NORTH CAROLINA STATE UNIVERSITY EVALUATES PERMEABLE PAVEMENTS

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The Biological and Agricultural Engineering Department at North Carolina State University is taking a second look at permeable pavements at a test site in Kinston, North Carolina. The project evaluates runoff from four types of permeable pavement and asphalt. Preliminary results show substantial runoff volume and peak flow reductions. While the jury is still out on pollutant reductions, the verdict is expected to confirm the effectiveness of permeable pavements in water quality improvement. The results speak to their effectiveness as a best management practice (BMP) and as a tool for residential and commercial low-impact development.

This magazine reported on earlier work headed by Professor Bill Hunt who examined the surface infiltration of various types and ages of permeable and grid pavements (August, 2004) as well as runoff from a small permeable pavement and asphalt parking lot in Goldsboro, North Carolina (May, 2006). Professor Hunt's work in Goldsboro, North Carolina has shown that when compared to runoff from an adjoining asphalt lot, PICP exfiltrates contained significantly lower concentrations of phosphorous and zinc, as well as reductions in total nitrogen. His research enabled the North Carolina Department of Environment and Natural Resources (DENR) to give pervious area credits to permeable pavements used in the eastern part of the state.

North Carolina and several other states recognize the surface runoff reduction benefits of permeable interlocking concrete pavement (PICP). These benefits have been expressed in several BMP or best management practice manuals to manage stormwater and reduce pollution of lakes, streams and rivers. While North Carolina has recognized the runoff reduction capabilities of PICP, DENR officials have yet to credit it with reducing pollutants and improving water quality. A reduction in stormwater runoff through the infiltration benefits of PICP has a corresponding reduction in pollutants. However, the extent of pollutant reduction requires further study before DENR decides to amend credits for water quantity reduction with water runoff quality improvement.

Figure 1. Runoff quantities and pollutants from asphalt and four permeable pavements are being evaluated by North Carolina State University in at a municipal-owned parking lot in Kinston, North Carolina.

Figures 1 and 2 show the parking lot with the various pavement types. The permeable pavement sections consist of PICP with 8.5% surface openings, PICP with 12.9% surface

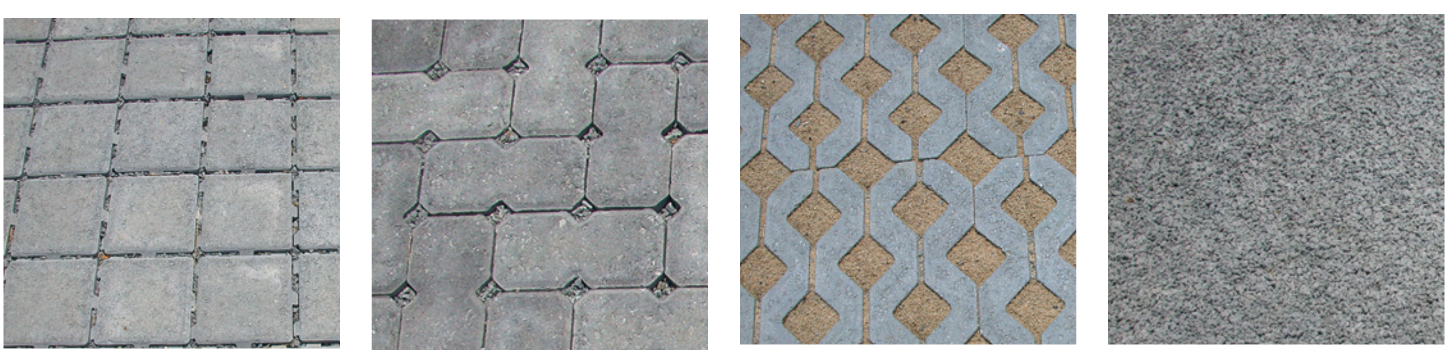

Figure 2. Four runoff-reducing surfaces under evaluation include two types of permeable interlocking concrete pavement with open-graded stone in the openings, concrete grid pavement with sand in the openings and pervious concrete.

