Biosystems and Agricultural Engineering
Oklahoma State University
Stillwater, OK

April 9, 2015

Tulsa Pervious Concrete Study: Long Term Infiltration Testing and Evaluation of Cleaning Techniques

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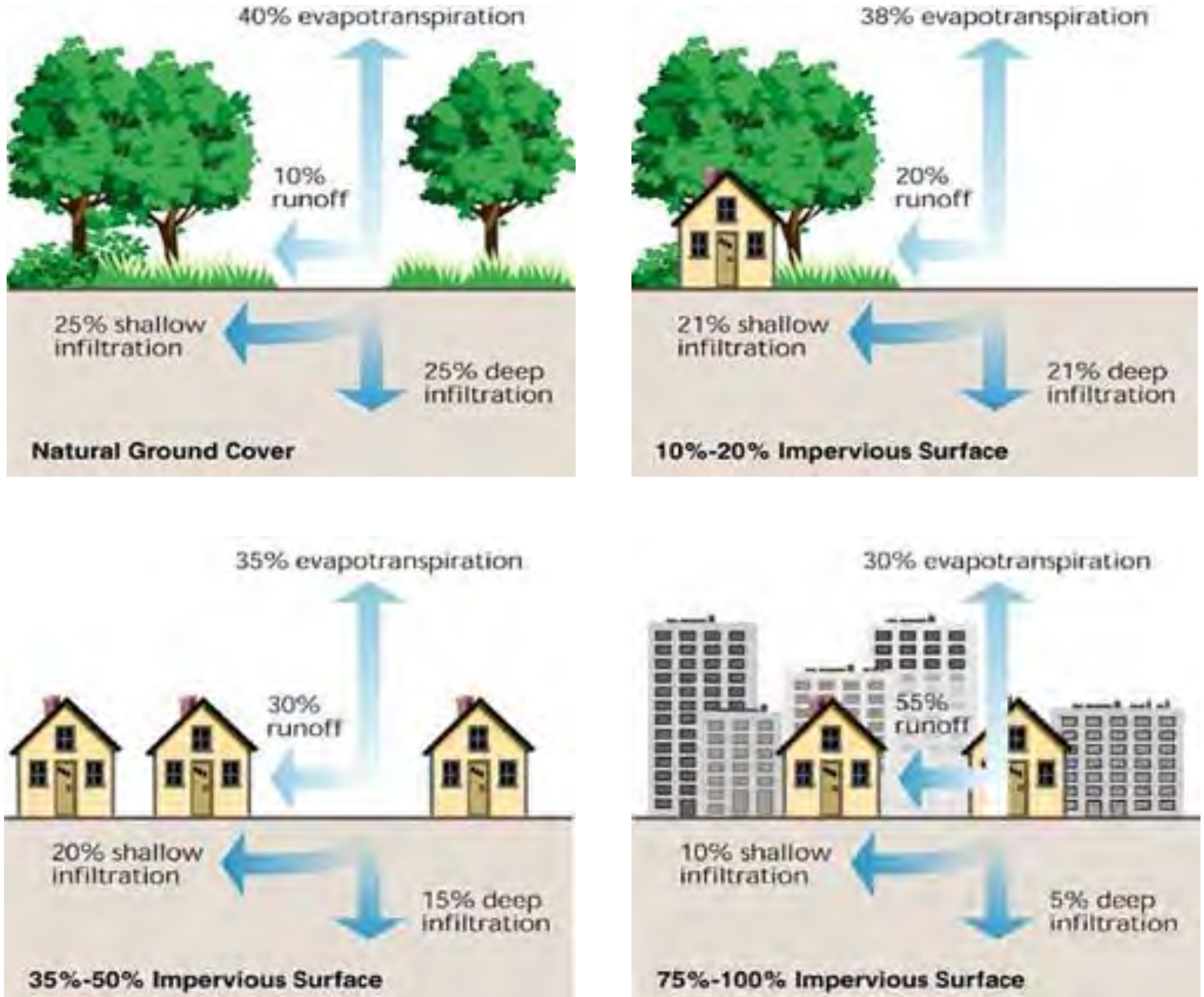
Land Use Impacts on Water Cycle

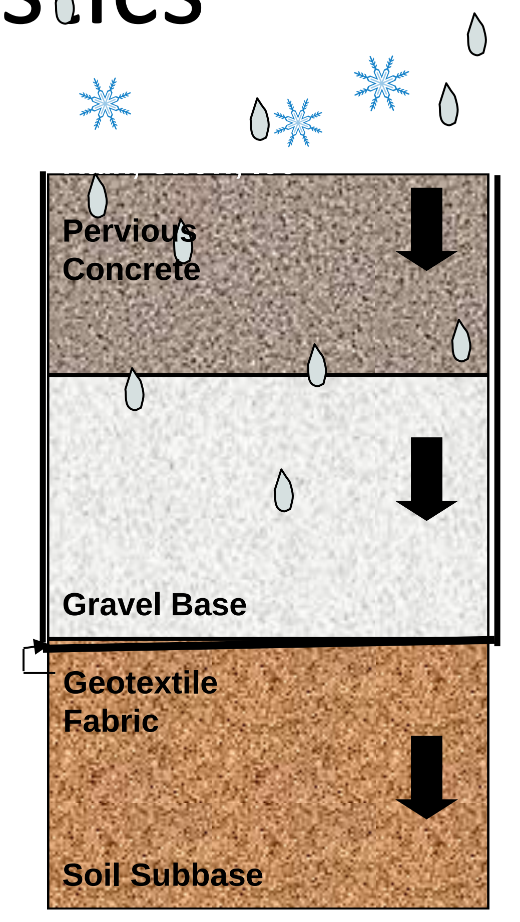


What is Pervious Concrete Made Of?

- Portland Cement Type I/II
- Water
- Aggregate
  - Little to no fines
- Admixtures

Pavement Characteristics

- Permeability
  - Not typically limiting factor
  - 15-25% voids
- Storage capacity
  - Pavement
  - Sub-base



Clogging: Run-on or wind-blown sediment and plant litter

Maintanance recommended quarterly to annually

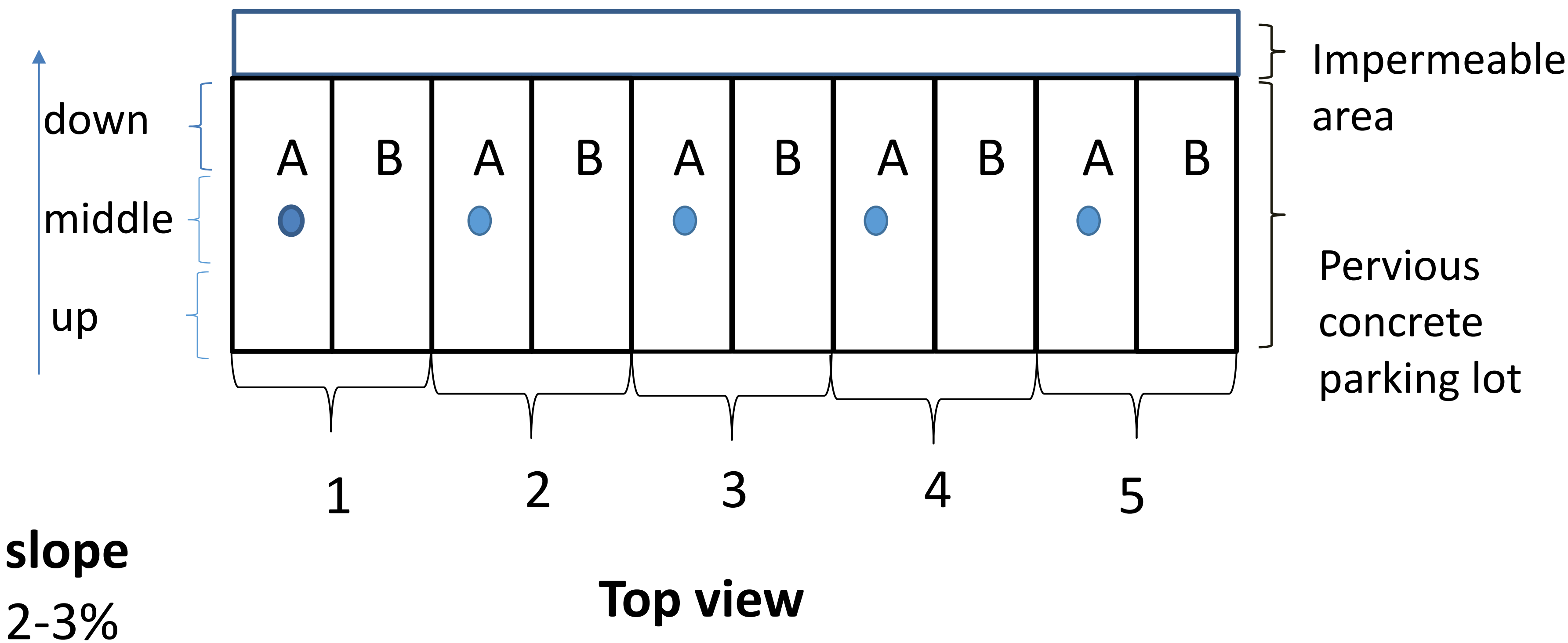
Hand Vacuum (small scale)

Vacuum sweeper

Pressure washer (not generally recommended)

Pressure wash and vacuum combination

Arrangement of pervious concrete parking lot



Pervious concrete donated by GCC, Eagle Ready-Mix, Arrow, Dolese, and Twin Cities. Installation completed by Canterra Concrete.

Pervious concrete mix design*

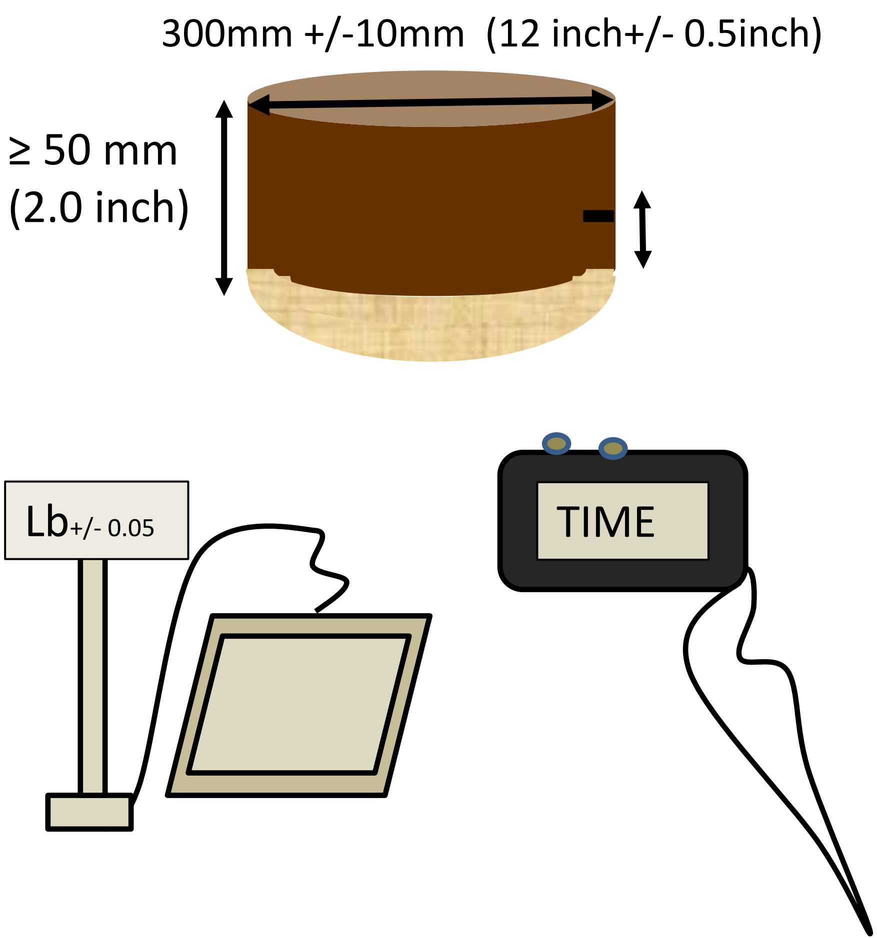
	Ratio: (Agg+Sand)/ (Cement+Fly Ash)	% Sand in Aggregate	Ratio: Fly Ash/ Cement	Ratio: Water/ (Cement + Fly Ash)	Nominal Aggregate Size	Admixtures
1	4.4	5.7%	0.33	0.30	3/8" coarse	No
3	3.5	20.0%	0.18	0.25	3/8“, also added 5/8”	Yes
4	4.0	5.9%	0.31	0.27	3/8"	Yes
5	4.3	0.0%	0	0.32	Size 8; 3/8" to 1/2"	Yes

