Permeable Pavement Technical Standard -

Rationale Behind Selected Performance Criteria in 1008

February 17, 2014

Roger Bannerman Judy Horwatich Bill Selbig USGS



Porous Asphalt

Pervious Concrete

Permeable Pavers

PERFORMANCE CRITERIA WE ARE GOING TO COVER

- Initial Surface Infiltration Rate –100 in/hr.
- Surface Infiltration Rate Decline Over Time 10 in/hr.
- Surface Clogging Capacity 0.06 lbs./ft²
- Restorative Cleaning Efficiency 50%
- Underdrain Discharge Credit TSS (55%) and TP (35%).

Industry Minimum = 100 inch/hour (David Smith, 2012)

WINSLAMM – VERSION 10.1.6

Porous Pavement Control Device

First Source Area Control Practice

Land Use: Commercial 1

Source Area: Paved Parking 1

Total Area: 4.000 acres

Porous pavement area (acres):

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Pavement Geometry and Properties

1 - Pavement Thickness (in)	6.0
Pavement Porosity (>0 and <1)	0.20
2 - Aggregate Bedding Thickness (in)	4.0
Aggregate Bedding Porosity (>0 and <1)	0.35
3 - Aggregate Base Reservoir Thickness (in)	12.0
Aggregate Base Reservoir Porosity (>0 and <1)	0.35
Porous Pavement Area to Agg Base Area Ratio	1.00

Outlet/Discharge Options

Perforated Pipe Underdrain D (inches)	4.00	
4 - Perforated Pipe Underdrai Elevation (inches above Datu	4.0	
Number of Perforated Pipe Ur	nderdrains (<250)	3
Subgrade Seepage Rate (in/ or enter	0.300	
Use Random Number Genera Uncertainty in Seepage Rate		
Subgrade Seepage Rate COV	/	
Underdrain Discharge Percer (0-100) or leave blank for prog	nt TSS Reduction gram to calculate	55
-Select Subgrade Seepa C Sand - 8 in/hr C Loamy sand - 2.5 in/hr C Sandy Ioam - 1.0 in/hr	n ge Rate C Clay Ioam - 0. C Silty Clay Ioan C Sandv Clay - (1 in/hr n - 0.05 in/hr 0.05 in/hr
C Loam - 0.5 in/hr C Silty clay - 0.0)4 in/hr

Clay - 0.02 in/hr

Surface Pavement Layer Infiltration Rate Data

 Initial Infiltration Rate (in/hr)
 100.00

 Surface Pavement Percent Solids Removal Upon Cleaning (0-100)
 50.0

Enter either these three values:

Percent of Infiltration Rate After 3 Years (0-100) Percent of Infiltration Rate After 5 Years (0-100) Time Period Until Complete Clogging Occurs (yrs)

Or this value:

1.000

Surface Clogging Load (lb/sf)

Select Particle Size Distribution File

Select File Not needed - calculated by program



- Never Cleaned
- C Three Times per Year
- Semi-Annually
- O Annually
 - Every Two Years
- C Every Three Years
- Every Four Years
- C Every Five Years
- C Every Seven Years
- C Every Ten Years

Porous Pavement Geometry Schematic Pavement Surface Percent of Total Area that is Porous Pavement 25.0 % 6.0" Porous Pavement Laver 4.0" Aggregate Bed Layer 22.0" 4.0" 12.0" Aggregate Base Layer 4.0" Copy Porous Paste Porous Subgrade Pavement Pavement Data Data Delete Control Cancel Continue

0.06

Source Area # : 13 Porous Pavement Device Number 1

Control Practice #: 1 Land Use #: 1

Sandy silt loam - 0.2 in/hr

Silt loam - 0.3 in/hr

ASTM METHOD C1701 (ASTM 2009).



