

Green Infrastructure at the Edison Environmental Center - Permeable Pavement

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Traditional Urban Drainage Problems

- Roads/parking lots account for **70%** total impervious cover ([NRC, 2009](#))
- **80%** of impervious cover, i.e. roads, parking lots, and roofs, are **directly connected to drainage system** ([NRC, 2009](#))
- “Urban municipal separate stormwater conveyance systems have been designed for flood control ...failed to address the more frequent rain events (**<2.5 cm**).... **small storms** may only generate runoff from paved areas and **transport** the “first flush” of **contaminants**.” ([NRC, 2009](#))

Edison Environmental Center (EEC) former Raritan Arsenal

Full-scale

- Permeable pavement
- Bioinfiltration

Roof runoff collection and use

Urban Water Research Facility

- Swales
- Rain gardens
- Rainwater sampling
- Pipelines

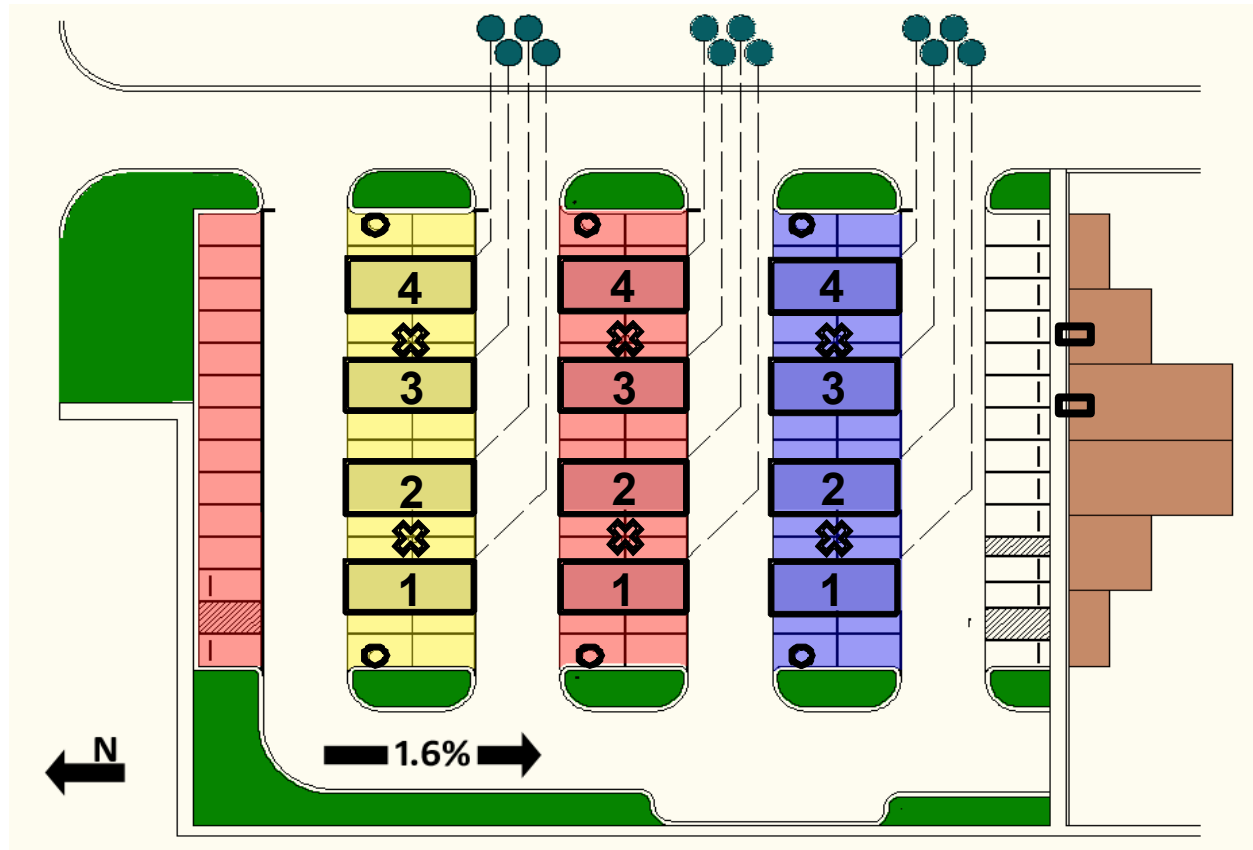


Permeable Pavement and Bioinfiltration Research and Demonstration Site



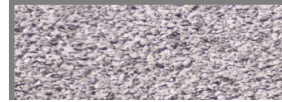
- Side by side testing of three permeable parking surfaces
- Evaluation of effect of hydraulic loading on bioinfiltration hydrologic performance
- Continuous and event-based sampling for water quantity and quality parameters

Final design incorporated monitoring capabilities for 3 permeable surfaces.

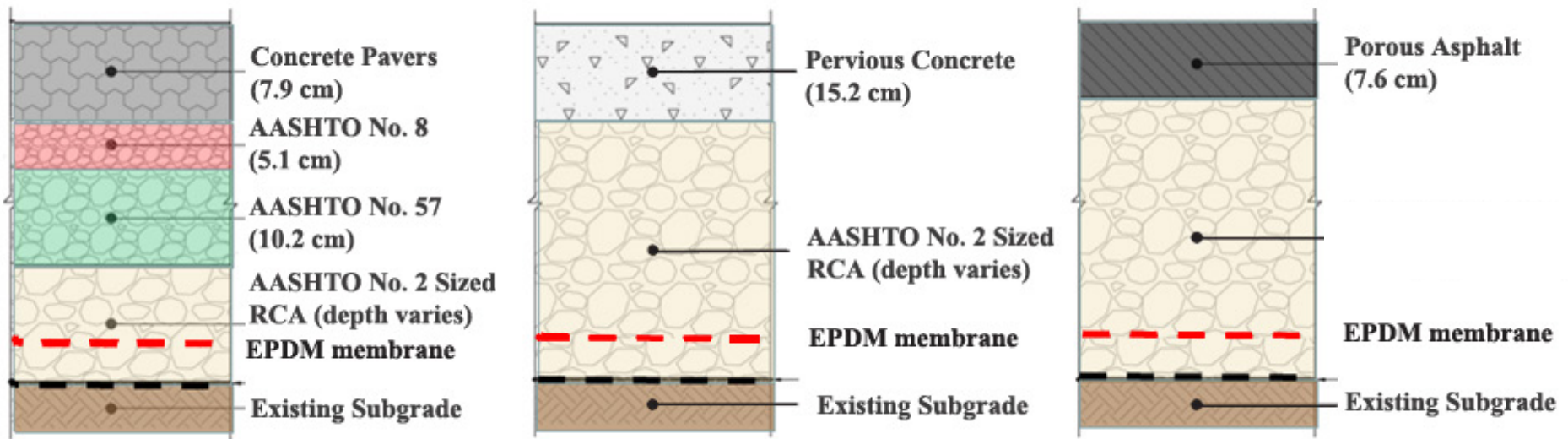


- | | | | |
|---------------------------|-------------------|-------------------------------------|--------------|
| Permeable pavers | Pervious concrete | Porous asphalt | Rain gardens |
| Buried distribution pipes | Tree islands | Hot mix asphalt | Curb cuts |
| Buried well/piezometers | Collection tanks | Buried Water Content Reflectometers | |

Vertical cross sections of permeable surfaces vary slightly from material to material.

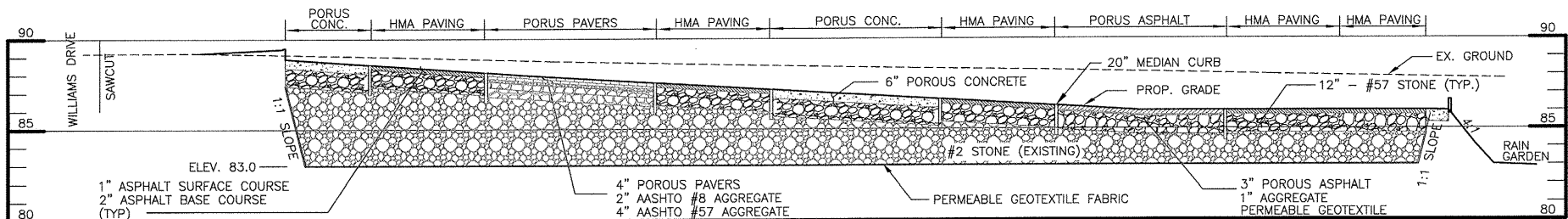


Not to scale



Based on engineering drawings from Morris & Ritchie Associates, Inc. 2009

Depth to EPDM membrane ~ 16 in.



SECTION A-A

SCALE: H: 1" = 20'
V: 1" = 5'

Construction began late 2008 with opening in October 2009.



