Runoff is being monitored from over 15,000 sf (1500 m^2) of permeable interlocking concrete pavement in the road and driveways of the Glen Book Green Subdivision in Waterford, Connecticut.

Research Demonstrates Performance of Permeable Interlocking Concrete Pavements

High-Impact Results from Low-Impact Development

A small residential subdivision near the southeastern coast of Connecticut is speaking a big message about the potential pollution reduction from permeable interlocking concrete pavements (PICPs). Glen Brook Green subdivision in Waterford, Connecticut includes over 15,000 sf (1500 m^2) of PCIP driveways and roads. These are mixed with asphalt driveways, and crushed stone driveways joined to single family homes (see plan in Figure 1).

A September 2003 report released by the University of Connecticut entitled "Annual Report – Jordan Cove Urban Watershed Section 319 National Monitoring Program Project" provides data that starkly contrasts differences in runoff quantities and pollutants released from residential driveways paved with asphalt, crushed stone, and PICPs. The report includes results of runoff and pollutants from Glen Brook Green Subdivision, and its driveways, all situated within the Jordan Cove Watershed.

Runoff Reduction and Rapid Infiltration

Infiltration tests on in 2002 and 2003 showed that the PICP built on a dense-graded, crushed stone base provided somewhat higher infiltration rates than the crushed stone driveways. Table 1 from the report verifies this even while the PICP was constructed over dense-graded base. The report also compared ratings for infiltration of other surfaces to those in the study to place the results in context. Table 2 suggests that the permeable interlocking concrete pavement could be categorized as having "rapid" infiltration.

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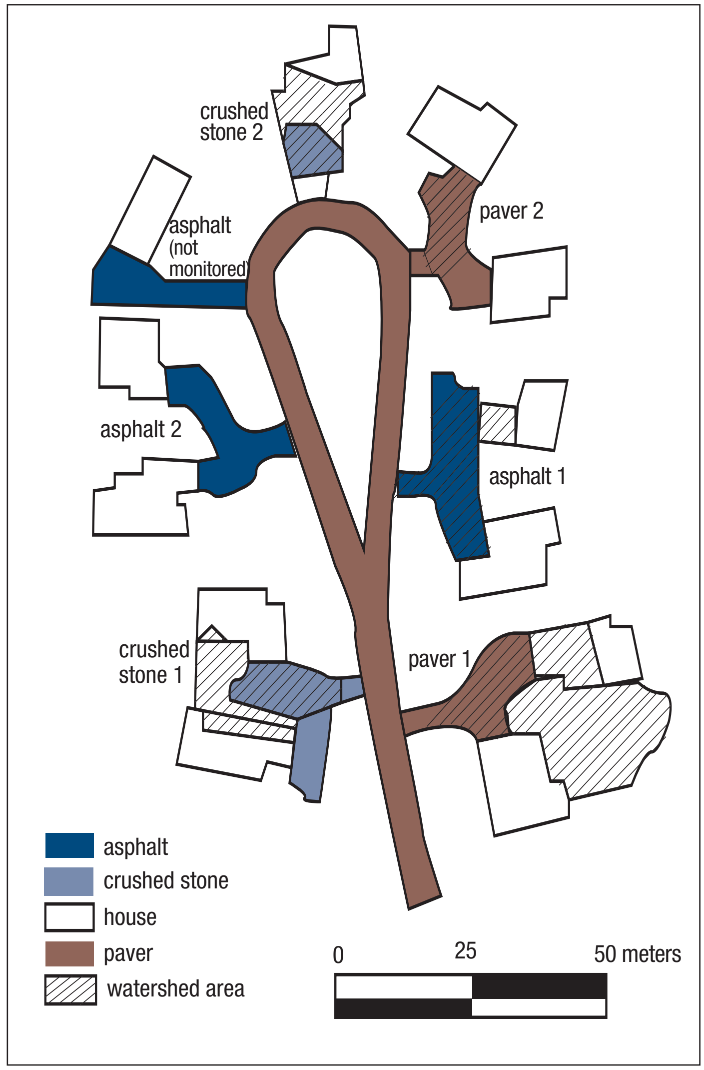

The report summary on the study of runoff from driveways in Glen Brook Green subdivision notes that, "Stormwater runoff and mass export of solids, nutrients, and metals was greater from the asphalt than the pavers and the crushed stone driveways. Concentrations of solids, nutrients and metals were lower in runoff from the paver driveways than the asphalt driveways. Concentrations of TP (total phosphorous) and Pb (lead) were lower in runoff from the crushed stone driveways than from the asphalt driveways."

Figure 2. Slot drains at the ends of the PICP driveways facilitated sampling and collection of runoff.

Figure 3. Grass swales rather than curb and gutters enable water to infiltrate and reduce the erosive effects from rapid discharges into streams.

Significant Reduction in Pollutants

Table 3 from the report provides an overview of the average weekly concentrations of various pollutants from the asphalt, paver and crushed stone driveways. The means followed by the same letter are not significantly different at the 95% confidence level.

Table 3 notes the statistically significant reductions of total suspended solids and nutrients (nitrogen compounds and phosphorous often from fertilizers) from the permeable pavement and the gravel driveway. Table 4 provides data from the US Environmental Protection Agency that places the data on metals in the Jordan Cove report in context with their toxicity to freshwater and saltwater aquatic life, as well as to humans.

