface is caked, silty, trash and grass in 75% of voids.

Maintenance Practice: As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.17	2.52	1.23	1.97

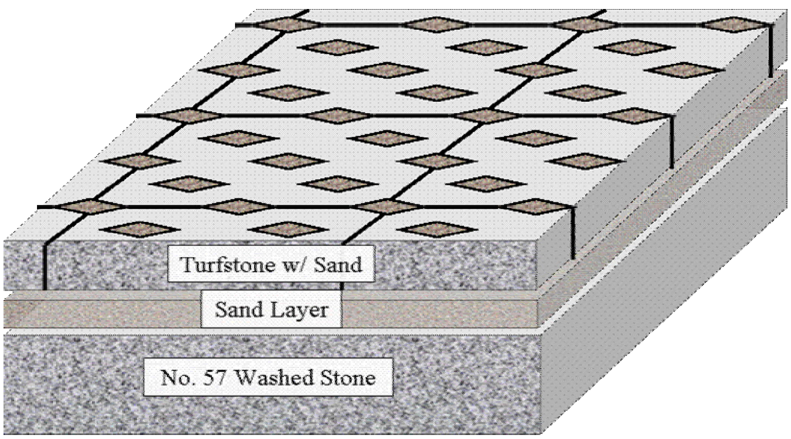
Post-Maintenance Condition Test (cfs/ac):

4.18	1.94	2.81	2.98

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 15:	Bainbridge Beach Access
Type of Surface:	Concrete Grid Pavers
Use:	Beach Access Parking

Size (stalls/sq. ft.):	6100 sq. ft.	16 stalls
Approximate Drainage Area:	9800 sq. ft.	
Construction Date:	1984	
Address:	S. Virginia Dare Tr. & Bainbridge St., Nags Head, NC	
Test Date:	July 16, 2003	
Visual Assessment:	Very sandy with grass in 30% of voids.	
Maintenance Practice:	As needed after large storms (a few times per year).	



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.58	1.07	2.32	1.66

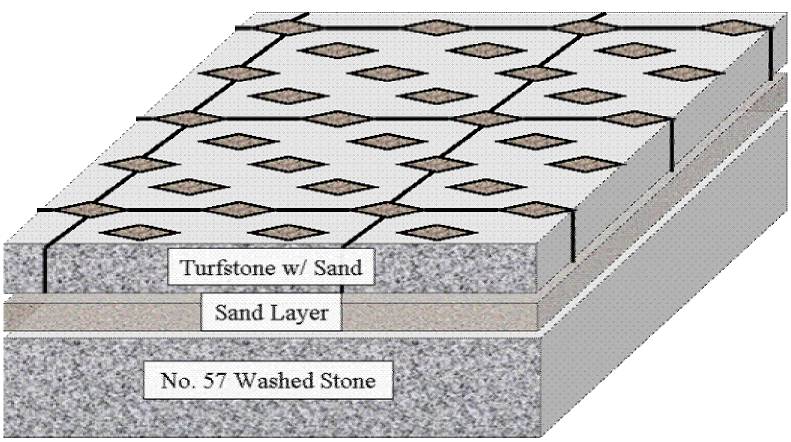
Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.57	1.77	2.16	1.83

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 16:	Conch Beach Access
Type of Surface:	Concrete Grid Pavers
Use:	Beach Access Parking

Size (stalls/sq. ft.):	8200 sq. ft.	20 stalls
Approximate Drainage Area:	9400 sq. ft.	
Construction Date:	1984	
Address:	S. Virginia Dare Tr. & Conch St., Nags Head, NC	
Test Date:	July 16, 2003	
Visual Assessment:	Very loose sand.	
Maintenance Practice:	As needed after large storms (a few times per year).	



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.98	6.26	1.68	3.64

Post-Maintenance Condition Test (cfs/ac):

2.48	3.47	5.93	3.96

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 17: Epstein Beach Access

Type of Surface: Concrete Grid Pavers

Use: Beach Access Parking

Size (stalls/sq. ft.): 12000 sq. ft.