November 26, 2008



December 18, 2008



February 26, 2009



March 25, 2009



June 1, 2009



August 5, 2009



October 6, 2009



October 8, 2009



October 28, 2009

Four equally-sized and spaced lined sections collect infiltrating water from each permeable surface.

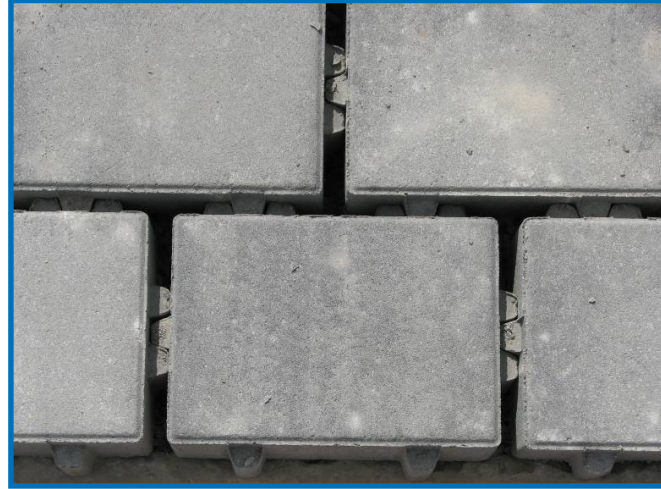


Lined sections 15'6" w x 18' long

Infiltrate drains from lined sections to 5,700 L (1,500 gal) tanks on east side of the 0.4 ha (1 acre) parking lot where it can be sampled. Tanks designed to collect 38 mm (1.5 in) event before bypass.



Permeable Interlocking Concrete Pavers (PICP)



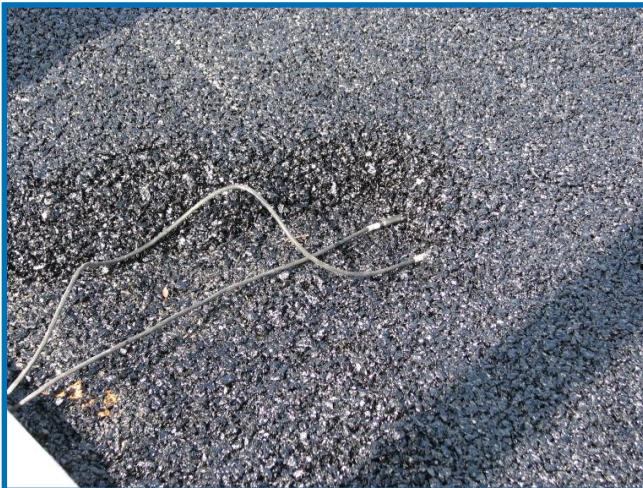
Pervious concrete (PC) was poured over two days and cured under plastic for a week.



Porous Concrete (PC)



Placing the porous asphalt (PA) took two days.



Permeable Surfaces during Rain

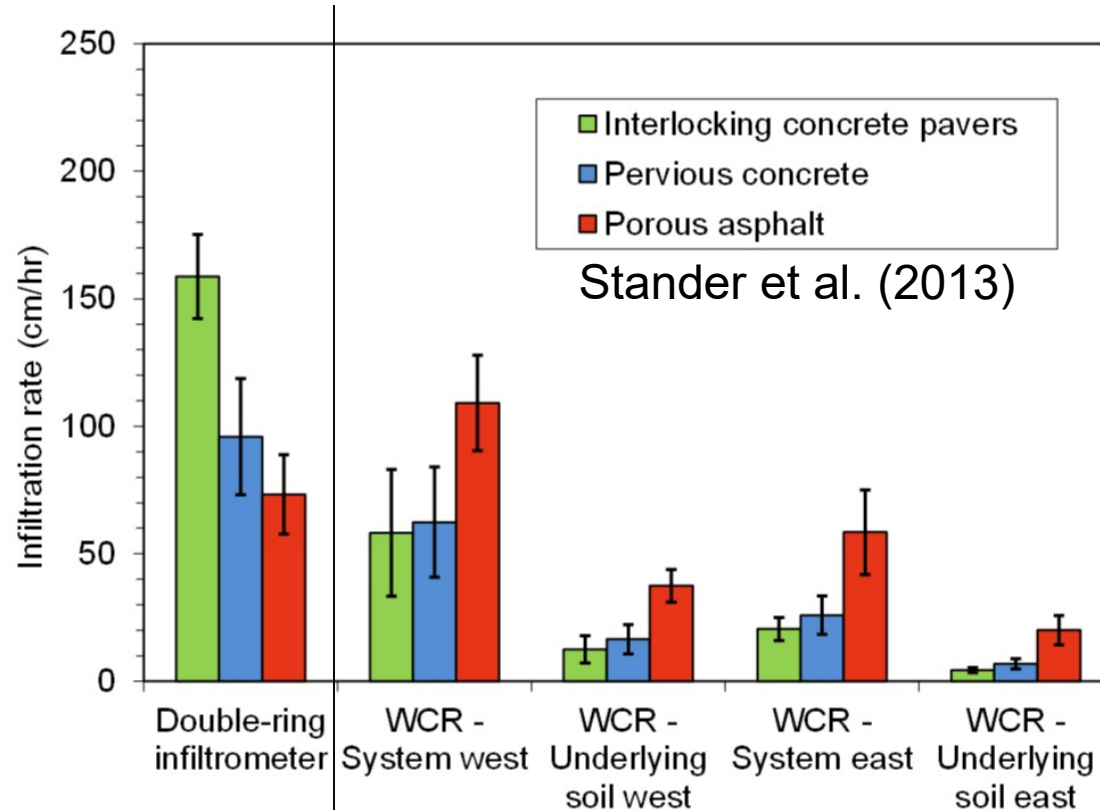


Results

- Infiltration Testing
- Water Quality



Underlying Pre-construction Soil Infiltration Testing Compared to Post-construction In-situ Moisture Measurements