* Test area #2 composition not released by manufacturer


CANTERA

LONG-TERM INFILTRATION TESTS

Infiltration tests completed using ASTM C1701



$$I = \frac{Volume\ of\ water}{(Area * time)}$$

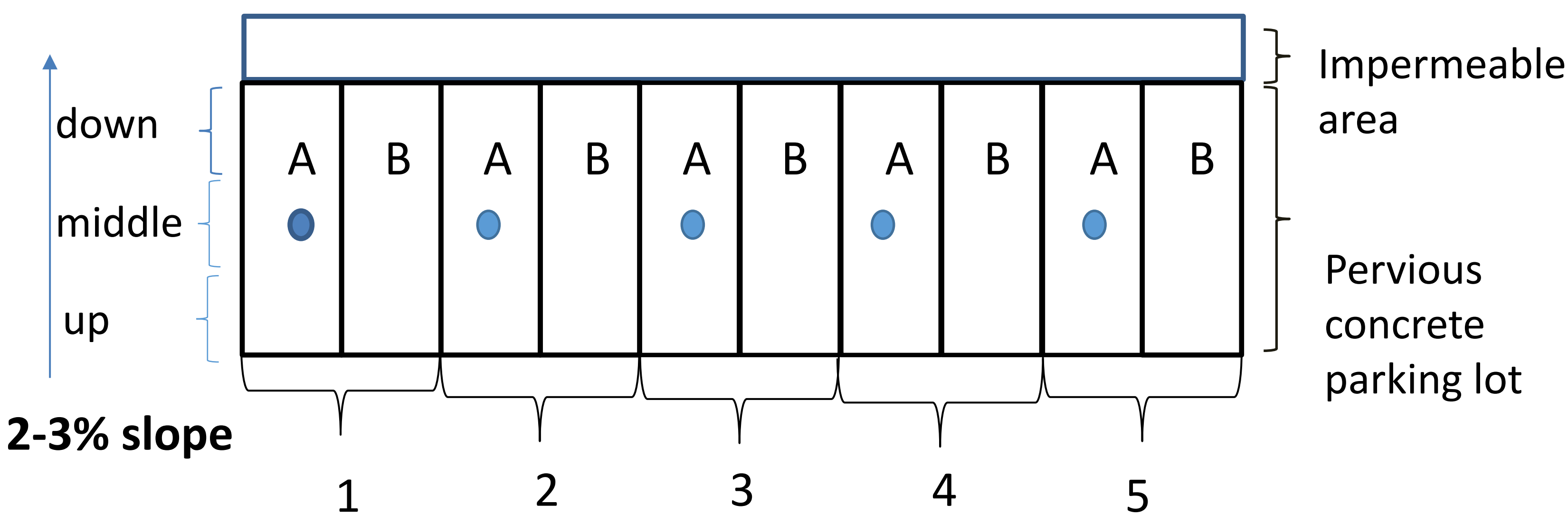
I= Infiltration rate (in. /h)

Test completed with 0.5 in of constant head (+/- 0.1 in)

Long-term Infiltration Measurements

- *Infiltration test at one location in center of side A*

- Parking lot opened to cars for since March 2012.
- Infiltration tests conducted quarterly during this period.



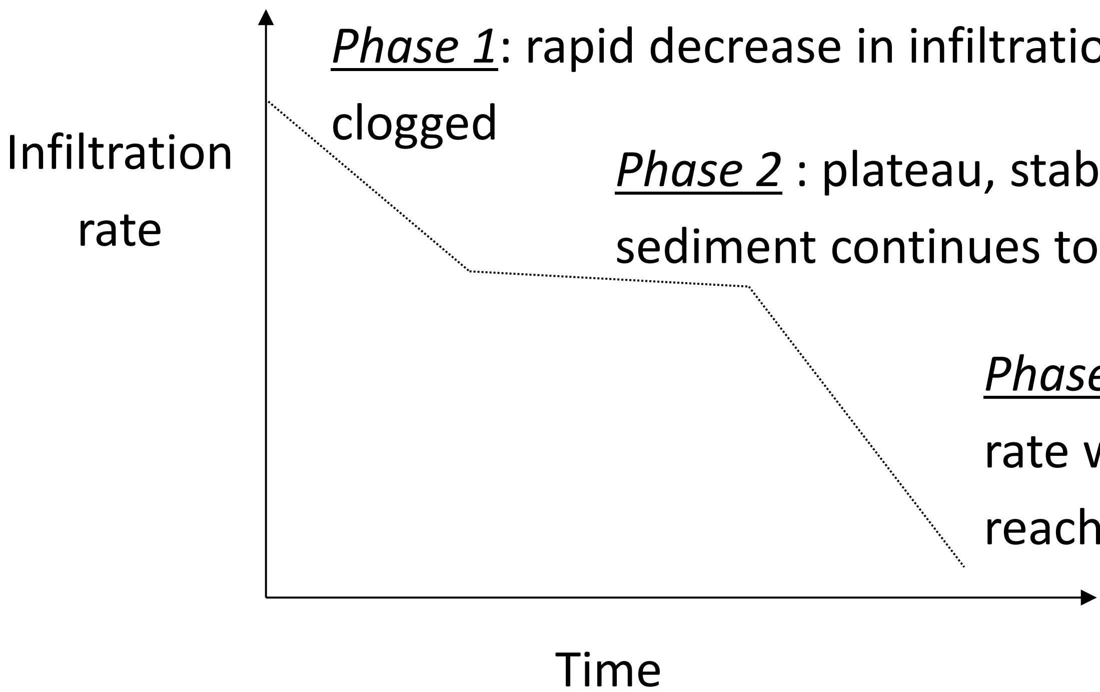
Top view

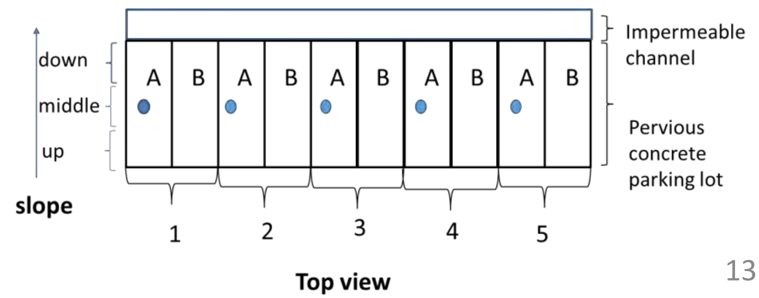
General Evolution of Infiltration on Sloped Pervious Concrete

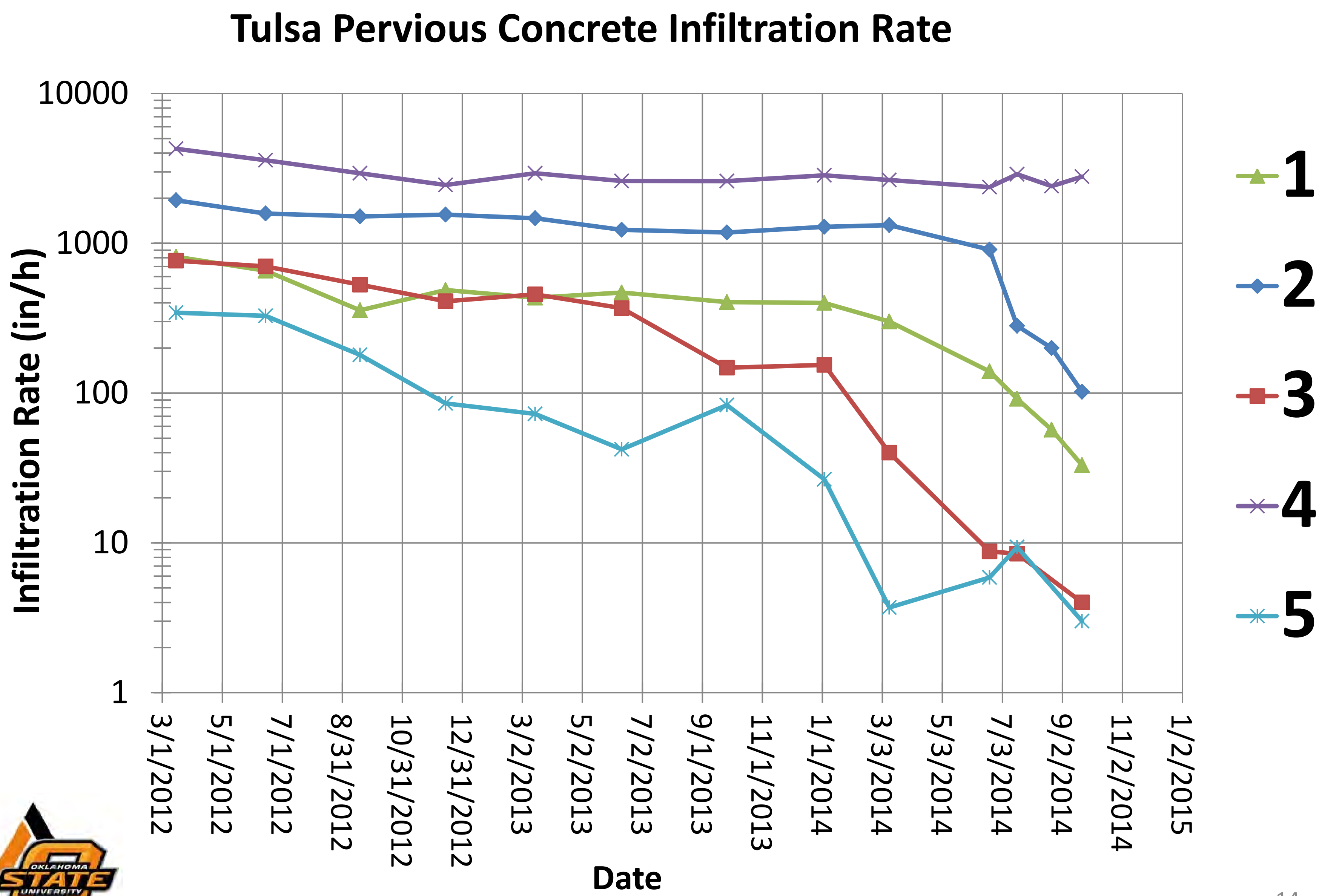
Phase 1: rapid decrease in infiltration rate; small pores are clogged

