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Surface Infiltration Rates of Permeable Surfaces: Six Month Update (November 2009 through April 2010)

Office of Research and Development
National Risk Management Research Laboratory - Water Supply and Water Resources Division

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Abstract

At the end of October 2009, EPA opened a parking lot on the Edison Environmental Center that included three parking rows of permeable pavement. The construction was a cooperative effort among EPA's Office of Administration and Resources Management, National Risk Management Research Laboratory, and the facility owner, Region 2. The lot serves as an active parking area for facility staff and visitors and also as a research platform.

Key unknowns in the application of green infrastructure include the long term performance and the maintenance requirements. The perceived uncertainty in these is a barrier to widespread adoption of the installation of permeable surfaces for stormwater management. EPA recognizes the need for credible long-term performance maintenance data and has begun a long-term monitoring effort on this installation.

This document outlines the methods and results of the surface infiltration monitoring of the permeable parking surfaces during the first six months of operation.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director

National Risk Management Research Laboratory

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

The U.S. Environmental Protection Agency (EPA) constructed a parking lot on the Edison Environmental Center that incorporates three permeable pavement surfaces. The parking lot has 110 spaces in three double (head-to-head parking) rows and two single car rows. The three double rows have permeable surfaces (interlocking concrete pavers, porous concrete, and porous asphalt). The northernmost (single) row is paved with porous concrete. The driving lanes and the southernmost single parking row are traditional impervious asphalt. All surfaces were placed during the fall of 2009 by installers certified by their respective trade organizations.

The lot is actively used, providing parking for facility staff and visitors. In addition to providing the facility with needed parking, EPA's National Risk Management Research Laboratory (NRMRL) is using the parking lot as a platform to monitor the performance of the three permeable surfaces as a stormwater management practice. The site is also being used as an outreach tool to demonstrate a working example of the stormwater control.

Part of the planned NRMRL research is to collect information that will allow users to create an *a priori* estimate of the maintenance requirements and predict the associated operating costs. While many owners will routinely clean the parking area for litter and debris control, a more aggressive cleaning may be required periodically to maintain or restore the surface infiltration capacity. Cahill and others (2003), for example, recommend maintaining with an industrial vacuum system twice each year while simultaneously noting that installations that have not been maintained continue to function well for many years. Baladés and others (1995) noted no reduction in infiltration rates during the first year and rapid reductions in unmaintained systems in the following year. Conceptually, the infiltration rate decreases as solids accumulate in the surface pores (Legret and Colandini 1999). The accumulated solids decrease the open area available for water passage and, therefore, decrease the surface infiltration capacity. Periodic cleaning removes the solids, reopening the passages and restoring the infiltration capacity. Currently there is insufficient information to forecast the cleaning frequency necessary to maintain the needed infiltration capacity or assess the effectiveness of the cleaning. This knowledge gap precludes generating estimates of operating and whole-life costs that, in turn, are perceived barriers to increased use.

The NRMRL research uses an imaginary north-south line to divide each permeable parking area into an eastern half and a western half. The planned research approach will clean half of each parking area after a certain decrease in infiltration. The remainder of the parking area will not be maintained until a later time to allow comparison. Monitored infiltration rates will provide clear results demonstrating the presumed infiltration capacity recovery produced by the periodic cleaning and demonstrate any longer-term degradation of the infiltration rate of the unmaintained surfaces.

Surface infiltration rates are measured monthly and the current plan is to use regenerative air vacuum systems to vacuum the lot based on measured changes in infiltration rates. This document presents the first set of infiltration measurements collected during the first six months of parking lot use. The period was predominantly the winter months. The first infiltration measurements were completed during December 2009, the second month that the parking lot was in use.

Chapter 2 Measurement Methods

Infiltration measurements were made following a modified version of the ASTM method C1701 (ASTM 2009). Although the method was developed specifically for porous concrete, this testing applies the same method to all three permeable surfaces. The sole modification was the sealing method between the 12-inch diameter PVC cylinder and the surface. The pipe used in this testing is 15 cm high with parallel black lines drawn 10 and 15 mm from the pipe bottom. This work substitutes ½-inch thick Neoprene sheeting compressed with applied weight (See Figure 1) for the plumbers' putty seal described in the ASTM method. The Neoprene sheeting is trimmed to align with the inside circumference of the pipe. The wooden frame holds 5-gallon buckets filled with stone. Tie-down straps spanning the PVC cylinder support the frame slightly above the parking lot surface. The weight of the buckets on the pipe compresses the Neoprene sheet to form a gasket with minimal leakage. When used on the pavers, additional Neoprene strips placed in the gaps between the individual paver blocks dam the openings. Similar sealing mechanisms have been used successfully by others (e.g., Bäckström and Bergström 2000; Bean 2007; Houle 2008).

After positioning the pipe and applying the weight, 3.60 kg of water is poured into the area isolated by the cylinder while keeping the water level between the two lines drawn on the interior during the pouring. The pipe is oriented so that the lines are at the lower (southern) side. The time required for the water to drain, called the prewet time, is measured and recorded. The time begins when the water first impacts the permeable surface and stops when water is no longer visible on the surface.

If the prewet time is less than 30 seconds, then the infiltration measurement is completed with 18.00 kg of water. If the time is 30 seconds or more, then the infiltration measurement is made using 3.60 kg of water. The testing is done within 2 minutes of the prewet measurement and measurement sites must be separated by at least 1 m. No testing is undertaken within 24 hours of measurable rainfall.