Approximate Drainage Area: 12000 sq. ft

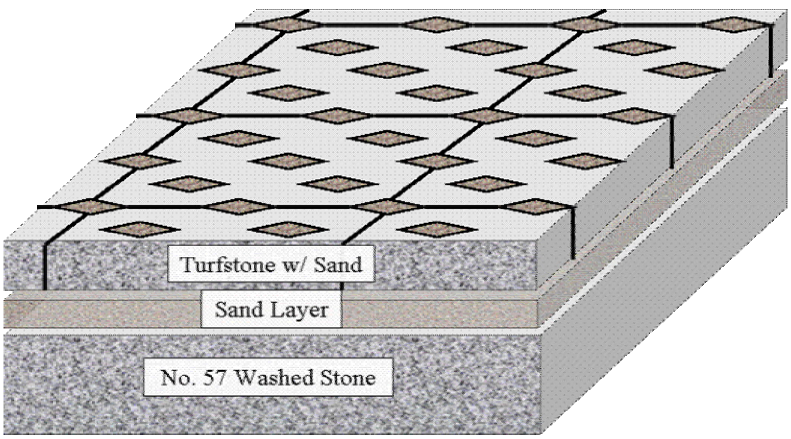
Construction Date: 1984

Address: S. Virginia Dare Trail & E. Blue Water Dr., Nags Head, NC

Test Date: July 15, 2003

Visual Assessment: Sand and some small grass plants in void spaces.

Maintenance Practice: As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

	Run #1	Run #2	Run #3	Average
Existing Conditions Test (cfs/ac)	0.44	3.57	1.01	1.67
Post-Maintenance Condition Test (cfs/ac)	3.03	1.08	7.39	3.84

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 18: Govenor Beach Access

Type of Surface: Concrete Grid Pavers

Use: Beach Access Parking

Size (stalls/sq. ft.): 17 stalls

Approximate Drainage Area: Additional 50' towards beach

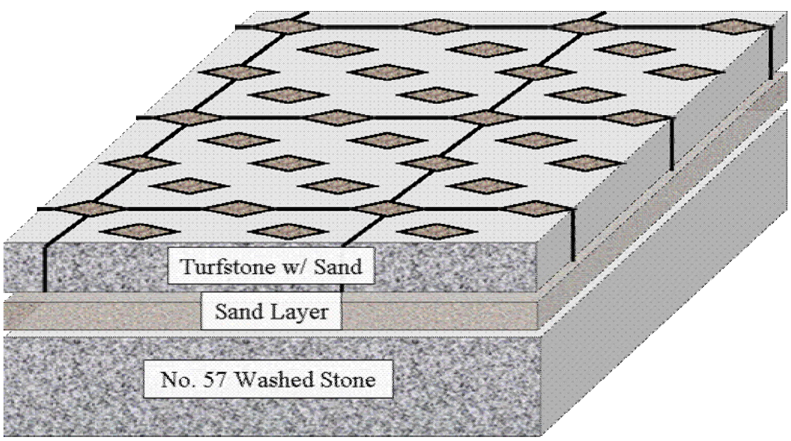
Construction Date: 1984

Address: S. Virginia Dare Tr. & Govenor St., Nags Head, NC

Test Date: July 17, 2003

Visual Assessment: Grass coverage varies from 20-70% and noticeable oil spots.

Maintenance Practice: As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.62	1.70	2.20	1.84

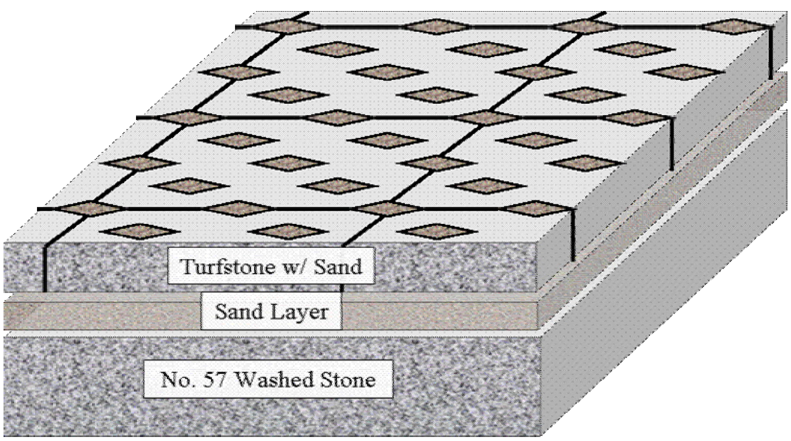
Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.66	2.54	5.00	3.40

Maintenance Performed: Removed top 0.75" of material from drainage pores.