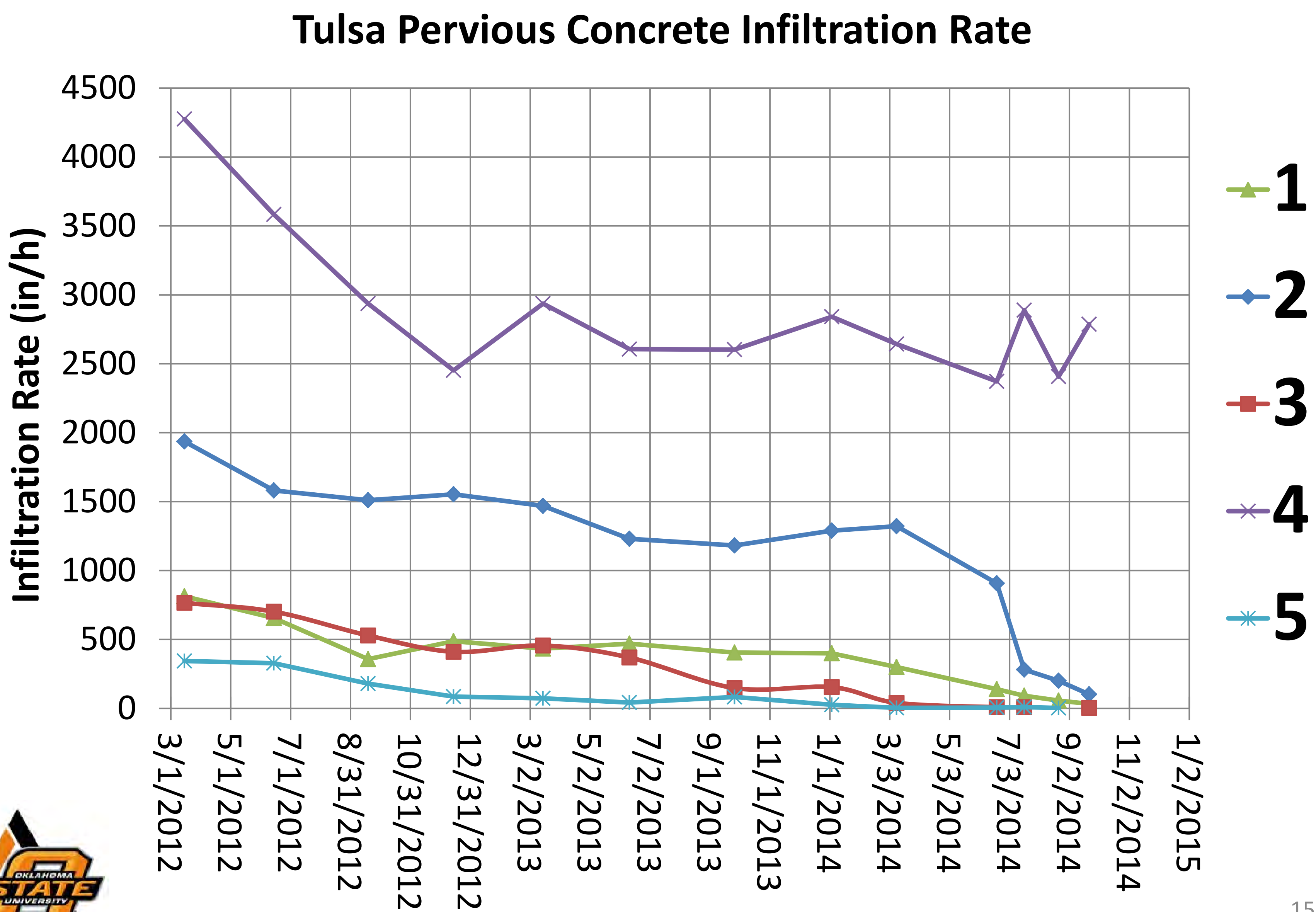
Phase 2 : plateau, stabilization of the infiltration values; sediment continues to pass through large pores

Phase 3: rapid decrease in infiltration rate when upgradient clogging front reaches measurement location






Tulsa Pervious Concrete Infiltration Rate
10000
1000
100
10
1
Infiltration Rate (in/h)
3/1/2012
5/1/2012
7/1/2012
8/31/2012
10/31/2012
12/31/2012
3/2/2013
5/2/2013
7/2/2013
9/1/2013
11/1/2013
1/1/2014
3/3/2014
5/3/2014
7/3/2014
9/2/2014
11/2/2014
1/2/2015
Date
1
2
3
4
5


Tulsa Pervious Concrete Infiltration Rate
Infiltration Rate (in/h)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3/1/2012
5/1/2012
7/1/2012
8/31/2012
10/31/2012
12/31/2012
3/2/2013
5/2/2013
7/2/2013
9/1/2013
11/1/2013
1/1/2014
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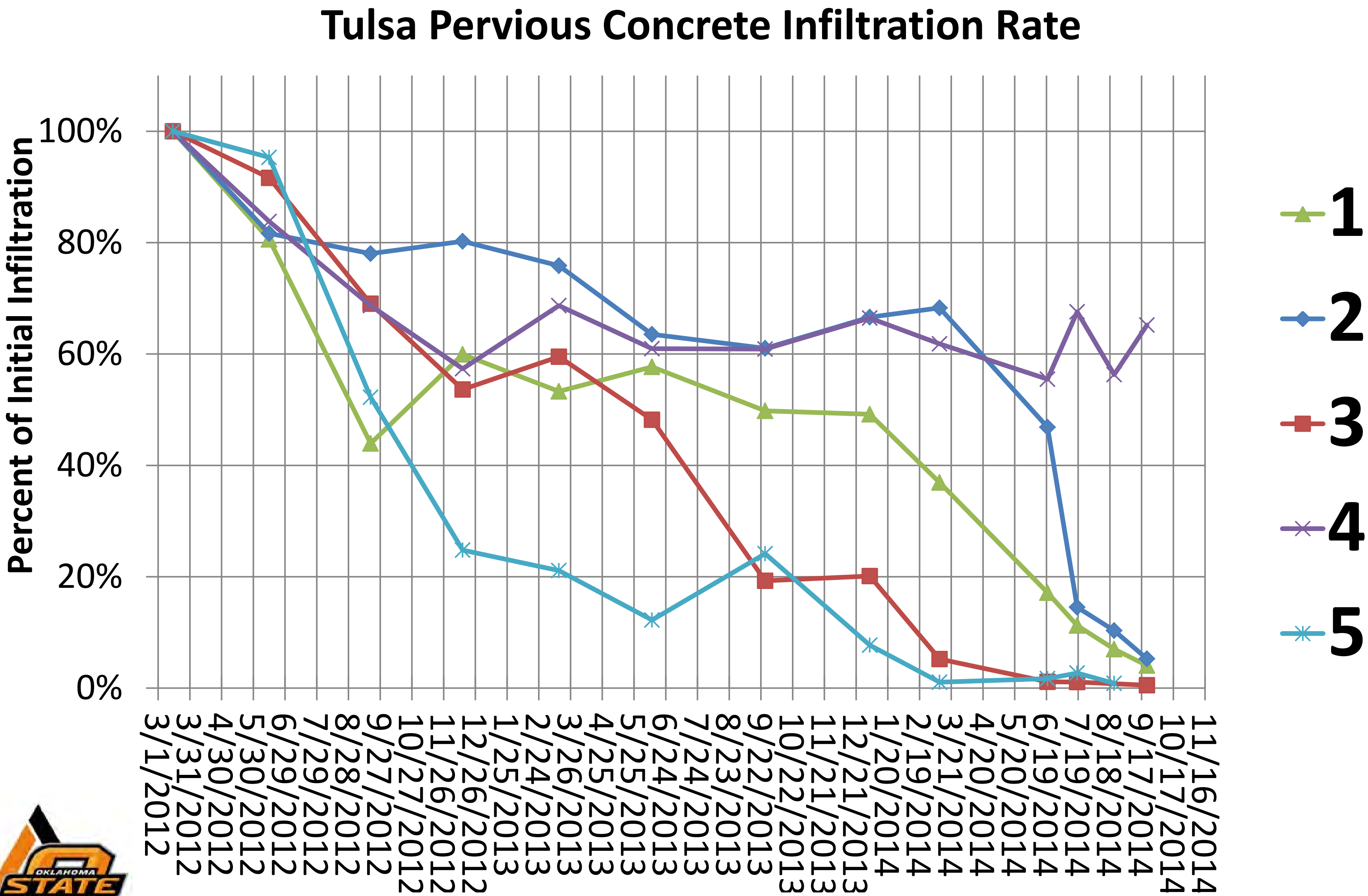
7/3/2014
9/2/2014
11/2/2014
1/2/2015
1
2
3
4
5


Tulsa Pervious Concrete Infiltration Rate
Percent of Initial Infiltration
100%
80%
60%
40%
20%
0%
3/1/2012
3/31/2012
4/30/2012
5/30/2012
6/29/2012
7/29/2012
8/28/2012
9/27/2012
10/27/2012
11/26/2012
12/26/2012
1/25/2013
2/24/2013
3/26/2013
4/25/2013
5/25/2013
6/24/2013
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9/22/2013
10/22/2013
11/21/2013
12/21/2013
1/20/2014
2/19/2014
3/21/2014
4/20/2014
5/20/2014
6/19/2014
7/19/2014
8/18/2014
9/17/2014
10/17/2014
11/16/2014
1
2
3
4
5

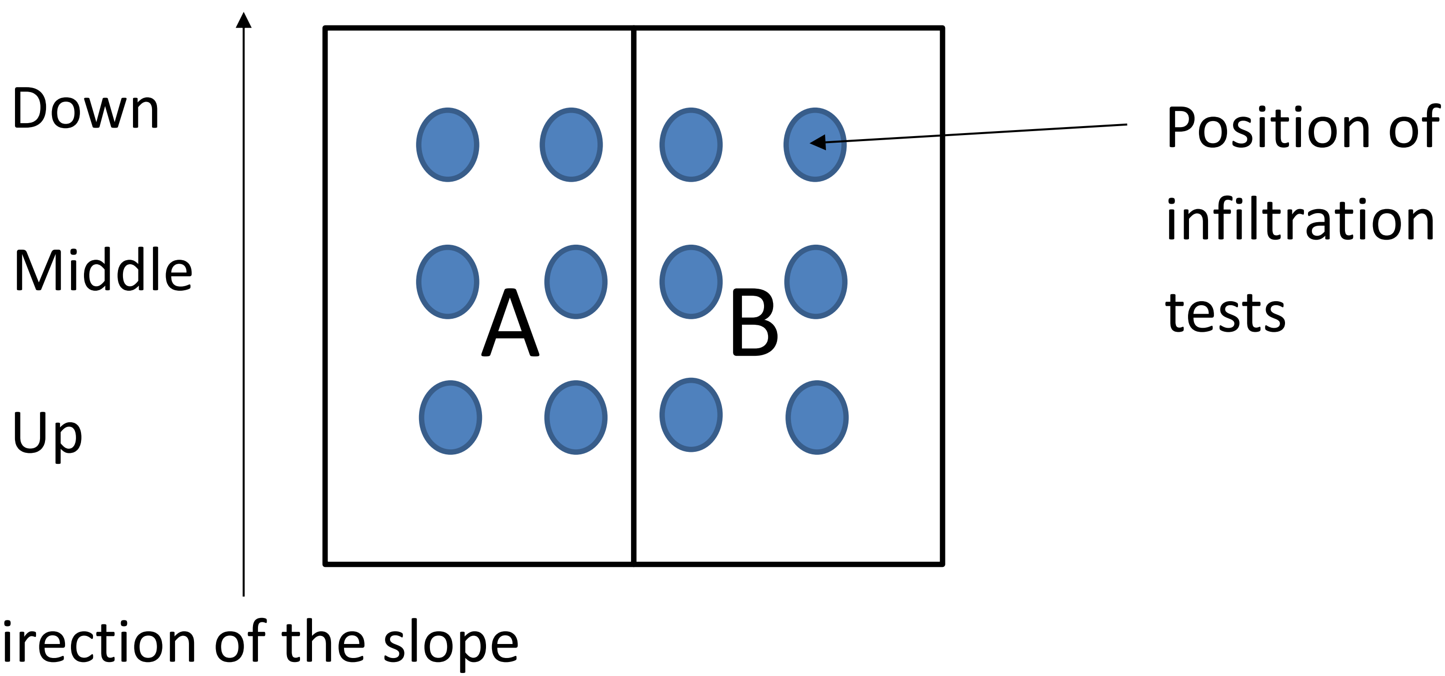
Clogging rate

	Initial clogging phase		Plateau		2nd Clogging phase	
concrete mix design	duration of the phase (days)	regression slope (in/hr-day)	duration of the phase (days)	regression slope (in/hr-day)	duration of the phase (days)	regression slope (in/hr-day)
1	**187**	-2.45	**472**	-0.007	**231**	-1.52
2	**91**	-3.90	**634**	-0.55	**196**	-6.70
3	**274**	-1.35	**327**	-0.23	**226**	-0.91
4	**274**	-6.67	**647**	-0.03	**NA**	NA
5	**274**	-1.01	**286**	-0.03	**165**	-0.49