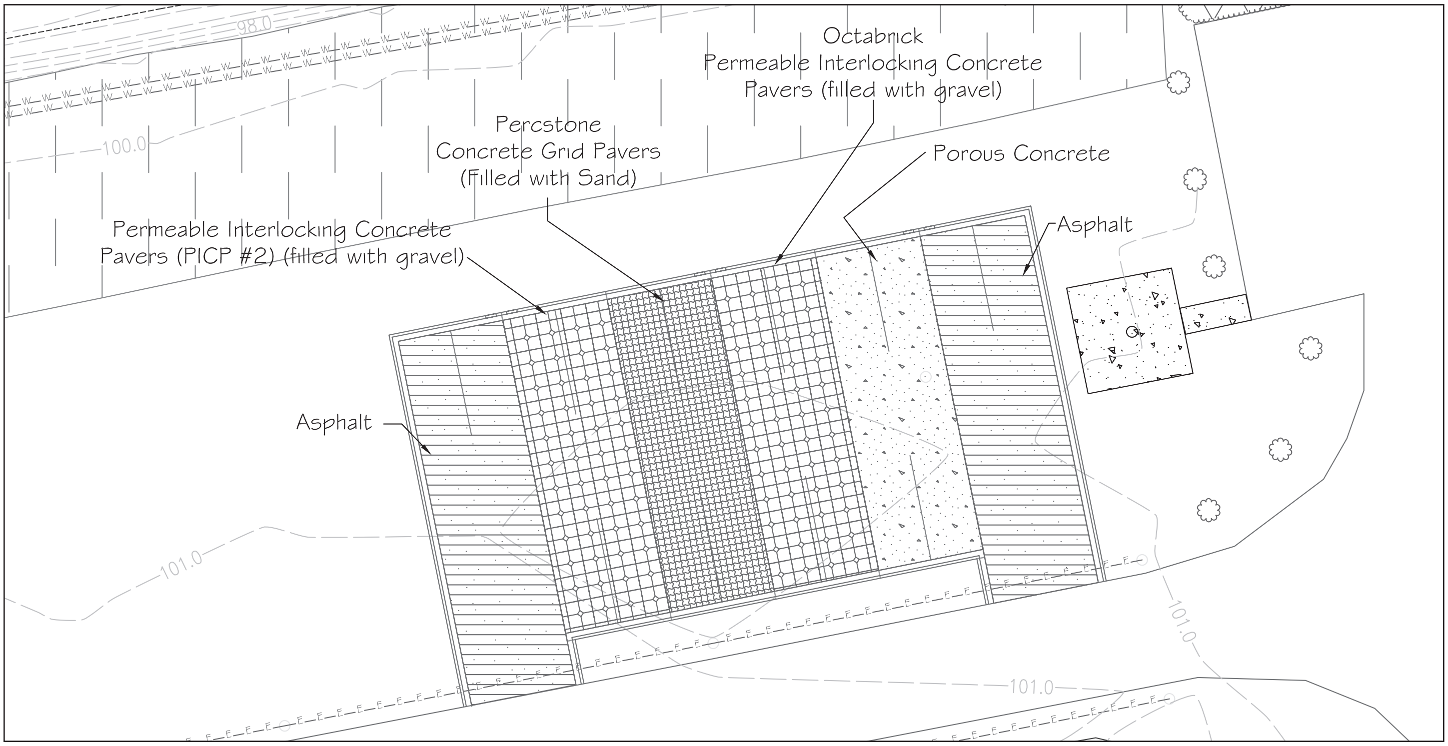

Figure 3. Parking lot plan showing the location of asphalt, pervious (porous) concrete, grid and two permeable interlocking concrete pavements.

