Permeable Pavement Technical Standard -

Rationale Behind Selected Performance Criteria in 1008

Porous Asphalt

Pervious Concrete

Permeable Pavers

February 17, 2014

Roger Bannerman
Judy Horwatich
Bill Selbig
USGS

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./ft^2**
- **Restorative Cleaning Efficiency** – **50%**
- **Underdrain Discharge Credit** – **TSS (55%) and TP (35%).**


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

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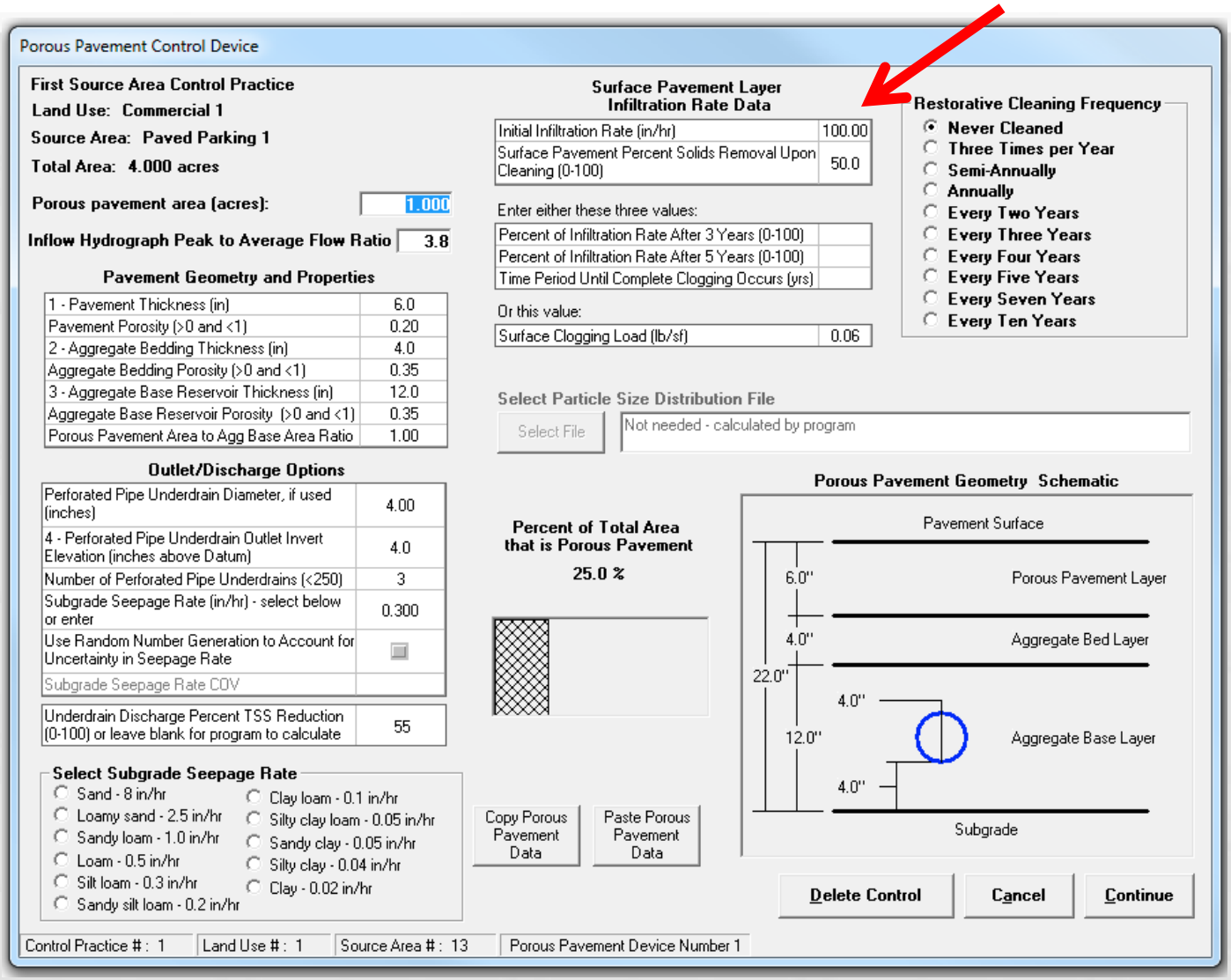
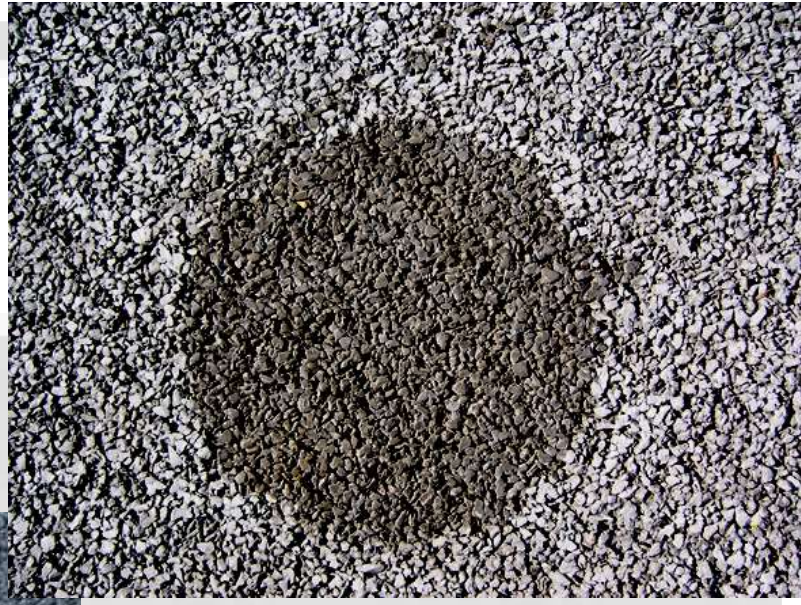
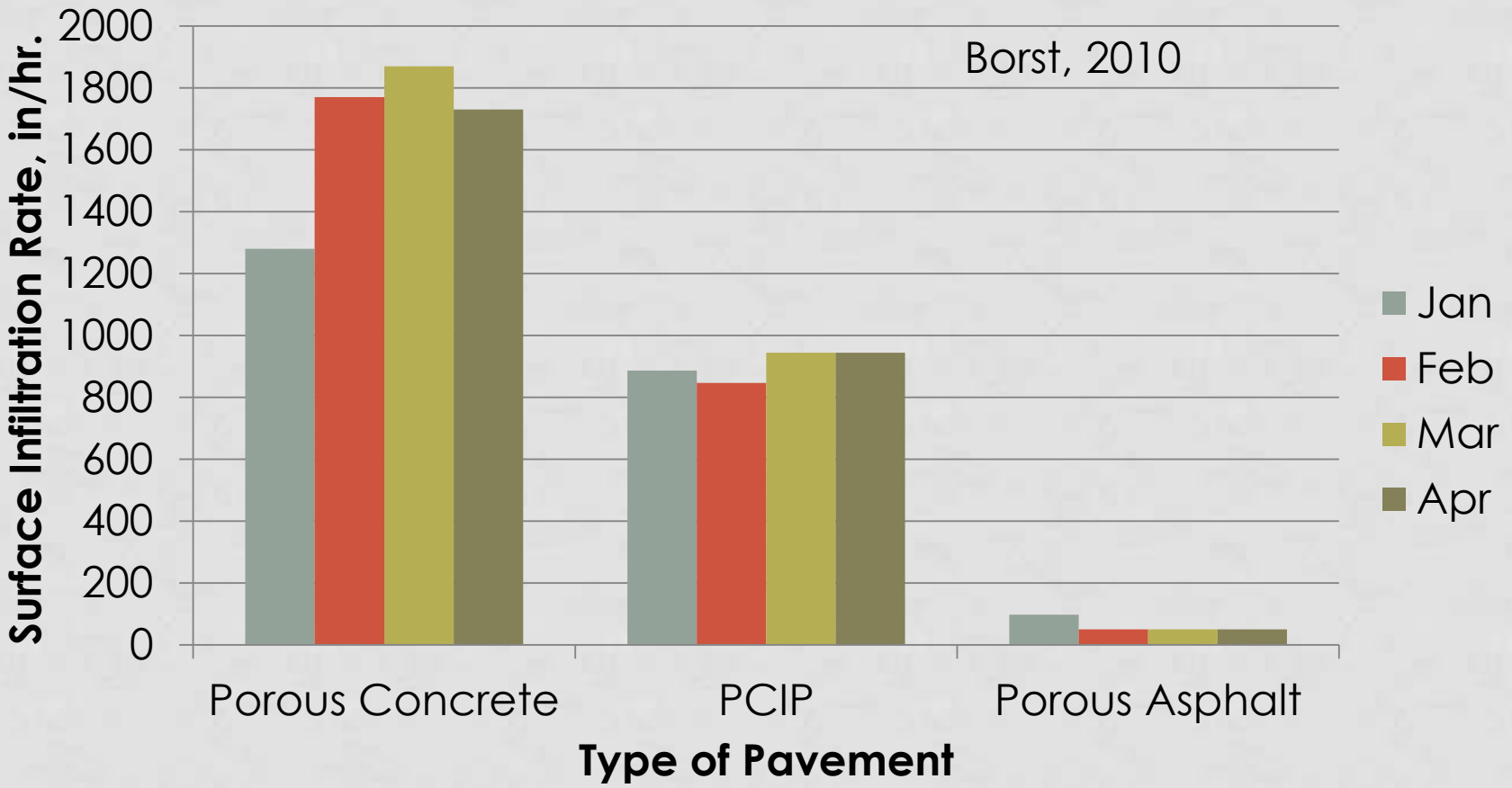


