Pervious Pavement System Evaluation

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Abstract

The use of a pervious pavement can be effective as a low impact development stormwater control. The Urban Watershed Management Branch is evaluating interlocking concrete paver systems as a type of porous pavement. Although the pavers are impermeable, the spaces between the pavers are backfilled with washed, graded stone that acts as structural support for the pavers and also allows water to infiltrate. After passing the paving stones, the stormwater moves through several bedding layers where pollutants are removed. Recent literature shows that the concentration of total suspended solids in the exfiltrate is substantially less than in the infiltrate. Other pollutant constituents are subject to removal by microbial communities that develop with time. Concrete paver systems were chosen for this investigation for several reasons. Layers of the system can be removed, examined, and replaced, facilitating long-term system monitoring and maintenance.

The overall objective of this ongoing project is to assess the pollutant removal efficiency of a pervious pavement system from parking lot runoff. One bench-scale study (hydraulic study) determined the flow rates and materials necessary for the full-scale experiment. Another bench-scale study (microbial study) will examine the role of microbial colonies in pollutant removal performance of this porous pavement micro-environment. Results from the two bench-scale experiments will be used to refine the full-scale investigation. This paper focuses on the hydraulic bench-scale study.

Background

Permeable interlocking concrete pavement is a stormwater best management practice (BMP). The pavers themselves are not permeable, but the spaces in between the pavers allow water to infiltrate. The gaps are filled with washed, graded stone that allows infiltration and provides structural support for the pavers. Recent literature has shown that the concentration of stressors in exfiltrate is substantially less than the infiltrate for other pervious pavement systems because the gravel layers under the surface provide some filtration (James and Thompson 1997, Rushton 2001, Clausen and Gilbert 2003, Ellis et al. 2004). Studies have shown that annual pollutant export in runoff from driveways was 86% lower for paver driveways than impervious asphalt driveways (Clausen and Gilbert 2003, Gilbert and Clausen 2006). The system can also potentially reduce urban heat island effect because the pavers reflect sunlight rather than absorbing it.

Objectives

The overall objective of this ongoing project is to assess the pollutant removal efficiency of a pervious pavement system from parking lot runoff. One bench-scale study (hydraulic study) determined the flow rates and materials necessary for the full-scale experiment. Another bench-scale study (microbial study) will examine the role of microbial colonies in pollutant removal performance of this porous pavement micro-environment. Results from the two bench-scale experiments will be used to refine the full-scale investigation.

This paper focuses on the hydraulic bench-scale study. The primary objectives of the ongoing hydraulic bench-scale study are to:

(1) Determine the flow rate of stormwater through the system;
(2) Compare the total suspended solids (TSS) of the influent stormwater with that of the effluent; and
(3) Determine the performance effects of the prescence/absence of a permeable geotextile filter fabric in the system and to determine performance differences between a woven and non-woven geotextile filter fabric.

Secondary goals of this hydraulic study are to:

(1) Determine the discharge volume of the system;
(2) Determine the breakthrough time of the effluent discharging out of the system;
(3) Monitor clogging of the system as the study progresses.

Experimental Design

Four small-scale pervious paver systems were constructed in 60cm x 60cm x 90cm HDPE plastic bins. Pavers of a minimum of 7.6cm thickness were placed on top of a 2.5cm layer of 1-cm diameter crushed stone and there is 1-cm crushed stone in the gaps between the pavers. There is a maximum of 1.27cm space between the pavers. Below that is a 12.7-cm layer of 1.6-cm diameter angular crushed stone, and a 3.8-cm diameter slotted PVC pipe is positioned at the bottom of the bin. This pipe routes all discharge through the bin wall. The bins are placed at a 1% angle, the same as that of the full-scale pervious pavement design. Two systems were installed with a woven geotextile permeable filter fabric (apparent opening size = 0.425mm, flow rate = 204 L/min/m^2) between the gravel layers, while the other two systems have no filter fabric (Figure 1). The filter fabric separates the gravel layers and possibly increases the solids removal from the stormwater infiltrate.