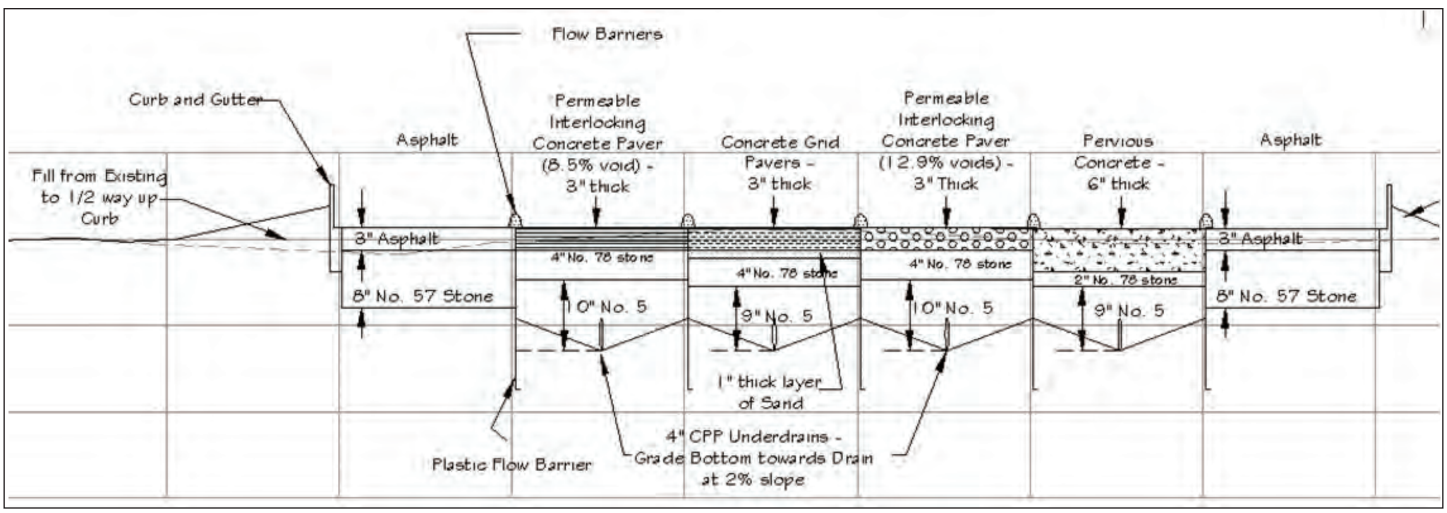

Figure 4. Parking lot cross section showing pavement and base thicknesses in inches (1 inch = 25.4 mm)

openings, concrete grid pavers (CGP) with about 40% open area, and pervious concrete (PC) with approximately 20% void space in its interior. Figures 3 and 4 illustrate the plan and section views.

Each test pavement covers about 1,200 sf and the permeable pavements are over a 10 to 14 in. (250 to 350 mm) thick open-graded base that serves as reservoir storage. The monitoring study began in February 2006 and will continue for a year. As a result of the research, it is expected that the state of North Carolina will be able to make an informed judgment on how much pollutant removal credit permeable pavements should receive when implemented as stormwater best management practices.

All permeable sections use open-graded aggregate reservoir layer consisting of washed No. 78 stone in the openings and bedding of the paving units and in the pervious concrete. The base under all of the permeable sections is open-graded No. 5 stone. This layer will support the anticipated traffic loads estimated at 60 vehicles per day in the 20-car parking lot.

For ease of installation, the excavation depth beneath permeable pavements was kept consistent. Assuming no exfiltration, conservative hydraulic analyses indicate that each

Figure 5. A concrete vault with flow gauges (enclosed in the boxes) and piping to samplers that collect water quality samples from the pavement surface runoff and subsurface exfiltrate

Figure 6. Flow meters and automatic samplers housed in a small shed collect runoff and subsurface exfiltrates from the pavements that drains to the adjacent concrete monitoring vault.

permeable pavement section would be capable of storing at least 3.5 in. (8.9 cm) of rainfall inside the 10 in. (250 mm) thick open-graded aggregate base layer. This storage capacity is close to the local two-year, 24-hour rainfall of 3.8 in. (9.65 cm).

The poorly-drained silty sand soil infiltrates some water but it requires underdrains to remove water for sampling and analysis as well as for heavy rain events. Sloping subgrade (0.042%) directs drain pipes under each permeable section at the bottom of the open-graded base reservoir layer. Each pavement base and soil subgrade hydraulically separated from the others with plastic sheets. Plastic sheets extend from the soil, through the base layer and to the parking lot surface. Small asphalt speed bumps were placed between sections to prevent surface flow moving from one pavement to another.