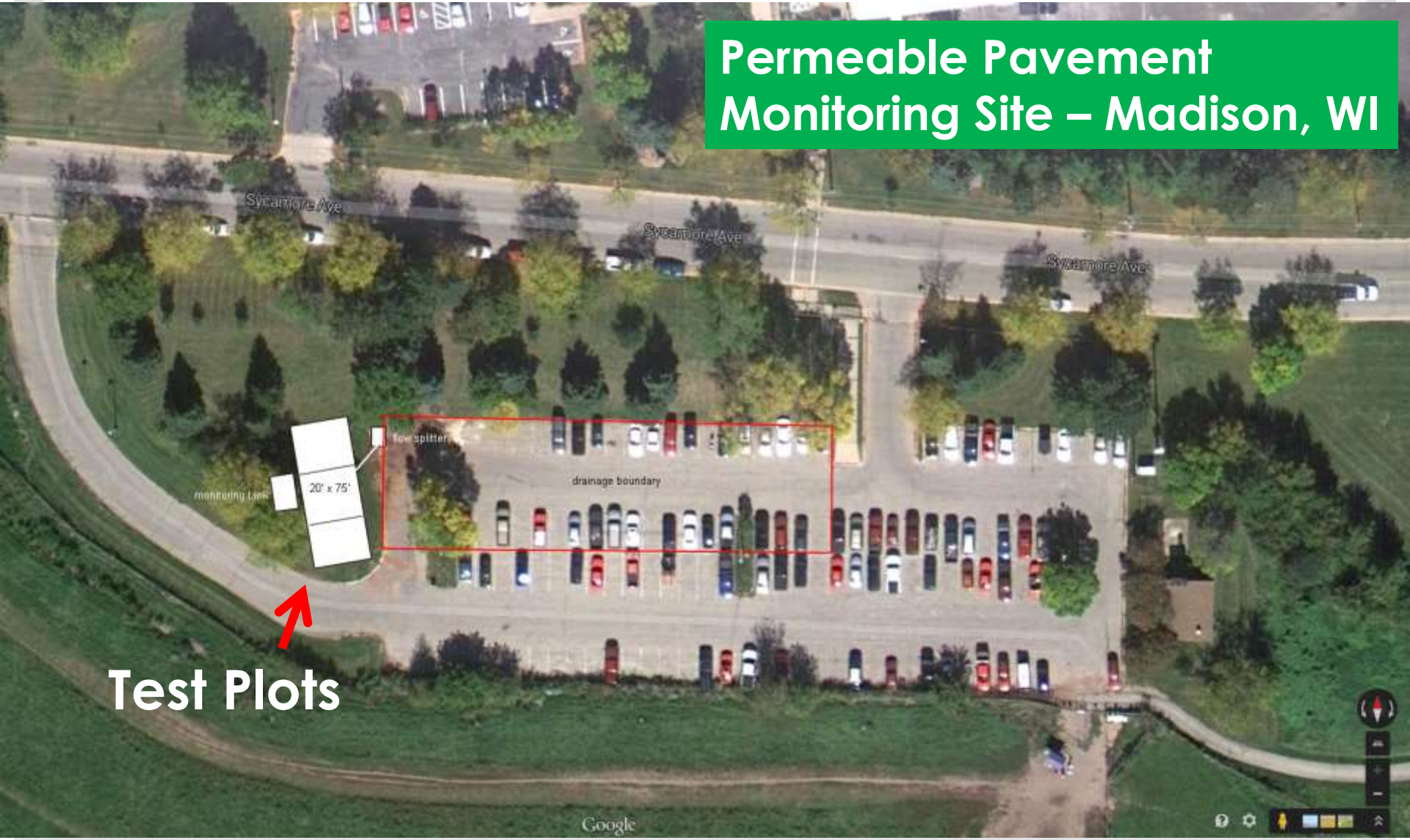
ASTM METHOD C1701 (ASTM 2009).



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
Sycamore Ave
Sycamore Ave
Sycamore Ave
flow splitter
drainage boundary
monitoring well
20' x 75'
Test Plots
Google

PERMEABLE PAVEMENT MONITORING & STANDARDS PARTNERS

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
Michelle Reynolds – DOT
Bob Roehrig – County Materials Corporation
Scot Schwandt – WI Asphalt Pavement Association
Tim Troester – City of Madison

USGS science for a changing world

WISCONSIN DEPT. OF NATURAL RESOURCES

WISCONSIN DEPARTMENT OF TRANSPORTATION

COUNTY MATERIALS CORPORATION

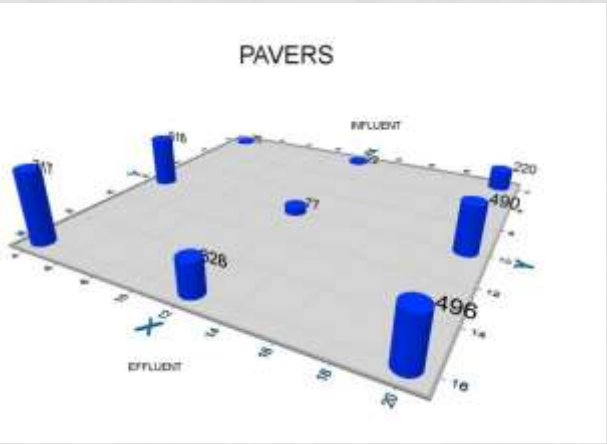

CAT

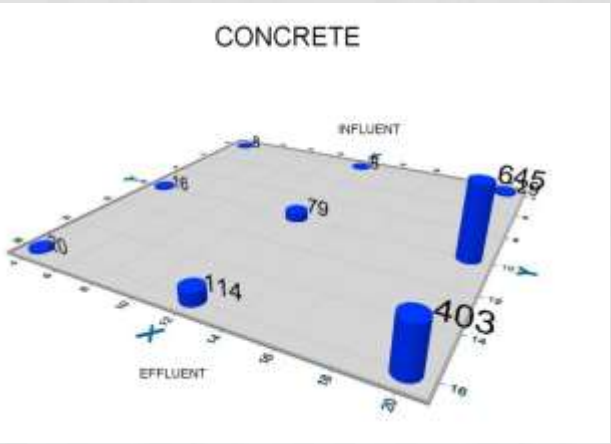
INFILTRATION RATES

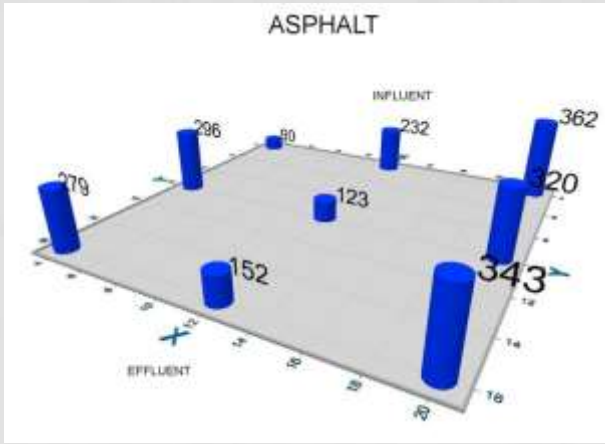
- Falling head permeameter test (ASTM-C1701)