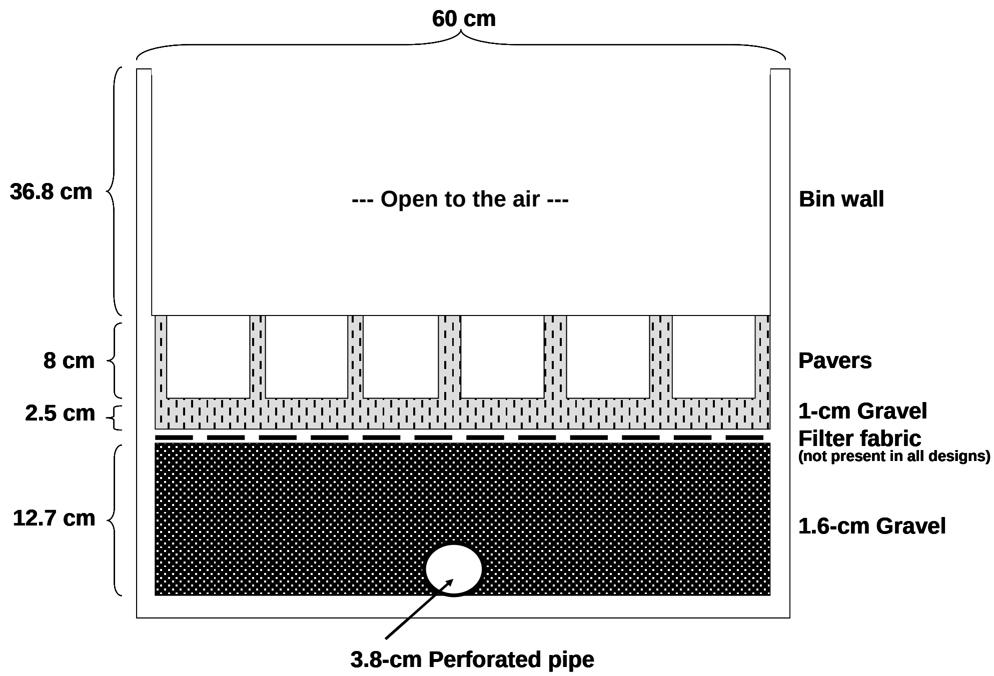

Figure 1. A schematic of the bench-scale porous pavement system. This schematic is not drawn to scale.

Approximately 17L of collected, homogenized, stormwater were "rained" over each tray every workday, twice daily, for 12 weeks. The stormwater gravity-drained from a 19-L bucket with 5-mm holes drilled in the bottom. The bucket was positioned over the center of each bin to ensure that the water landed on the pavers and did not flow down the sides of the bin (Figure 2). The stormwater drained out of the influent bucket in less than 1 hour. The 17L stormwater introduction is the equivalent of a 3cm rain event for the bench-scale paver system (90cm x 60cm). After 12 weeks the study boxes received the equivalent 380 cm of rain, which is 3 times the mean annual precipitation for New Jersey (124 cm/year) (Robinson 2007). By simulating 3 years of rain (introduced as stormwater), the solids loading on the system is accelerated and the effects on the hydraulic and pollutant removal performance on the system can be observed.

The discharge from the bins was collected and the volume was recorded. The depth changes with time in both the influent and effluent bucket were recorded via Global Water meters. Both the influent (stormwater) and the effluent that flowed out of the pipe were analyzed for total suspended solids (TSS). Volatile suspended solids (VSS) were analyzed for selected paired influent (stormwater) samples and effluent samples.