The location for each measurement was selected using the random number[1] function in an Excel spreadsheet (Microsoft Corp. 2003). The spreadsheet was created to identify a set of three locations on the eastern and western half of each surface. The surface area of each half of the double parking rows is about 250 m². The ASTM method requires measurements at three

[1] Microsoft has tested the algorithm used in the RAND function of Excel 2003 using the Diehard tests. The testing shows that the pseudo random number generator repeats only after 10^{13} function calls. See http://support.microsoft.com/kb/828795

locations for areas up to 2,500 m² with one additional measurement for each additional 1,000 m² of area. The locations are specified as a distance from the adjacent curb and from the north edge of the permeable surface with all measurements rounded to the nearest inch. A pair of spare locations was also designated for situations where parked vehicles prevented the measurement for multiple days. Figure 2 shows the locations where measurements were completed. Locations where the positioning of the ring spanned a painted line were noted and, after the December measurements, the water temperature was measured and recorded.

The 24 monthly measurements can be completed in a single day by two people if the water containers are prepared the previous day and there are no complications during the process. The measurements must be scheduled around the weather as the method requires a 24-hr antecedent dry period, and rain events trigger other sampling procedures in the parking lot. Weather and other factors combined to delay the February measurements until March 1, 2010. The March measurements were mostly completed on March 10, 2010. The time between the measurements is not uniform from month to month.

Figure 1. The weight of the 5-gallon buckets of stone applied to the PVC compresses the Neoprene sheeting to form a leak-free seal with the parking surface. Collectively the buckets weigh 150 to 200 kg.

Thermistors embedded in the surface material during construction monitor the pavement temperature at 10-minute intervals. The temperature of the surfaces are noted to potentially adjust for known temperature-related effects (Bäckström and Bergström 2000; Braga, Horst et al. 2007; Emerson and Traver 2008) that may introduce seasonal infiltration patterns.

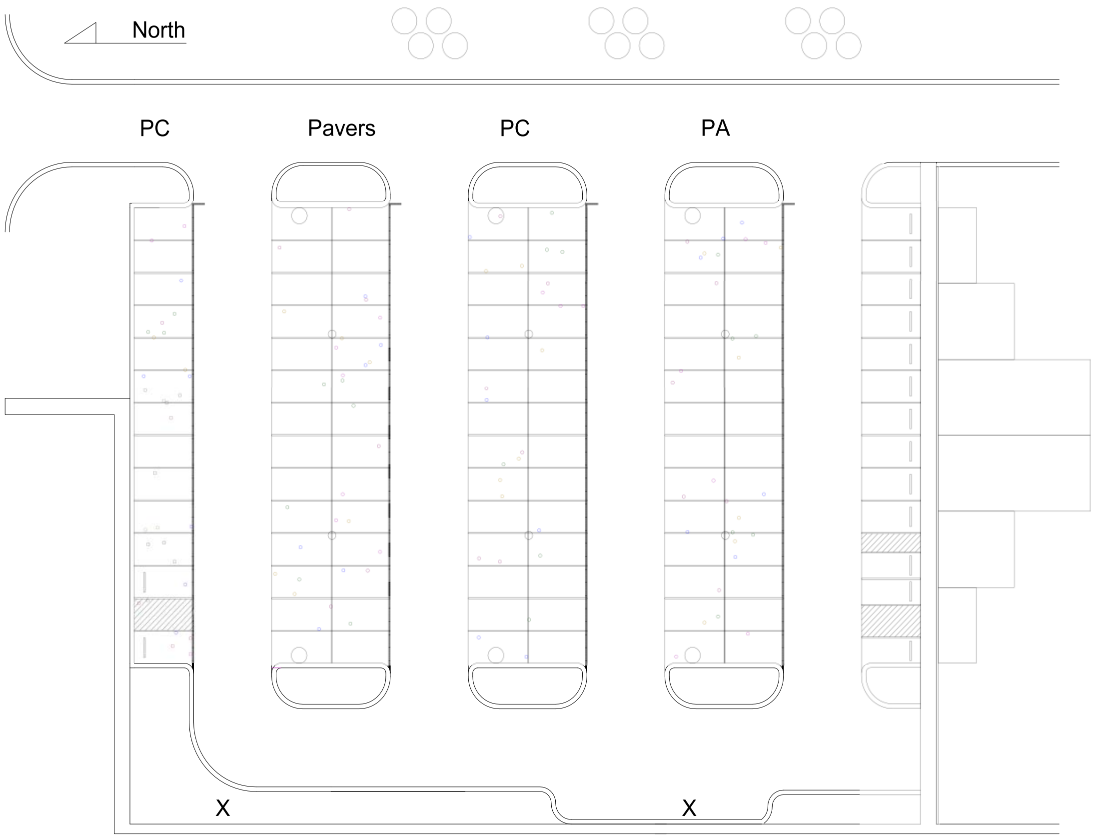

Figure 2. The location of the measured infiltration rate was selected using a random number generator within each half of each permeable section. PC designates porous concrete, PA designates porous asphalt. The X's show the location of entry doors to the building at the bottom. Colors indicate the month the measurements were made. The far right-hand parking row is traditional impervious asphalt. The circles are to approximate scale. The color codes are December, January, February, March, and April.

Chapter 3 Statistical Methods

Using the known area and water mass (either 3.60 kg or 18.00 kg, depending on the measured prewet time), the measured time required for the water to drain from the pipe through the surface was converted to an infiltration rate. Each measurement is associated with a permeable surface material, measurement date, and location in the parking lot (east or west) in anticipation of the future vacuuming. The two porous concrete areas are identified separately as either the middle (row 2) or northern row (row 0). All analyses used Statistica 9.0 (Statsoft 2010) with the significance levels set to 95% (α=0.05). Other than the testing for H5 that uses a one-way analysis of variance (ANOVA), the results are analyzed as a repeated-measures ANOVA.