Flow Direction

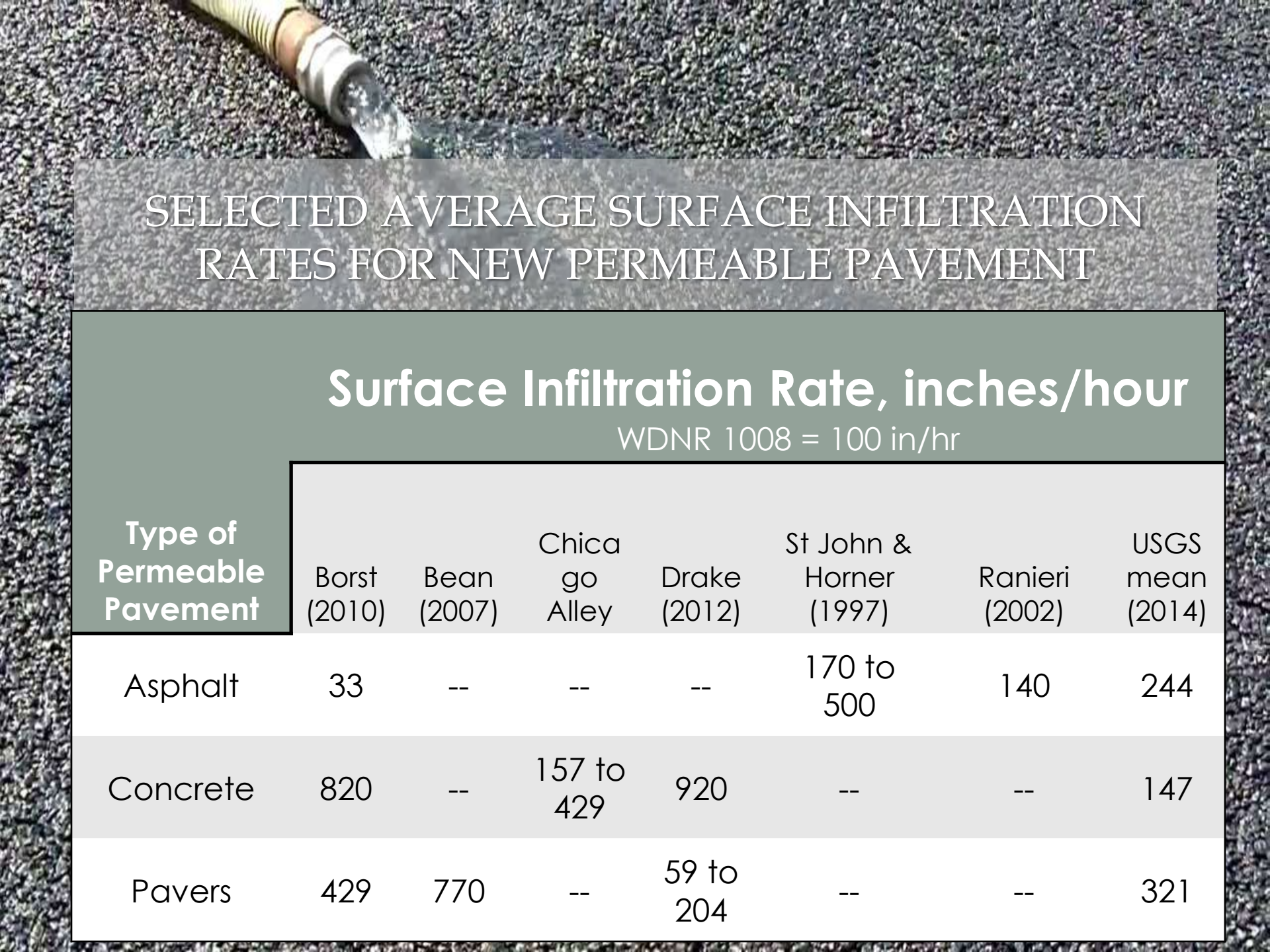
PAVER INFLUENT			CONCRETE INFLUENT			ASPHALT INFLUENT		
23	22	220	8	8	29	90	232	362
516	77	490	16	79	645	296	123	320
717	328	496	20	114	403	279	152	343
EFFLUENT			EFFLUENT			EFFLUENT		







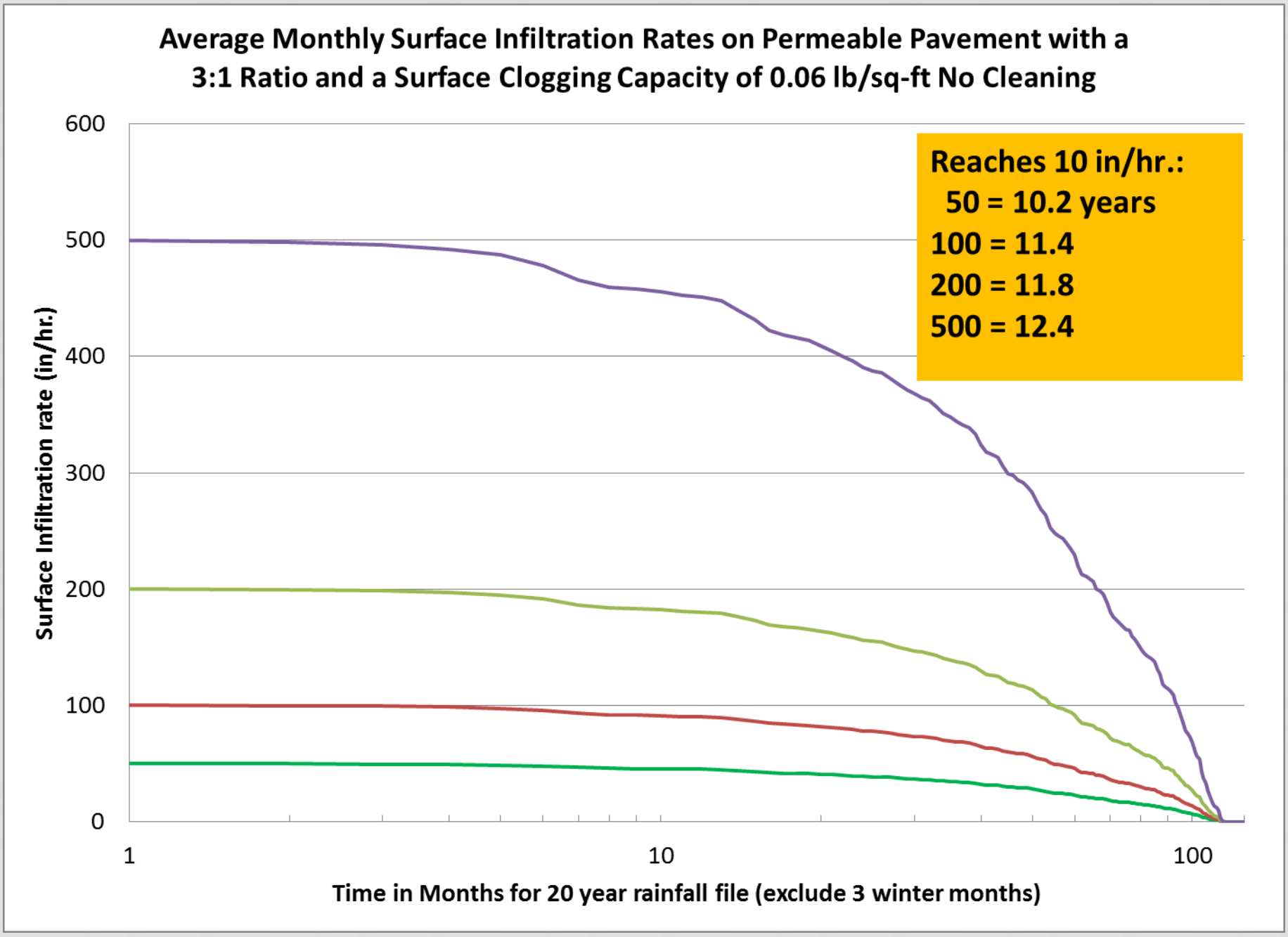
All values are in inches/hour



SELECTED AVERAGE SURFACE INFILTRATION RATES FOR NEW PERMEABLE PAVEMENT

Type of Permeable Pavement	Surface Infiltration Rate, inches/hour (WDNR 1008 = 100 in/hr)						
	Borst (2010)	Bean (2007)	Chicago 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