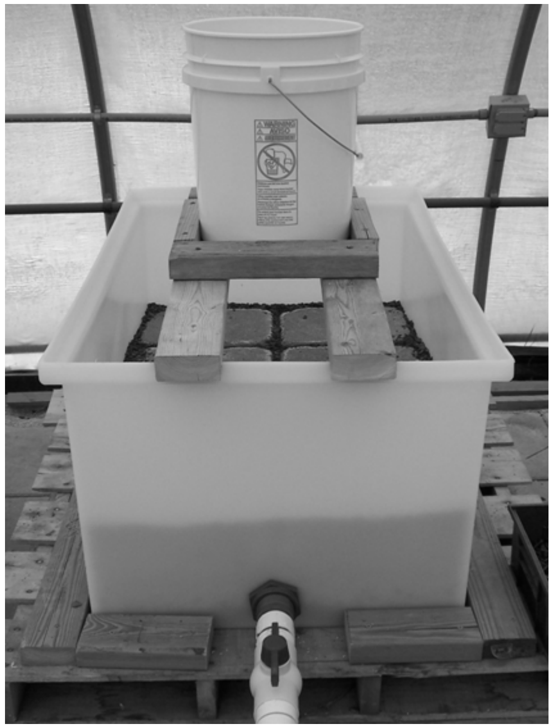

Figure 2. Bench-scale pervious pavement system demonstrating stormwater delivery method.

A second four-bin study was run with two boxes containing a non-woven geotextile filter fabric (apparent opening size = 0.212mm, flow rate = 6095 L/min/m^2) between the gravel layers, and two bins with no filter fabric. This allows a performance comparison between the two filter fabrics. The woven filter fabric has a grid-like polypropylene weave, the apparent opening size is relatively large, and the flow rate is relatively low, while the non-woven filter fabric is made up of needlepunched, polypropylene staple filaments, has a smaller apparent opening size, and has a relatively high flow rate.

Preliminary Results and Discussion

All results discussed here pertain to bins with the woven filter fabric (“lined”) and bins without filter fabric (“unlined”). Results are pending for the experiments with the non-woven filter fabric.

The TSS concentration was measured in both the influent and the discharge from the pervious pavement systems. The influent TSS concentration ranged from 18 mg/L to 228 mg/L over the first 12 weeks of the study. The relative percent removal was larger in the lined bins compared to the unlined bins, but the unlined bins also removed solids. TSS removal by the systems increased as the study progressed, which may indicate that the retained solids increased the filtration efficiency of the systems with time. This retention of solids may also eventually lead to clogging and failure of the systems. This study will continue for at least another 12 weeks. The unlined bins both reached more than 60% TSS removal, while the bins with woven filter fabric both plateaued at over 90% TSS removal (Figure 3).