Surface runoff from each of the six sections drains to a partitioned gutter and then to a monitoring vault, where flow is measured using v-notch weir boxes and data loggers attached to a pulley-float system. Subsurface flow from the four permeable sections drains through the underdrains to a monitoring vault where four additional weir boxes measure exfiltration flow rates. Figure 5 shows the open vault that receives pipes from the pavements surfaces and subsurfaces and measures flow within the enclosed boxes.

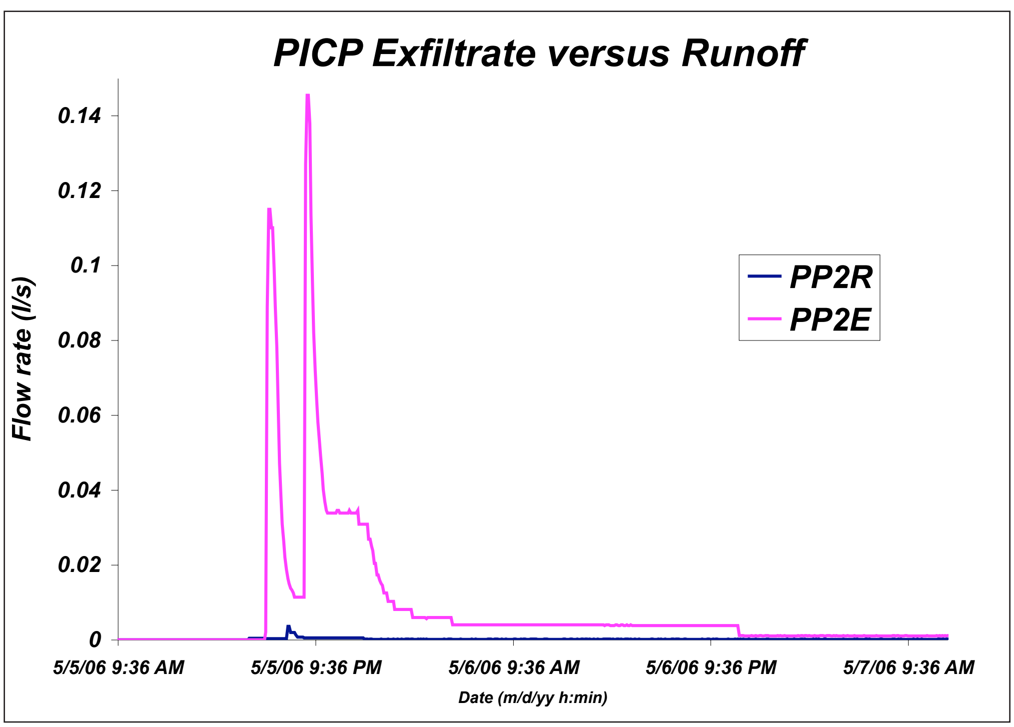

Figure 7. PICP exfiltrate versus runoff hydrograph in early June 2006 for PICP with 8.5% voids

This concrete monitoring vault located downslope of the parking lot houses the weirs and pulley-float system. All flow measurements and water quality sampling occur within this vault and the water exits to a nearby stream. During each rainfall event, automatic samplers take water quality samples from the surface runoff from each of the two asphalt areas and exfiltrate samples from under each permeable pavement section. Automatic flow meters continuously measure flow while samples are taken. Figure 6 illustrates the flow meters