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
Reaches 10 in/hr.:
50 = 10.2 years
100 = 11.4
200 = 11.8
500 = 12.4
Surface Infiltration rate (in/hr.)
600
500
400
300
200
100
0
1
10
100
Time in Months for 20 year rainfall file (exclude 3 winter months)

Pavement Infiltration Rate =

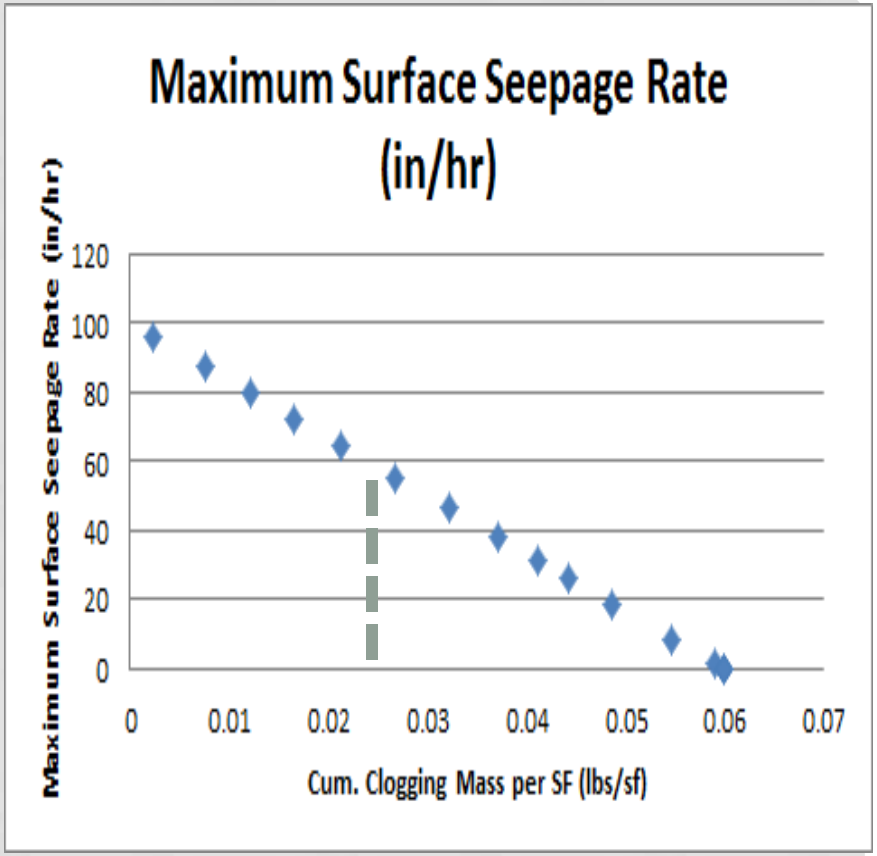
ISIR – [(ISIR/Clogging Mass) x Cumulative Clogged Mass]

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

PIR = 100 – [(1667) x 0.025 lbs/sf]

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

PIR = 100 – (1667 x 0.06) = 100 – 100 = 0



PIR = 500 – (8333 x .06) = 500 – 500 = 0

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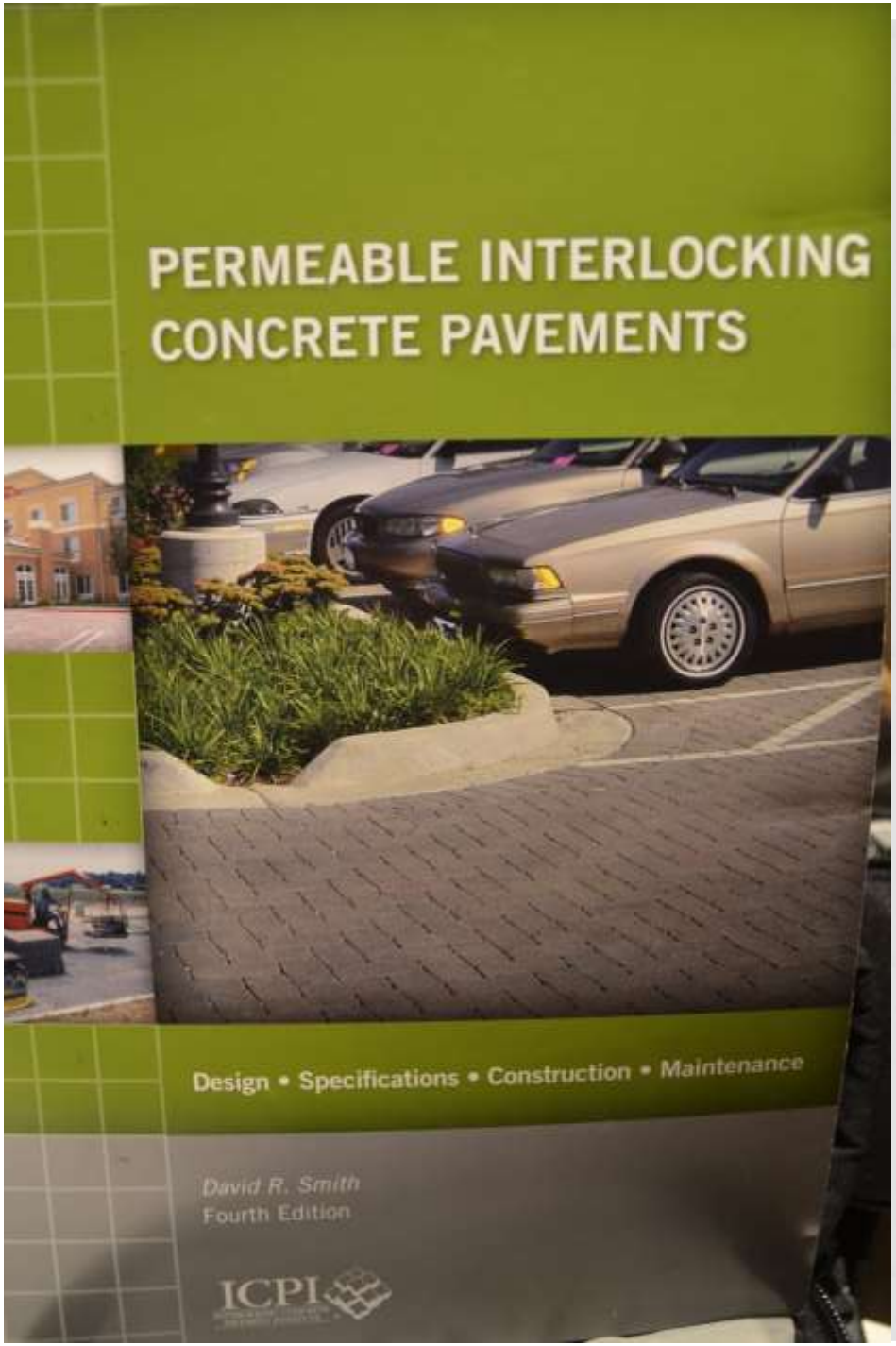
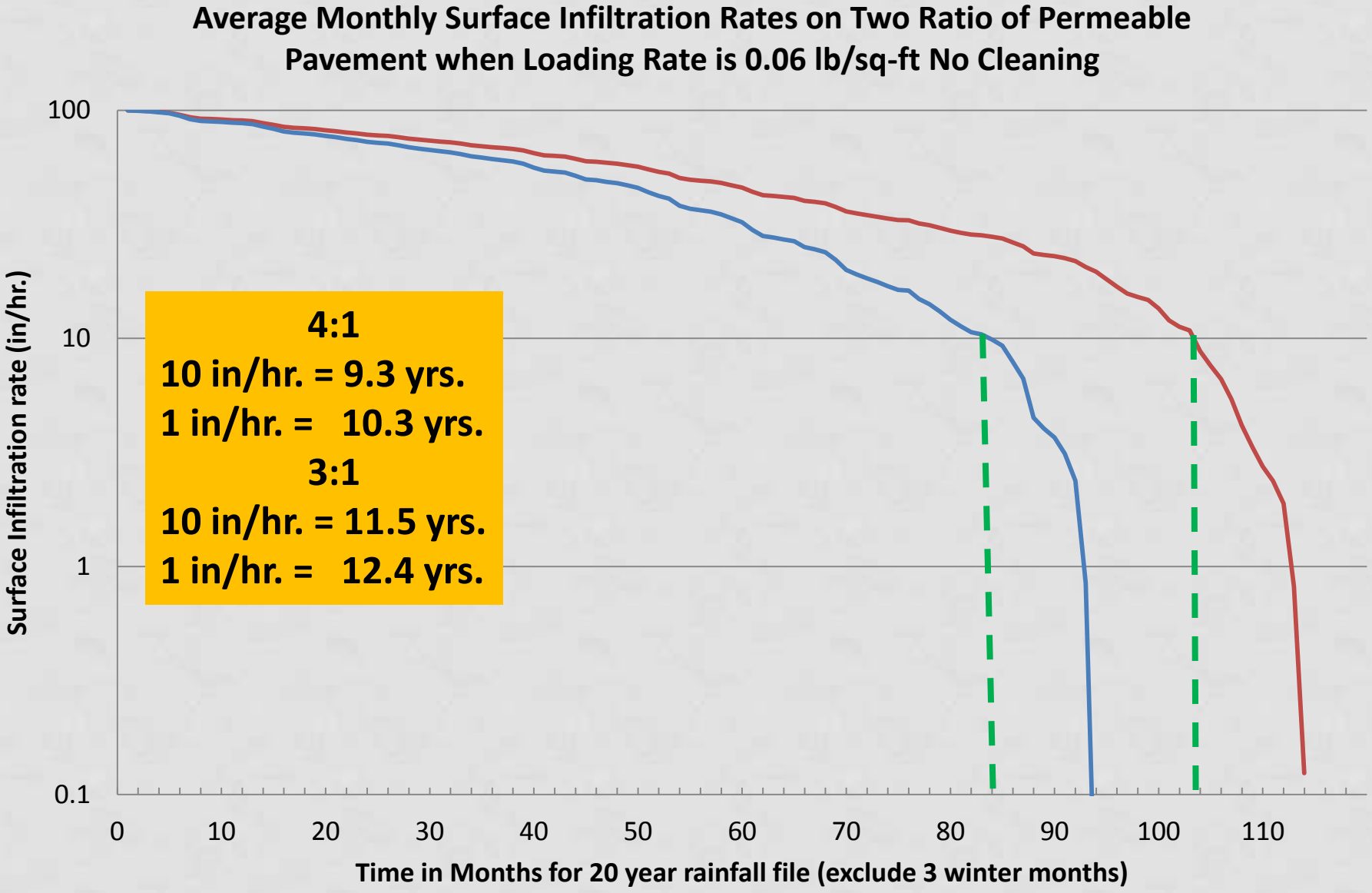
- **Restorative Cleaning Efficiency** – 50%
- **Underdrain Discharge Credit** – TSS (55%) and TP (35%).



