A Solution to Clogging of Porous Pavements

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Porous pavements are designed to allow moisture to flow through the surface into an underlying reservoir or into the subgrade soil. Porous pavements prevent pollutants from entering into the water table and therefore, are considered sustainable construction. However, porous pavements eventually fill with debris and get clogged, preventing water infiltration. Thus, the greatest barrier to use of porous pavements is susceptibility to clogging. Therefore, a major maintenance cost for porous pavements is preventing clogging of the void spaces within the pavement. Currently, this maintenance is done using vacuum sweepers and high pressure water. However, this process is expensive and potentially can damage the pavement. This paper describes a potential process of removing particles trapped in the pores of the pavement by flushing water from the bottom to the top of pavement. Four variables were evaluated in this laboratory experiment to determine effects on particle removal. These were: 1) water pressure, 2) clogging material, 3) pavement porosity, and 4) number of flushes. Results indicate the reverse flush process was effective on both types of clogging material evaluated, was independent of the pavement porosity and worked for the lowest pressure tested.

Keywords: Porous pavement, pavement maintenance, storm water retention, sustainable paving, clogging

INTRODUCTION

Increased runoff rates from traditionally paved surfaces have increased peak flow through stream channels causing erosion and stream bank instability and overland erosion (Bean, Hunt, Bidelspach, & Smith, 2004; Leopold, Wolman, & Miller, 1964). In addition, thermal enrichment is a critical stressor of aquatic habitats and ecology downstream of urban areas (James, W., & Langsdorff, H., 2003). Consequently, drainage has become more of an issue in site development all over the world. Porous pavements are an alternative to traditional asphalt or concrete surfaces which may help alleviate some of these issues. Porous pavements are asphalt or concrete pavement surfaces designed to allow moisture to flow through the surface into an underlying reservoir or into the subgrade soil (Bachtle, 1974). Porous pavements prevent pollutants from entering into the water table and therefore, are considered sustainable construction (United States Environmental Protection Agency, 1999). This allows cleaner water to replenish ground water or flow into lakes and streams (Mississippi Concrete Industry Association, 2005). Porous pavement was constructed for the first time at the Franklin Institute, Philadelphia, Pennsylvania (Bachtle, 1974). Unlike traditional asphalt which has approximately 4 to 6 percent void volume (Asphalt Institute, 2003), porous pavements typically provide a void content of 15 to 25 percent, offering improved filtration and an enormous amount of surface area to catch oils and chemical pollutants (National Ready Mix Concrete Association, 2004).

Porous pavements are recommended on sites with gentle slopes, porous soils, and relatively deep water table and bedrock levels. Soils should be well or moderately well drained. Since, subgrade soils differ in their capacity to percolate water, design of porous pavements varies based on soil type. (The Urban Land Institute, 1992). Porous concrete systems should be used with slopes no greater than 2 percent. If low spots are unavoidable in the pavement, it is advisable to install drop inlets to divert runoff into the stone reservoir more quickly (Urban Land Institute, 1981). Because this pavement type has the ability to retain stormwater it is recognized as a best management practice (BMP) for stormwater management by the U.S. Environmental Protection Agency (The Pervious Company, 2005).

Porous pavements contain four layers as shown in Figure 1. These are:

1. Porous Pavement Layer – The porous pavement layer consists of an open-graded paving mixture varying in thickness depending on pavement design requirements. Porous concrete is designed to compressive strengths between 4137 kPa (600 psi) and 10,342 kPa (1500 psi) (National Ready Mix Concrete Association, 2004). Porous asphalt pavement is an open-graded mixture from two to four inches thick depending on structural requirements. This mixture consists of an asphalt concrete containing less fine aggregate than a dense graded mixture, with a void volume of approximately 16 percent compared to 4 percent for conventional asphalt concrete (The Urban Land Institute, 1981). Pervious pavement is much more porous than underlying soils. Typical infiltration rates are 635 to 762 cm/hr (250 to 300 inches per hour) (Permeable Pavement, 2000).
2. Top Filter Layer – Consists of 12.5 mm (1/2 inch) crushed stone in a thickness of 2.5 to 5 cm (1 to 2 inches) This layer serves as a base course for the porous pavement layer.
3. Reservoir Layer – The reservoir gravel base course consists of washed 37.5 to 62.5 mm (1.5 to 2.5 inch) gravel with a void volume of approximately 40 percent. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void volume, but typically ranges from two to four feet with a minimum depth of nine inches.
4. Bottom Filter Layer – The surface of the subgrade should be covered with a geotextile filter fabric and then either a 6 inch layer of sand (ASTM C-33 concrete sand) or a 50 mm (2 inch) thick layer of 12.5 mm (1/2 inch) crushed. This layer serves to stabilize the reservoir layer, to protect the underlying soil from compaction, and act as the interface between the reservoir layer and the filter fabric covering the underlying soil.