Borst, Michael, Rowe, Amy A., Stander, Emilie K., O'Connor Thomas P., 2010, Surface Infiltration Rates of Permeable Surfaces: Six Month Update (November 2009 through April 2010), EPA/600/R-10/083 | June 2010 | www.epa.gov /nrmrl

AVERAGE MONTHLY MEASURED SURFACE INFILTRATION RATE OF EACH SURFACE



Permeable Pavement Monitoring Site – Madison, WI

10-10-1

A. A. Bata

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Test Plots

VE al Monte //

20' x 75'

6168 1616

Google

IR R

A A

Pete Wood - Team Leader WDNR

Gini Knight – SOC Coordinator WLCA **Roger Bannerman – WDNR Bob Givens – OMNI Associates** Kate Gleason – WDNR Josh Harder – Dane County LCD Chris Homburg – Homburg Contractors Inc. Laura Fenley – DOT Jason Kruger – WI Ready Mixed Concrete Association David Liebl – UW Extension John McCarthy – Graef USA Tom Price – Conservation Design Forum Science for a changing world Michelle Reynolds – DOT **Bob Roehrig – County Materials** NISCONSIA Corporation Scot Schwandt – WI Asphalt Pavement DEPARTME Association Tim Troester – City of Madison

PERMEABLE PAVEMENT **MONITORING & STANDARDS PARTNERS**



OFTR



DEPT. OF NATURAL RESOURCES



INFILTRATION RATES

 Falling head permeameter test (ASTM-C1701)





		Flow	Direction					
PAVER INFLUENT			CONCRETE INFLUENT ASPHALT INFLUENT			IENT		
23	22	220	8	8	29	90	232	362
516	77	490	16	79	645	296	123	320
717	328	496	20	114	403	279	152	343
	EFFLUENT	-	1	EFFLUENT			EFFLUENT	



All values are in inches/hour



SELECTED AVERAGE SURFACE INFILTRATION RATES FOR NEW PERMEABLE PAVEMENT

Surface Infiltration Rate, inches/hour WDNR 1008 = 100 in/hr

Type of Permeable Pavement	Borst (2010)	Bean (2007)	Chica go Alley	Drake (2012)	St John & Horner (1997)	Ranieri (2002)	USGS mean (2014)
Asphalt	33				170 to 500	140	244
Concrete	820		157 to 429	920			147
Pavers	429	770		59 to 204			321

Permeable Pavement Lasted 20 Years -All model runs use 20 year rainfall record

BUMP

Average Monthly Surface Infiltration Rates on Permeable Pavement with a 3:1 Ratio and a Surface Clogging Capacity of 0.06 lb/sq-ft No Cleaning



Pavement Infiltration Rate = ISIR – [(ISIR/Clogging Mass) × Cumulative Clogged Mass]

PIR = 100 - [(100/0.06 lbs/sf) X 0.025 lbs/sf]

 $PIR = 100 - [(1667) \times 0.025 \text{ lbs/sf}]$

PIR = 100 in/hr. – 41.7 in/hr. = 58.3 in/hr.

 $PIR = 100 - (1667 \times 0.06) = 100 - 100 = 0$



 $PIR = 500 - (8333 \times .06) = 500 - 500 = 0$

PERFORMANCE CRITERIA WE ARE GOING TO COVER

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PERMEABLE INTERLOCKING CONCRETE PAVEMENTS



David R. Smith Fourth Edition



The minimum surface infiltration rate should not be less than 10 inches/hour. (David Smith, 2011)

Go to Model's detailed output file to find date surface infiltration rate is 10 in/hr.



Average Monthly Surface Infiltration Rates on Two Ratio of Permeable Pavement when Loading Rate is 0.06 lb/sq-ft No Cleaning

PERFORMANCE CRITERIA WE ARE GOING TO COVER

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Permeable pavement with gaps clogged with silty-clay soil (Hunt,2008).

Author	Pavement Type	Time, yrs.	Surface Infil. Rate, in/hr.	
Bean, 2007	Pavers (sandy)	20	3 to 4	
Bean, 2007	Pavers (clay)	20	0.4	
Gerrits, 2001	Pavers	8	5.9	
ITC, 2012	Concrete	2	1.3	
Drake, 2012	Pavers	2	13 to 55 (59 to 204)	
Drake, 2012	Concrete	2	534 (<mark>920</mark>)	
Bean, 2007	Pavements usually had rate at least 1 in/hr.			