Hypotheses

The data are analyzed to test five hypotheses on the infiltration rates (I) of the pavers, porous concrete (PC) and porous asphalt (PA) surfaces during this six-month pre-maintenance period.

H1: The infiltration rates differ from surface to surface.

$$I_{Pavers} \neq I_{PC} \neq I_{PA}$$

H2: The infiltration rates of the east and west side of a given surface are equivalent..

$$I_{i,E} = I_{i,W} \text{ for } i = \text{Pavers, PC, PA}$$

H3: The infiltration rates of the two porous concrete sections are equivalent.

$$I_{PC,0} = I_{PC,2}$$

H4: The infiltration rates of each section decrease with passing time.

$$I_{i,Dec} > I_{i,Jan} > I_{i,Feb} > I_{i,Mar} \text{ for } i = \text{Pavers, PC, PA}$$

H5: Measuring on a paint stripe will reduce the measured infiltration rate.

$$I_{i,stripe} < I_{i,no\ stripe} \text{ for } i = \text{Pavers, PC, PA}$$

Chapter 4 Results

Table 1 through Table 5 list the locations, measured infiltration times and calculated infiltration rates for each measurement made from December 2009 through April 2010.

The prewet times required that the tests use 18.00 kg of water for all measurements on the pavers and the porous concrete. The pre-wet time required 3.60 kg of water for all measurements on the porous asphalt but one during the January measurements that used 18.00 kg.

H1: Infiltration rate by surface type

The first hypothesis tests whether the surface infiltration rates vary from surface to surface. The ANOVA groups the two porous concrete rows into a single category and shows that the surface infiltration rates are significantly different ($F(2, 21)=119.5$, $p<<0.001$). The trend (observed unweighted means) is from porous concrete (4000 cm/hr) to pavers (2,400 cm/hr) to porous asphalt (200 cm/hr). Figure 3 shows the results for the three surfaces.

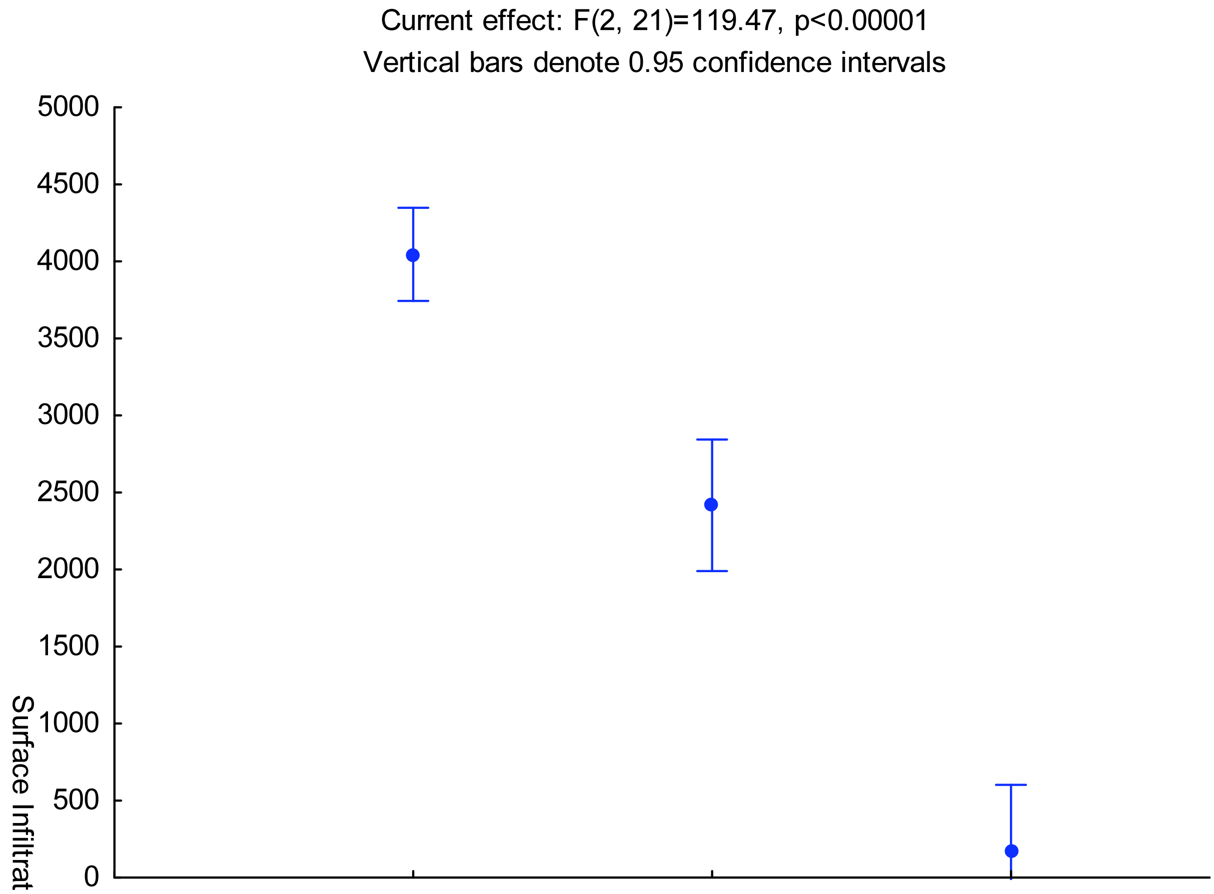

Figure 3 The ANOVA shows differences in the infiltration rate of the three surface materials. This analysis pools the porous concrete measurements across both rows.