The susceptibility of a porous pavement to clogging is a major disadvantage in porous pavement applications (Siew-Ann et al., 2003). Periodic maintenance is critical, and surfaces should be cleaned with a vacuum sweeper at least three times per year (Permeable Paving, 2006). The clogging of the void spaces within the porous base by foreign particles can severely reduce its drainage capacity. This reduces the service life of the porous base layer within the pavement. (Siew-Ann et al., 2003).

Clogging can be remedied by maintenance, either by vacuum truck, street sweeper or high pressure washing (Balades et al., 1995; Bean et al., 2004). To maintain the infiltrative capacity of porous pavements, quarterly vacuum sweeping in conjunction with jet hosing or jet hosing alone is recommended (Schueler et al., 1992). Therefore, the installation of porous pavement Best

Management Practices (BMP) in regions that lack the equipment or resources for routine maintenance is not recommended (Pratt et al., 1995).

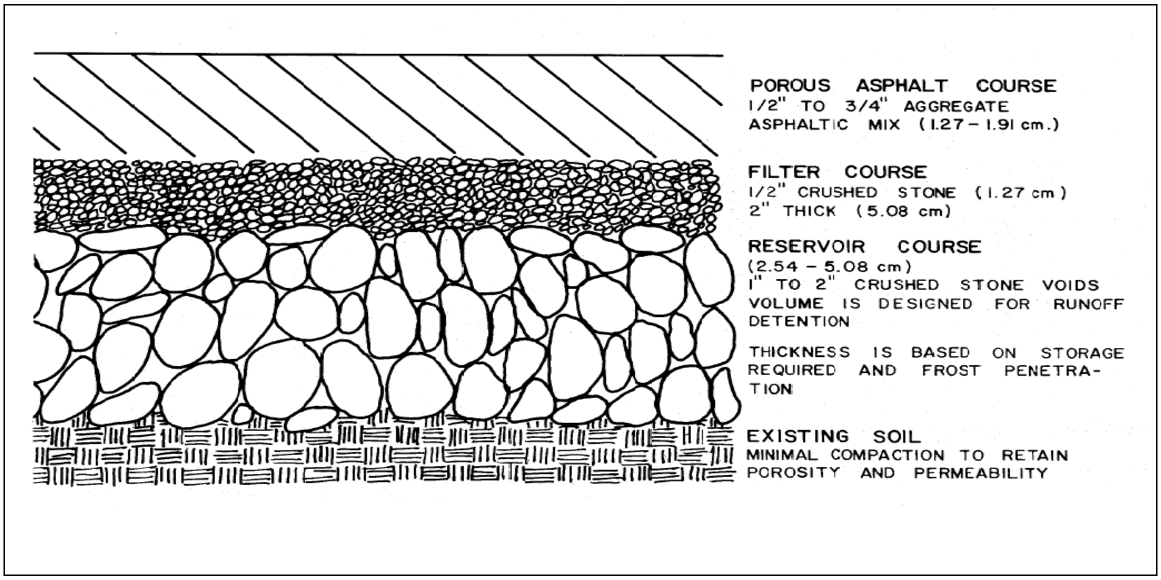

Figure 1. Typical Cross-section of Porous Pavements. (The Urban Land Institute, 1992)

METHOD

Maintaining permeability of porous pavements is cumbersome using present surface vacuum and high pressure spraying techniques. These processes are capable of restoring permeability, but they require regular scheduling and potentially can reduce the service life of asphalt pavements due to stripping of the asphalt film by the water. Therefore, this research investigated an alternative method of cleaning porous pavement structures using a reverse water flushing process. This reverse flushing method consists of moving water through the pavement from the bottom to the top with enough pressure to remove the debris particles trapped in the pavement pores.