Site 19:	Hargrove Beach Access
Type of Surface:	Concrete Grid Pavers
Use:	Beach Access Parking

Size (stalls/sq. ft.):	8800 sq. ft.	22 stalls
Approximate Drainage Area:	8800 sq. ft.	
Construction Date:	1984	
Address:	S. Virginia Dare Tr. & Hargrove St., Nags Head, NC	
Test Date:	July 17, 2003	
Visual Assessment:	Grass in 60% of voids and looks very sandy.	
Maintenance Practice:	As needed after large storms (a few times per year).	



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
0.79	0.71	0.49	0.67

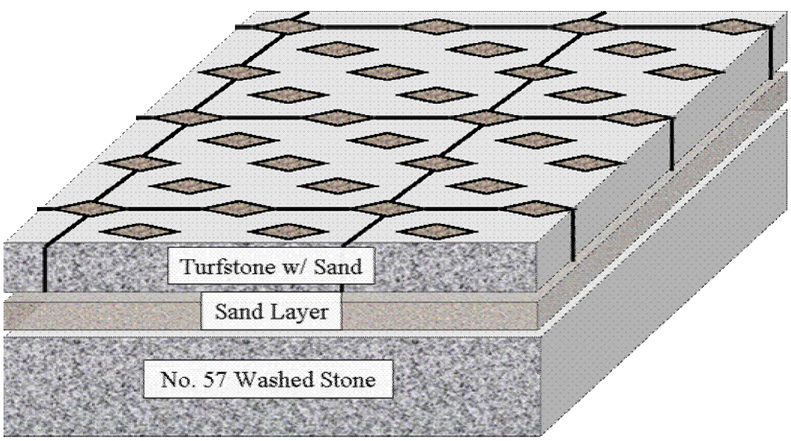
Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.18	1.61	4.95	2.58

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 20:	Loggerhead Beach Access
Type of Surface:	Concrete Grid Pavers
Use:	Beach Access Parking

Size (stalls/sq. ft.):	8600 sq. ft.
Approximate Drainage Area:	11500 sq. ft.
Construction Date:	1984
Address:	S. Virginia Dare Rd. across from Engagement Hill Loop Nags Head, NC
Test Date:	July 15, 2003
Visual Assessment:	Fairly well maintained, some small sprigs in voids.
Maintenance Practice:	As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
1.71	1.59	1.00	1.43

Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.85	1.94	6.28	3.69

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 21: Town of Nags Head Municipal Building

Type of Surface: Concrete Grid Pavers

Use: Parking for beach access, library, and municipal building

Size (stalls/sq. ft.): 4127 sq. ft. 13 spots

Approximate Drainage Area: 6000 sq. ft.

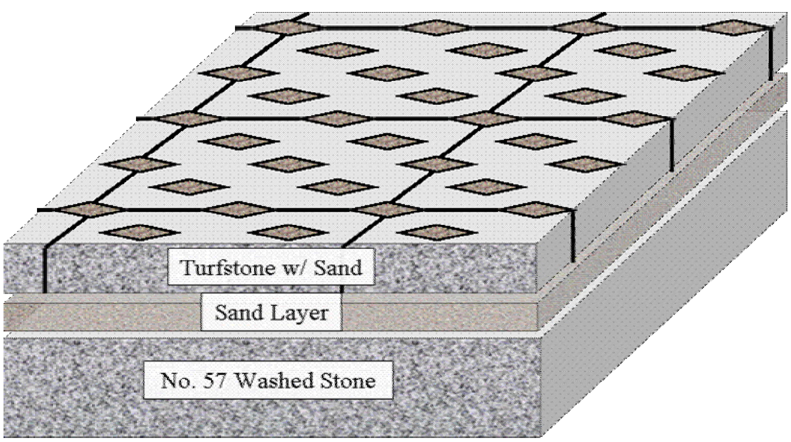
Construction Date: 1982

Address: S. Virginia Dare Trail & Municipal Complex, Nags Head, NC

Test Date: July 14, 2003

Visual Assessment: Grass in voids, fines only on surface of blocks in low lying areas.