H2: Infiltration rate by side

The east and west side of each surface have received nearly the same treatment during the first six months of operation. The time required for the installation of any surface was no more than a few days. The lot is used to near capacity so most parking stalls are routinely filled during the work day; however the west side of the parking lanes is nearer the building entrance and may receive preferential parking when there are excess spaces. Snow management has been similar on each side of the lot with plowing using a rubber-edged blade and salt applications but no sand application. Overall, the expectation is that before maintenance occurs to differentiate the two sides, the east and west sides of each parking row will have the same infiltration rate.

In comparing the infiltration rates of the halves, the parking rows are each tested separately. The infiltration rate of the western side of the middle porous concrete row (4,000 cm/hr) is significantly ($F(1, 4)=9.3$, $p=0.038$) smaller than the infiltration rate of the eastern half of that row (5,000 cm/hr). Figure 4 shows the differences in infiltration rates for the middle porous concrete row. The infiltration rates on the eastern and western halves of the northern concrete row, the interlocking pavers, and the porous asphalt are not significantly different.

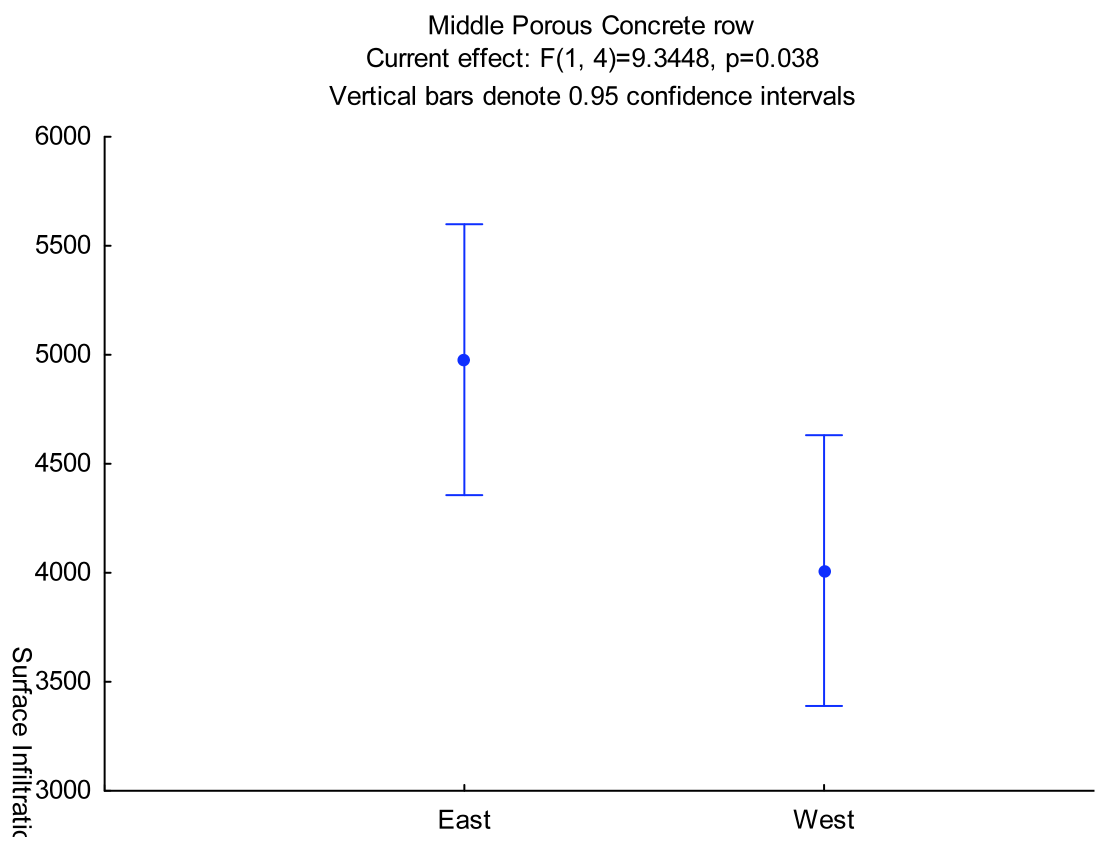

Figure 4. The infiltration rate of the east and west sides of the middle porous concrete are significantly different

H3: Infiltration rate of porous concrete sections

The third hypothesis, that the infiltration rate of the two porous concrete rows is the same, recognizes that the two rows were poured during the same two-day period and have received similar use and maintenance as already outlined. The northern row includes some parking spaces designated as handicapped parking that appear to be used less frequently than the remaining parking spaces. The larger gap between the handicapped parking spaces to allow for wider door openings is not generally used for parking. The northern row is a single row which means that the infiltration measurements are denser than the measurements in middle row, which is a double row. This approach maintains the minimum of three measurements locations for an area outlined in the ASTM test method. During the installation, it was noted that the northern parking row is thicker than the middle concrete row (20 cm vs. 15 cm).

The ANOVA shows that the infiltration rate of the northern row (3,600 cm/hr) is significantly ($F(1,10)=9.050$, $p=0.013$) smaller than the infiltration rate of the middle parking row (4,500 cm/hr).

H4: Infiltration rate changes with time

The fourth hypothesis addresses the research on the maintenance needs of the permeable surfaces by tracking the infiltration rate. The expectation is that, with time, the vehicles using the parking lot will transport particulates to the parking surface that, along with wind-blown particulates, accumulate in the surface openings. The accumulation of particulates will progressively block the openings and reduce the infiltration capacity. Solids accumulate from, among other sources, particulates carried by the vehicles, tire deterioration, wind-blown solids and run on from adjacent areas. Anecdotally, the particulates accumulate more rapidly when roadways receive traction sand that is carried onto the surface by vehicles even if it is not directly applied to the permeable surfaces.