Variables that seemed likely candidates for study were tested in a laboratory apparatus to determine the effect of each on permeability. These factors were: initial permeability, water pressure, clogging material type, and number of flushes.

Experiment Design

An experiment was designed to evaluate the effect of the four independent variables described above on permeability restoration. The experiment was designed as a full factorial with replication according to the model shown below:

$$Y_{ijklm} = \mu + P_i + B_j + C_k + N_l + PB_{ij} + PC_{ik} + PN_{il} + BC_{jk} + BN_{jl} + CN_{kl} + PBC_{ijk} + PBN_{ijl} + BCN_{jkl} + PBCN_{ijkl} + \varepsilon_{ijklm}$$

where,

Y_{ijklm} = permeability for the ith permeability, jth backflush, kth clogging material, lth flush and mth replicate

μ = the overall mean

P_i = effect of the ith permeability, i = 1, 2

B_j = effect of the jth pressure, j = 1, 2, 3, 4

C_k = effect of the kth clogging material, k = 1, 2

N_l = effect the lth number of flushes, l = 1, 2

PB_{ij}, PC_{ik}, PN_{il}, BC_{jk}, BN_{jl}, CN_{kl}, PBC_{ijk}, PBN_{ijl}, BCN_{jkl}, $PBCN_{ijkl}$ = interaction effects

ε_{ijklm}= random error

Initial permeability was controlled by designing two porous concrete mixtures with significantly different porosity. Backflush pressure was varied by establishing differing constant water pressure heads for the backflush process. These were set at 3.5, 7.0, 14.0, and 21 kPa (0.5, 1.0, 2.0 and 3.0 psi). The materials used to clog the porous concrete samples were selected as a well graded and a poorly graded sand to replicate likely materials actually causing clogging in the field. Two flushes were evaluated to determine if a second flush provided any gain in permeability. This design produced an experimental matrix consisting of a 4 x 2 x 2 x 2 = 32 x 3 replicate factorial requiring 96 runs of the experiment. Testing sequence was selected at random from the matrix so that data analysis could be accomplished using conventional analysis of variance (ANOVA) techniques.

Experimental Process

The experiment was conducted by building the variable head permeameter shown in Figure 2 using the two different porous concrete mixes described in Table 1.