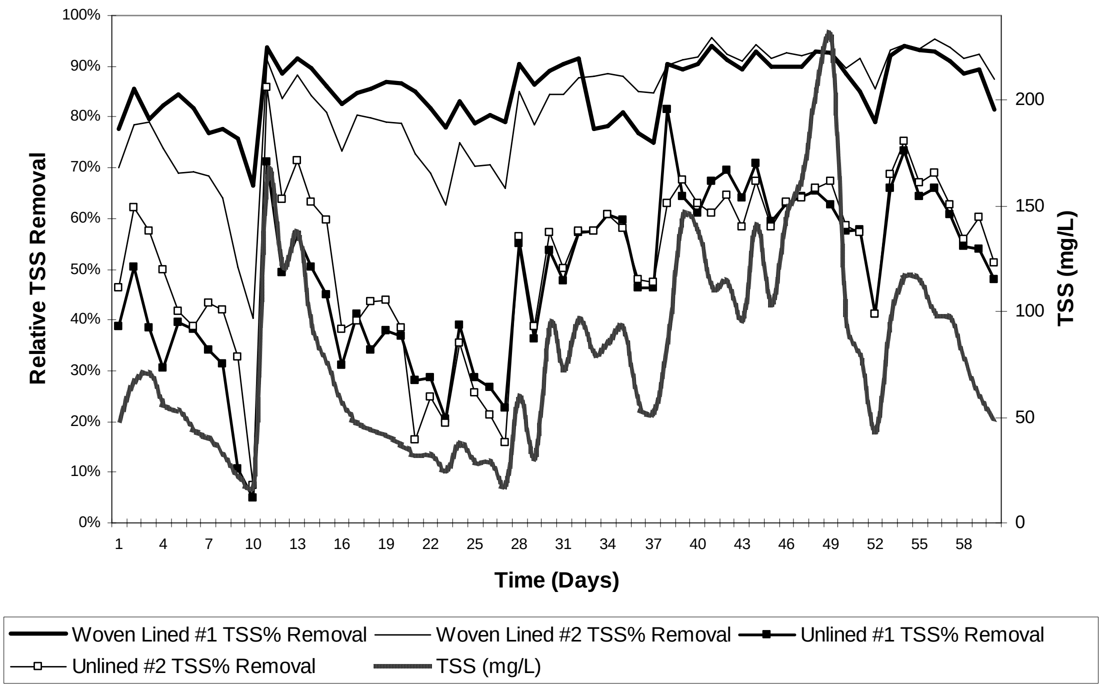

Figure 3. Relative removal of TSS (left axis) for systems with the woven liner and unlined systems for the duration of the study and the daily influent TSS concentration (right axis).

Generally, it appears that relative TSS removal is linked to the TSS concentration of the stormwater influent, although there were days that did not follow that trend. The lined bins, on average, removed about 84% of TSS during the first 12 weeks of the study, while the unlined bins, on average, removed 50% of TSS over that time. TSS removal, the concentration of the effluent subtracted from the concentration of the influent, is linearly correlated with the TSS influent concentration (Figure 4). Both the lined and unlined systems have R^2 values greater than 0.98. The lined bins show a slope of 0.95 and the offset from the 1:1 line is 7. The unlined bins have a much shallower slope at 0.73 and an offset of 13. Both the lined and unlined boxes remove TSS well, but the lined bins show greater efficiency than the unlined bins, especially when the influent TSS concentrations are higher than average.

The effluent flow rates differed between the lined and unlined systems, as well. The lined bins infiltrated more slowly and peaked at a lower flow rate than the unlined bins (Figure 5). This finding may have ramifications for the full-scale parking lot because the drainage time for a large storm event may be significantly longer if a filter fabric is installed; however, this longer detention time may lead to more efficient pollutant removal.

Average peak exfiltration rates were consistently higher in the unlined bins than the lined bins. This is likely due to the resistance to flow that the liner presents. The unlined average peak infiltration rate was 7% higher than that of the lined (Table 1).