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
Surface Infiltration rate (in/hr.)
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
110
Time in Months for 20 year rainfall file (exclude 3 winter months)
4:1
10 in/hr. = 9.3 yrs.
1 in/hr. = 10.3 yrs.
3:1
10 in/hr. = 11.5 yrs.
1 in/hr. = 12.4 yrs.

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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 (920)
Bean, 2007	Pavements usually had rate at least 1 in/hr.		

Permeable Pavement

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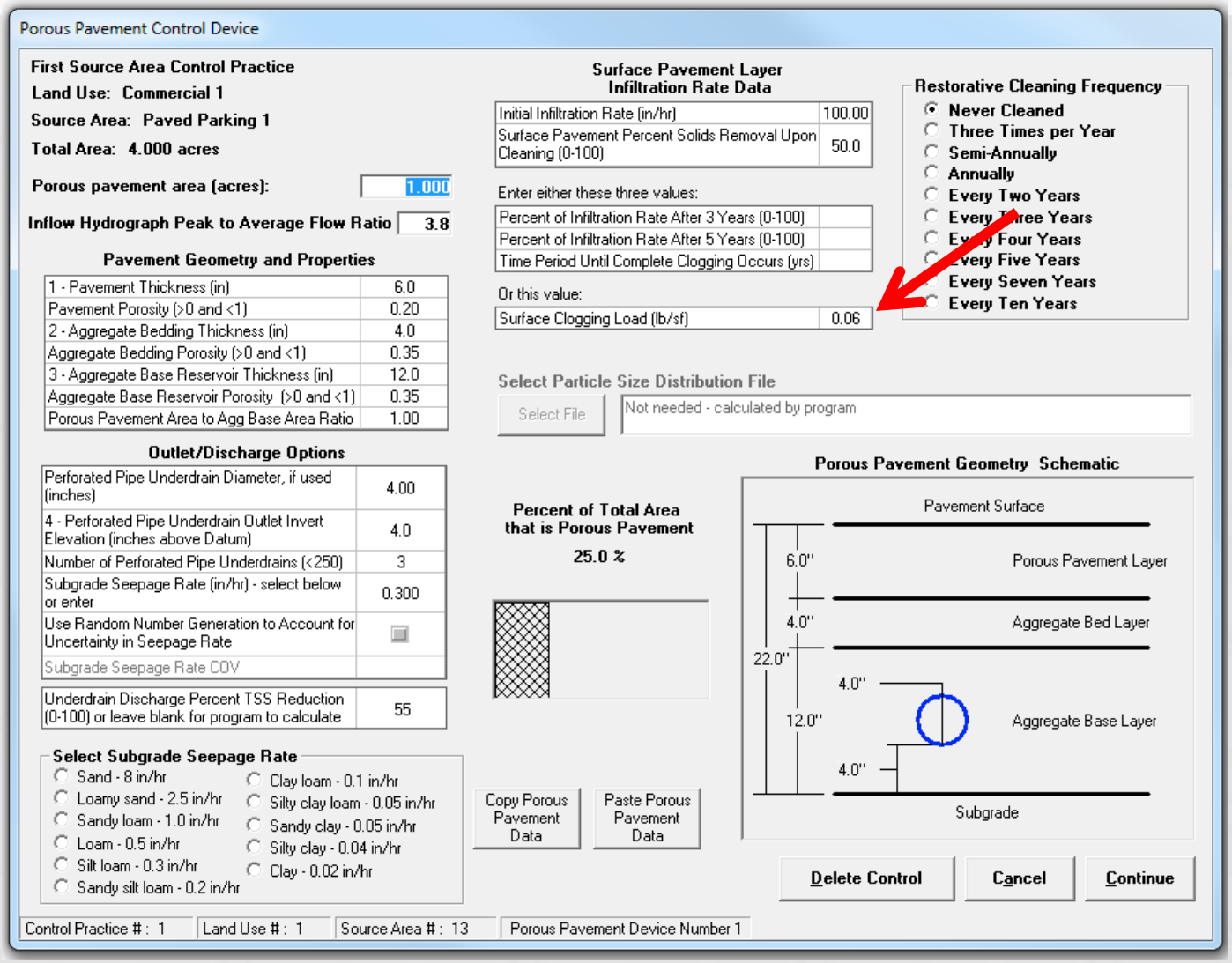