Pre-construction infiltration test

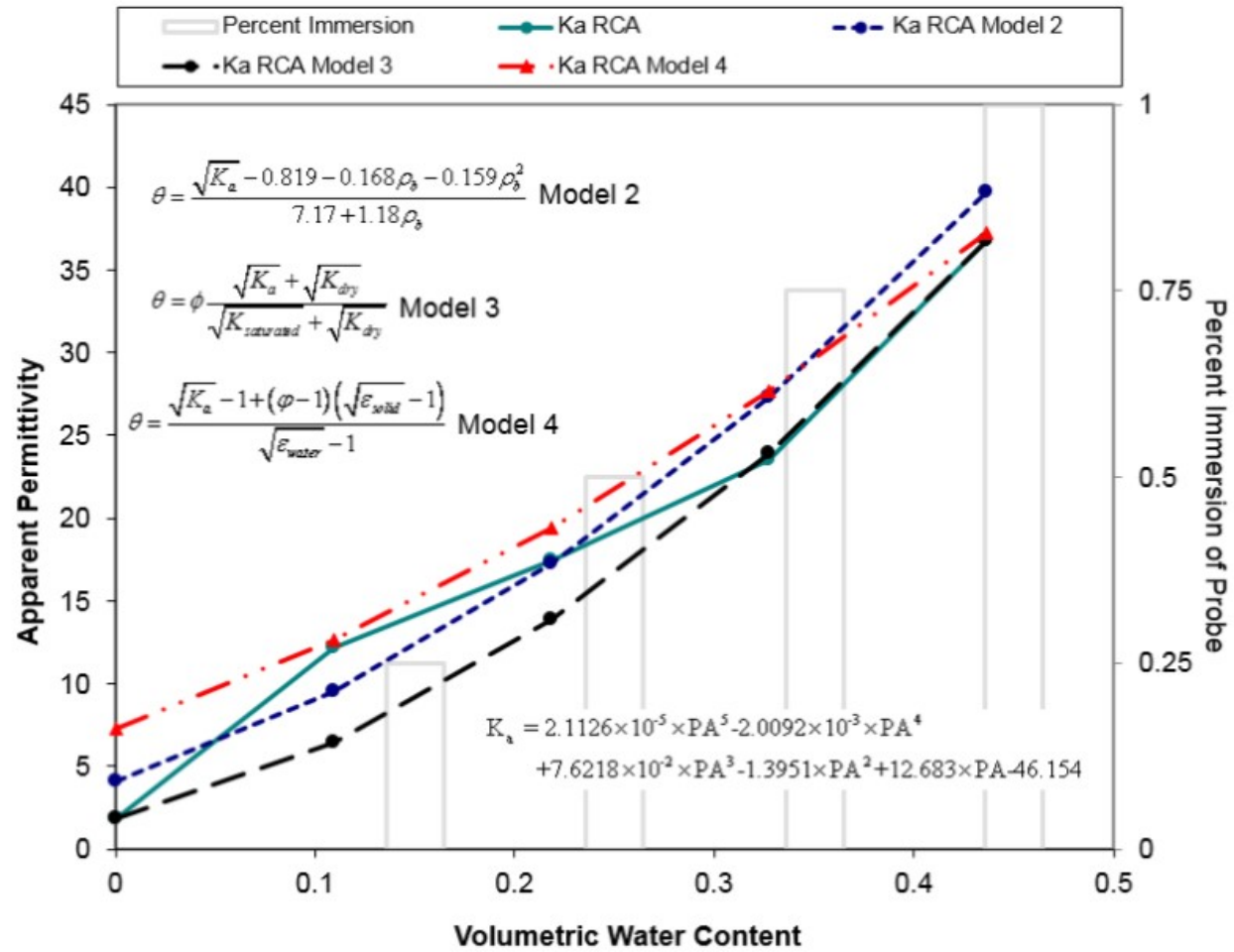


Post-construction soil moisture measurements

Water content reflectometer (WCR) installation

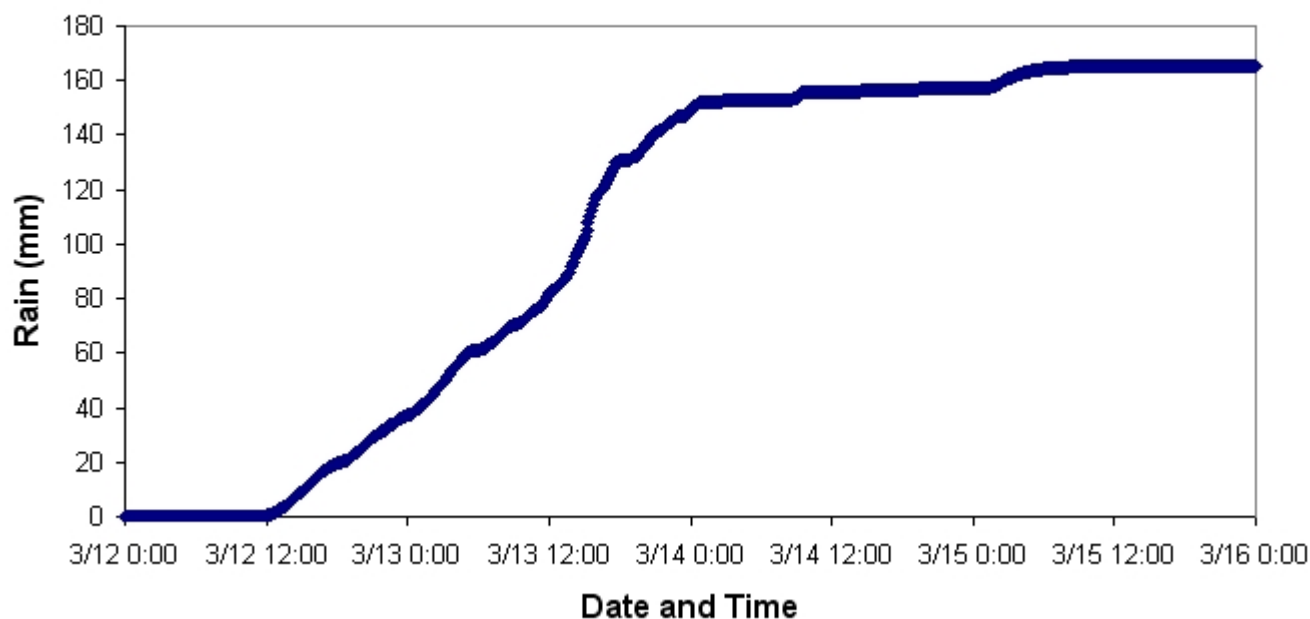
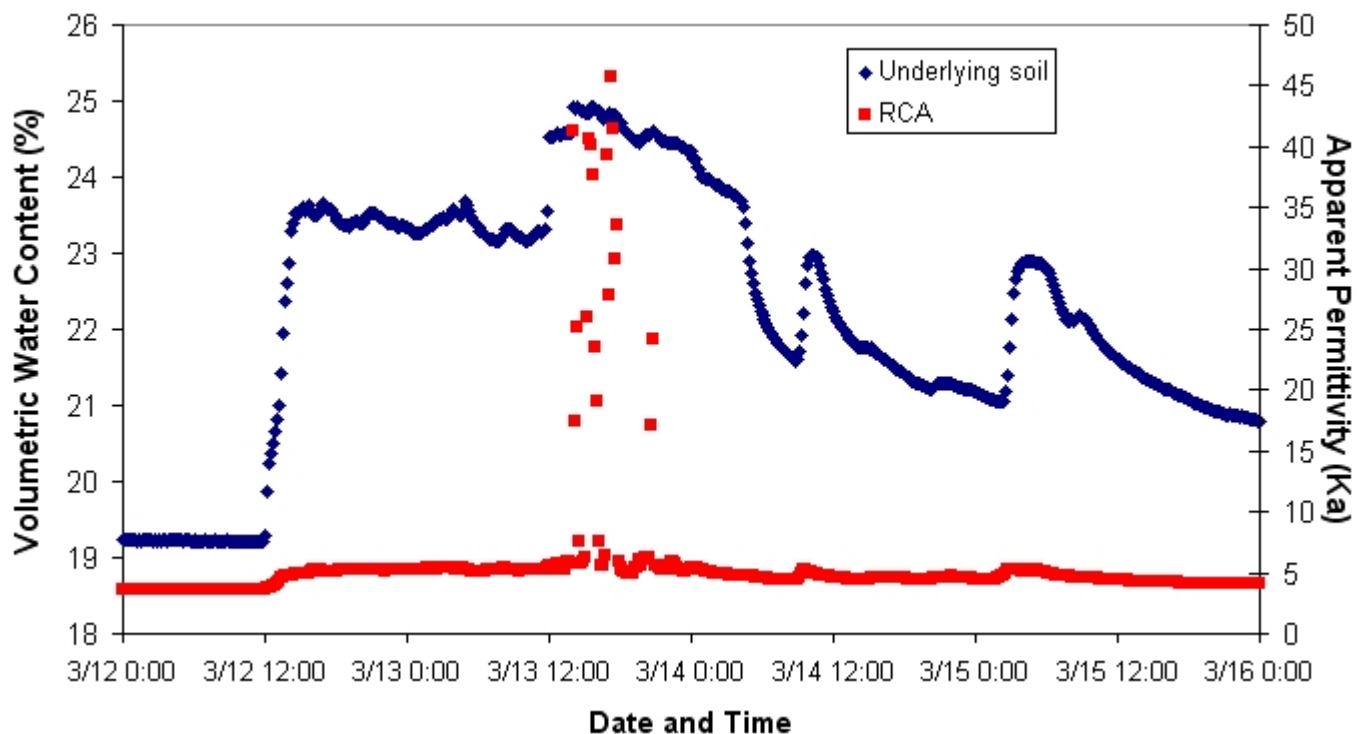


Calibration of Water Content Reflectometers in Large Aggregate



**Calibration led
to interpretation
of data – on
afternoon of 3/13/10
> 19% water content
or > 10 Ka apparent
permittivity implies
saturation or
inundation in
portion of storage
gallery.**

Stander et al. (2013)