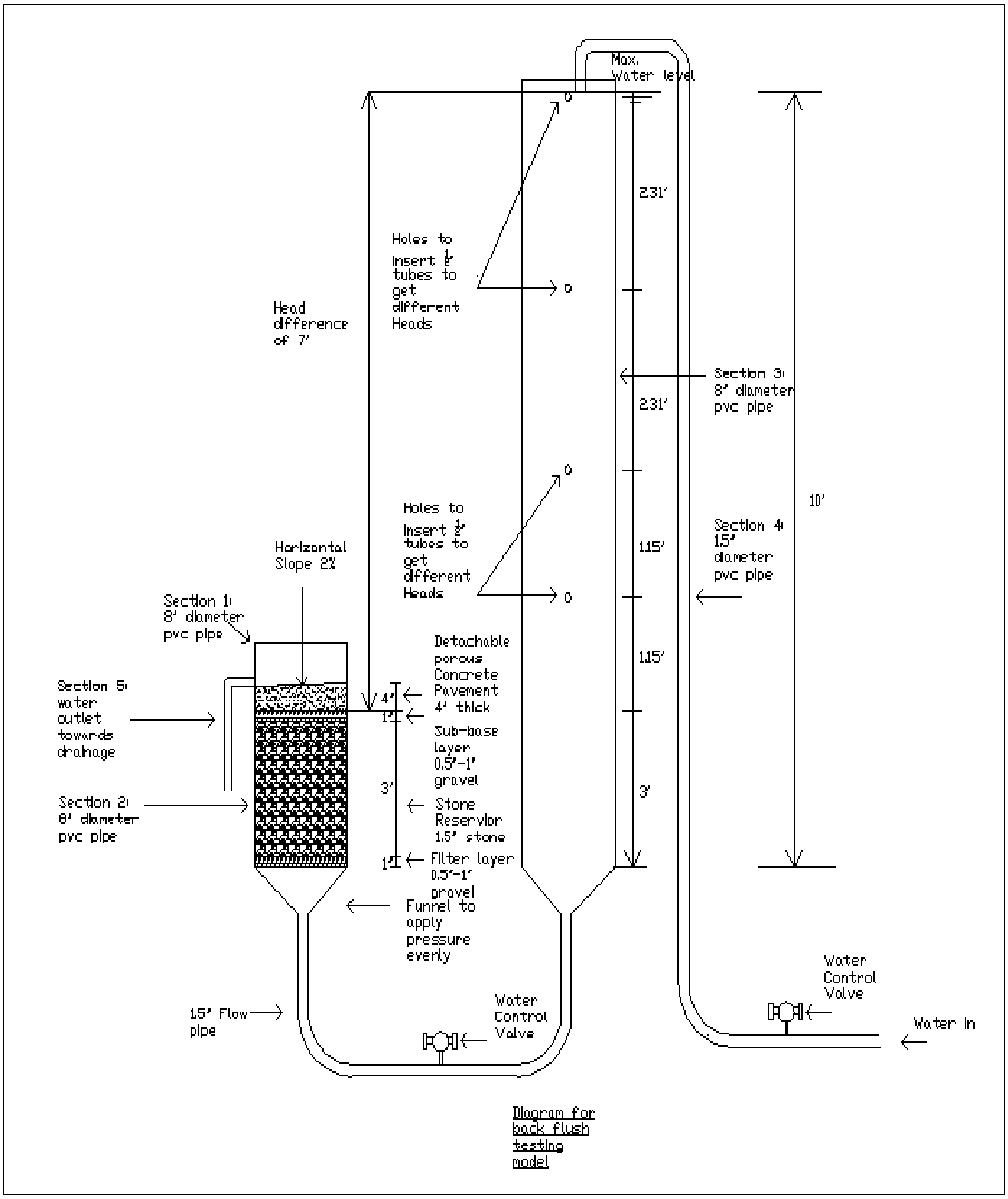

Figure 2. Experimental Apparatus

Table 1. Porous Concrete Specimens

	Concrete 1	Concrete 2
Type I/II Cement, kg (lbs)	272 (600)	272 (600)
3/8" Gravel, kg (lbs)	1315 (2900)	1315 (2900)
Water, kg (lbs)	110 (242)	110 (242)
28 day Compressive Strength, kPa (psi)	6171 (895)	8026 (1164)
Initial Porosity, cm/hr (in/hr)	2431 (957)	1214 (478)

* Differing porosity was achieved by compacting Concrete 2

The 3/8 inch gravel consisted of 100 percent passing the 9 mm (3/8 inch) sieve, 2 percent passing the 4.75 mm (No. 4) sieve and 0 percent passing the 2.38 mm (No. 8) sieve.

Two sands were selected to clog the voids of the concrete test specimens. The properties of these sands are shown in Table 2.

Table 2. Properties of Clogging Sands

	Passing, %	
Sieve Size	Sand 1	Sand 2
9 mm (3/8 in)	100	100
4.75 mm (No. 4)	96	100
2.36 mm (No. 8)	82	93
1.18 mm (No. 16)	62	70
0.60 mm (No. 30)	42	45
0.30 mm (No. 50)	24	16
0.15 mm (No. 100)	10	2
0.075 mm (No. 200)	1	0
Classification,ASTM D2487	SW	SP

The pavement test specimen consists of four segments. The top layer is a detachable, 100 mm (4 inch) thick porous concrete layer. Next is a 50 mm (2 inch) thick filter layer consisting of 12.5 mm (½ inch) gravel. The next layer consists of 37.5 mm (1-1/2 inch) crushed stone 75 mm (3 inches) thick. Finally, a 25 mm (1 inch) thick layer of 12.5 mm (½ inch) gravel is placed as a filter layer. A bell shape funnel is connected at the bottom of the pavement test specimen to apply water pressure gradually and evenly into the pavement section.