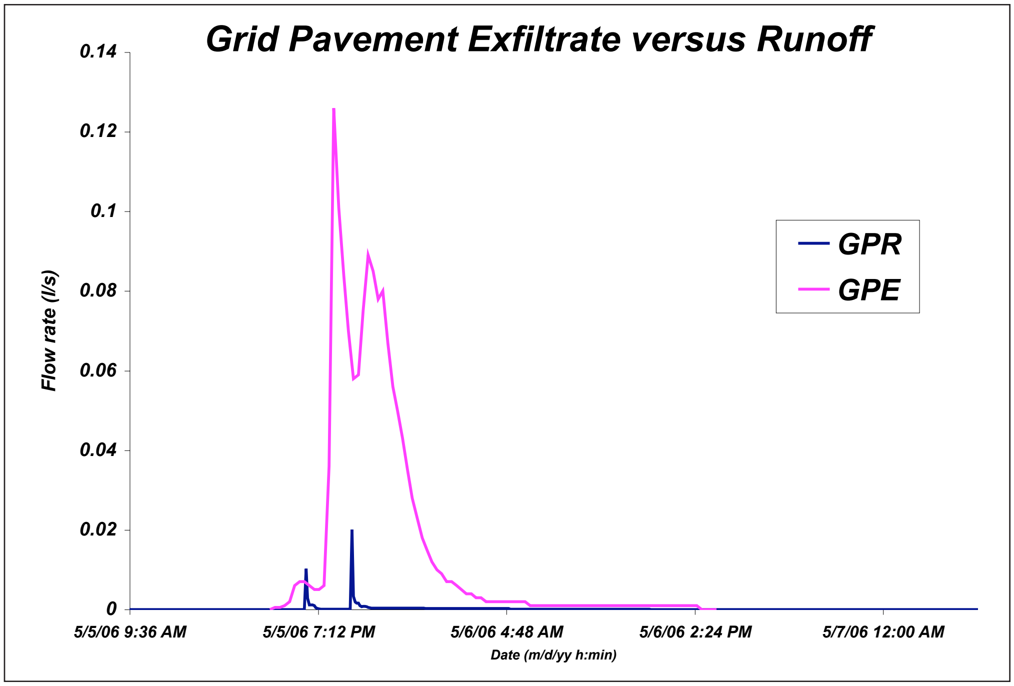

Figure 8. Subsurface exfiltrate is compared to runoff flow for the grid pavement under the same rain event shown in Figure 7. The grids generate a bit more runoff.

and samplers housed next to the concrete monitoring vault. Rainfall depth is measured on site in order to determine the total runoff and infiltration for each pavement.

Runoff samples collected from the exfiltrate of each permeable pavement with asphalt surface runoff and rainfall samples are transported to the Biological and Agricultural Engineering Department's Environmental Analysis Laboratory for immediate analysis. Water quality analyses of each sample includes total nitrogen and nitrogen forms, total phosphorous, zinc, copper and total suspended solids. Water quality data for each pavement type is compared and evaluated for a given rainfall event.

Preliminary results include dramatic reduction of surface runoff volumes from all permeable pavements. During most storm events, very little to no runoff come from the pervious concrete and PICP surfaces. A small amount of runoff is generated from rain falling on the uncovered gutters next to the permeable pavements, thereby contributing to a small portion of the runoff data. Figure 7 shows a runoff versus exfiltrate curve for PICP with 8.5% void space during a 0.88 in. (2.24 cm) rainfall event. PP2E refers to the subsurface exfiltrate from the pervious pavement and PP2R refers to surface runoff.

DATE	RAINFALL mm	% Reduced	% Reduced	% Reduced	% Reduced
		Pervious Concrete	PICP1	Grids	PICP2
6/5	7.37	89.1	91.4	99.4	80.5
6/8	4.32	86.0	93.0	100.0	63.2
6/13	18.29	52.1	71.9	76.0	46.3
6/14	20.32	32.8	46.4	50.3	31.3
6/21	6.09	91.5	98.9	100.0	84.6
6/25	27.43	56.7	53.4	59.2	37.5
7/3	9.39	80.7	89.5	99.2	71.1
7/4	23.36	30.8	25.6	33.6	21.7
7/6	14.22	77.4	85.4	90.9	68.0
7/15	13.2	70.2	80.9	98.0	67.4
7/23	14.73	45.2	72.2	92.5	12.1
7/25	5.58	98.0	100.0	99.0	88.8
7/27	5.58	93.7	100.0	100.0	85.2
8/5	6.35	56.9	61.2	35.9	23.1
8/11	10.66	41.5	62.6	83.6	23.6
8/21	17.27	54.1	68.9	84.5	49.8
8/22	12.44	69.6	78.6	76.8	44.9
	Average % Reduction	66.3	75.3	81.1	52.9

Table 1. The effects of base storage and soil infiltration may explain the high percent reduction in peak flow rates from the permeable pavements compared to peak flows from the asphalt surface.