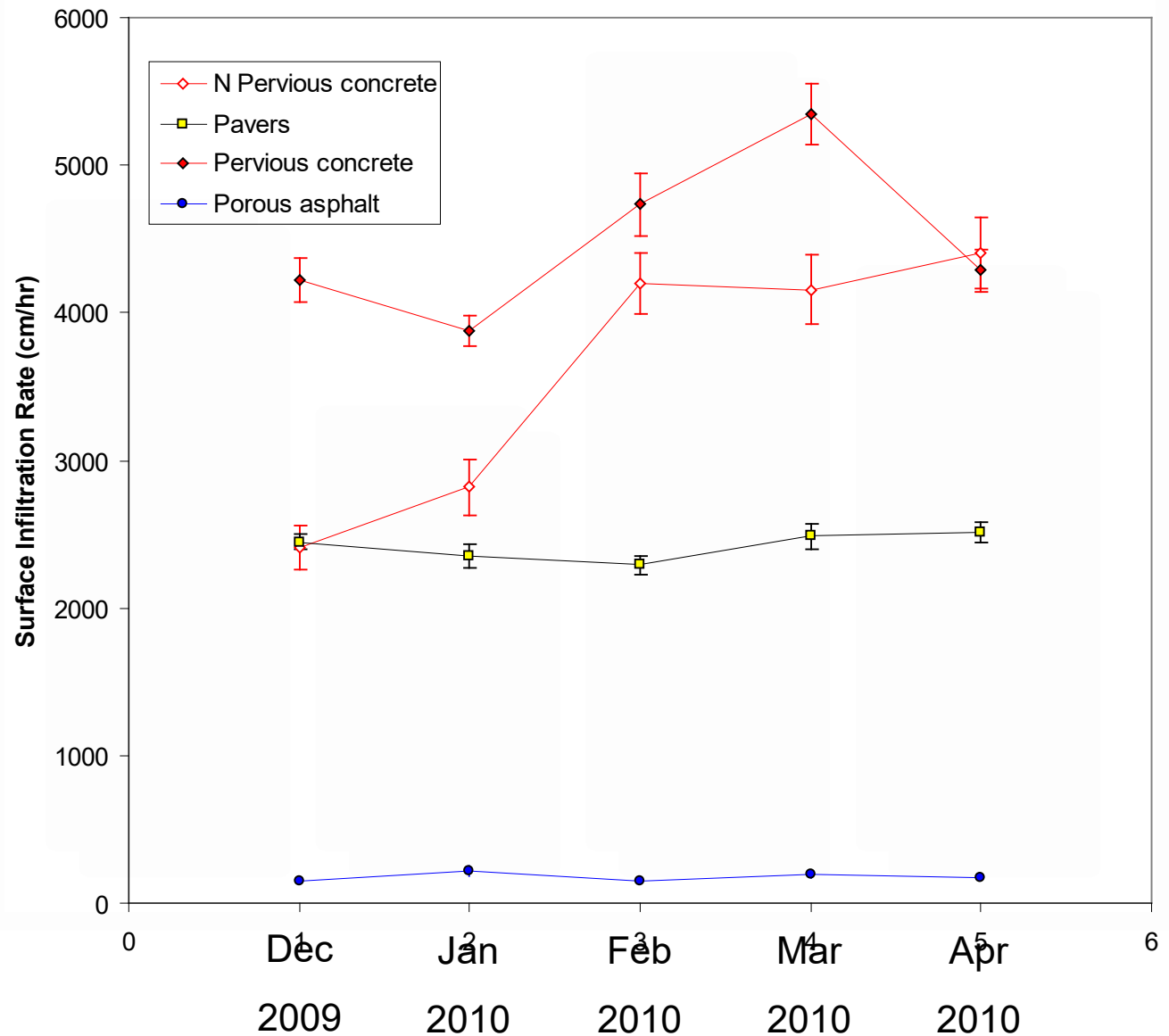
Initial Surface Infiltration Rates



Modified ASTM C1701 apparatus

Surface type	Initial surface infiltration rate (cm/hr \pm 1SD)	Literature reported infiltration rate (cm/hr)
Permeable Interlocking Concrete Pavers	2440 \pm 305	2000 (Bean et al., 2007)
Pervious Concrete	4220 \pm 876	4000 (Bean et al., 2007)
Porous Asphalt	147 \pm 43	430 (Ferguson, 2005)

Surface Infiltration Rates



**Sediment accumulates (and clogging progresses)
from the upgradient edge.**



Measured surface infiltration rates using modified version of ASTM C1701 at monthly intervals for three years.



Modifications were:

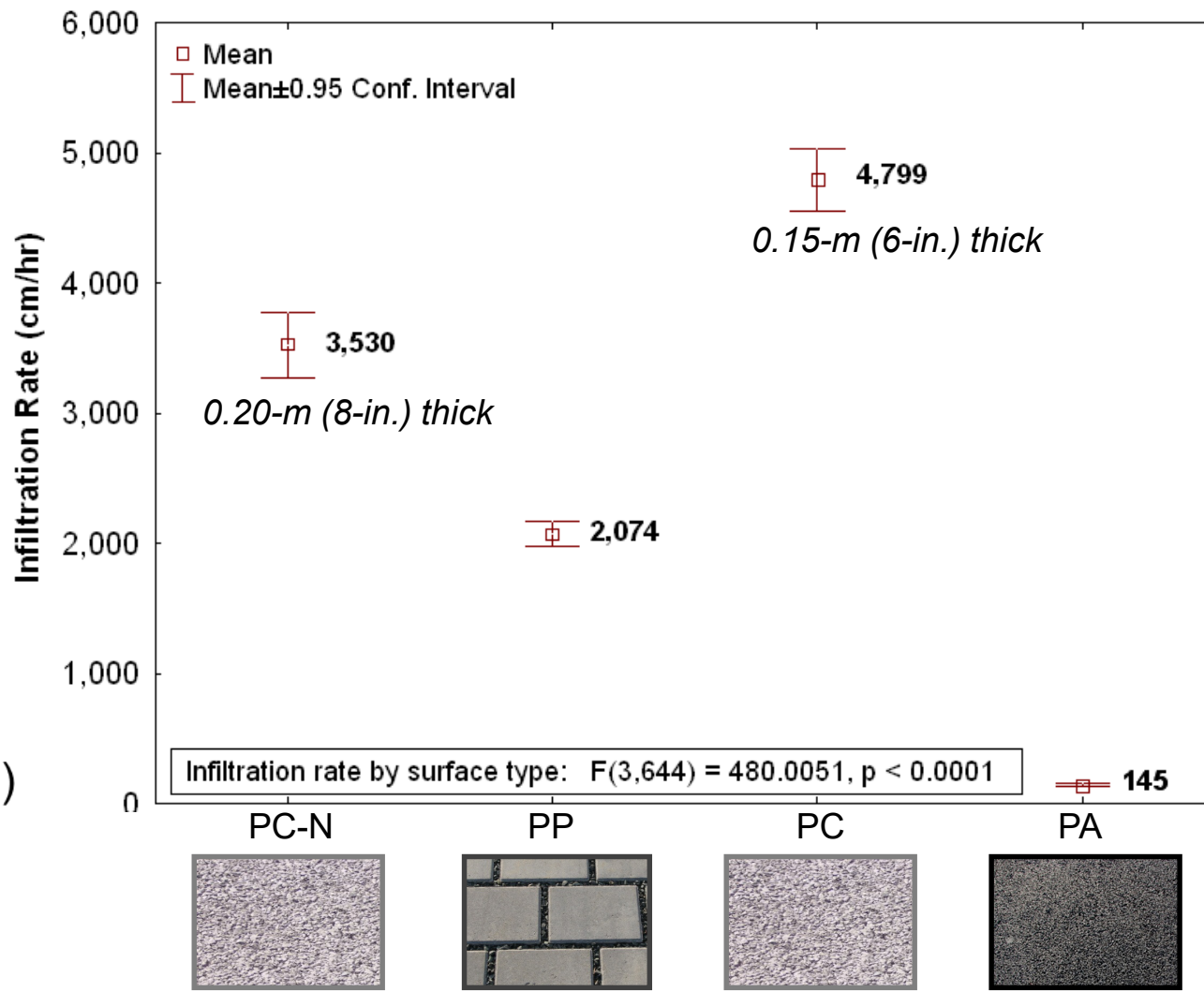
- (1) how the seal was achieved between the ring and the surface;
- (2) added temperature measurements of surface and water.

Infiltration rates vary among four tested surfaces, but all surfaces can infiltrate maximum expected direct rainfall rates.