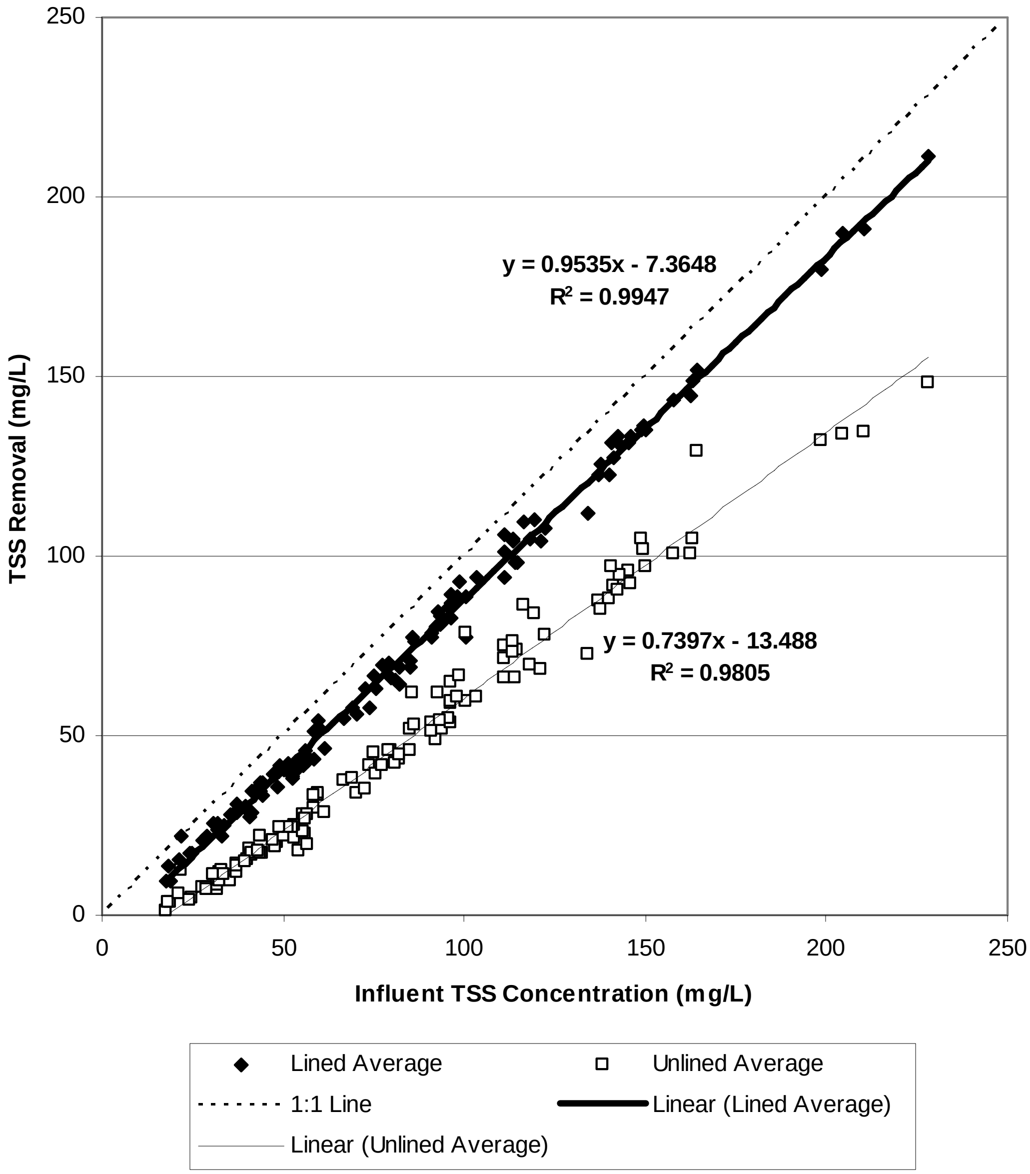

Figure 4. Average TSS removal for lined and unlined bins compared to the influent TSS concentration. The linear equation and R^2 values for the regressions are shown.

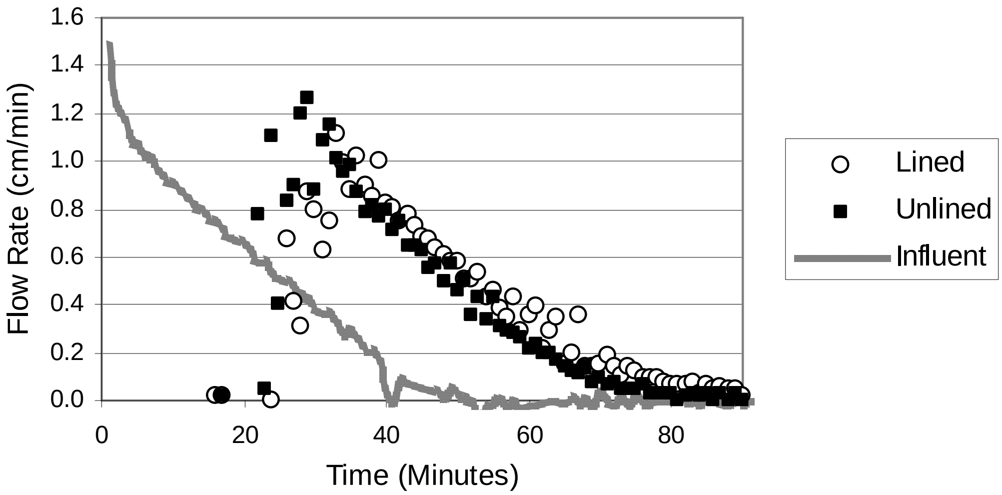

Figure 5. Average effluent flow rates for the two types of systems for one rain event with influent rate shown.