The measurements show no significant changes in the infiltration rate of the porous asphalt or the pavers during the monitored period. The porous concrete, however, shows a more surprising trend. The infiltration rates measured from February through April are larger than the December and January measurements. Figure 5 shows the monthly mean infiltration rate for each permeable surface.

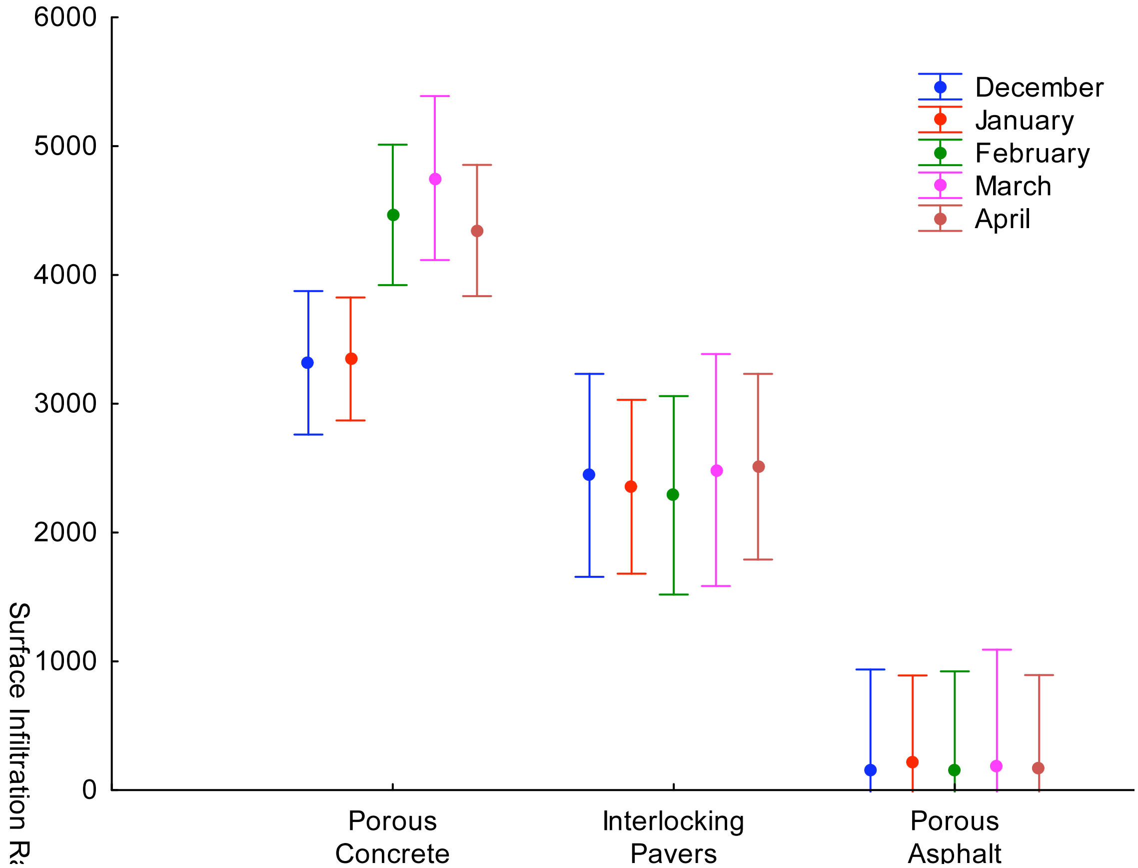

Figure 5. The monthly measured surface infiltration rate of each surface is shown above. This analysis pools the measurements from both rows of porous concrete. There is no change in the measured infiltration rates of the interlocking pavers or porous asphalt, but the infiltration rates of the porous concrete increase.

H5: Stripe effect

The construction specifications call for waterborne acrylic traffic paint to be used for the stripes and other traffic markings on the parking lot. The lines designating the parking stalls and the diagonal striping between handicap stalls are four inches wide. The lines designating the handicapped parking are blue and the remaining lines are white. If the selected sampling location happens to center on a line crossing; the painted surface can theoretically be more than 70% of the available infiltration area. If the paint hinders flow through the surface, then the infiltration rate of the surfaces will be smaller when the measurement location spans a painted surface.

Of the 120 sites where infiltration was measured during this period, 21 are noted to have included a partly painted area. Most (16) measurements that span or partially span a line are on the porous concrete surface. For the remainder, 3 are on the porous asphalt and only 1 is on pavers. The one-way factorial ANOVA suggests that making a measurement where paint is partly on the infiltrating areas does not affect the measured infiltration rate ($F(1, 118)=0.1$, $p=0.90$) for any of the surfaces. Examining the porous concrete as a subset because of the large fraction of the measurements including a stripe made on the concrete supports the conclusion the paint does not affect the measurements ($F(1, 58)=0.04$, $p=0.91$).

Chapter 5 Conclusions

The compressed Neoprene sheet forms an effective seal that prevents leaks between the pipe and the parking surface. Minimal leakage was observed on the porous asphalt and nearly no leakage was observed on either the pavers or the porous concrete (see Figure 6).

Figure 6. The wetted area after removing the test apparatus shows the limited leakage through the seal formed by the compressed Neoprene sheeting.

The infiltration capacity of all three surfaces is very large. Although the surface infiltration rates vary by more than an order of magnitude, each is much larger than the reasonably expected rain event. This translates into a difference in the amount of available excess capacity or the amount of impervious surface that can be serviced. The values are in reasonable agreement with values reported by others (e.g., Ferguson 2005; Bean 2007) in the literature.