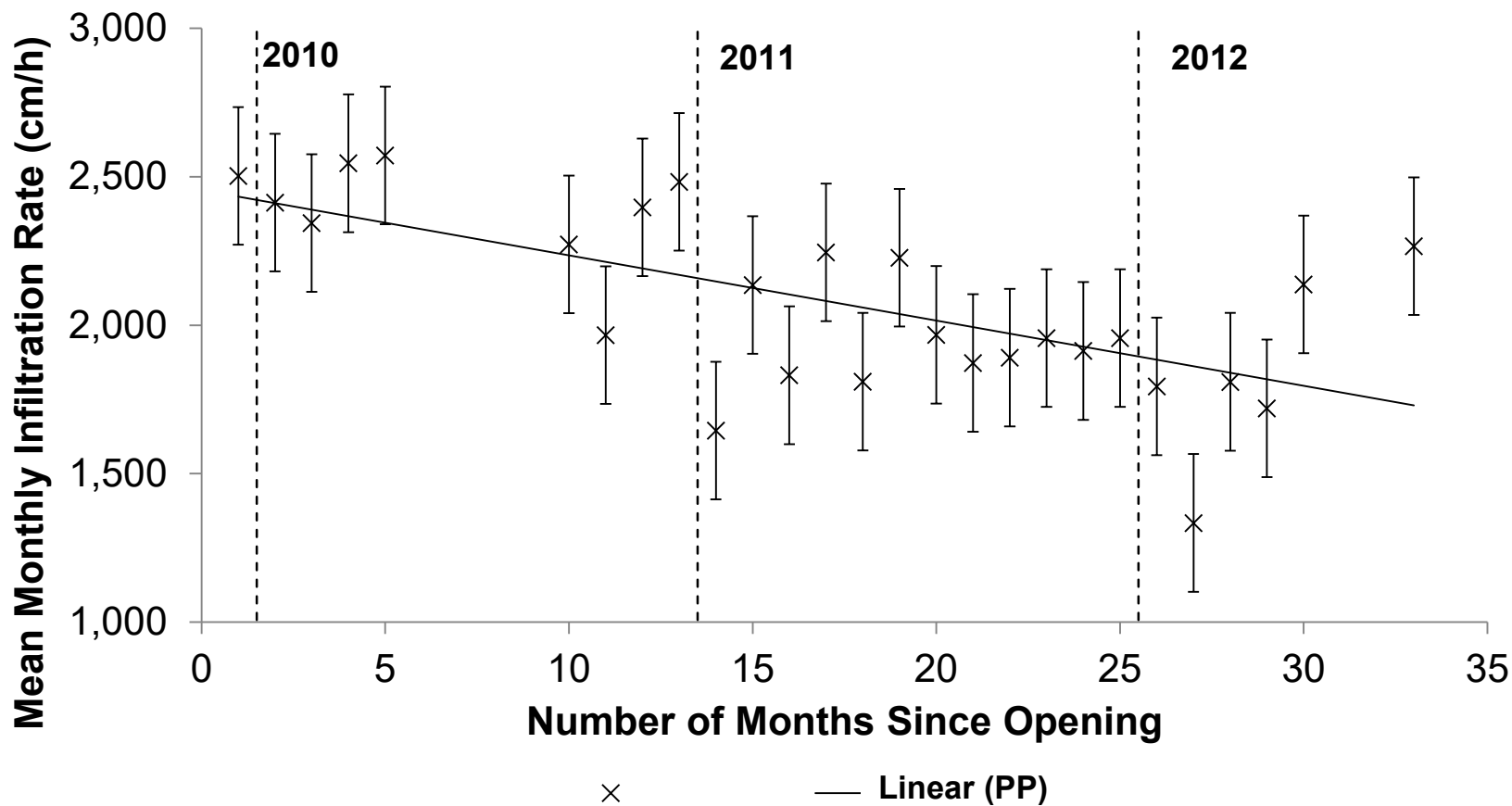
**100-year, 5-minute
rainfall intensity**

• Edison, NJ
20.8 cm/hr (8.2 in/hr)

Brown and Borst (2014)



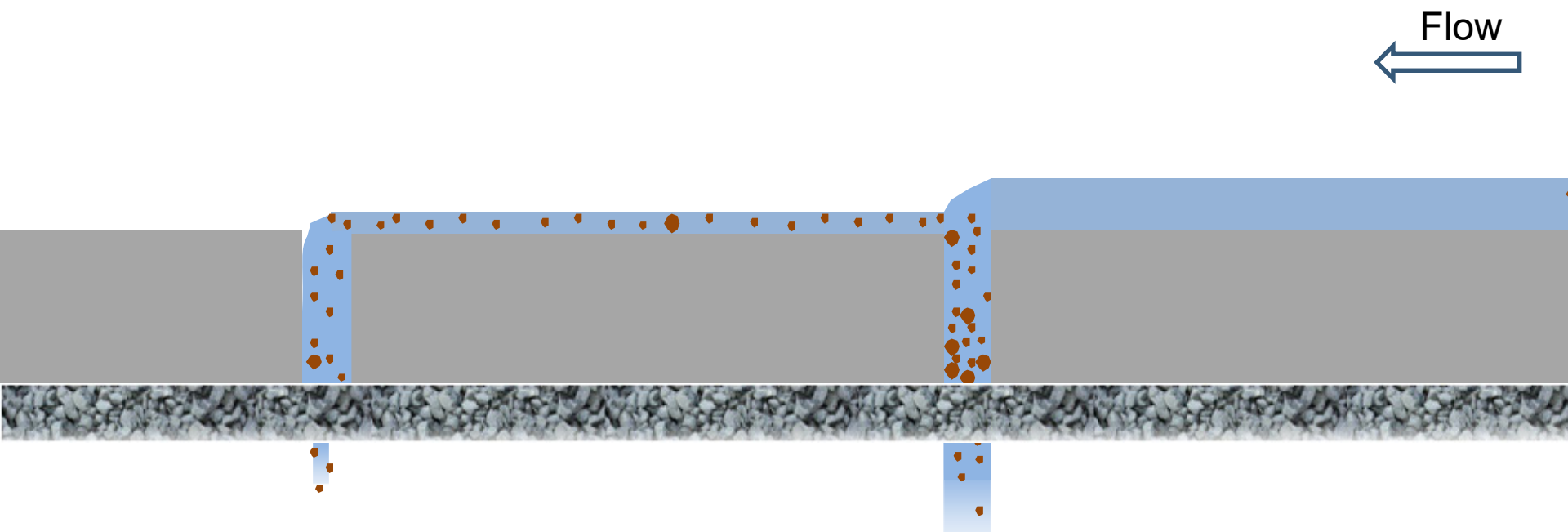
Infiltration decreases with time for surfaces that receive runoff from driving lane.



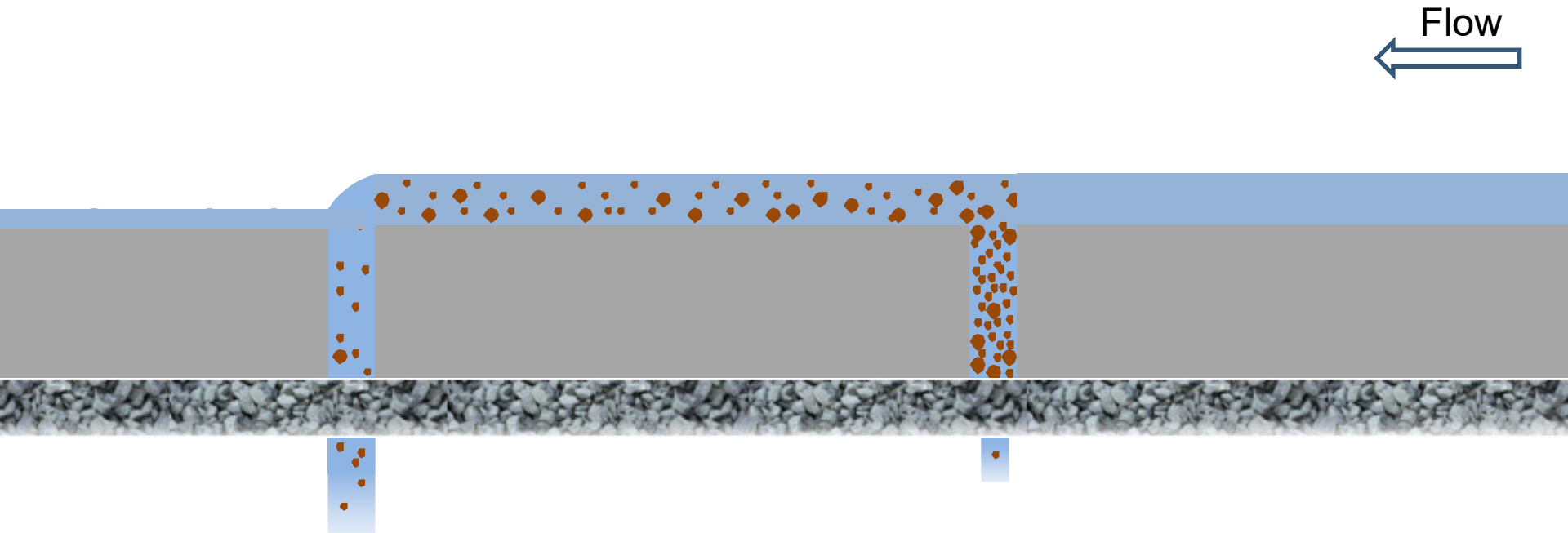
Error bars represent standard error.

Brown and Borst (2014)

Hypothesis of the mechanics of the infiltration/clogging processes.



**As gaps fill with sediment,
location of highest infiltration
area move downgradient.**



Sediment accumulates (and clogging progresses) from the upgradient edge.