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Porous Pavement Control Device

First Source Area Control Practice

Land Use: Commercial 1

Source Area: Paved Parking 1

Total Area: 4.000 acres

Porous pavement area (acres):

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Pavement Geometry and Properties

1 - Pavement Thickness (in)	6.0
Pavement Porosity (>0 and <1)	0.20
2 - Aggregate Bedding Thickness (in)	4.0
Aggregate Bedding Porosity (>0 and <1)	0.35
3 - Aggregate Base Reservoir Thickness (in)	12.0
Aggregate Base Reservoir Porosity (>0 and <1)	0.35
Porous Pavement Area to Agg Base Area Ratio	1.00

Outlet/Discharge Options

Perforated Pipe Underdrain D (inches)	4.00	
4 - Perforated Pipe Underdrai Elevation (inches above Datu	4.0	
Number of Perforated Pipe Ur	nderdrains (<250)	3
Subgrade Seepage Rate (in/ or enter	0.300	
Use Random Number Genera Uncertainty in Seepage Rate		
Subgrade Seepage Rate CO ^v	V	
Underdrain Discharge Percer (0-100) or leave blank for prog	nt TSS Reduction gram to calculate	55
- Select Subgrade Seena	nga Bata	
C Sand - 8 in/hr	C Clay loam - 0.	1 in/hr
C Coarry sand - 2.5 in/hr	 Silty clay loan 	n - 0.05 in/hr
Sandy loam - 1.0 in/hr	Sandy clay - (0.05 in/hr
🗢 Loam - 0.5 in/hr	Silty clay - 0.0)4 in/hr

Surface Pavement Laver Infiltration Rate Data

Initial Infiltration Rate (in/hr) 100.00 Surface Pavement Percent Solids Removal Upon 50.0 Cleaning (0-100)

Enter either these three values:

Percent of Infiltration Rate After 3 Years (0-100) Percent of Infiltration Rate After 5 Years (0-100) Time Period Until Complete Clogging Occurs (yrs)

Or this value:

1.000

Surface Clogging Load (Ib/sf)

Select Particle Size Distribution File

Not needed - calculated by program Select File



0.06

Restorative Cleaning Frequency

C Three Times per Year

Every Two Years

Every Three Years

Ev y Four Years very Five Years

Every Seven Years

Every Ten Years

Never Cleaned

Semi-Annually

O Annually

Sandy silt loam - 0.2 in/hr

Land Use # : 1

Clay - 0.02 in/hr

Silt loam - 0.3 in/hr

Control Practice # : 1

Source Area # : 13

HELPFUL FACTS TO SELECT SURFACE CLOGGING CAPACITY

Depth of Clogging

Pitt (2003) - 0.4 to 0.8 inches

Przybylowski (2003) – 0.75 inches

Void space:

Hunt (2008) -

Asphalt – 15 to 20% Concrete – 15 to 25% Permeable Pavers (no gravel) – 8 to 15%

Permeable Pavers (with gravel) – 5% (assume gravel 35% void)



Calculate Surface Clogging Capacity Based on Void Space in Pavement

Assumptions:

- Clogging depth of 0.4 inches
 Spec. grav. of 1.3 or
 - Spec. grav. of 1.3 or 80 lbs./ft³ 5% x 1452
- 3. Void space of 5%.4. 1 acre parking lot 80 lbs./

Example Calculation: 43560 ft²x 0.033 ft. = 1452 ft³ 5% x 1452 ft³= 73 ft³ 80 lbs./ft³ x 73 ft³= 5808 lbs 5808 lbs./ 43560 ft² = $0.13 lbs./ft^2$

Assume Depth of Clogging is 0.2 inches or 0.016 ft. Clogging capacity = 0.065 lbs./ft²

Surface Clogging Capacity, Ibs./sf.	Years to Reach 10 inches/ hour
	Ratio of 3:1
0.01	1.9
0.03	5.6
0.04	7.3
0.05	9.6
0.06	10.3
0.08	14.6
0.10	18.4

Assume pavement should last no more than about 10 years without cleaning.



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- Underdrain Discharge Credit TSS (55%) and TP (35%).