The data are highly variable with relative standard deviations usually exceeding 10% of the mean value. The confidence interval for the mean infiltration rate made on a given surface in a given month average 700 cm/hr and range from 480 to 900 cm/hr. This is partially attributable to the high infiltration rates making the measurement difficult to execute. Pouring 18 kg of water into the 12-inch diameter pipe while trying to maintain the water depth between the markings 5 mm apart in the pipe is awkward. The high variability will make it difficult to detect meaningful change. For example, the confidence interval for the porous asphalt does not exclude zero so, if current uncertainty levels continue, even complete blockage will not be statistically different from the current readings (see Figure 3 and Figure 5).

The surface infiltration rates of the east and west halves of the middle porous concrete row are significantly different. The infiltration rate of the western half is smaller than the infiltration rate of eastern half. If this difference is the result of preferential parking, then the western rate would have decreased from the common starting point. The data do not support this, however. Post hoc testing does not show significant time based changes for either half of the lot ($F(4, 16)=0.74$, $p=0.58$) suggesting the cause is other than users selectively parking near the building.

The painted stripes do not affect the measured infiltration rates on the porous concrete. On the concrete, the paint appears to mostly coat the surfaces surrounding the opening and not seal the openings. All the measurements completed to date on a painted surface have been situated such that the painted surface blocks a relatively small portion of the infiltrating area which may be masking the potential effect. The large infiltration capacity of the unpainted area, particularly with the variability of the measurements, will mask any effects.

The anticipated reduction in infiltration capacity from clogging has not occurred during this period. The anecdotal information on infiltration reductions closely associated with winter operations failed to materialize. The differences in the porous concrete measurements suggest an increase in infiltration capacity with passing time during this period. The available temperature data are rough estimates of the temperature of the infiltrating water and are not adequate to test temperature-related effects. The water temperature, average air temperature, and temperature recorded by the thermistors embedded in the wearing surface do not show an obvious correlation to measured infiltration rates.

Table 1. Location and results of the December 2009 surface infiltration measurements.

Row	Half	Location Number	Distance from curb Ft	Distance from curb In.	Distance from North edge Ft	Distance from North edge In.	Pre-wet Time (s)	Weight of water used (lkg)	Test Time (s)	Infiltration Rate (cm/h)	On Line?	Average (cm/h)	Std Dev (mm/h)	RSD
		L3‡	59	8	15	1	16.5	18.0	57.3	615				
	E	A1‡	37	4	9	5	9.1	18.0	27.2	1296		776	461	59%
		A2‡	62	0	10	11	9.2	18.0	84.6	417	Y			
0		L1‡	20	5	1	11	9.8	18.0	31.3	1126				
	W	L2‡	9	8	18	6	8.5	18.0	32.4	1088		1124	36	3%
		L3‡	60	4	6	2	7.0	18.0	30.4	1159				
		L1‡	30	8	30	9	8.4	18.0	32.3	1091				
	E	L2‡	14	7	2	11	9.4	18.0	39.8	885		1027	123	12%
		L3‡	2	4	28	11	10.5	18.0	31.9	1105				
1		L1	19	5	19	6	11.4	18.0	44.5	792				
	W	L2	68	7	34	10	10.0	18.0	37.9	930		898	94	10%
		L3	30	5	31	4	9.0	18.0	36.3	971				
		L1	25	3	26	0	6.4	18.0	15.9	2216				
	E	L2	57	6	6	4	6.5	18.0	23.5	1500		1820	364	20%
		L3	4	7	10	9	5.5	18.0	20.2	1745				
2		L1	33	2	10	7	6.2	18.0	19.7	1789				
	W	L2	66	8	17	9	7.1	18.0	29.7	1187		1505	303	20%
		A2	34	2	3	11	10.3	18.0	22.9	1539				
		L1	55	8	2	12	55.0	3.6	83.8	84				
	E	L2	25	2	16	12	88.0	3.6	151.8	46		64	19	29%
		A1	12	4	7	8	60.1	3.6	112.8	62				
3		L2	24	5	17	10	103.2	3.6	144.6	49				
	W	L3	53	1	6	6	57.6	3.6	102.1	69		52	15	29%
		A2	51	8	20	3	118.1	3.6	178.6	39				

. ‡ Measurements made on December 11, 2009, remaining measurements were completed on December 15, 2009

Row 0 is the northernmost parking row and, like row 2, is constructed of porous concrete. Row 1 is constructed from interlocking concrete pavers and row 3 is constructed of porous asphalt. Locations L1 though L3 are the three primary locations selected using the spreadsheet. Locations A1 and A2 are the alternate locations.

Water temperature was not recorded. The average air temperature recorded on site from 08:00 through 16:00 EST was -2.4 ºC on December 11, 2009 and 9.1ºC on December 15, 2009. Air temperature was recorded at 10-minute intervals using an Onset (Pocasset, MA) weather station on the Edison Environmental Center but not adjacent to the parking lot.

The average temperature recorded by thermistors embedded in each surface listed from 08:00 through 16:00 the day of measurement (December 11, 2009) for rows 1 through 3 is below. Row

0 does not have embedded thermistors. The temperature of the driving surface is recorded at 10-minute intervals using Campbell Scientific (Logan, UT) thermistors (model 107 and 108) and loggers (model CR1000X).

Row	Surface	T East (^oC)	T West (^oC)
1	Pavers	7.7	-1.7
2	Porous Concrete	5.6	6.8
3	Porous Asphalt	7.1	7.8

Table 2. Location and results of January 2010 surface infiltration measurements.

