permeable pavements

Stormwater performance of permeable pavement systems

Background

Wherever grasslands and forest are replaced by rooftops and roads, the movement of water across the landscape is radically altered. Yet some of the changes are unintended and can have severe consequences. Flooding, channel erosion, landsliding, and destruction of aquatic habitat are some of the unanticipated changes that can also result from these alterations, recognized by many decades of studies because of the loss of both lives and property that sometimes result. With urbanization, stream channels expand catastrophically to consume adjacent land never before affected by either flooding or erosion, sediment inundates low-lying areas seemingly far away from active channels, stormwater facilities are overwhelmed by frequent flows far beyond their design capabilities, and populations of aquatic organisms are decimated.

Nearly all of these problems result from one underlying cause: loss of the water-retaining function of the soil in the urban landscape. This loss may be literal, in that the loose upper layers of the soil are stripped away to provide a better foundation for roads and buildings. The loss may also be functional, if the soil remains but precipitation is denied access to it by paving or rooftops. In either case, a stormwater runoff reservoir of tremendous volume is removed from the stormwater runoff system; water that may have lingered in this reservoir for a few hours or a few days or many weeks now flows rapidly across the land surface and arrives at the stream channel in short, concentrated bursts of high discharge.

Traditionally, this problem has been addressed by replacing the lost functions of the soil reservoir with a new, constructed reservoir. A stormwater collection system routes the runoff from paved surfaces into an excavated "detention pond," designed to mimic the functions of the soil reservoir by accepting water at whatever rate it flows off the developed land surface and releasing it at a much slower, "natural" rate.

However, this strategy has proven to be surprisingly ineffective. The primary reason is one of scale—the volume of water retention in the soil that is lost, typically several inches to nearly a foot of depth over the to-be-developed area, is replaced by only a few tenths of an inch. This represents a reduction in "reservoir" volume of perhaps 90 percent or more, and so there should be little surprise that substantial downstream consequences result. Most detention ponds, unless designed to truly extraordinary (and thus no less costly) standards, are of limited effectiveness.

Permeable pavements for stormwater management

As an alternative to traditional detention ponds, many stormwater managers are turning to methods of runoff dispersion and infiltration. One of these technologies is permeable pavements, which are surfaces that can be driven over while permitting rapid infiltration of water into the underlying soil. Although this approach has been in limited use for many years, increasing awareness of stormwater problems has led to greater recent applications. To evaluate this approach for the Pacific Northwest, in 1997 the Center constructed a test facility as part of a new employee parking lot, monitoring the infiltration and water-quality performance using four different surfaces over six years of daily use. Our goals were to evaluate long-term durability of the surfaces, persistence of infiltration, and the chemistry of the infiltrate being released to groundwater.

Results

Surface durability, infiltration capacity, and water-quality performance of the tested permeable pavement systems all compared well, and in several regards extremely well, with the classic asphalt surface. Structurally, all permeable pavement systems in this study have held up to six years of daily usage. Two systems in particular (Turfstone® and UNI Eco-Stone®) are apparently as durable as the asphalt surface under at least this magnitude and frequency of loading; even the flexible plastic systems (Grasspave2® and Gravelpave2®) showed only minor wear that presented no impediment to use. All four

	Hardness (mg $CaCO_3$/l)	Conductivity (σmhos/cm)	Copper (σg /l)	Zinc (σg /l)	Motor Oil (mg/l)
Infiltration Samples					
Gravelpave2®	22.6	47	0.89 (66% <MDL)	8.23 (22% <MDL)	<MDL
	[20.3]	[63]	[1.9 (67% <MDL)]	[2.0 (67% <MDL)]	
Grasspave2®	14.6	38	<MDL	13.2	<MDL
	[22.8]	[94]	[21.4 (33% <MDL)]	[2.5 (67% <MDL)]	
Turfstone®	47.6	114	1.33 (44% <MDL)	7.7 (33% <MDL)	<MDL
	[49.4]	[111]	[1.4 (67% <MDL)]	[<MDL]	
Uni Eco-Stone®	49.5	114	0.86 (77% <MDL)	6.8 (33% <MDL)	<MDL
	[23.0]	[44]	[14.3 (33% <MDL)]	[7.9 (33% <MDL)]	
Surface Runoff Samples					
Asphalt	7.2	13.4	7.98	21.6	0.164 (11% <MDL)
	[6.1]	[17.0]	[9.0 (33%<MDL)]	[12]	