Spatial Investigation of Clogging

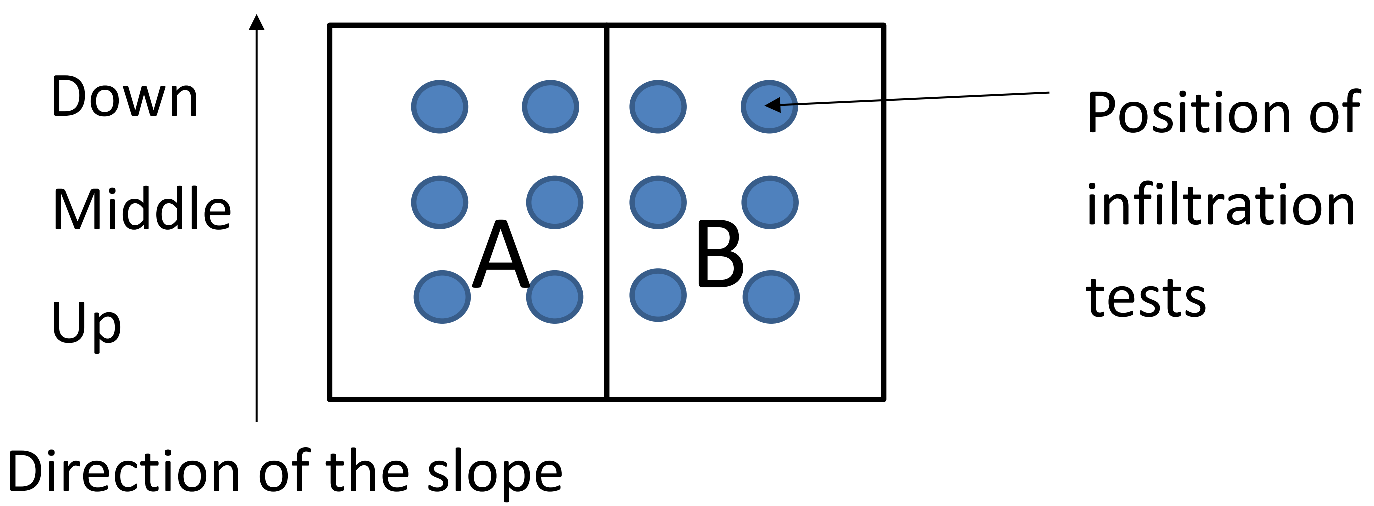
- *Infiltration test at several points: spatial data*
- *June-September 2014*

- 1A, 1B, 2A, 2B, 4A, 4B
- 4 times before the beginning of the cleaning phase



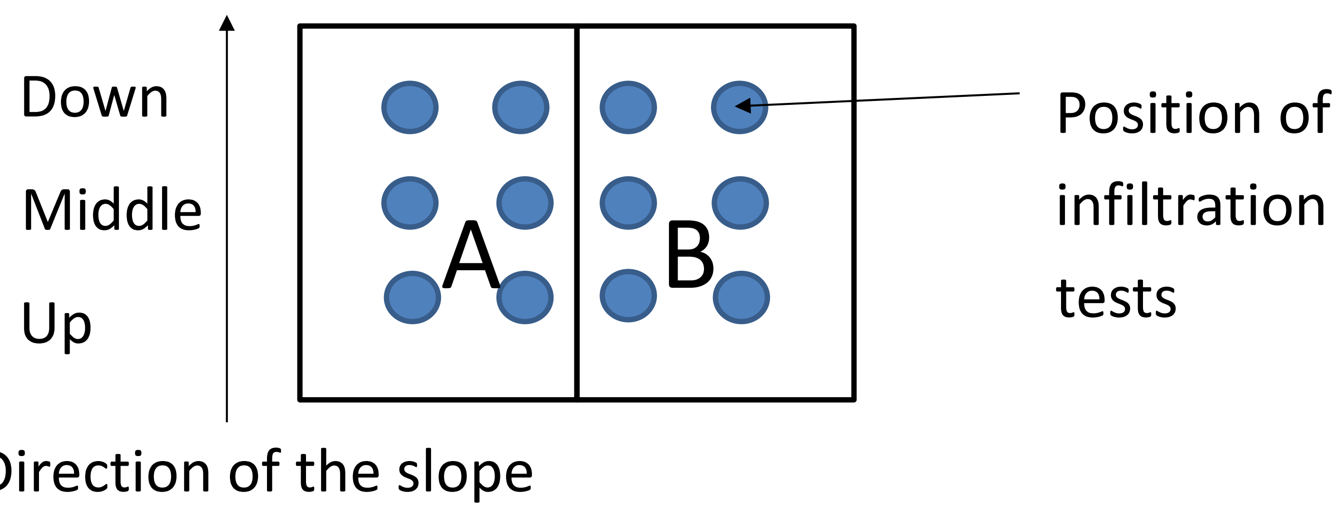
Spatial Data

	Plot 1	Plot 2	Plot 4
	Mean Infiltration (in/hr)		
down	57	796	2495
middle	39	660	2853
up	24	418	2674



Spatial Data

	Plot 1	Plot 2	Plot 4
	P(T<=t)		
down vs. up	**<0.001**	**0.002**	**0.046**
down vs. middle	0.110	0.120	**<0.001**
middle vs. up	0.160	**0.023**	0.094



CLEANING TESTS

Cleaning Tasks

- ***Sequential cleaning by***
  - Dry vacuum
  - Wet vacuum
  - Dry street sweeper
  - Wet street sweeper
  - Vactor Truck with water jet (only one plot complete)

- ***Particle distribution of collected sediment***

- ***Infiltrometer measurements before and after cleaning***

Cleaning Tests

- Dry hand vacuum (09/24/2014)
- Wet hand vacuum (09/29/2014)
- Dry vacuum sweeper (10/15/2014)
- Wet vacuum sweeper (10/31/2014)

6 infiltration tests for each plot after cleaning: a total of 30 infiltration tests on each day

5. Cleaning phase

- *Handle vacuum cleaning (dry and wet cleaning)*
  - **Only the A sides** were cleaned (dry and wet cleaning)
  - A broom attachment was fixed to the hose of the vacuum (Shop vacuum 549705)

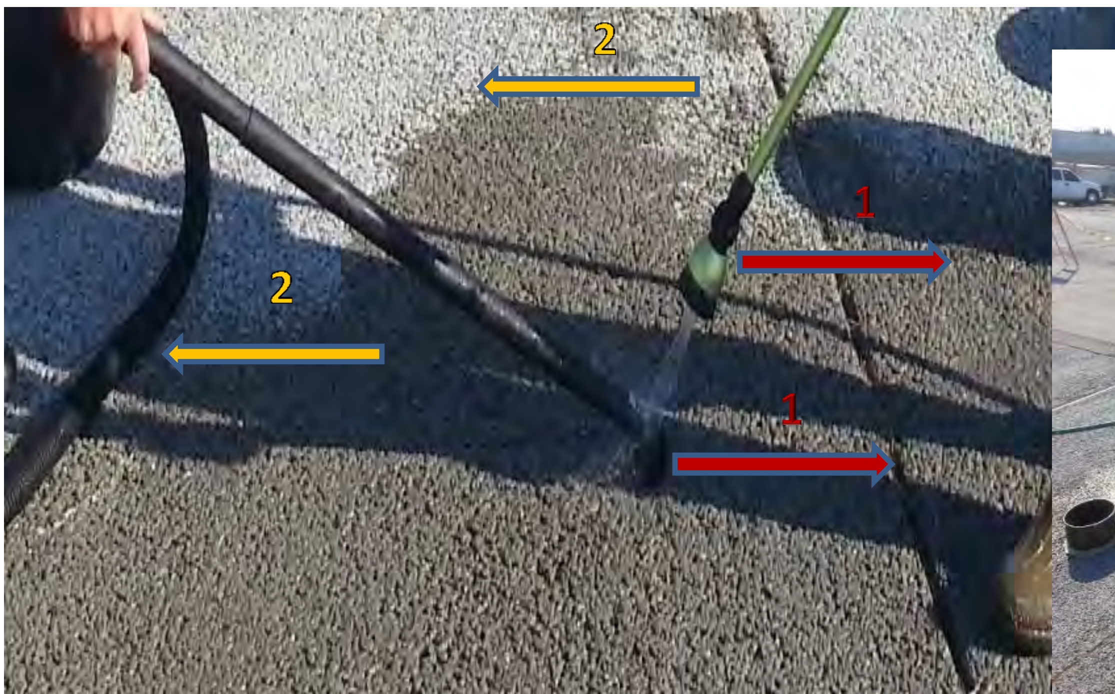
- *Dry cleaning (09/24/2014):*

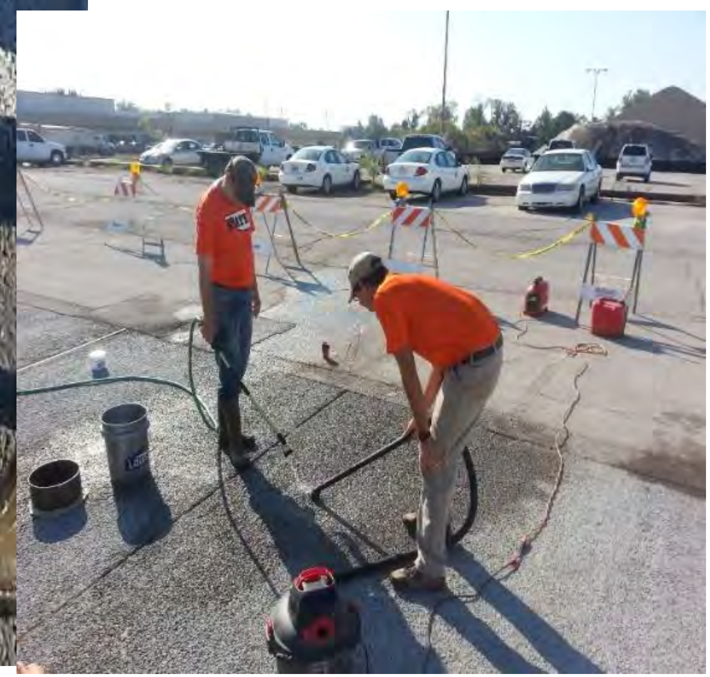
Each A side was cleaned for **40 min** in such a way as to every part of the parking lots was **homogeneous cleaned**.