Table 1. Average peak infiltration rates for the systems for the last three weeks of the study.

System.	Average Peak Exfiltration Rate ± Standard Deviation (cm/min)
Lined #1	1.28 ± 0.19
Lined #2	1.25 ± 0.36
Lined Average	**1.26 ± 0.02**
Unlined #1	1.44 ± 0.21
Unlined #2	1.28 ± 0.27
Unlined Average	**1.36 ± 0.11**
7% difference between lined and unlined peak infiltration rates.	

Future Work

Once the hydraulic studies are complete, the microbial bench-scale study will begin. The role of microbial communities on the performance of the pervious pavement systems will be examined. Microbial removal of pollutants can be an effective method for reducing concentrations at contaminated sites (Hutchins et al. 1998, Ellis et al. 2000, Townsend et al. 2003, Shi et al. 2005).Therefore, pollutant removal in porous pavement systems may be further enhanced with the expedited establishment of microbial colonies in the gravel layers. Microbial growth effects will be observed with respect to the following variables: inoculation of microbes on the filter fabric, the presence and location of a carbon source in the system, and the detention of stormwater in the system.

The full-scale study is expected to start in the fall of 2008. The full-scale study, in cooperation with EPA's Region 2, will focus on a 1-acre parking lot with 110 parking spaces that will have three porous pavement systems: porous asphalt, porous concrete, and porous pavers. The roadways of the parking lot will be conventional asphalt and the parking islands will be pervious. The pervious asphalt parking area will be installed to the specifications of the National Asphalt Pavement Association, the pervious concrete will be constructed following Standard 522.1 of the American Concrete Institute, and the porous pavers will be installed to the specifications of the Interlocking Concrete Pavement Institute.

The exfiltrate from the porous parking islands will be collected and monitored for selected water quality parameters and pollutants. The parking lot will also be installed with monitoring equipment to measure a variety of other parameters such as: sub-grade moisture, sub-grade temperature, water depth, ambient temperature, meteorological conditions, and parking lot usage (car counter). The lot will be maintained (sweeping, vacuuming), but schedules will be varied to determine maintenance recommendations for these types of pervious surfaces. The parking lot will also be observed for signs of aging, surface degradation, clogging of surfaces, and system failure. Monitoring of the lot will continue until lot failure; however, it is expected that monitoring will be scaled back after the first 10 years of use. The expected parking lot lifetime is 20 years.

Conclusions

The hydraulic bench-scale study yielded results that are critical for achieving success in the full-scale parking lot study. Both lined and unlined systems removed TSS, the removal improved with time, and the lined systems showed 84% relative TSS removal, on average. The increased relative TSS removal over time may indicate that there is a solids buildup, which may result in system clogging. The hydraulic bench-scale study has been extended to determine if clogging will lead to system failure. The second hydraulic bench-scale study has begun and the performance of a non-woven geotextile filter fabric will be compared to that of the woven fabric. This study showed that the stormwater in the systems with liners infiltrates more slowly than in the systems without liners. The peak exfiltration rates were also 7.2% lower for the lined bins compared to the unlined.

It has been shown that, at the bench-scale level, porous paver systems remove TSS from stormwater runoff. It has also been shown that the use of a filter fabric liner in a pervious pavement system has both advantages and disadvantages (higher TSS removal vs. slower infiltration rates, higher possibility of clogging due to higher retention of solids). The success of the full-scale parking lot is dependent on proper design and these bench-scale studies will help direct those design decisions.

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