Figure 7 is typical of runoff versus exfiltrate curves for the pervious concrete and both PICP sections. Not surprisingly, a larger amount of surface runoff was generated by the sand-filled grid pavers. The same 2.24 cm rainfall event yielded the hydrograph shown in Figure 8 where GPE refers to the grid pavement exfiltrate and GPR is the surface runoff from the same area. Overall, there is a greater volume of runoff from this section, as well a higher surface runoff peak flow rate than the PICP.

Table 1 compares the percent reduction of subsurface flows from all permeable pavements compared to surface runoff from the asphalt pavement. Average reductions for each system are provided at the bottom of the table. The aggregate base reservoir storage and infiltration into the soil likely account for the significant

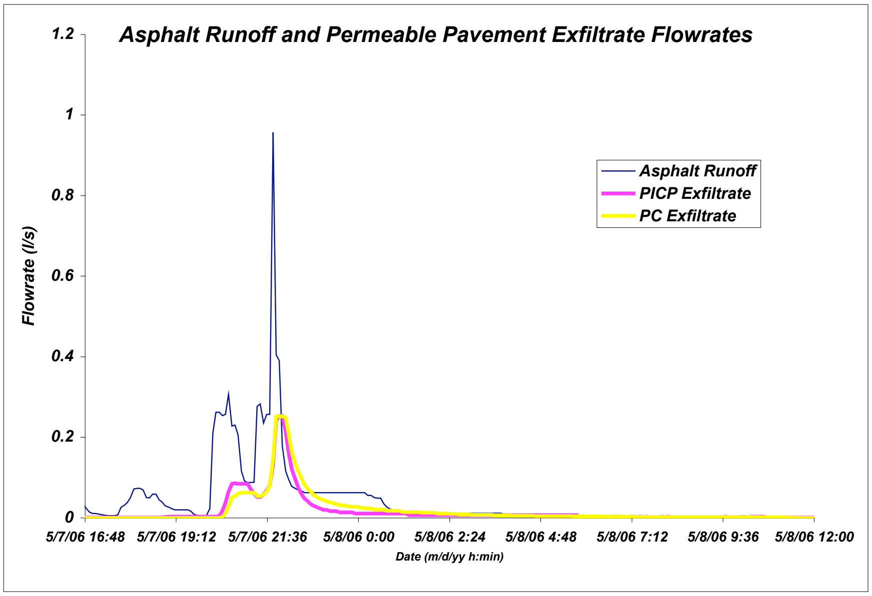

Figure 9. Asphalt runoff versus PICP and pervious concrete exfiltrate flow rates for an early May 2006 rain event

reductions in flow rates.

Figure 9 shows flow data for three pavement sections during two rainfall events separated by roughly 90 minutes. During the first rainfall of 0.23 in. (5.8 mm), a large reduction in the peaks for both permeable sections occurred. The latter rainfall event 0.39 in. (9.9 mm) resulted in a smaller peak flow reduction for the same permeable pavements. Peak flows, however, were still lower than that from the asphalt runoff. Because of the close proximity of rainfall event and slow draining soil, the storage volume of the permeable pavements was reduced.

Preliminary data suggests that peak flow reduction may depend on the time between rainfall events, as well as rainfall amount and intensity. Differences between the various types of permeable pavements have yet to be analyzed. Substantial volume reductions occurred in the total amount of water leaving the permeable pavement sections as runoff and exfiltrate. Using the measured rainfall amount from each storm, the total volume of water that falls on each pavement section can be estimated. This total volume is slightly overestimated due to rainfall variability as well as evaporation on each pavement surface.

Table 2 shows the runoff volumes that pass from each pavement (asphalt surface and permeable surface and exfiltrate) and the percent reduction from the estimated total volume of rain that fell on each pavement surface. Overall, greater reductions are observed for the permeable sections than the asphalt. Again, base storage capacity and soil infiltration may explain the reductions. Some of the volume reduction on the asphalt may be from evaporation more than the reductions on the permeable pavements.

Water Quality

Only water from four storms have been collected to date, so the data are only preliminary as shown on Table 3. As of late June 2006, results are inconclusive. A complete analysis will be preformed as more samples are obtained.