Row	Half	Location Number	Distance from Curb Ft	Distance from Curb In.	Distance from North edge Ft	Distance from North edge In.	Pre-wet time (s)	Weight of water used (kg)	Test time (s)	Infiltration Rate (cm/h)	On Line?	Average(cm/h)	Std Dev (cm/h)	RSD	Water Temp (^oC)
0		L2	53	8	18	3	7.0	18.0	31.6	1115					
	E	A1	24	4	15	6	11.8	18.0	65.9	535		1070	514	48%	10.4
		A2	53	8	3	6	6.5	18.0	22.6	1559	Y				
		L1	11	5	13	10	11.7	18.0	55.1	640					
	W	L2	43	11	18	9	8.2	18.0	21.6	1632		1149	496	43%	15.8
		L3	26	2	16	10	6.8	18.0	30.0	1175					
1		L1	44	6	35	6	10.2	18.0	38.8	908					
	E	L2	29	7	30	6	8.2	18.0	38.5	915		988	132	13%	8.3
		A1	50	8	30	7	6.9	18.0	30.9	1141					
		L2	30	6	23	6	9.8	18.0	54.9	642					
	W	L3	12	6	15	9	7.5	18.0	31.3	1126	Y	867	244	28%	7.8
		A2	37	7	9	9	9.3	18.0	42.3	833					
2		L2	61	1	6	5	7.6	18.0	19.8	1780	Y				
	E	L3	41	10	6	8	7.5	18.0	22.0	1600	Y	1670	96	6%	16.5
		A1	11	0	1	0	7.1	18.0	21.6	1632					
		L1	4	0	19	1	6.6	18.0	27.2	1296	Y				
	W	L2	42	9	23	2	5.3	18.0	20.8	1694	Y	1383	278	20%	8.6
		A1	9	11	3	10	7.8	18.0	30.4	1159					
3		L2	17	3	11	11	102.8	3.6	187.8	38					
	E	L3	11	5	19	2	191.8	3.6	293.2	24		31	7	22%	16.0
		A2	6	6	25	2	104.3	3.6	233.2	30					
		L1	34	7	23	1	36.6	3.6	72.6	97					
	W	L3	53	10	32	2	20.1	18.0	153.9	229		139	78	56%	9.9
		A1	42	3	7	9	42.2	3.6	76.9	92	Y				

The average surface temperature recorded by thermistors embedded in each surface listed from 08:00 through 16:00 EST the day of measurement (January 14, 2010) for rows 1 through 3 is below. Row 0 does not have embedded thermistors. The average air temperature for the same period was 3.2 ºC.

Row	Surface	T East (^oC)	T West (^oC)
1	Pavers	2.3	4.9
2	Porous Concrete	-2.9	-1.1
3	Porous Asphalt	4.6	1.4

Table 3 Locations and results for February 2010 surface infiltration measurements.

Row	Half	Location Number	Distance from Curb		Distance from North edge		Pre-wet time (s)	Weight of water used (kg)	Test time (s)	Infiltration Rate (cm/h)	Line?	Average(cm/h)	Std Dev (cm/h)	RSD	Water Temp (o C)
			Ft	In.	Ft	In.									
		L2	33	2	13	4	6.2	18.0	22.5	1566	Y				
	E	L3	39	0	10	0	5.1	18.0	17.7	1991	Y	1949	363	19%	8.7
0		A1*	38	9	4	11	4.5	18.0	15.4	2288					
		L2*	4	10	13	11	6.0	18.0	33.0	1068					
	W	L3*	5	2	17	9	11.1	18.0	30.6	1152	Y	1358	432	32%	14.9
		A1	47	4	16	11	7.7	18.0	19.0	1855					
		L1	53	7	23	2	8.6	18.0	35.3	998					
	E	L3	61	6	26	9	11.5	18.0	37.4	942		999	56	6%	17.7
1		A2	54	9	17	3	7.9	18.0	33.4	1055					
		L1	14	2	25	10	9.4	18.0	39.2	899					
	W	L2	27	9	9	5	12.2	18.0	57.9	609		804	169	21%	10.3
		A2	49	10	5	7	10.3	18.0	39.0	904					
		L1*	13	5	25	8	8.9	18.0	15.7	2242					
	E	L2*	14	1	30	8	5.9	18.0	17.9	1969		2219	240	11%	16.1
2		A2	20	7	19	2	4.8	18.0	14.4	2447	Y				
		L2	35	0	23	6	6.2	18.0	24.1	1462					
	W	L3	63	0	11	9	4.4	18.0	17.9	1969	Y	1507	441	29%	13.7
		A2	15	4	20	0	6.8	18.0	32.3	1091					
		L1	41	5	28	9	32.8	3.6	64.3	110	Y				
	E	L3	42	2	22	2	79.1	3.6	149.3	47	Y	72	33	47%	11.7
3		A3‡	16	4	17	6	70.5	3.6	121.6	58					
		L1	9	11	13	5	200.0	3.6	302.0	23					
	W	L2	6	10	16	6	68.0	3.6	165.0	43		48	27	57%	16.3
		L3*	47	4	8	4	50.3	3.6	91.7	77					

* Snow cleared before measuring infiltration rate

‡ Site L2 and both A1 and A2 were unavailable. Site selected by tossing a coin onto the available series of spaces.

The average surface temperature recorded by thermistors embedded in each surface listed from 08:00 through 16:00 EST the day of measurement (March 1, 21010) for rows 1 through 3 is below. Row 0 does not have embedded thermistors. The average air temperature was 7.7ºC during the same period

Row	Surface	T East (°C)	T West (°C)
1	Pavers	6.2	12.7
2	Porous Concrete	2.1	0.2
3	Porous Asphalt	4.4	6.4

Table 4. Locations and results for March 2010 surface infiltration measurements.