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Restorative Cleaning Frequency

Never Cleaned

Semi-Annually

Annually

0

С

C

0

C Three Times per Year

Every Two Years

Every Three Years

Every Seven Years

Every Ten Years

Every Four Years Every Five Years

Porous Pavement Control Device

First Source Area Control Practice

Land Use: Commercial 1

Source Area: Paved Parking 1

Total Area: 4.000 acres

Control Practice # : 1

Porous pavement area (acres):

1.000

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Pavement Geometry and Properties

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Porous Pavement Area to Agg Base Area Ratio	1.00

Outlet/Discharge Options

Perforated Pipe Underdrain D (inches)	liameter, if used	4.00	
4 - Perforated Pipe Underdrai Elevation (inches above Dat	n Outlet Invert um)	4.0	that
Number of Perforated Pipe U	nderdrains (<250)	3	
Subgrade Seepage Rate (in/ or enter	hr) - select below	0.300	
Use Random Number Genera Uncertainty in Seepage Rate	ation to Account for		
Subgrade Seepage Rate CO	V		
Underdrain Discharge Percer (0-100) or leave blank for pro	nt TSS Reduction gram to calculate	55	
-Select Subgrade Seepa	age Rate		7
C Sand - 8 in/hr C Loamy sand - 2.5 in/hr C Sandy Ioam - 1.0 in/hr C Loam - 0.5 in/hr	 Clay loam - 0. Silty clay loan Sandy clay - 0. Silty clay - 0.0 	1 in/hr n - 0.05 in/hr 0.05 in/hr 14 in/hr	Copy Po Paverr Data
 C Silt Ioam - 0.3 in/hr C Sandy silt Ioam - 0.2 in/h 	C Clay - 0.02 in.	'hr	

Land Use #: 1

Source Area # : 13

Infiltration Rate Data	
Initial Infiltration Bate (in/hr)	100.00
Surface Pavement Percent Solids Removal Upon Cleaning (0-100)	50.0
Enter either these three values:	
Percent of Infiltration Rate After 3 Years (0-100)	
Percent of Infiltration Rate After 5 Years (0-100)	
Time Period Until Complete Clogging Occurs (yrs)	
Or this value:	
Surface Clogging Load (lb/sf)	0.06

Surface Payement Laver



Select Particle Size Distribution File

ile Not needed - calculated by program



Cleaning 'Frequencies



In Maryland and North Carolina, Bean et al. (2007) simulated maintenance of permeable pavements using an approach similar to Gerrits (2001). Of the 14 concrete grid paver sites tested, 13 exhibited notably higher infiltration rates than the sites that had not undergone maintenance. The mean infiltration rate increased by 66%.

An assumption was made cleaning could restore 50% of the infiltration lost during the previous time period.

For example, the decline in the infiltration rate from 100 in/hr to 90 in/hr in one year is 10 in/hr. To determine the benefit of cleaning, the 10 in/hr is multiplied by 50% and the result added to 90 in/hr. The new starting infiltration rate for the next year would be 95 in/hr.

Average monthly infiltration rate on 3:1 ratio of Permeable Pavement when Loading Rate is 0.06 lb/sq-ft No Cleaning and Cleaning Twice per Years



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Permeable Paver Pollutant Credits from Various States (Smith, 2011)- With Underdrains

State	Reduction Credits, %					
	Volume	TSS	TP			
VA	45	75	25			
NH		90	45			
PA		85	85			
MN			80			

Application	Location or Author	TSS	TP			
	Porous Asphalt					
Parking Lot	Durham	99	42			
Parking Lot	Legret, 1999	59				
Parking Lot	Pagotto, 2000	80				
Parking Lot	Rosen, 2007	98	40			
	Permeable Interlocking Concrete Pavers					
Drive Way	Jordon Cove	67	34			
Parking Lot	Goldsboro	71	65			
Parking Lot	Renton, WA					
Parking Lot	King College	81	53			
Parking Lot	Drake, 2012	88	88			
Parking Lot	Bean, 2005	70	62			
Parking Lot	Gilbert, 2006	70				
	Pervious Concrete					
Parking Lot	Tampa	91				
Parking Lot	Drake, 2012	79	51			



Monitored Results: TSS: 59 to 99% TP: 34 to 88%





Issues with Permeable Pavement Studies in the Literature:

- 1. Tests in laboratory cannot duplicate solids in runoff.
- 2. Data not collected on quality of run-on water.
- 3. Permeable pavement did not have any run-on.
- 4. Bottom was not sealed so water could infiltrate into native soil.
- 5. Ground water level higher than bottom of system.