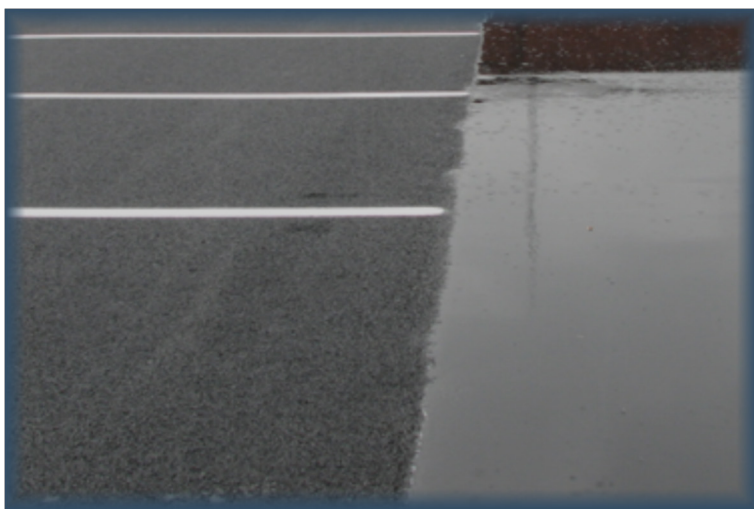
No sediment

Sediment

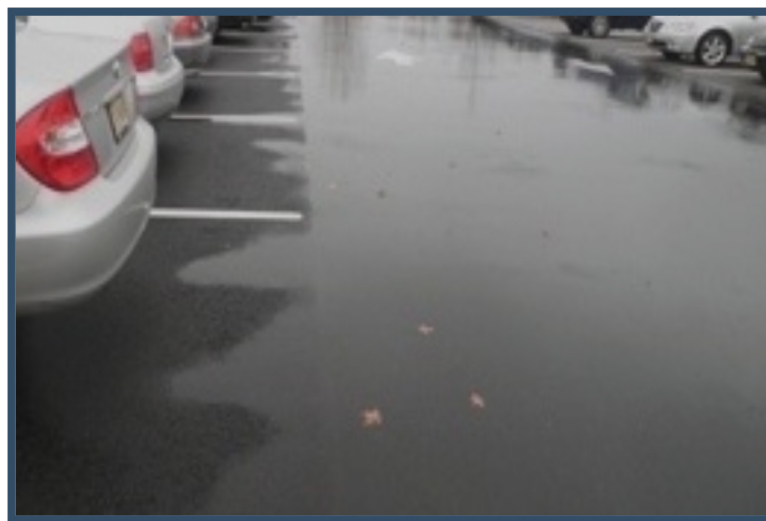
Permeable Interlocking Concrete Pavers Immediately after Installation



Inspection of porous asphalt supports proposed mechanism.



After installation



After use

Removal of pavers shows how clogging advances filling gaps with fines.



**With aggregate between the pavers,
most fines are trapped
in the top 20 mm.**



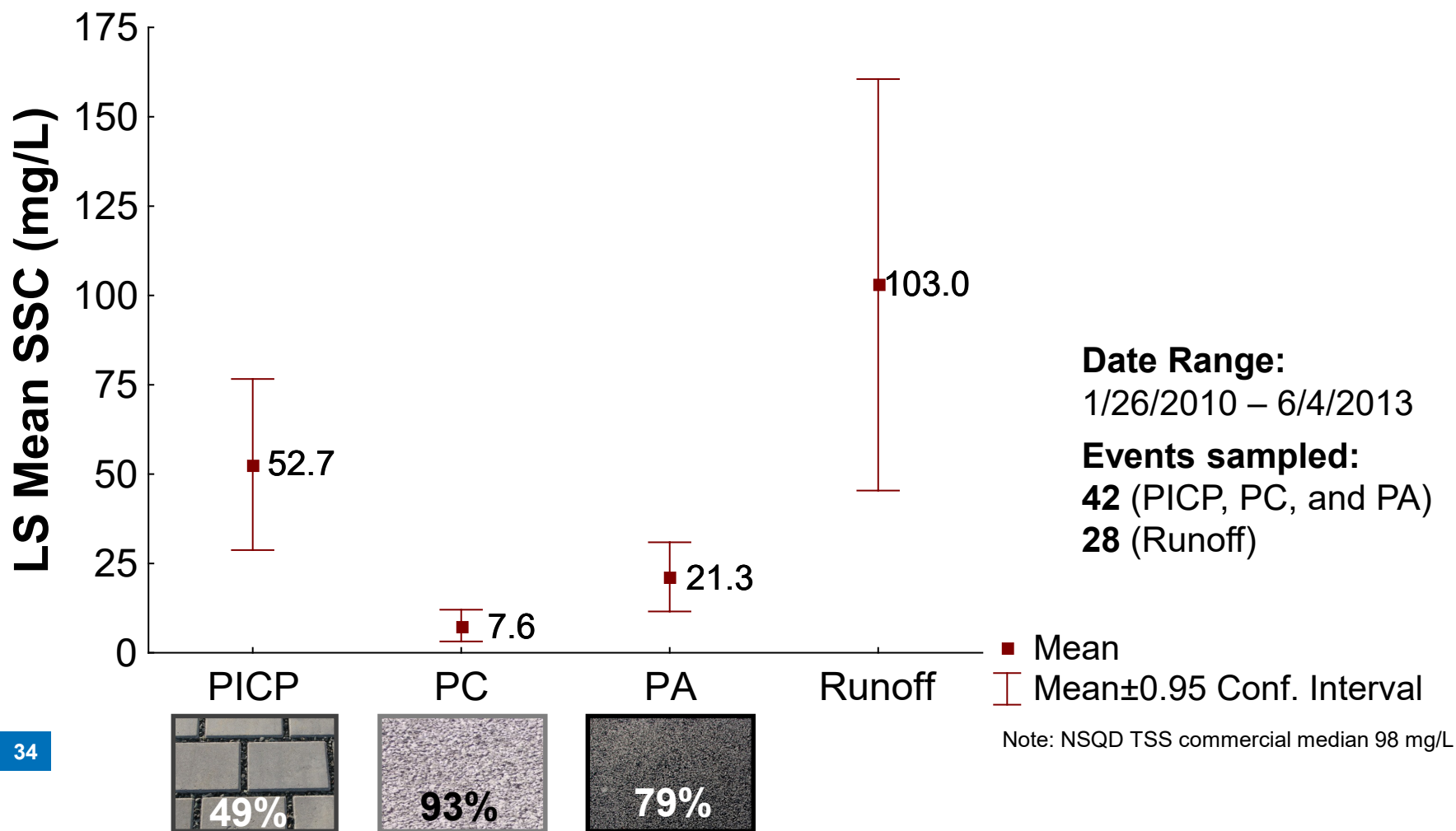
The permeable pavement parking lot at the EEC allows evaluation of water quality effects.

- Published results
 - Chloride
 - Speciated nitrogen
 - Organic carbon
 - Phosphate
 - pH
 - SVOCs
 - Metals
 - Microbial indicators