Row	Half	Location Number	Distance from Curb		Distance from North edge		Pre-wet time (s)	Weight of water used (kg)	Test time (s)	Infiltration Rate (cm/h)	On line?	Average(cm/h)	Std Dev (cm/h)	RSD	Water Temp (^oC)
			Ft	In.	Ft	In.									
0		L1	41	10	6	9	5.9	18.0	15.6	2259	Y				
	E	L3	61	5	10	0	5.9	18.0	27.4	1286	Y	1466	721	49%	8.4
		A1	51	9	16	10	8.0	18.0	41.4	851	Y				
		L3	5	5	13	7	5.0	18.0	25.5	1382					
	W	A1	43	7	7	11	7.4	18.0	15.8	2230		1807	424	23%	7.6
		A2	42	11	4	1	4.2	18.0	19.5	1807	Y				
1		L1	48	0	31	11	6.7	18.0	29.6	1191					
	E	A1	40	8	23	0	8.8	18.0	32.4	1088		1140	51	5%	11.7
		A2	32	5	4	6	6.9	18.0	30.9	1141					
		L2	45	7	25	3	8.4	18.0	38.1	925					
	W	L3	29	5	1	8	11.0	18.0	54.9	642		817	153	19%	11.5
		A2	23	3	7	11	9.3	18.0	39.8	885					
2		L1	19	11	6	2	4.6	18.0	17.8	1980					
	E	L2	44	4	24	2	4.7	18.0	17.1	2061		2135	203	10%	11.0
		L3	18	4	17	8	4.6	18.0	14.9	2365					
		L1	58	2	10	8	3.8	18.0	13.8	2554					
	W	L3	64	10	16	8	6.5	18.0	29.1	1211		2076	751	36%	8.1
		A1	53	2	11	4	6.5	18.0	14.3	2464					
3		L1	12	9	37	7	42.4	3.6	63.2	112					
	E	L2	23	0	8	8	114.0	3.6	197.5	36		88	46	52%	10.6
		A1	37	11	34	7	38.1	3.6	59.7	118					
		L1‡	56	9	7	0	85.0	3.6	155.0	45					
	W	L2‡	39	5	22	11	61.6	3.6	92.3	76		61	15	25%	14.1
		A1	46	7	24	2	82.8	3.6	115.0	61					

‡ **Measurements made on March 18, 2010.**

The average surface temperature recorded by thermistors embedded in each surface listed from 08:00 through 16:00 the day of most measurement (March 10, 2010) for rows 1 through 3 is below. Row 0 does not have embedded thermistors. The average air temperature during the same period was 10.7°C.

Row	Surface	T East (^oC)	T West (^oC)
1	Pavers	9.2	9.2
2	Porous Concrete	8.0	8.6
3	Porous Asphalt	10.2	8.9

Table 5. Locations and results for April 2010 surface infiltration measurements.

Row	Half	Location Number	Distance from curb Ft	Distance from curb In.	Distance from North edge Ft	Distance from North edge In.	Pre-wet Time (s)	Weight of water used (kg)	Test Time (s)	Infiltration Rate (cm/h)	On Line?	Average (cm/h)	Std Dev (cm/h)	RSD	Water Temp. (oC)
0	E	L1*	57	1	2	12	5.7	18.0	24.6	1433		2084	606	29%	19.4
		A1*	66	1	11	3	8.7	18.0	13.4	2630					
		A2*	10	12	5	1	4.9	18.0	16.1	2189	Y				
	W	L2*	4	4	18	0	5.7	18.0	22.8	1546		1383	281	20%	13.4
		A1*	20	10	4	3	5.1	18.0	22.8	1546	Y				
		A2*	6	10	12	3	6.5	18.0	33.3	1058					
1	E	L2*	44	9	20	2	10.0	18.0	39.3	897		885	15	2%	19.1
		A1*	52	10	22	4	9.4	18.0	39.6	890					
		A2*	35	2	34	3	9.6	18.0	40.6	868					
	W	L1*	43	3	23	5	9.1	18.0	39.9	883		1092	181	17%	19.3
		L3*	32	5	14	4	7.7	18.0	29.6	1191					
		A2*	68	10	13	4	7.5	18.0	29.3	1203					
2	E	L1*	27	4	23	7	9.4	18.0	17.1	2057		1953	106	5%	19.3
		L2*	31	0	37	2	8.2	18.0	19.1	1845	Y				
		A2*	31	2	29	1	5.6	18.0	18.0	1958					
	W	L2*	52	3	8	3	5.3	18.0	20.5	1719		1423	257	18%	14.2
		L3*	3	11	20	11	6.5	18.0	27.5	1282					
		A1*	6	1	25	3	5.4	18.0	27.8	1268					
3	E	L1‡	12	2	31	9	43.6	3.6	65.8	107	Y	82	28	34%	18.6
		L2‡	51	1	4	8	57.5	3.6	134.4	52					
		A2‡	10	7	25	4	38.0	3.6	80.8	87					
	W	L1‡	57	0	15	2	83.2	3.6	169.8	42		54	12	23%	13.0
		L3‡	3	2	3	1	56.4	3.6	106.1	66					
		A1‡	10	1	26	2	68.4	3.6	129.8	54					

‡ Measurements made April 24, 2010 * Measurements made April 23, 2010

The average surface temperature recorded by thermistors embedded in each surface listed from 08:00 through 16:00 EST the days of measurement for rows 1 through 3 is below. Row 0 does not have embedded thermistors. The average air temperature for the period on April 23, 2010 was 16.8°C and on April 24, 2010 it was 19.2°C.

Row	Surface	T East (°C)	T West (°C)
1	Pavers	17.9	15.7
2	Porous Concrete	13.1	15.8
3	Porous Asphalt	29.4	31.4

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