5. Cleaning phase

- *Wet cleaning (09/29/2014)*

Side A only





5. Cleaning phase

- *Vacuum street sweeper cleaning:*

dry (10/15/2014) and wet condition (10/31/2014).

- City of Tulsa vacuum street sweeper

- Steel wire broom, diameter of 1m

The entire plot was cleaned at this time

Clogging Particle Characterization

- Hand vac only (wet and dry)
- Particles collected in vacuum tank
- For wet condition, particles collected as a slurry

Category	Min Size (mm)	Max Size (mm)
Remainder	0.01	0.053
No. 270	0.053	0.149
No. 100	0.149	0.25
No. 60	0.25	0.425
No. 40	0.425	1
No. 18	1	2
No. 10	2	4
No. 5	4	6.3
0.250-0.3125	6.3	8
0.3125-0.375	8	9.5
0.375-0.500	9.5	12.5
0.500-0.750	12.5	19
>0.750"	19	25

Sieving

- For **dry** condition, particles were dry sieved
- For **wet** cleaning, particles were wet sieved

Infiltration recovery during the cleaning phase

- *Dry hand vacuum*

Plot 1A

Infiltration recovery during the cleaning phase

- *Wet hand vacuum*

BEFORE

AFTER

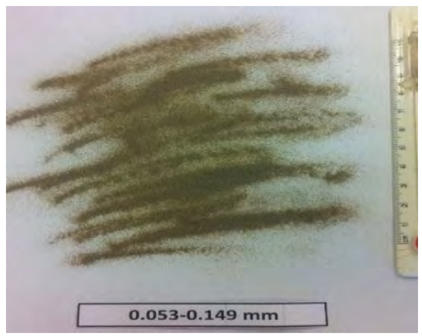
Plot 3A

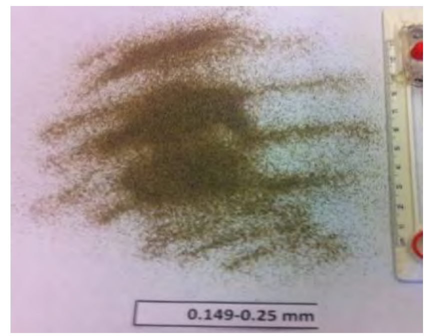
Infiltration recovery during the cleaning phase

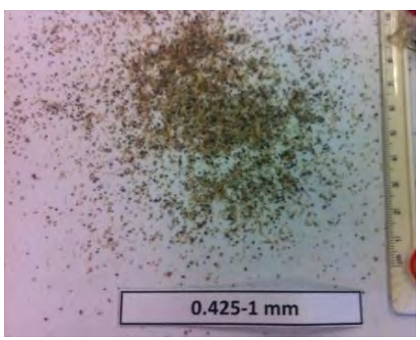
	Dry Vacuum 09/24/2014		Wet Vacuum 09/29/2014		Dry Vacuum Street Sweeper 10/15/2014		Wet Vacuum Street Sweeper 10/31/2014	
	Change Since 09/22/2014		Change Since 9/24/2014		Change Since 09/29/2014		Change Since 10/15/2014	
	in./h	%	in./h	%	in./h	%	in./h	%
1	-2	**-0.3**	23	**2.8**	-15	**-1.9**	8.8	**1.1**
2	-8	**-0.4**	380	**19.5**	66	**3.4**	-1.76	**-0.1**
3	-2	**-0.3**	7	**0.9**	-3	**-0.4**	4.5	**0.6**
4	150	**3.5**	-280	**-6.6**	-300	**-7.1**	303	**7.1**
5	-1	**-0.3**	5	**1.5**	-5	**-1.4**	2	**0.6**

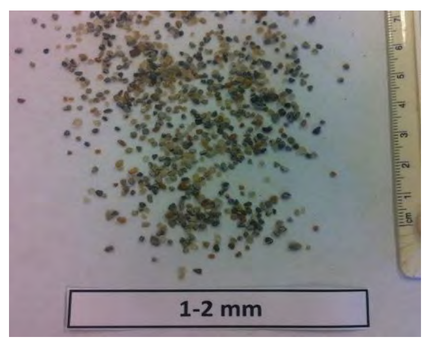
Particle Size Distribution and Particle Mass Distribution

- Clogging particles (plot 1A dry vacuum)





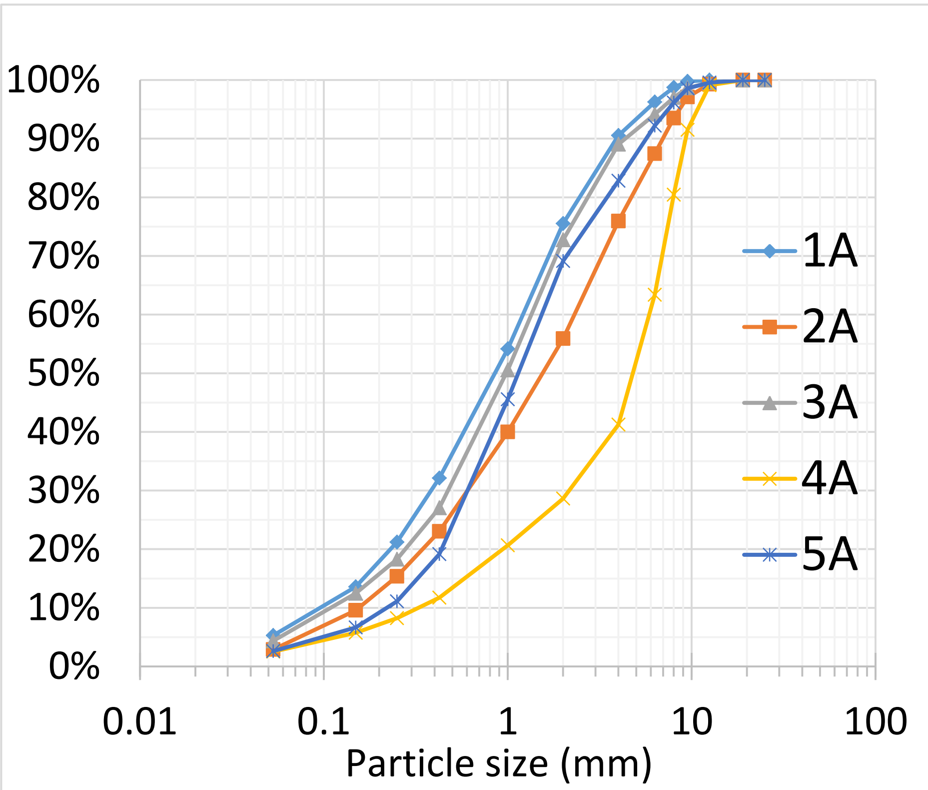




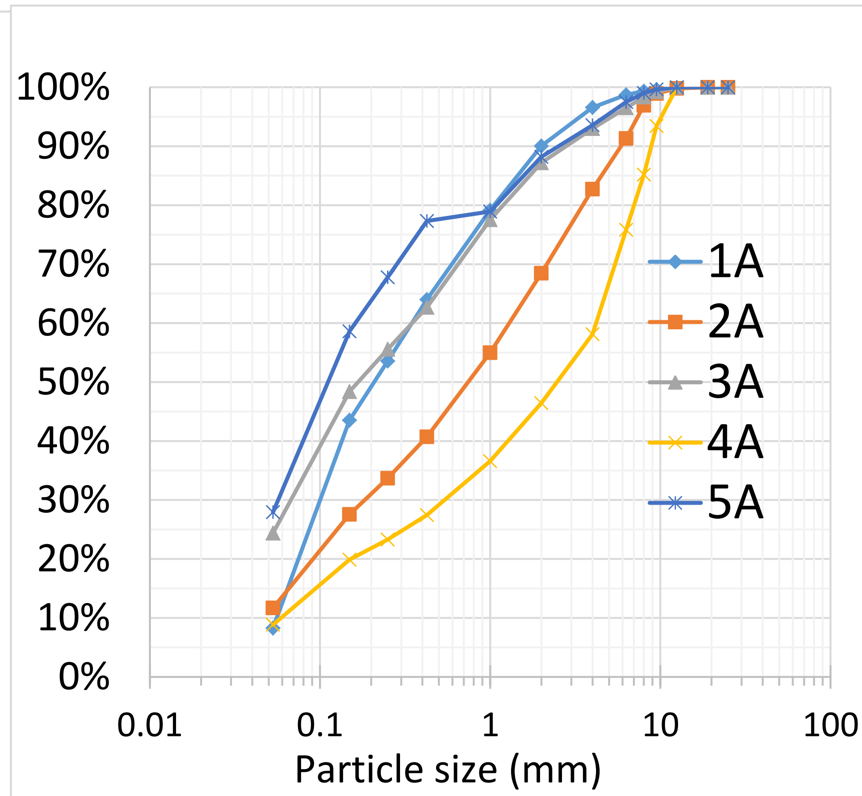
Particle Size Distribution and Particle Mass Distribution

- Raveled particles (plot 1A)

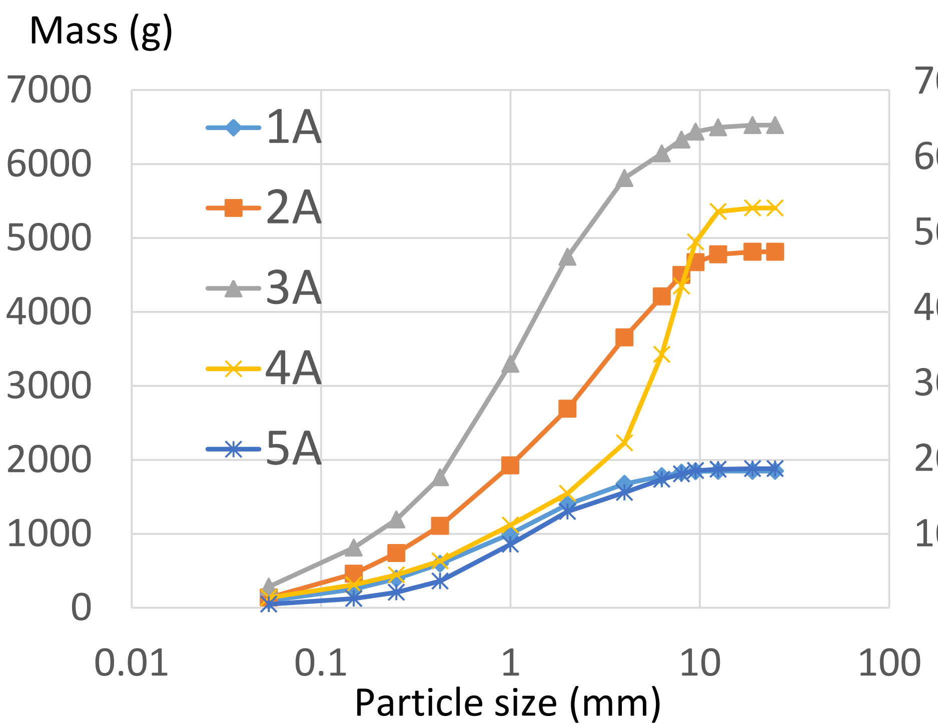
Cumulative Particle Size Distribution (Dry)