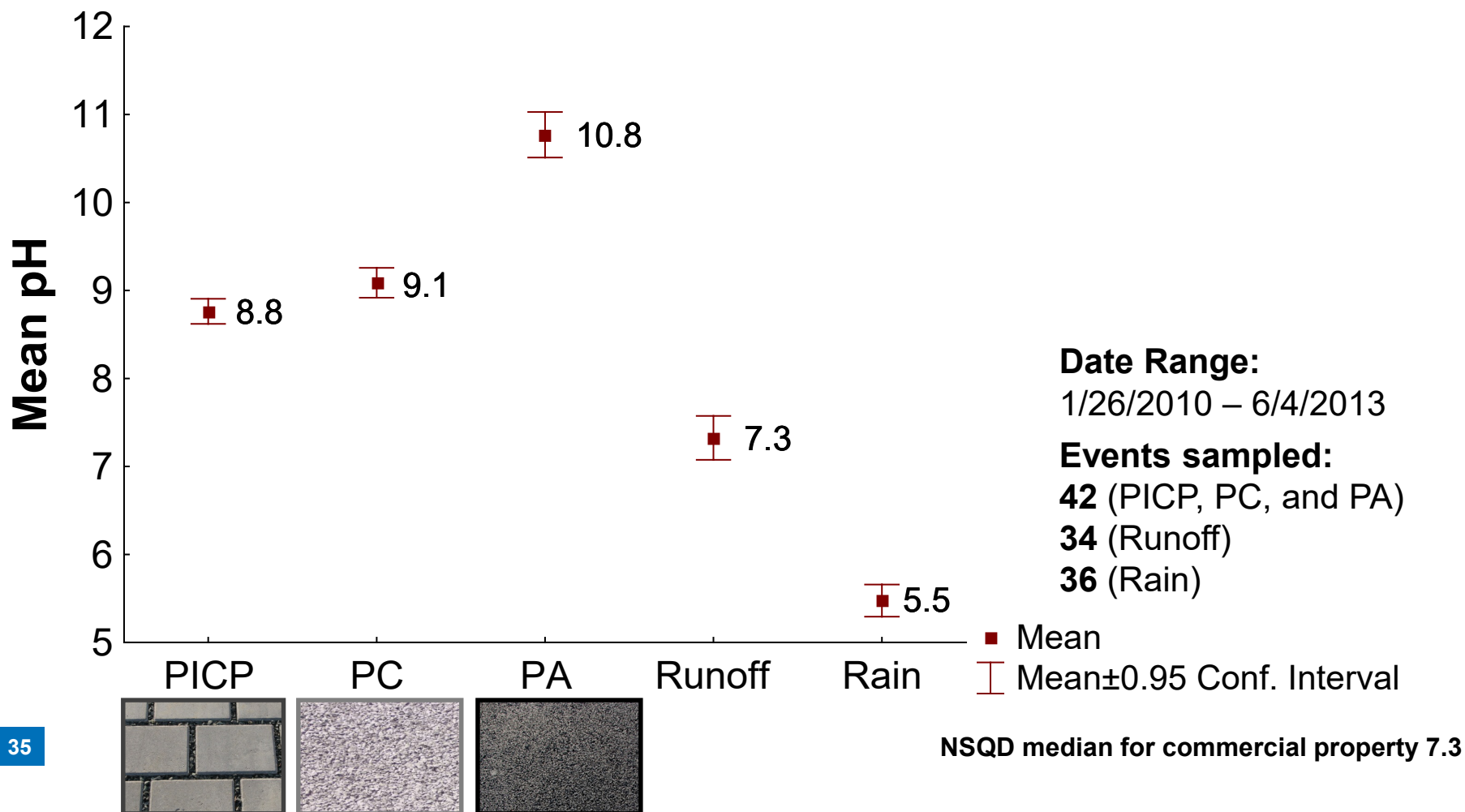


1,500-gallon collection tanks

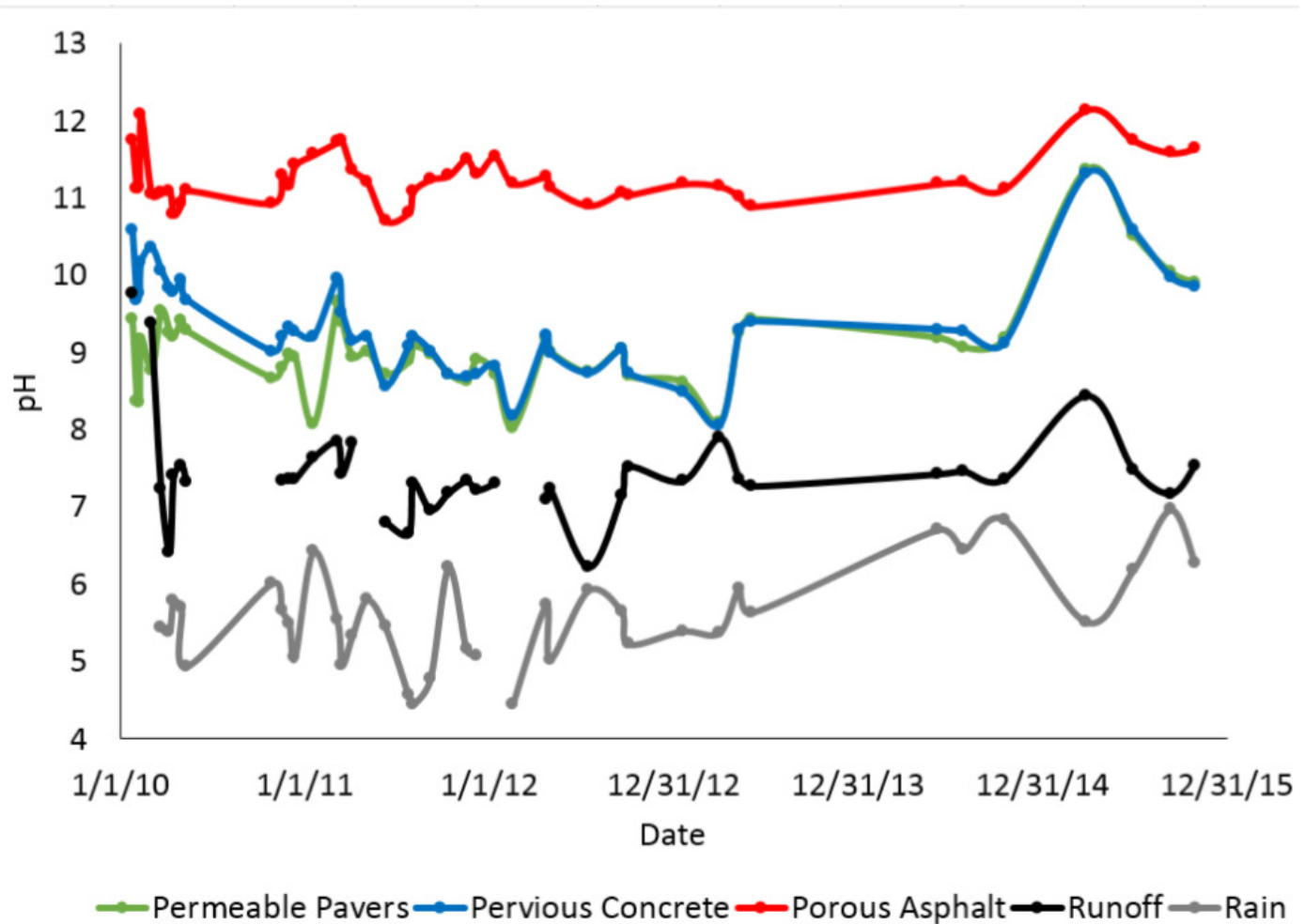
All permeable surfaces reduced suspended sediments concentration (SSC).



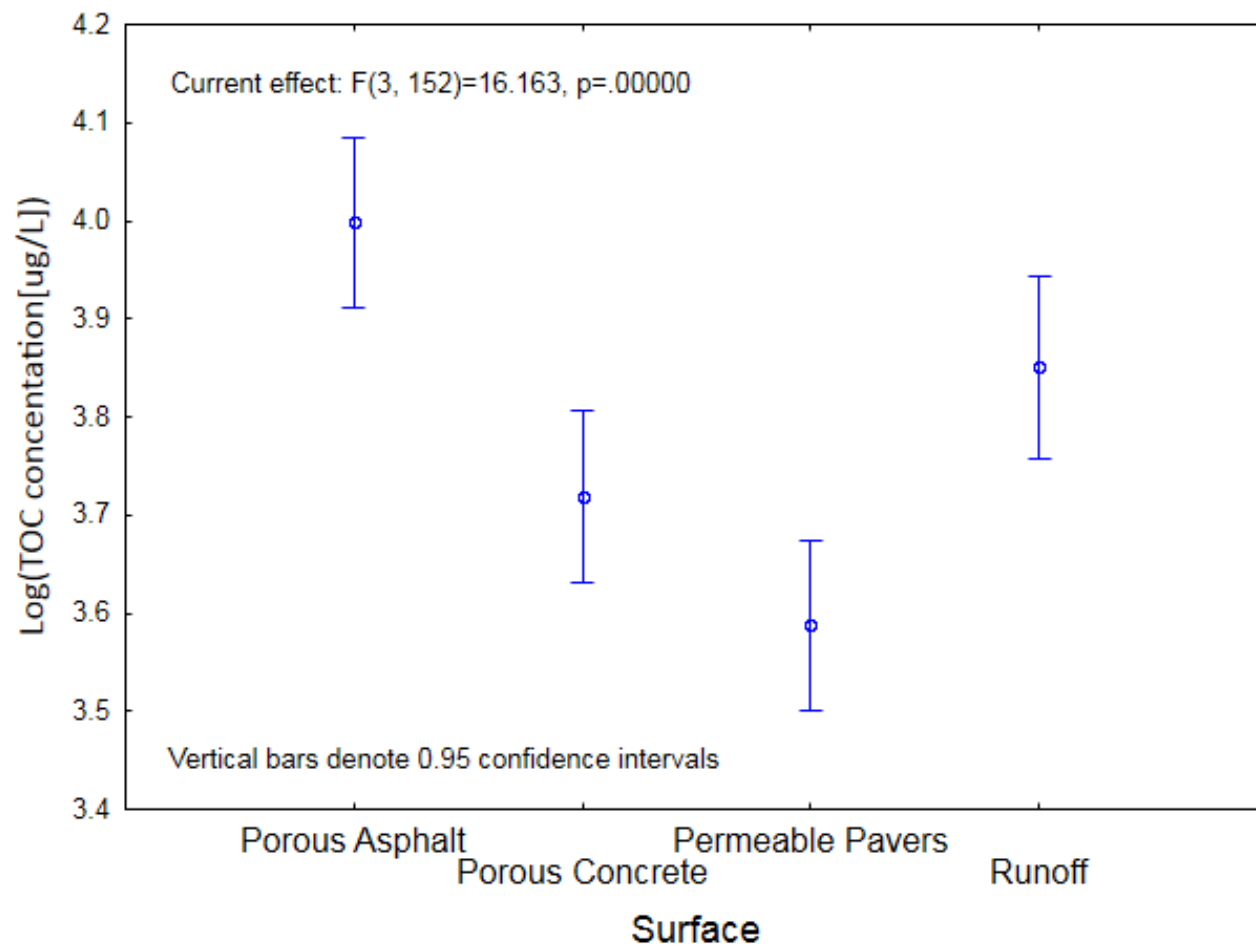
Acidic rainfall is buffered by all pavement surfaces, and PA exfiltrate is surprisingly basic.