HELPFUL FACTS TO SELECT SURFACE CLOGGING CAPACITY

Depth of Clogging

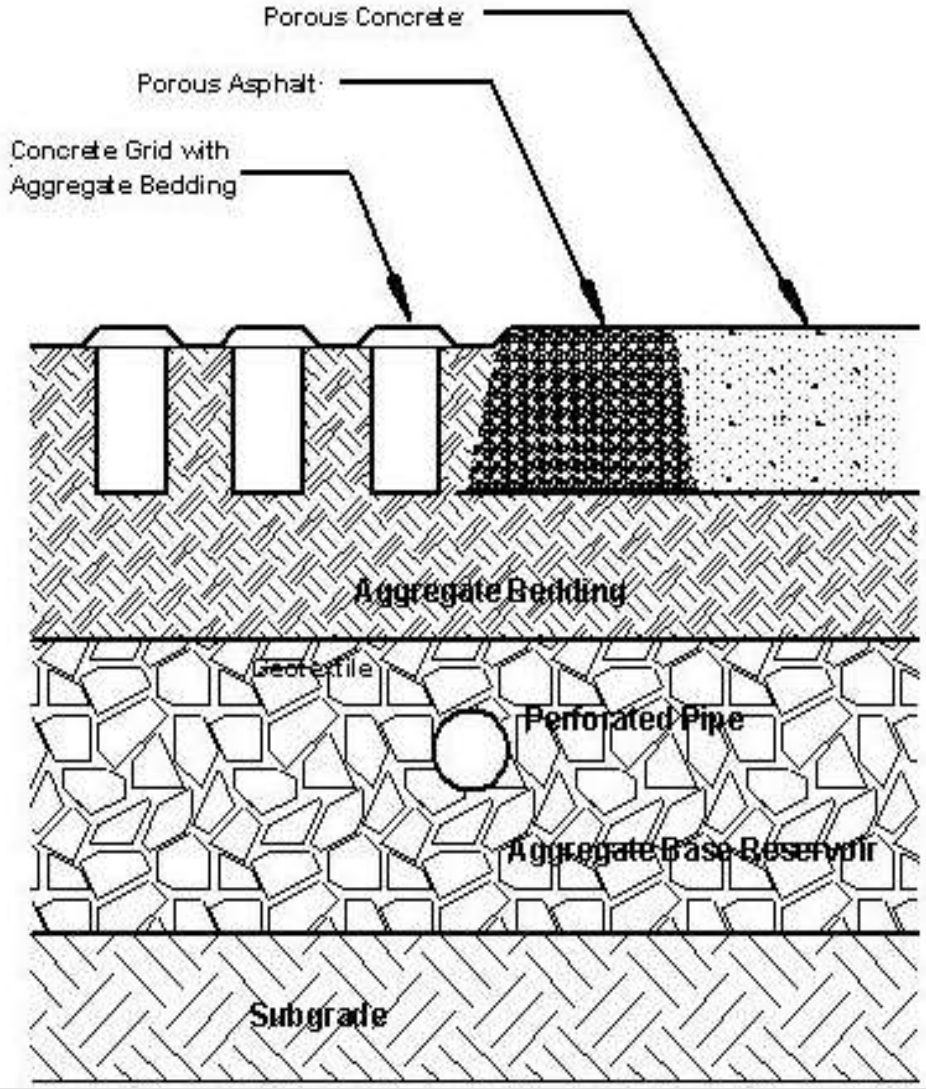
Pitt (2003) – 0.4 to 0.8 inches

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:

1. Clogging depth of 0.4 inches
2. Spec. grav. of 1.3 or 80 lbs./ft^3
3. Void space of 5%.
4. 1 acre parking lot

Example Calculation:

43560 ft^2 x 0.033 ft. = 1452 ft^3

5% x 1452 ft^3 = 73 ft^3

80 lbs./ft^3 x 73 ft^3 = 5808 lbs

5808 lbs./ 43560 ft^2 = **0.13 lbs./ft^2**

Assume Depth of Clogging is 0.2 inches or 0.016 ft.

Clogging capacity = 0.065 lbs./ft^2

Surface Clogging Capacity, lbs./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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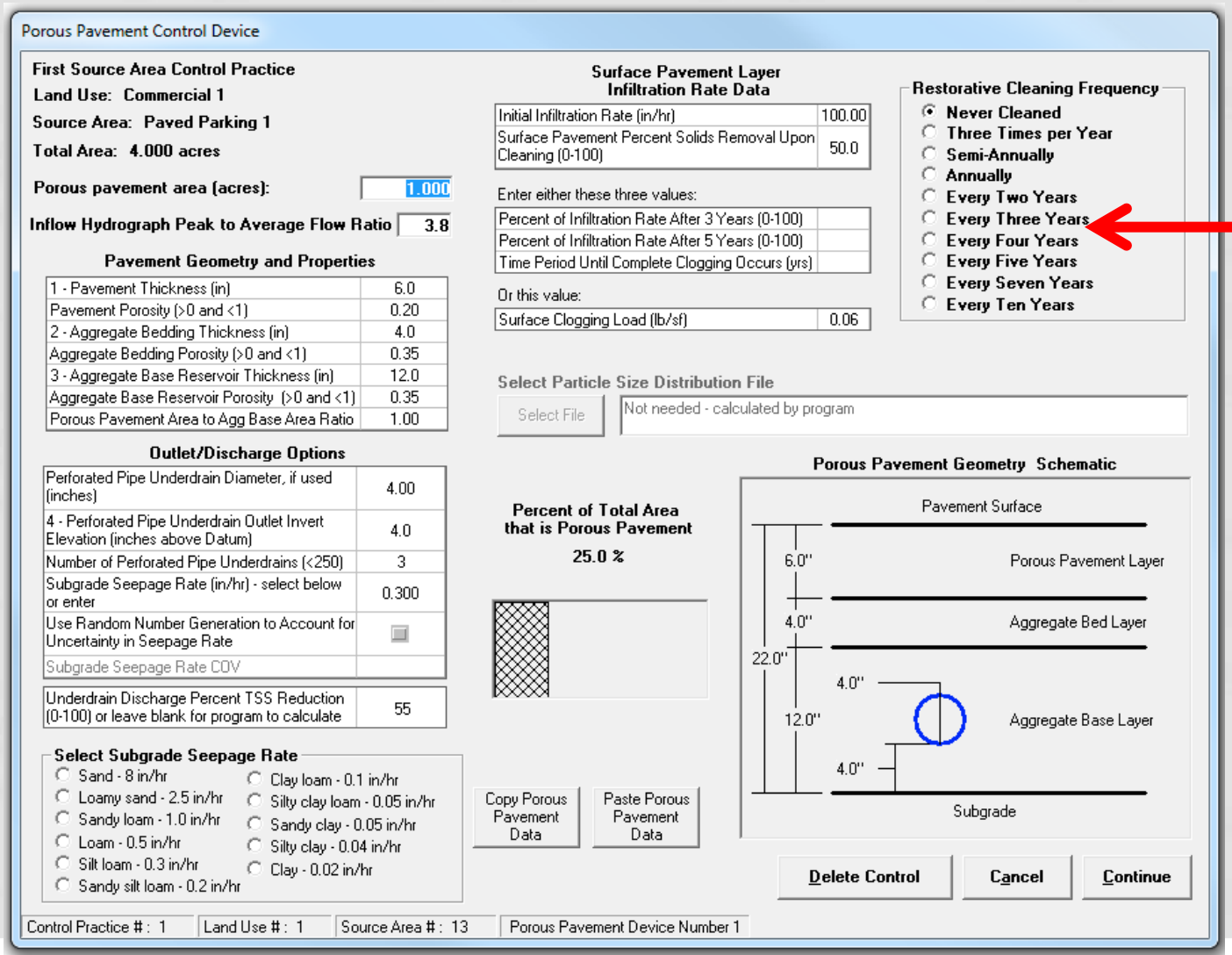
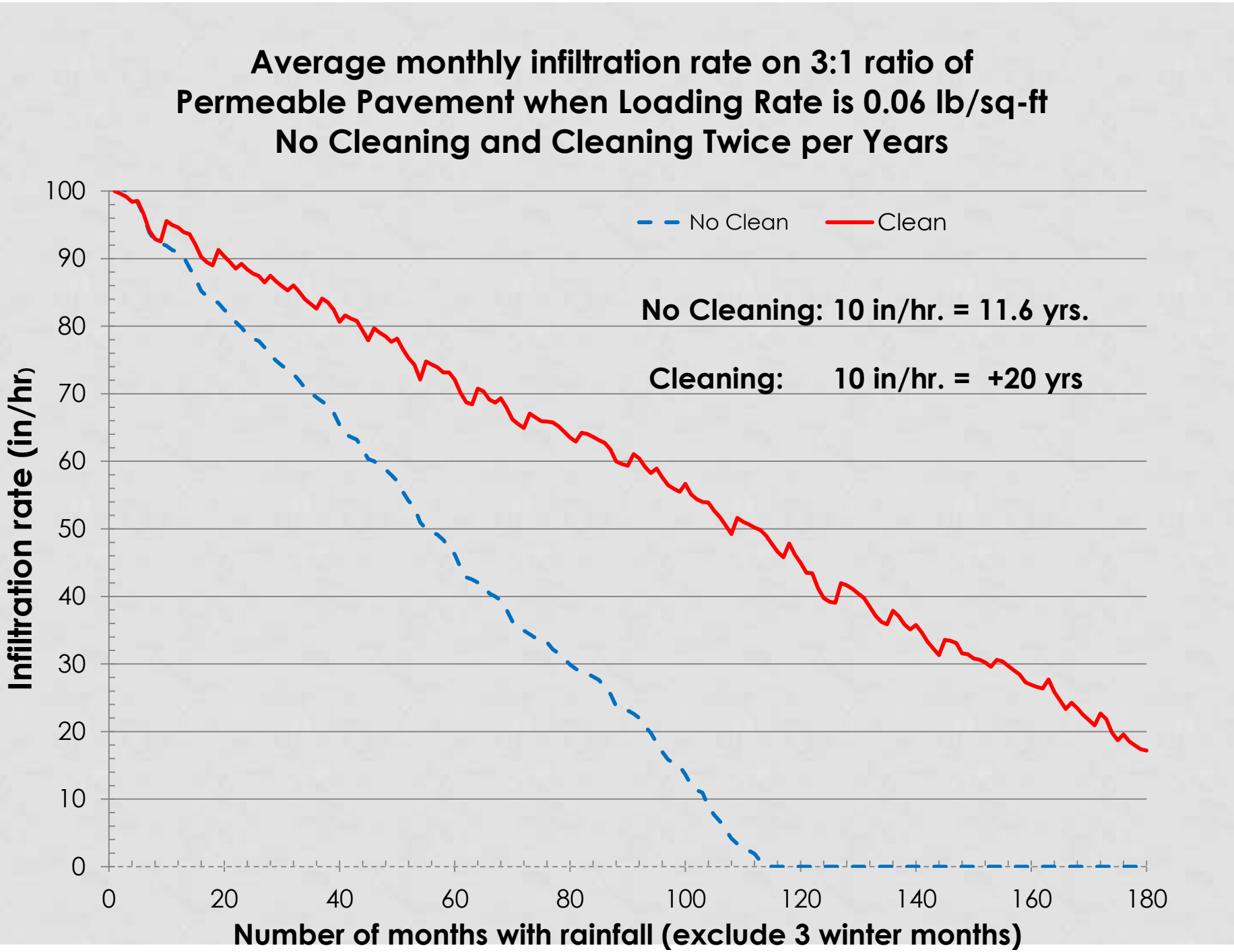