The coefficient of permeability was calculated according to the following formula:

$$k = \frac{QL}{Ath}$$

where,

k = permeability, cm/sec (in/sec)
Q = quantity of flow, cm^3 (in^3)
L = length of specimen, cm (in)
A = cross-sectional area of specimen, cm^2 (in^2)
t = interval of time over which flow Q occurs, s
h = difference in hydraulic head across the specimen, cm (in)
(Maupin, 2000).

The efficiency of the reverse-flush was determined by calculating the percentage removal of particles as follows:

Percentage of clogged particles removed after reverse-flushing =

$$\frac{\text{Permeability after Reverse Flushing}}{\text{Permeability before Clogging}} \times 100$$

RESULTS

The full factorial experimental matrix shown in Table 3 was analyzed using a conventional multiple ANOVA to determine whether the independent variables or their interactions had a statistically significant effect on clogging removal at $\alpha = 0.05$.

Table 3. Percentage Removal of Clogged Particles After Reverse-Flushing

Porosity >	2431 cm/hr (957 in/hr)				1214 cm/hr (478 in/hr)			
Clog >	SW		SP		SW		SP	
Flush >	1	2	2	2	1	2	1	2
Pressure, kPa (psi) 3.5 (0.5)	59.24 54.21 77.17	65.43 72.25 85.12	54.30 91.08 73.51	71.20 59.25 49.41	52.76 70.21 74.48	53.53 74.08 68.25	64.30 48.26 67.41	72.78 49.98 80.49
7.0 (1.0)	68.06 66.23 52.53	79.30 78.26 63.19	56.00 95.15 59.62	49.41 83.67 59.27	72.61 55.11 39.61	78.34 45.49 66.79	45.08 82.51 64.08	46.74 83.47 77.19
14.0 (2.0)	87.01 80.10 69.75	94.92 83.21 65.25	60.59 94.68 56.78	58.67 75.28 43.81	75.01 82.96 54.93	70.28 90.21 81.44	43.80 81.08 87.39	58.91 69.53 80.48
21.0 (3.0)	52.44 87.87 78.53	72.43 88.13 80.35	81.85 61.30 84.63	74.00 69.80 74.23	65.71 73.66 89.74	82.42 81.17 94.61	79.56 95.99 94.53	84.08 81.75 90.10

The results of this analysis are shown in Table 4.

Table 4. ANOVA for Percent of Clogging Sand Removed

Source	DF	F	Pr > F	Sig @ α=0.05?
Pressure	3	5.58	0.0018	Yes
Porosity	1	0.03	0.8602	No
Clogging	1	0.40	0.5291	No
Flush	1	0.47	0.4962	No
Clogging*Flush	1	3.39	0.0700	No*

* Almost significant

In addition, the data was further analyzed using the Student Newman-Keuls procedure to determine which of the significant variables were significantly different. The results of this analysis are shown in Table 5.

Table 5. Student Newman-Keuls for Percent of Clogging Sand Removed

Pressure, psi	Mean	Grouping*
3.0	79.95	A
2.0	72.75	BA
0.5	66.19	B
1.0	65.32	B

*Like letters are not statistically significant at $\alpha = 0.05$

Analysis indicates the pressure used for reverse-flushing is a significant main factor affecting removal of the clogging of the porous concrete. This is good since it is intuitive this would be true. The ANOVA indicates an F-statistic for pressure as 5.58 which results in a probability of the critical F statistic exceeding this of 0.0018 which is below the $\alpha = 0.05$ threshold. Further analysis by the Student-Newman-Keuls test indicates the 21 kPa (3 psi) pressure is significantly different than 3.5 kPa (0.5 psi), and 7 kPa (1 psi) pressure levels, but not different than 14 kPa (2 psi). And, 3.5, 7, and 14 kPa (0.5, 1, and 2 psi) pressure levels are not significantly different from each other. This means there is no significant difference between 72.75 percent (14 kPa (2.0 psi)) and 66.19 percent (3.5 kPa (0.5 psi)) clogging removed. But there is a significant difference between 79.95 percent (21 kpa (3.0 psi)) and 65.32 percent (7 kPa (1.0 psi)).