INSTRUMENTATION





Influent

Effluent

UNDER DRAIN DISCHARGE CREDIT, %



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Porous Pavement Area to Agg Base Area Ratio	1.00

Outlet/Discharge Options

Perforated Pipe Underdrain Diameter, if used (inches)	4.00
4 - Perforated Pipe Underdrain Outlet Invert Elevation (inches above Datum)	4.0
Number of Perforated Pipe Underdrains (<250)	3
Subgrade Seepage Rate (in/hr) - select below or enter	0.300
Use Random Number Generation to Account for Uncertainty in Seepage Rate	
Subgrade Seepage Rate COV	
Underdrain Discharge Percent TSS Reduction (0-100) or leave blank for program to calculate	55
Select Subgrade Seepage Rate	

Clay loam - 0.1 in/hr

Silty clay loam - 0.05 in/hr

Source Area # : 13

Sandy clay - 0.05 in/hr

Silty clay - 0.04 in/hr

Clay - 0.02 in/hr

Surface Pavement Laver Infiltration Rate Data

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Enter either these three values:

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Or this value:

1.000

Surface Clogging Load (lb/sf)

Select Particle Size Distribution File

Not needed - calculated by program Select File

Restorative Cleaning Frequency

- Never Cleaned
- C Three Times per Year
- C Semi-Annually

O Annually

- Every Two Years
- C Every Three Years
- O Every Four Years
- C Every Five Years
- C Every Seven Years
- C Every Ten Years



0.06

Control Practice # : 1 Land Use # : 1

C Loamy sand - 2.5 in/hr

Sandy loam - 1.0 in/hr

Sandy silt loam - 0.2 in/hr

C Loam - 0.5 in/hr.

Silt loam - 0.3 in/hr

Porous Pavement Device Number 1

Land Uses		Junctions			Control Practices	
File Name:						
D:\JAHData\urban\SLAMM\2014\Porous F	Pavement test v10.1\	Com_PLot4ac_I	RunOn1_SInf100_	UInf03_Clog06_UD5	5_SemiAClean.mdb	
	Out	tfall Outpu	ut Summary	/		
	Runoff Volume F (cu. ft.)	Percent Runoff Reduction	Runoff Coefficient (R∨)	Particulate Solids Conc. (mg/L)	Particulate Solids Yield (lbs)	Percent Particulate Solids Reduction
Total of All Land Uses without Controls Outfall Total with Controls	5.992E+06	67.24 %	0.64	130.0 50.36	48628 6172	87.31 %
Current File Output: Annualized Total After Outfall Controls	98180	Years in Mo	del Run: 1	9.99	308.7	
Clogging capacity = 0.06 lbs/ft ³ Infiltration rate = 0.3 in/hr Sweeping Initial Infiltration rate = 100 in/hr 55% for Drain Tile						
Print Output Summary to Text File File File	Total Area Modeleo 4.000	d (ac)		Rocoi	ving Water Ir	nnaote
Total Control Practice Costs Capital Cost UNA Due To Stormwater Runoff (CWP Impervious Cover Model)					Runoff Model)	
Land Cost N/A Annual Maintenance Cost N/A Present Value of All Costs N/A Annualized Value of All Costs N/A			Perform Outfall Flow Duration Curve Calculation	s Without Co	Calculated Rv ontrols 0.64 ontrols 0.21	Approximate Urban Stream Classification Poor Poor

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EXAMPLE TSS AND VOLUME REDUCTIONS DETERMINED WITH WINSLAMM

	TSS Reduction, %			Volume Reduction, %		
Tile TSS Control	No Cleaning & infiltration	With Cleaning & infiltration	With Cleaning & no infiltration	No Cleaning & infiltration	With Cleaning & infiltration	With Cleaning & no infiltration
55%	55	87	59	45	67	0
Modeled	58	93	82	45	67	0

Assumptions:

- 1. Initial infiltration rate = 100 in/hr.
- 2. Surface Clogging Load = 0.06 lbs./sf
- 3. Infiltration in native soil = 0.3 in/hr
- 4. Ratio Regular pavement/permeable pavement= 3:1

Initial Surface Infiltration Rate –100 in/hr.

Surface Infiltration Rate Decline Over Time – 10 In/hr.

Surface Clogging Capacity – 1.06 lbs.///2

Restorative Cleaning Efficiency – 50%

Underdrain Discharge Credit

- TSS (55%) and TP (35%).



Questions?



Lots one-hour after plowing, -4*C (11AM on 2/3/07)

Robert Roseen, 2011