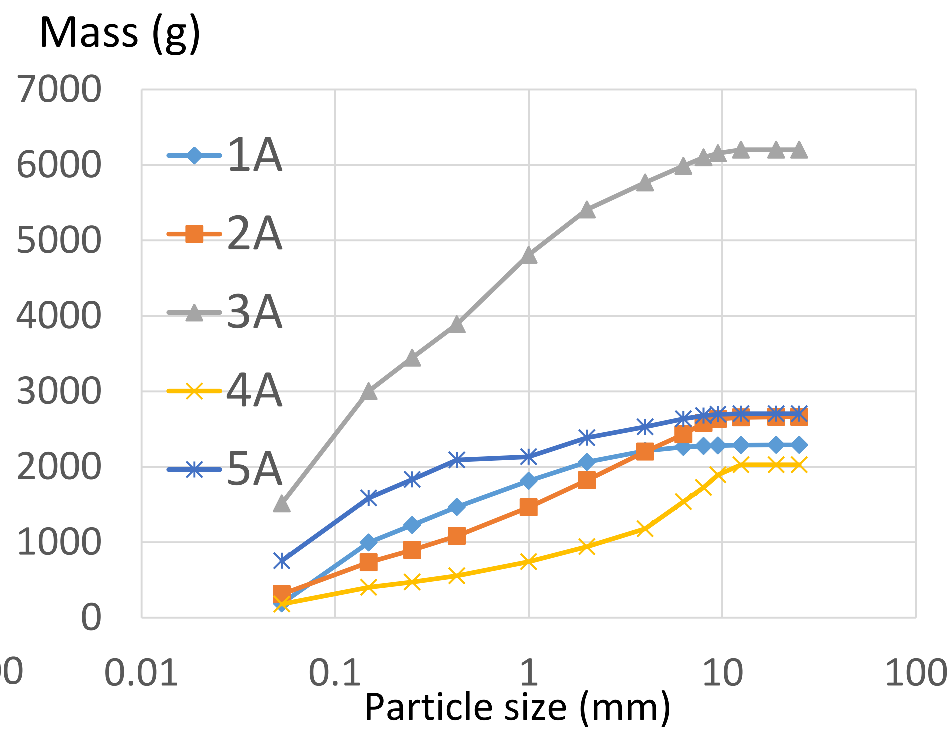
Cumulative Particle Size Distribution (Wet)

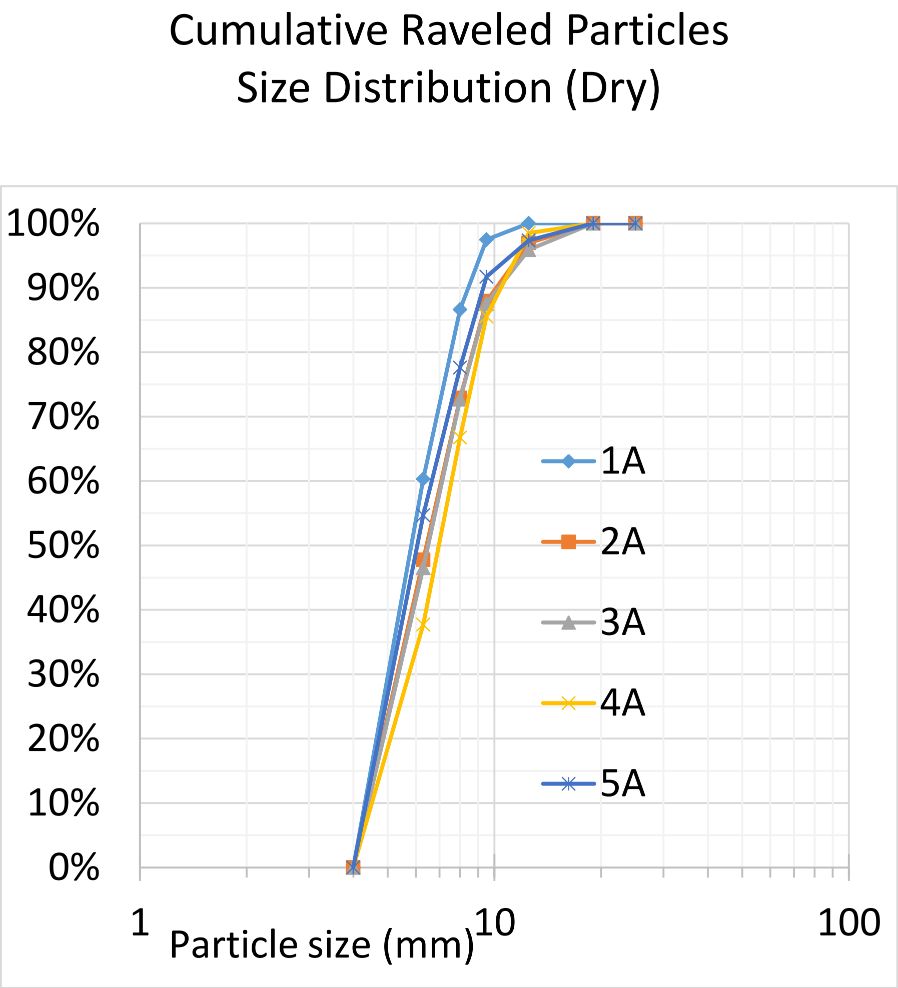


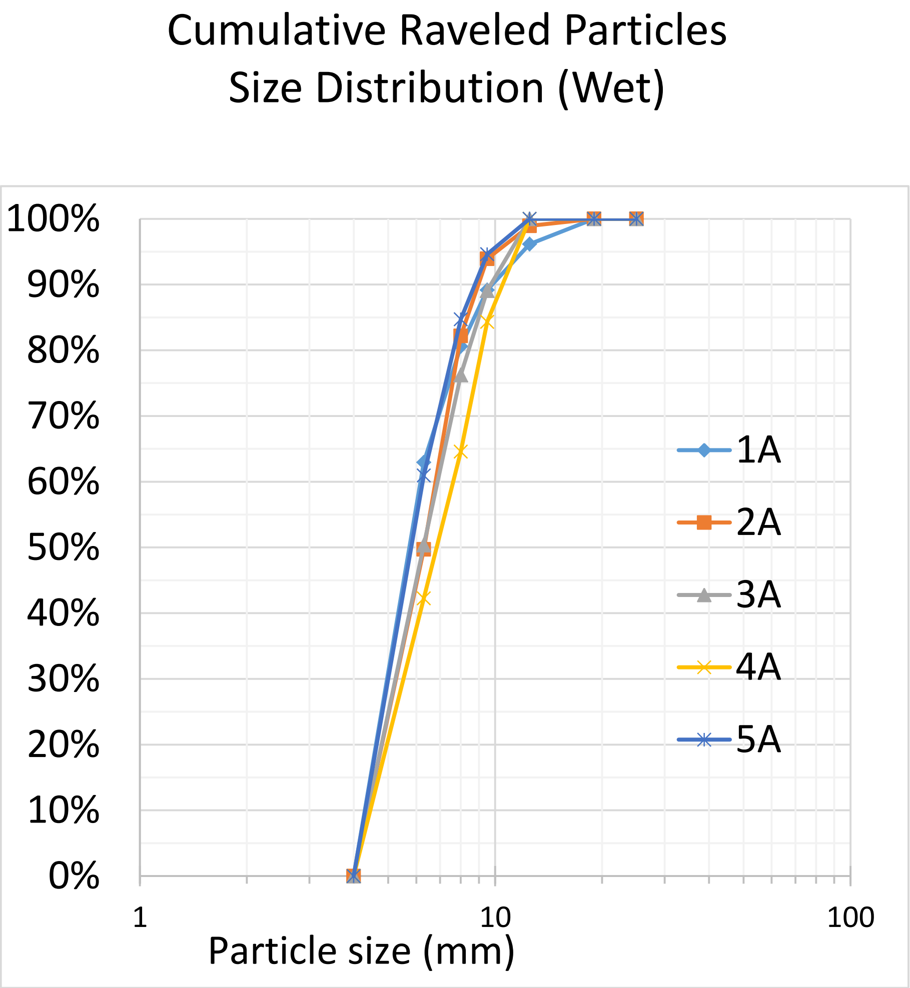
Cumulative Particle Distribution (Dry)



Cumulative Particle Distribution (Wet)