Maintenance Practice: As needed after large storms (a few times per year).



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
3.43	3.53	2.50	3.15

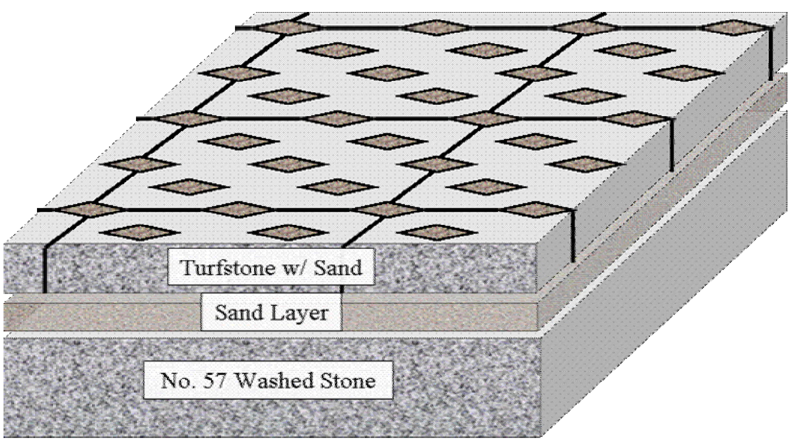
Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
22.82	2.82	6.00	10.56

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 22:	Carrabba's Resteraunt
Type of Surface:	Concrete Grid Pavers
Use:	Overflow parking for multiple resteraunts

Size (stalls/sq. ft.):	14 stalls
Approximate Drainage Area:	3x Pemeable Area
Construction Date:	1999
Address:	15 Van Campen Blvd., Wilmington, NC
Test Date:	July 23, 2003
Visual Assessment:	Grass in 60-80% of void spaces.
Maintenance Practice:	None.



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
2.44	1.41	2.03	1.96

Post-Maintenance Condition Test (cfs/ac):

Run #1	Run #2	Run #3	Average
3.65	2.33	2.91	2.96

Maintenance Performed: Removed top 0.5" of material from drainage pores.

Site 23: Kinston TS

Type of Surface: Concrete Grid Pavers

Use: Police vehicle parking

Size (stalls/sq. ft.): 6300 sq. ft. 20 stalls

Approximate Drainage Area: 6300 sq. ft.

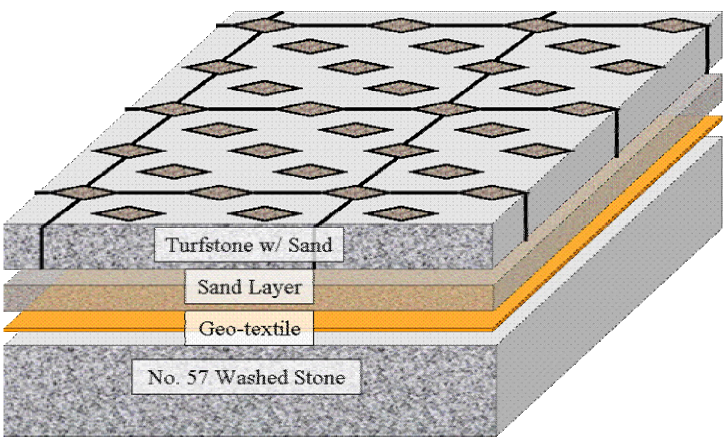
Construction Date: Summer 1999

Address: 207 E. King St., Kinston, NC

Test Date: July 21, 2003

Visual Assessment: Very sandy with less than 10% grass in void spaces.