The only two way interaction that was somewhat significant was the Clogging*Number of Flushes interaction with a probability of being greater than the critical F statistic at 0.07. This would mean that when the type of sand is combined with the number of flushes, the amount of particle removal may be affected.

DISCUSSION

1. The pressure used to unclog the porous concrete in this experiment was the only significant variable affecting percent removal of clogged particles at $\alpha = 0.05$. The highest pressure of 21 kPa (3.0 psi) and the next highest of 14 kPa (2.0 psi) removed particles equally well with no statistical difference at about 80 and 73 percent, respectively. Although statistically different at these pressure levels, percent removal at 3.5 kPa (0.5 psi) of about 66 percent is encouraging.
2. The number of flushes used to clear the test specimen, the type of sand used to clog the test specimen and the porosity of the test specimen were not significant variables with respect to removal of particles. This is also encouraging since it indicates a minimal

number of flushes could clean porous pavements in practice, the method is insensitive to the character of the particles, and variability with respect to porosity of the pavements would not affect particle removal.

3. The results of this experiment indicate that reverse flushing of porous pavements with water at relatively low pressure levels should be an effective process for maintaining pavement porosity.

RECOMMENDATIONS

1. A wider variety of clogging materials should be evaluated. Two classifications of sand used in this experiment did not significantly affect the removal process. However, sand mixed with clay or pure clay might be more difficult to remove and would provide a wider representation of materials. The interaction effect of clogging*number of flushes which was nearly significant at $\alpha = 0.07$ may be an indication of this.
2. Although two porosities of concrete were used in this experiment, and reflect representative concrete used in the field for porous pavements, a wider range of porosities would be desirable to reflect every possibility that could be encountered. This data could be used to develop a model to predict the amount of pressure needed to unclog a wider variety of pavements.
3. A full-scale experimental trial should be conducted to determine how this technology could be implemented.

REFERENCES

Asphalt Institute, *Mix Design Methods for Asphalt Concrete and Other Hot Mix Types*, MS-2, 2003.

Bachtle, E. (1974, February). Ecological parking lot has porous pavements. *Water Well Journal*, *105*(2), 18-19.

Balades, J., Legret, M., & Madiec, H. (1995). Permeable Pavements: Pollution Management Tools. *Water Science and Technology*, *32*(1), 49-56.

Bean, E., Hunt, W., Bidelspach, & D. Smith, J. (2004, May). Study on the surface infiltration rate of porous pavements. Washington, DC: Interlocking Concrete Pavement Institute.

James, W., & Langsdorff, H. (2003, October). Computer aided design of porous concrete block pavement for reducing stressors and contaminants in an urban environment. Retrieved on November 2, 2005 from, http://www.advancedpavement.com/028.pdf

Leopold, L., Wolman, M., & Miller, J. (1964). Fluvial Processes in Geomorphology. San Francisco, C. A.: W.H. Freeman and Company.

Mississippi Concrete Industry Association, retrieved on 20th October, 2005 from, http://www.mississippiconcrete.com

National Ready Mix Concrete Association (2004). Concrete in Practice, Retrieved on October 13th 2006 from http://www.concretetechnologyforum.org/documents/CIP%2038.pdf
Permeable Pavement (2000). Natural Approaches to Stormwater Management, Retrived on October 12, 2006 from, http://www.psat.wa.gov/Publications/LID_studies/porous_pavement.htm

The Pervious Company retrieved on 15th October from, www.secement.org

Pratt, C., Mantle, J., & Schofield, P. (1995). UK Research into the Performance of Permeable Pavement, Reservoir Structures in Controlling Stormwater Discharge Quanitity and Quality. *Water Science and Technology*. 32(1): 63-69.

Siew-Ann, T., Tien-Fang, F., & Chong-Teng H. (2003, May/June). Clogging Evaluation of Permeable Bases. *Journal of Transportation Engineering*, 309-315.

United States Environmental Protection Agency (1999), retrieved on October 10, 2005 from http://www.epa.gov

The Urban Land Institute (1981). Porous Asphalt Pavement. Retrieved on October 3, 2005 from, http://www.deq.state.mi.us/documents/deq-swq-nps-pap.pdf