Table 1. Mean concentrations of detected constituents from storm samples in 2001-02 (1996 results from Booth and Leavitt [1999] in square brackets). Nine storms sampled in 2001-02; three in 1996. In parenthesis is the percent of samples that fell below detectable levels. Lead was not detected in 2001-02 but was present in 5 of 15 samples in 1996; motor oil was not tested in 1996. <MDL = all samples below minimum detection limit.

permeable pavement systems infiltrated virtually all precipitation, even during the most intense storms experienced during the study period.

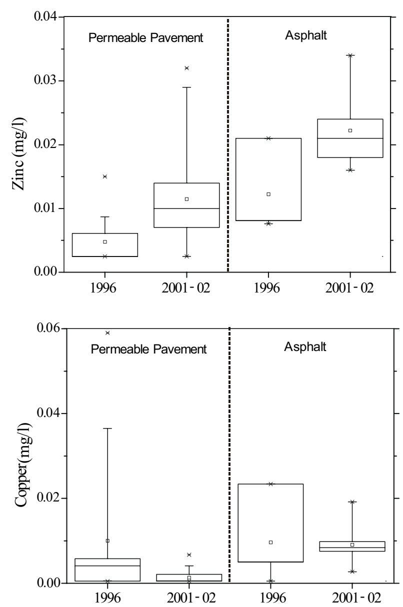
While this study demonstrated long-term success for infiltration, it does not assure uniformly good performance everywhere. Pacific Northwest has generally low rainfall intensities. The highest rainfall intensity observed during the study was 7.4 mm per hour. Our extremely positive infiltration results may not apply as well in other locales that receive higher rainfall intensities. The site itself was specifically chosen because of good underlying drainage characteristics, and so infiltration during extended storms would probably not be as effective in areas underlain with less permeable soils. Windblown dust or particulate matter washed off cars could also reduce permeability over time; we observed such deposits, but the infiltration capacity here has not fallen in consequence to levels approaching the rainfall intensities experienced (typically <5 mm/hour).

The water quality results from this study demonstrate clear differences between the subsurface infiltrate and surface runoff from asphalt. For nearly all storms and constituents, water quality of the infiltrated water was significantly different, and better, than the surface runoff from the asphalt parking area. For both copper and zinc, infiltration of the stormwater had a dramatic effect on water quality (Table 1): toxic concentrations were reached in 97 percent of the asphalt runoff samples; but in 31 of 36 infiltrate samples, concentrations fell below toxic levels and in a majority of samples below even detectable levels.

The long-term degradation of water-quality performance may be a modest, but probably not problematic, phenomenon of permeable pavement systems. Zinc concentrations in both permeable pavement infiltrate and asphalt runoff exhibited significant increases during the six-year study period. Yet two of the systems, Grasspave2® and UNI Eco-Stone®, showed simultaneous decreases in copper concentrations. Lead, present in a third of the 1996 samples, was not detected during the current survey. Conductivity and hardness remained relatively constant between the two studies.

These results suggest both positive and negative changes in runoff water quality after six years, all generally quite modest and providing no basis for serious concern. Furthermore, subsurface flow paths for this experimental system were less than 10 cm, a far shorter path to groundwater tables than would occur in most field installations. Longer flow paths would presumably lead to greater attenuation of pollutant loads and a corresponding decrease in the potential for long-term groundwater impacts.

For more information, see B.O. Brattebo and D.B. Booth, 2003, Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems: Water Research, v. 37, p. 4369-4376.



A comparison of zinc and copper concentrations in samples collected in 1996 and 2001-02. Concentrations for permeable pavement are averages of infiltrated samples from all four paving systems. For 1996, n = 12 from the permeable pavements and n = 3 from the asphalt runoff. For 2001-02, n = 27 from permeable pavements and n = 9 from asphalt runoff. The large box represents the 25th percentile, median, and 75th percentile; the whiskers represent the 5th and 95th percentiles; the small box represents the mean.

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