Cleaning Frequencies

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
No Clean
Clean
No Cleaning: 10 in/hr. = 11.6 yrs.
Cleaning: 10 in/hr. = +20 yrs
Infiltration rate (in/hr)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
Number of months with rainfall (exclude 3 winter months)

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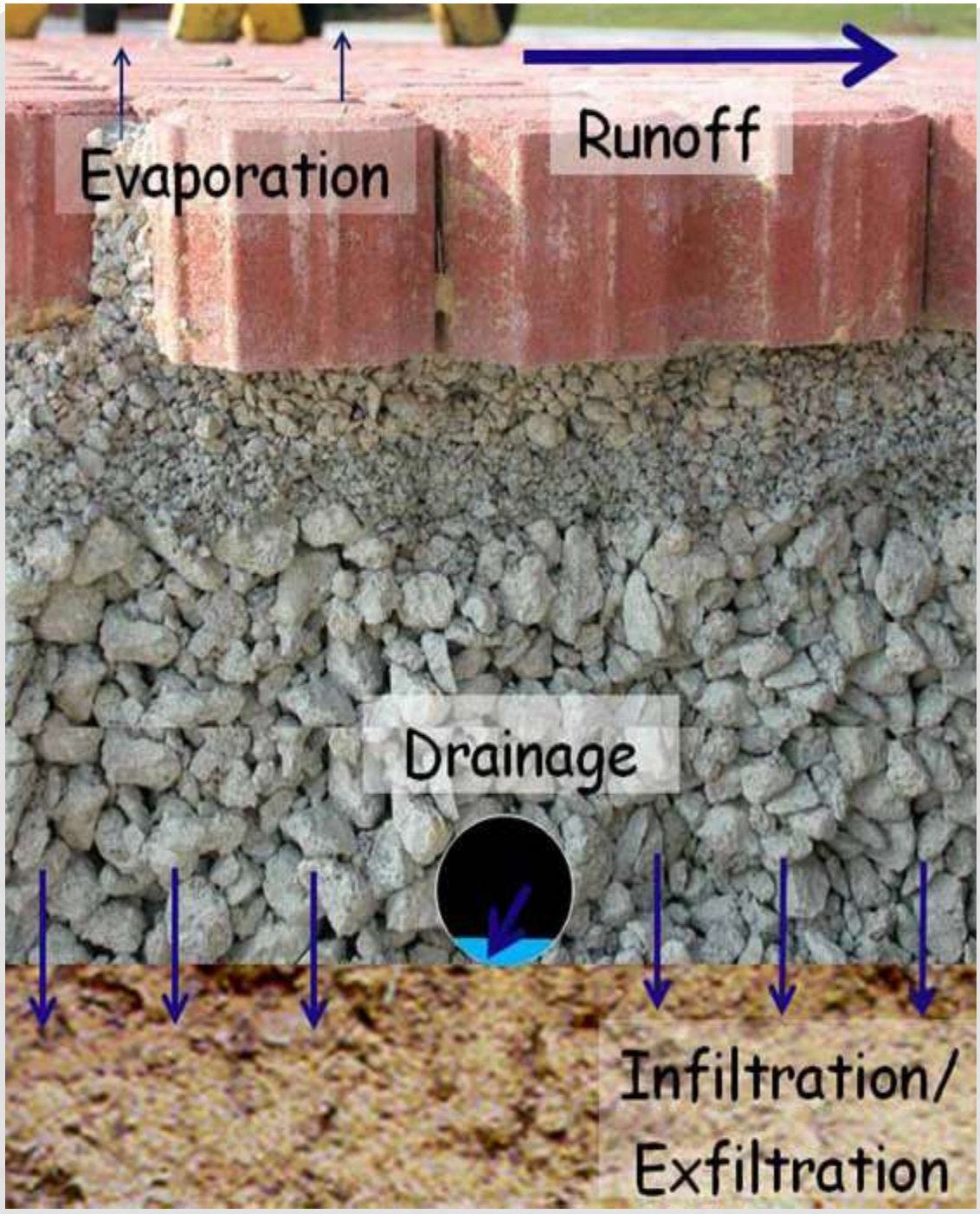
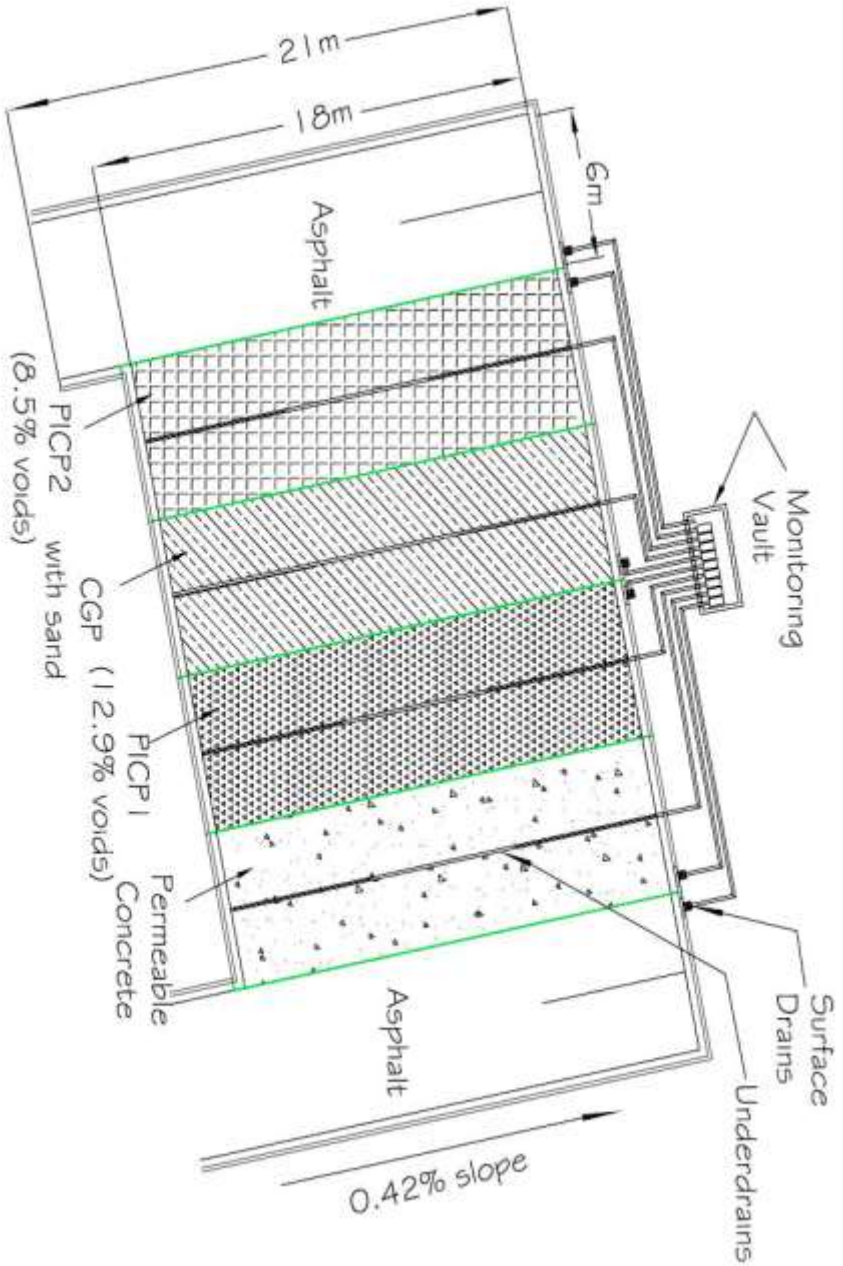