The study results will be updated at a presentation by Professor Bill Hunt and Kelly Collins at the 8th International Conference on Concrete Block Paving, November 6-8, 2006 in San Francisco, California. The paper title is "Evaluation of

DATE	Rainfall	Rainfall Volume	% Reduction			
	mm	Liters	----Asphalt------	---Pervious Concrete----	---Grid Pavers-----	-------PICP--------
			Surface	*Exfiltrate*	*Exfiltrate*	*Exfiltrate*
5/14	13.20	1,473	47.64	65.57	79.76	60.68
6/5	7.36	821	45.81	59.33	97.93	72.48
6/8	4.32	481	57.83	60.12	49.52	57.41
6/12-13	18.29	2,039	30.94	36.04	74.74	45.80
6/14	20.32	2,265	29.46	11.76	42.61	21.03
6/21	6.09	680	50.85	76.75	98.97	64.24
6/25	27.43	3,058	2.17	46.57	59.06	33.56
		Average % Reduction	37.81	50.88	71.80	50.74

Table 2. Rainfall volumes and permeable pavement reduction rates compared to that from asphalt. Runoff volumes are likely reduced from the base storage, soil infiltration and evaporation.

DATE	AREA	TKN	NH3N	NO3N	TP	FSS	VSS
6/5/2006	Rainfall	1.42	0.72	0.31	0.35	44	22
	Asphalt	3.62	0.56	0.97	0.59	266	62
	PCE	2.53	0.07	0.68	0.6	146	81
	PP1E	1.35	0.03	2.3	0.28	15	14
	PP2E	0.65	0.02	0	0.53	50	19
	GPE	-	-	-	-	-	-
6/12/2006	Rainfall	1	0.49	0.4	0.18	7	7
	Asphalt	1.55	0.43	0.67	0.25	12	12
	PCE	3.3	0.06	0.37	0.6	188	108
	PP1E	1.35	0.02	3.77	0.36	107	19
	PP2E	0.83	0.02	2.52	0.22	14	14
	GPE	1.08	0.07	0.7	0.3	-	-
6/13/2006	Rainfall	0.75	0.27	0.2	0.45	17	17
	Asphalt	0.45	0.23	0.24	0.56	18	15
	PCE	1.31	0.24	0.5	0.62	147	82
	PP1E	0.6	0.01	2.35	0.49	61	20
	PP2E	0.45	0.01	1.83	0.45	30	15
	GPE	0.9	0.03	3.03	0.45	54	22
6/15/2006	Rainfall	0.24	0.14	0.09	0.6	2	2
	Asphalt	0.43	0.11	0.17	0.53	6	6
	PCE	1.61	0.22	0.37	0.68	81	38
	PP1E	0.47	0	1.34	0.7	52	17
	PP2E	0.52	0.01	1.15	1.29	57	25
	GPE	0.88	0	1.42	0.81	70	21

Table 3. Water quality data for rainfall, asphalt surface runoff and exfiltrates from the permeable pavements. All data are in milligrams/liter. PCE = pervious concrete exfiltrates, PP1E = 12.9% void space PICP exfiltrate; PP2E = 8.5% void space PICP exfiltrate; GPE = Grid pavement exfiltrates. TKN = Total Kjeldahl Nitrogen, NH3N = Ammonia nitrogen; NO3N = Nitrite nitrogen; TP = Total Phosphorous; FSS = Fixed Suspended Solids; VSS = Volatile Suspended Solids

Various Types of Permeable Pavement with Respect to Water Quality Improvement and Flood Control." Hurricane Ernesto deposited 8.5 inches (216 mm) of rainfall in early September so we anticipate hearing about the response of these pavements to this deluge at the International Conference. In the meantime, it's apparent that all permeable pavement sections appear to cause substantial reductions in surface runoff volume and peak flows. These reductions may be dependent on type of pavement or pavement fill but all suggest that impervious asphalt is a thing of the past for parking lot surfaces.

We hope that the emerging water quality data will be sufficient to convince the North Carolina DENR and even other states to credit PICP with pollutant as well as water quantity reductions. Professor Hunt's research will likely reverberate to other states and localities struggling to reduce runoff, non-point source water pollution and related public costs. Like his and other's research on PICP, their work underscores its positive contribution to the environment that's transforming attitudes toward the role of segmental concrete pavement in society. ❖