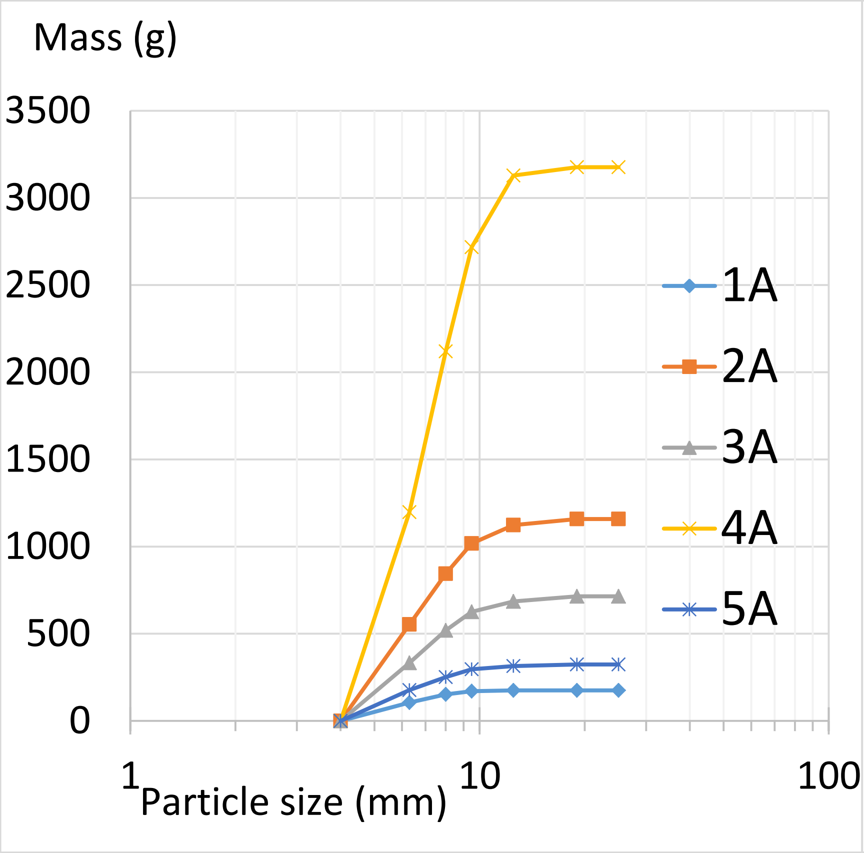


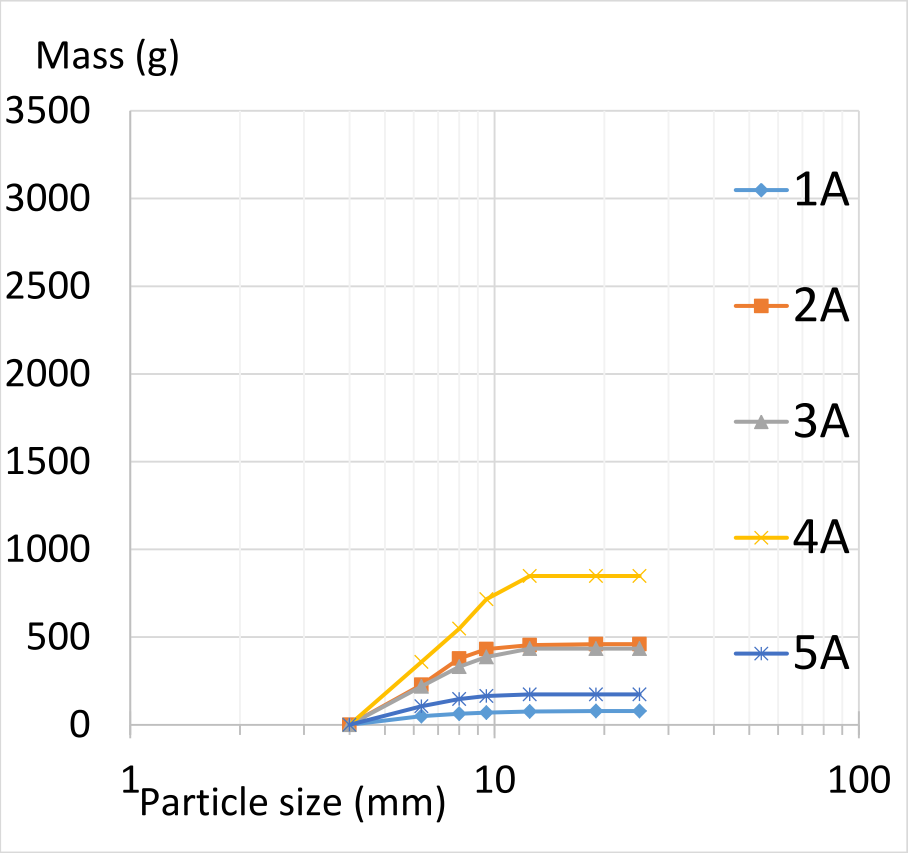

Cumulative Raveled Particles
Size Distribution (Dry)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
10
100
Particle size (mm)
1A
2A
3A
4A
5A


Cumulative Raveled Particles
Size Distribution (Wet)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
10
100
Particle size (mm)
1A
2A
3A
4A
5A

Cumulative Raveled Particle Mass Distribution (dry)

Cumulative Raveled Mass Distribution (wet)

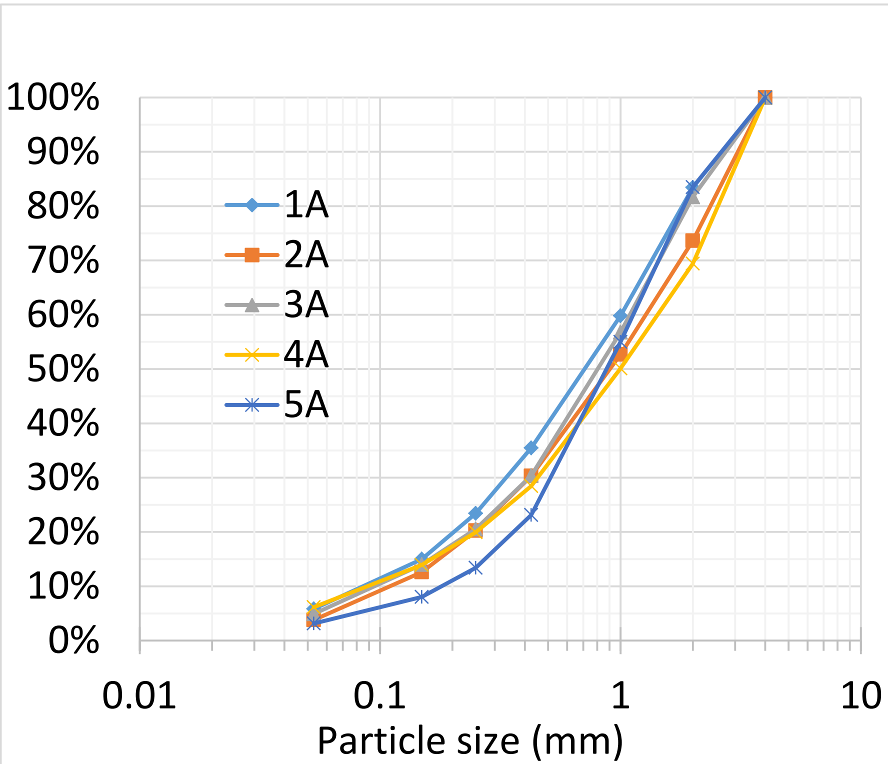




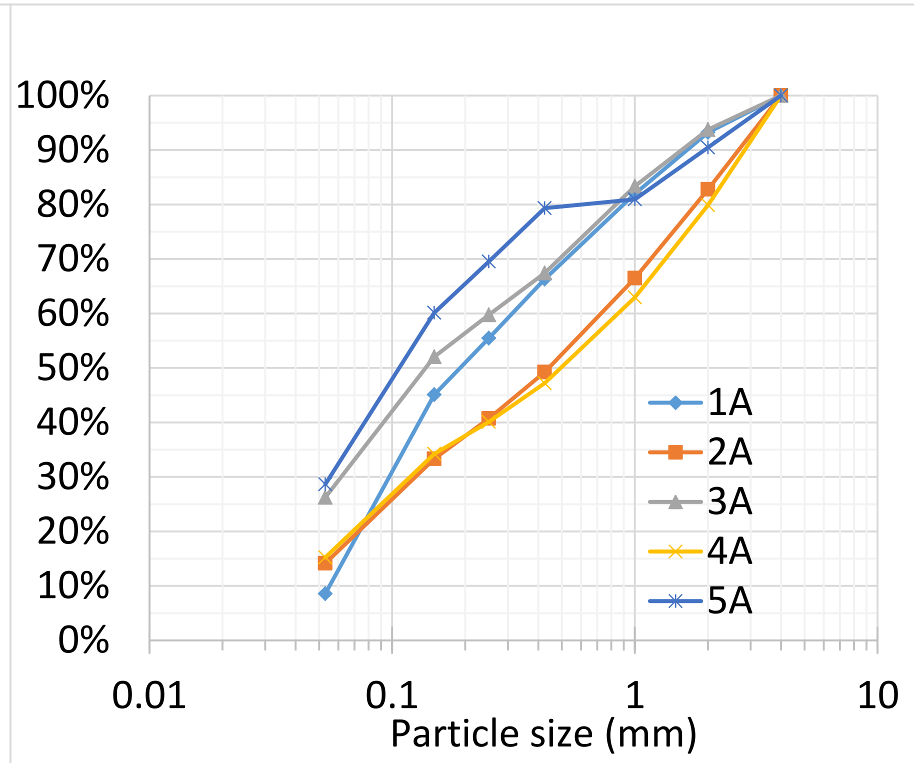
Raveled Particles

Concrete Mix design	Dry		Wet		Total Dry + Wet	
	Number of particles	Particle mass (g)	Number of particles	Particle mass (g)	Number of particles	Particle mass (g)
1	**732**	175	**336**	78	**1070**	253
2	**3770**	1158	**1400**	460	**5170**	1617
3	**2170**	715	**1480**	434	**3650**	1149
4	**8170**	3177	**2470**	849	**10600**	4025
5	**1180**	323	**709**	174	**1880**	497

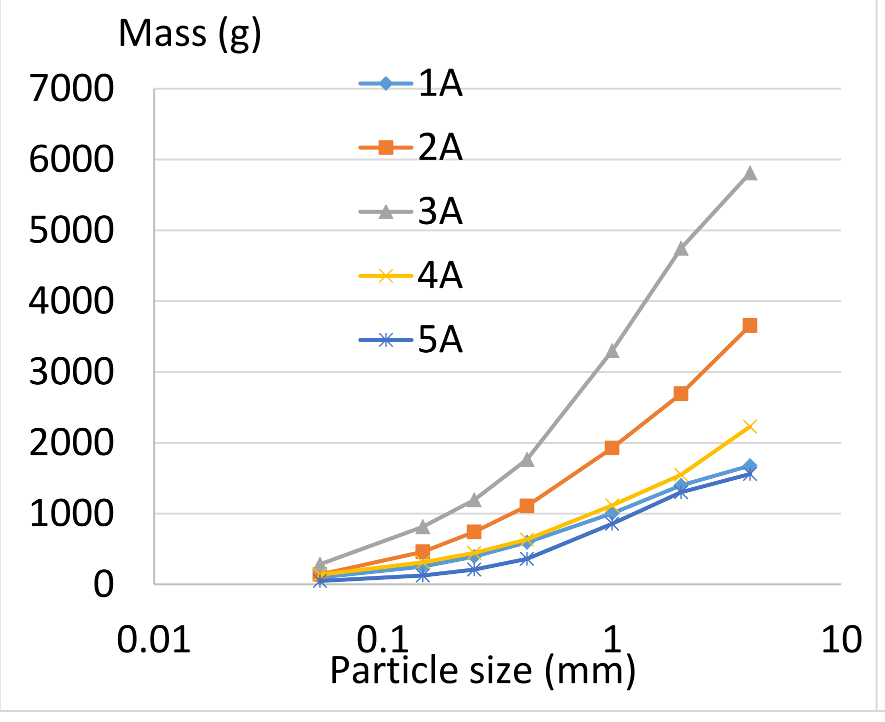
Cumulative Clogging Particle Size Distribution (Dry)



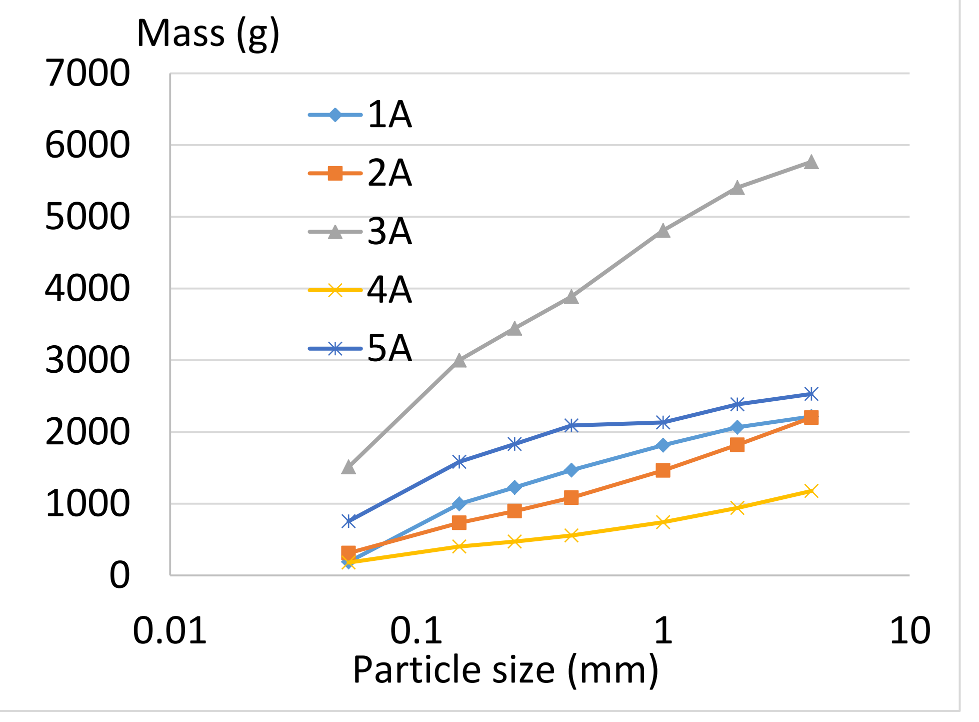
Cumulative Clogging Particle Size Distribution (Wet)



Cumulative Clogging Particle Mass Distribution (Dry)