Permeable Paver Pollutant Credits from Various States (Smith, 2011)- With Underdrains

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, %

Pollutant	WDNR 1008	Other Studies	Madison Study after 5 Events (SOL)		
			Pavers	Concrete	Asphalt
TSS	55	59-99	25	26	22
Total P	35	34-88	10	17	-7

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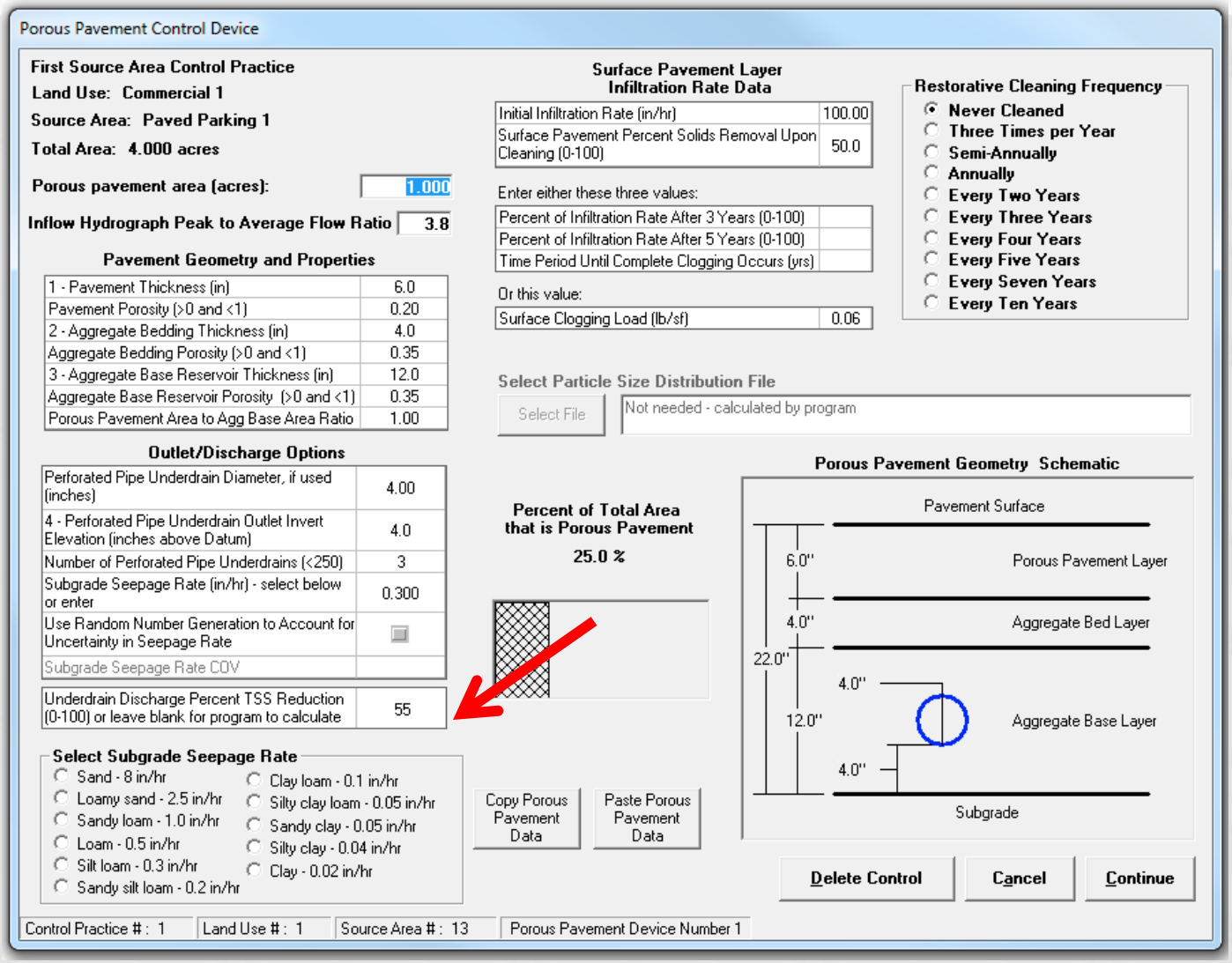

Land Uses | Junctions | Control Practices

File Name:

D:\JAHData\urban\SLAMM\2014\Porous Pavement test v10.1\Com_PLot4ac_RunOn1_SInf100_UInf03_Clog06_UD55_SemiAClean.mdb

Outfall Output Summary

	Runoff Volume (cu. ft.)	Percent Runoff Reduction	Runoff Coefficient (Rv)	Particulate Solids Conc. (mg/L)	Particulate Solids Yield (lbs)	Percent Particulate Solids Reduction
Total of All Land Uses without Controls	5.992E+06		0.64	130.0	48628	
Outfall Total with Controls	1.963E+06	67.24 %	0.21	50.36	6172	87.31 %
Current File Output: Annualized Total After Outfall Controls	98180	Years in Model Run:	19.99		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

Print Output Summary to .csv File

Total Area Modeled (ac): 4.000

Total Control Practice Costs

Capital Cost	N/A
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 Calculations

Receiving Water Impacts Due To Stormwater Runoff

(CWP Impervious Cover Model)

	Calculated Rv	Approximate Urban Stream Classification
Without Controls	0.64	Poor
With Controls	0.21	Poor

EXAMPLE TSS AND VOLUME REDUCTIONS DETERMINED WITH WINSLAMM

Tile TSS Control	TSS Reduction, %			Volume Reduction, %		
	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 – 0.06 lbs./ft^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