Maintenance Practice: One sweep per year with a street sweeper.



Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
33.14	12.67	22.74	22.85

Site 24: Wynn Plaza

Type of Surface: Concrete Grid Pavers (w/ Pea Gravel)

Use: Park and beach parking

Size (stalls/sq. ft.): 8 stalls

Approximate Drainage Area: Permeable Area

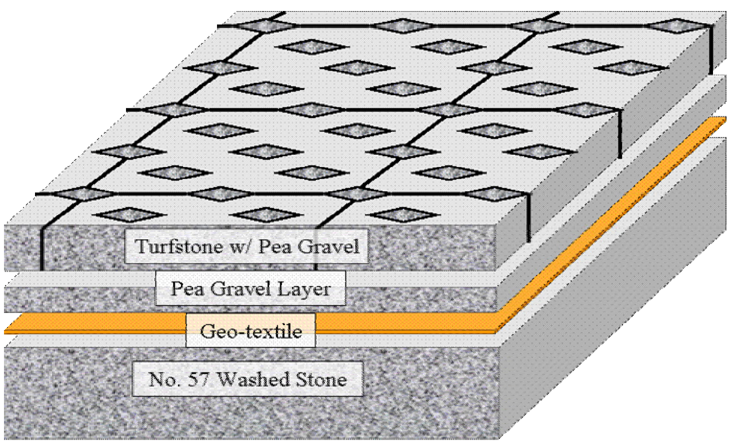
Construction Date: 2001

Address: 101 S. Lumina Ave., Wrightsville Beach, NC

Test Date: July 23, 2003

Visual Assessment: Some sand filled in voids, and negligible grass growth.

Maintenance Practice: Once every two weeks with a street sweeper. (Tracy Dail, Wrightsville Beach)



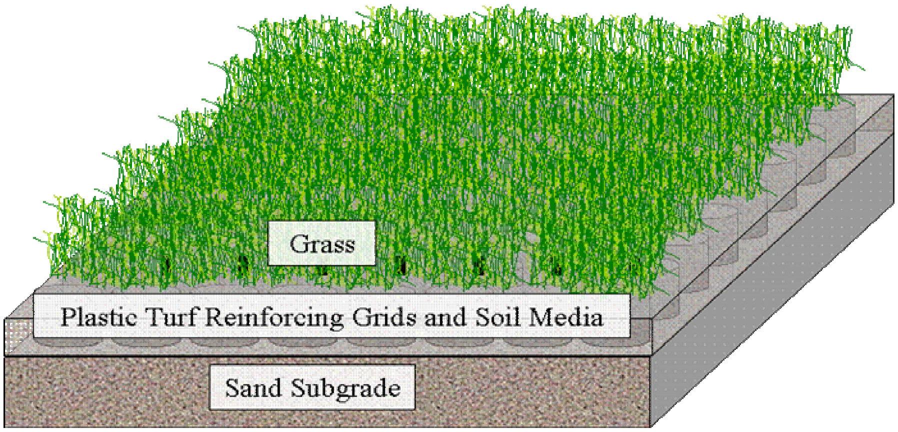
Existing Conditions Test (cfs/ac):

Run #1	Run #2	Run #3	Average
5.19	3.28	5.12	4.53

Site 25:	Kinston PTRG
Type of Surface:	Plastic Turf Reinforcing Grids
Use:	Police Vehicle Parking

Size (stalls/sq. ft.):	1900	sq. ft.	6 stalls
Approximate Drainage Area:	1900	sq. ft.	

Construction Date:	Summer 1999
Address:	207 E. King St., Kinston, NC
Test Date:	July 21, 2003
Visual Assessment:	Some areas with no grass, but grass seems to do well.
Maintenance Practice:	Mowing when needed.



Bare Area (cfs/ac)

Run #1	Run #2	Run #3	Average
3.08	2.09	5.68	3.62

Grassy Area (cfs/ac)

Run #1	Run #2	Run #3	Average
10.96	13.46	12.75	12.39