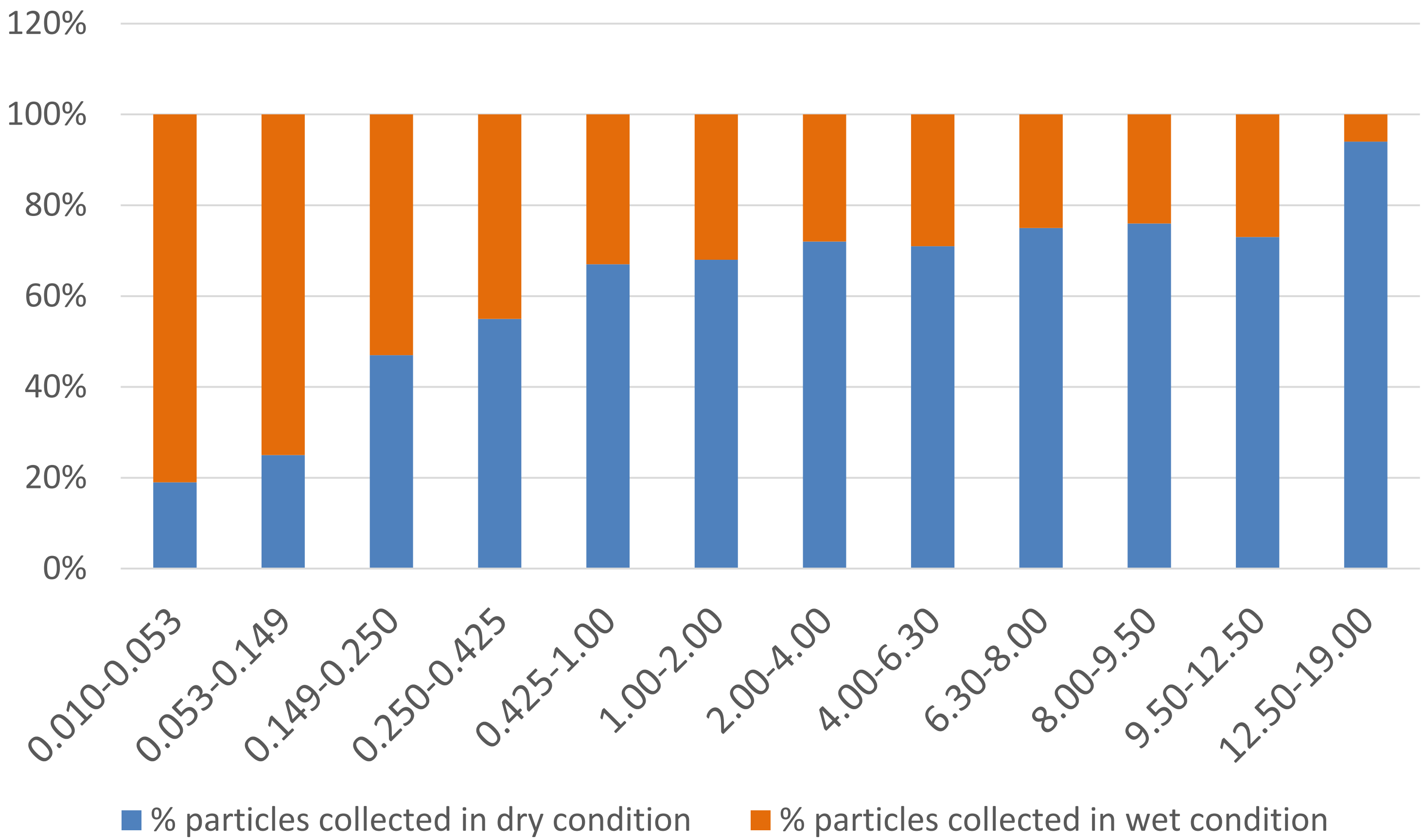


Cumulative Clogging Particle Mass Distribution (wet)



Efficiency of wet cleaning with handle-vacuum

20 kg particle collected in dry cleaning,
14 kg particles collected in wet cleaning



Statistical analysis

	(Aggregate + Sand)/ (Cement + Fly Ash)	% sand in aggregate	Ratio Fly Ash/ Cement	Water/ (Cement+ Fly Ash)	Unit weight (pcf)	Number of raveled particles (dry+wet)	Initial Infiltrati on rate
Number of raveled particles (dry+wet)	-0.24	0.03	0.40	-0.49	-0.90	1.00	
Initial Infiltration rate	-0.03	-0.10	0.56	-0.39	-0.98	0.97	1.00
Initial Clogging Slope	0.11	-0.19	0.66	-0.31	-0.99	0.77	0.98
Duration Initial Clogging Phase	-0.37	0.28	-0.39	-0.18	0.16	0.22	0.03
Duration of Plateau	0.23	-0.25	0.76	-0.21	-0.92	0.74	0.82

PLOT 1A

Vactor Truck 12/17/2014	
Change Since 10/31/2014	
in./h	%
188	23.1

Conclusions

- **Long-term infiltration:**

Infiltration rate and clogging rate seem to depend on the pore size and the density of pervious concrete.

- **Cleaning processes:**

- overall not much improvement in infiltration with the cleaning techniques that we investigated, but
- wet hand vacuum permits the collection of more small particles,
- the vactor truck shows promise as a cleaning method for extremely clogged pervious concrete

Conclusions

- **Big Picture:**

From a water quality standpoint, the addition of a relatively small amount of sand in the mix appears to be beneficial because it traps smaller sediments on the surface where it can be removed using a wet vacuum.

This has the potential to move pervious concrete mix design into a new direction.

QUESTIONS???

OSU Low Impact Development Research and Extension Program

- Low Impact Development

  A comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developed watersheds.

  Post-development Runoff = Predevelopment Runoff

- Extension

  An educational opportunity provided by colleges and universities to people who are not enrolled as regular students.

- Goal of the program

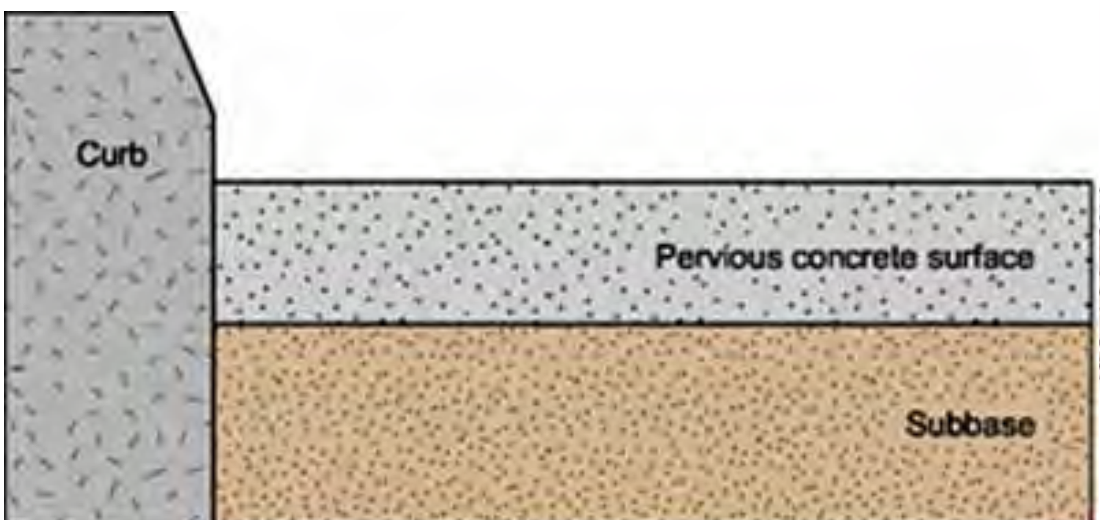
  Provide information and design aids related to low impact development that will make an impact on stormwater management in Oklahoma.

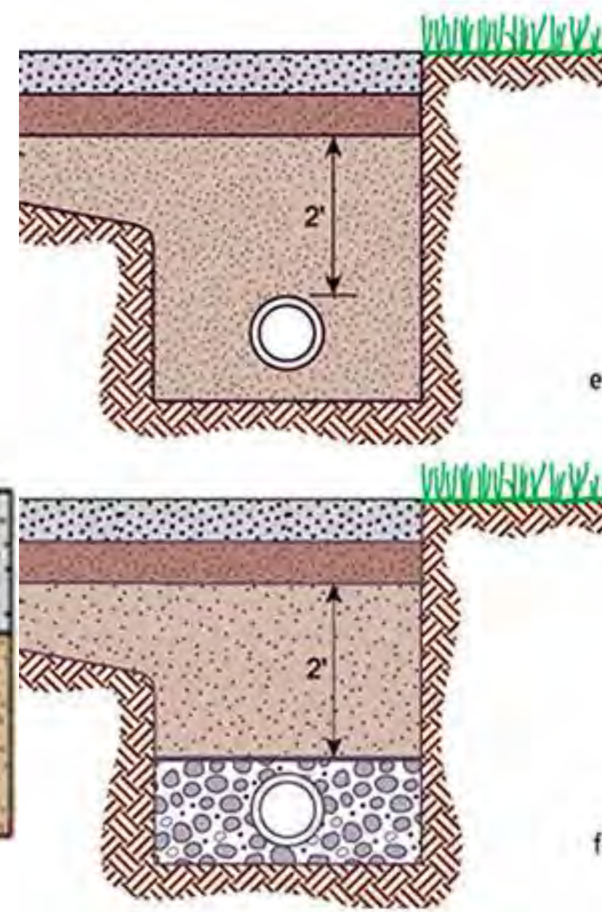
Sub-base and Subgrade Soils

- >8 inches permeable sub-base (>12 inches for vehicular traffic)
- Percolation rate ≥1/2 in./hr
- Sub-base should have:
  - 38% void content by weight
  - Clean washed with >2% on the 100 sieve
  - Maximum top size of 1.5 inches
- Clayey soils require modifications
  - Excavation and replacement
  - Filter reservoirs
  - Sand sub-base over pavement drainage fabric
  - Wells or drainage channels

Design

- Pervious concrete 4-8”
- Subbase >8” (>12 for vehicles)





Perviouspavement.org

Benefits

- Runoff Quantity Reduction and Flood Control
- Water Quality Treatment
- Recharges Groundwater
- Reduction in Stormwater Infrastructure (Piping, Catch-Basins, Ponds, Curbing, etc.)
- Suitable for Cold-Climate Applications, Maintains Recharge Capacity When Frozen
- Reduction of stormwater fees (where applicable)
- LEED points

Benefits

- No Standing Water or Black Ice Development During Winter Weather Conditions
- Maintains Traction While Wet
- Reduced Surface Temperatures; Minimizes the Urban Heat Island Effect
- Extended Pavement Life Due to Well Drained Base and Reduced Freeze-Thaw
- Less Lighting Needed Due to Highly Reflective Pavement Surface

Limitations

- Requires Routine (Quarterly to Yearly) Maintenance
- Often requires a Certified Pervious Concrete Craftsman for Installation
- Proper Soil Stabilization and Erosion Control are Required to Prevent Clogging
- Not for use where there is a strong likelihood of a hazardous waste spill

Limitations

- Quality Control for Material Production and Installation are Essential for Success
- Concrete Must Cure Under Plastic for at Least 7 Days After Installation
- Not as strong as traditional concrete (can be up to 5,000 psi depending on admixtures.

Cost

- Total project cost comparable for pervious concrete with reduced stormwater infrastructure vs. standard pavement applications where stormwater infrastructure is required
- Dependent on Materials, Site, Project size, Regional experience
- Materials cost is ~10-100% more than traditional concrete
- Need for skilled craftsman increases installation costs