"The data looks impressive," says Bruce Morton with AquaSolutions, a private ecosystem management company that provides guidance on the runoff monitoring project. "The permeable pavement has a direct benefit in this project by reducing runoff and water pollutants." He further noted that runoff from the driveways was sampled from drains at their ends. Figure 2 shows a typical drain location.

The subdivision project sits within the Jordan Cove Urban Watershed on the Connecticut side of Long Island Sound. Jordan Cove is an estuary whose primary watercourse is Jordan Brook emptying into Long Island Sound. Runoff and pollutants are being monitored from three types of residential developments within an urbanizing watershed. The 4,846 acre (1961 ha) watershed includes a 10.6 acre (4.3 ha) residential project using traditional building techniques.

Test and Year	Asphalt	Permeable Pavement in./hr (cm/hr)	Crushed Stone in./hr (cm/hr)
Single Ring Infiltrometer test 2002	0	7.7 (19.6)	7.3 (18.5)
Single Ring Infiltrometer test 2002	0	6 (15.3)	5 (12.7)
Flowing infiltration test 2003	0	8.1 (20.7)	2.4 (6)

Table 1. Average infiltration rates from asphalt, permeable pavement, and crushed stone driveways

Category	Infiltration rate in./hr (cm/hr)	Reference
Very rapid	> 9.8 (25)	Novotny, 1993
Rapid	4.9 - 9.8 (12.5 - 25)	Novotny, 1993
Moderately rapid	2.5 - 4.9 (6.3 - 12.5)	Novotny, 1993
Moderate	0.8 - 2.5 (2.0 - 6.3)	Novotny, 1993
Moderately slow	0.2 - 0.8 (0.5 - 2.0)	Novotny, 1993
Slow	0.06 - 0.2 (0.12 - 0.5)	Novotny, 1993
Very slow	< 0.06 (0.12)	Novotny, 1993
Comparison of Infiltration Rates		
Non-compacted sandy soil	15 (38.1)	USEPA, 1999
Compacted sandy soils	3 (7.62)	USEPA, 1999
Non-compacted dry clay	8.9 (22.4)	USEPA, 1999
All other clay soils	0.7 (1.8)	USEPA, 1999
Undisturbed forest floor	2.4 (6)	Chow, 1964
Oak Hickory forest	3 (7.6)	Chow, 1964
Unimproved pasture	0.9 (2.4)	Chow, 1964

Table 2. Comparison of infiltration rates

Figure 4. A rain garden in the center of the cul-de-sac soaks up runoff in a space that would otherwise be paved with an impervious surface.

Variable	Asphalt		Permeable Pavement		Crushed Stone	
Runoff depth, mm	1.8	a	0.5	b	0.04	c
Total suspended solids, mg/l	47.8	a	15.8	b	33.7	a
Nitrate nitrogen, mg/l	0.6	a	0.2	b	0.3	ab
Ammonia nitrogen, mg/l	0.18	a	0.05	b	0.11	a
Total Kjeldahl nitrogen, mg/l	8.0	a	0.7	b	1.6	ab
Total Phosphorous, mg/l	0.244	a	0.162	b	0.155	b
Copper, ug/l	18	a	6	b	16	a
Lead, ug/l	6	a	2	b	3	b
Zinc, ug/l	87	a	25	b	57	ab

Table 3. Mean weekly pollutant concentration in stormwater runoff from asphalt, paver and crushed stone driveways. Within each variable, means followed by the same letter are not significantly different at $\alpha = 0.05$.

Concentrations of toxic levels to aquatic life:	Copper	Lead	Zinc
Freshwater (acute / chronic), ug/l	13 / 9.0	65 / 2.5	120 / 120
Saltwater (acute / chronic), ug/l	4.8 / 3.1	210 / 8.1	90 / 81
Human consumption, ug/l	1300	0	9100

Table 4. Toxic concentrations of metals (USEPA, 1999)

mg/l = milligrams per liter
ug/l = micrograms per liter

A 6.9 acre (2.8 ha) area of residential homes uses best management practices (BMPs) including PICP intended to reduce water pollution and runoff. A third residential area of 13.9 acres (5.6 ha) serves as a control for the multi-year monitoring program. Besides PICP, the BMP area includes several management practices such as using grass swales instead of curb and gutters and rain gardens or areas for runoff to infiltrate into the soil. Figures 3 and 4 show examples of these BMPs.

The University of Connecticut, The US Environmental Protection Agency (USEPA) and AquaSolutions, a private consulting firm specializing in stormwater monitoring and management have been monitoring runoff from construction and use since 2002. Water quality monitoring is overseen by Dr. John C. Clausen with the University of Connecticut.

The water quality objectives of the monitoring project are to:

- Implement BMPs on 100% of the lots in the BMP portion of the subdivision
- Retain sediment on site during construction
- Reduce nitrogen, bacteria, and phosphorous export by 65%, 85% and 40% respectively
- Maintain post-development runoff peak flow rates and volume at pre-development levels
- Maintain the total suspended solids load to predevelopment levels

Most of these goals have been met thanks in great part to low-impact site design and application of BMPs. These included PICP which contributed to decreased runoff and water pollution while providing a driveway and street surface.