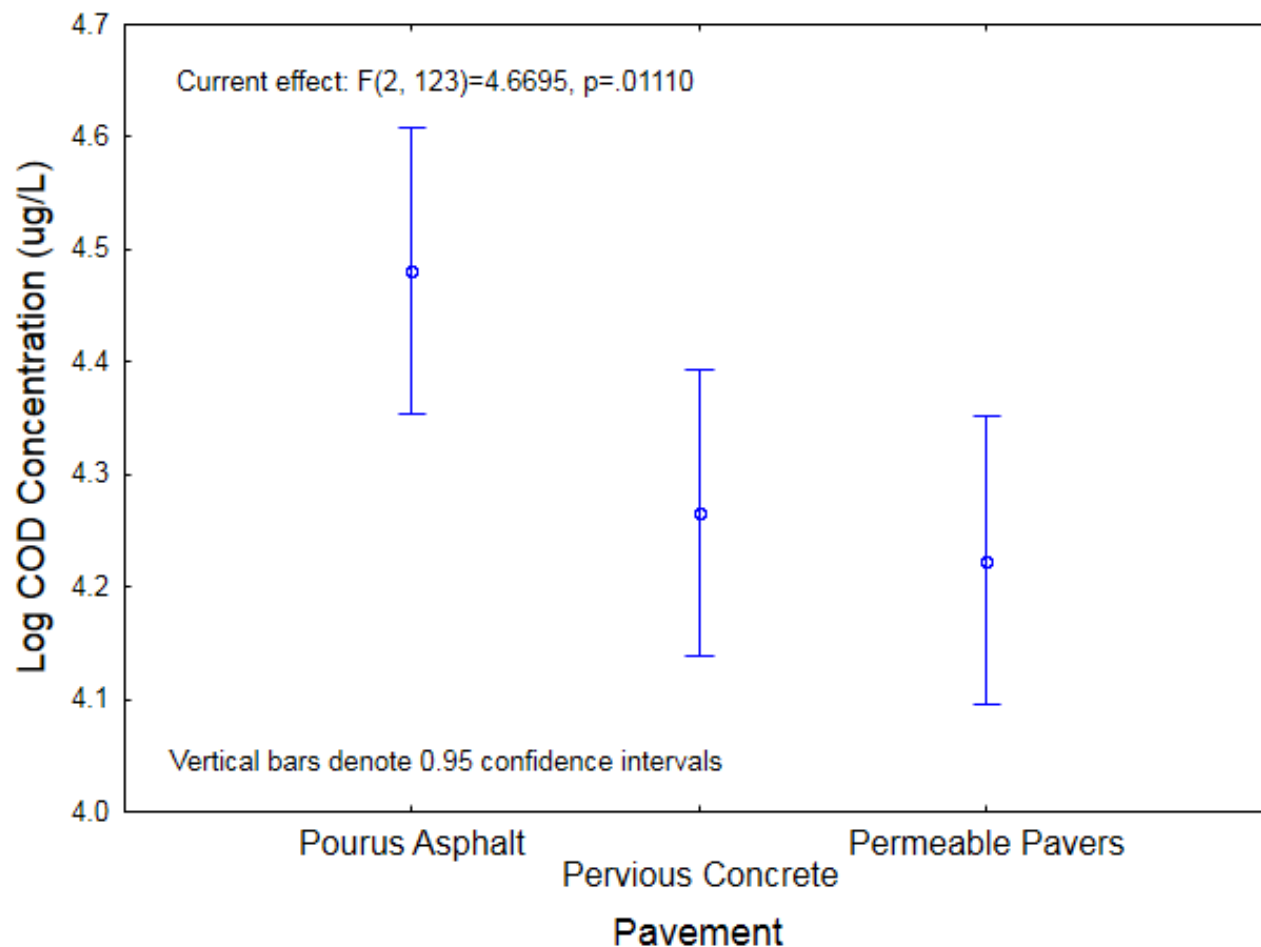
Mean pH per surface per sampling event over time



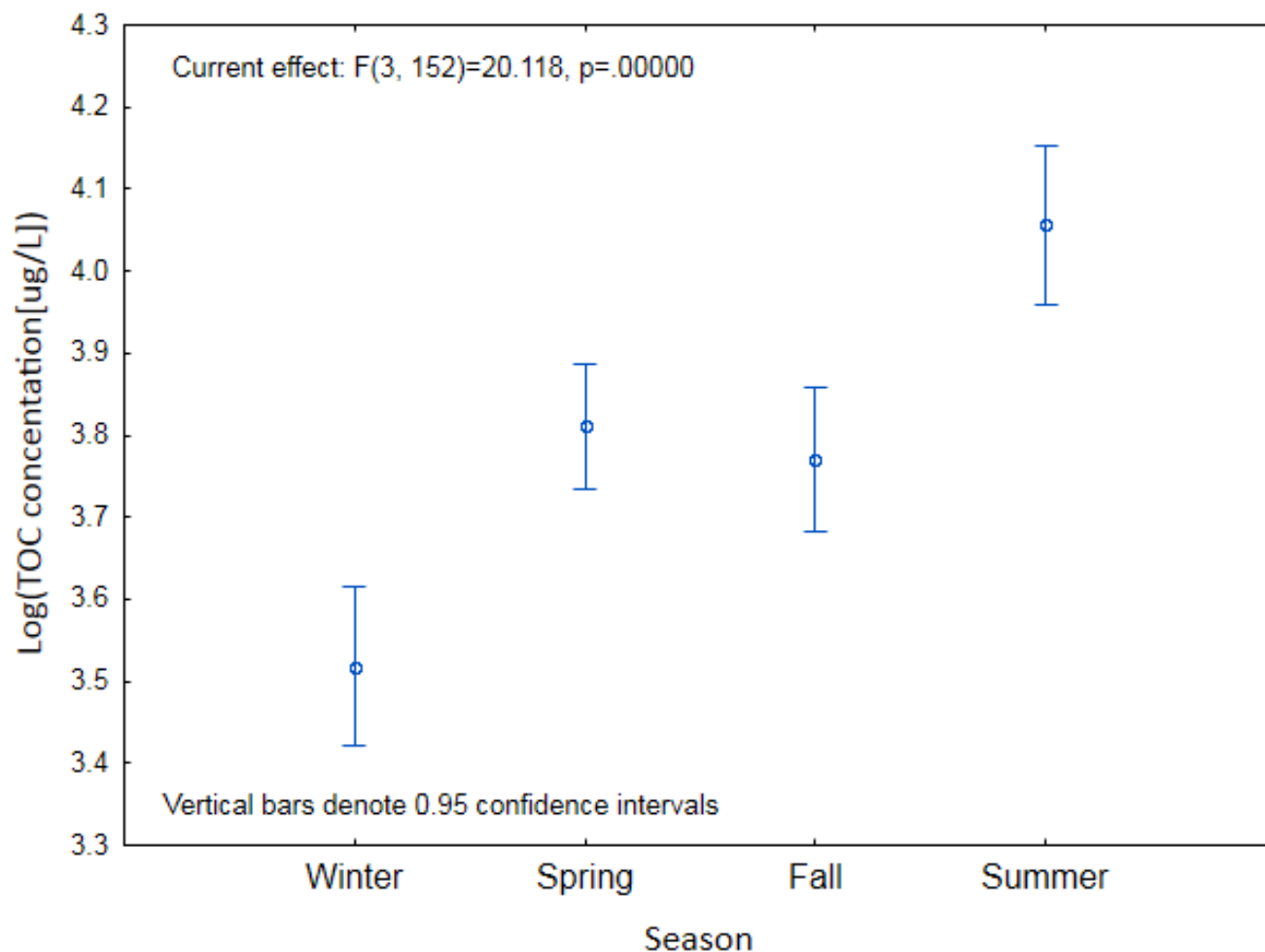
One-way ANOVA Type of Pavement Effect on Log Total Organic Carbon (TOC)



One-way ANOVA Type of Pavement Effect on Log Chemical Oxygen Demand (COD)



One-way ANOVA Seasonal Effect on Log TOC

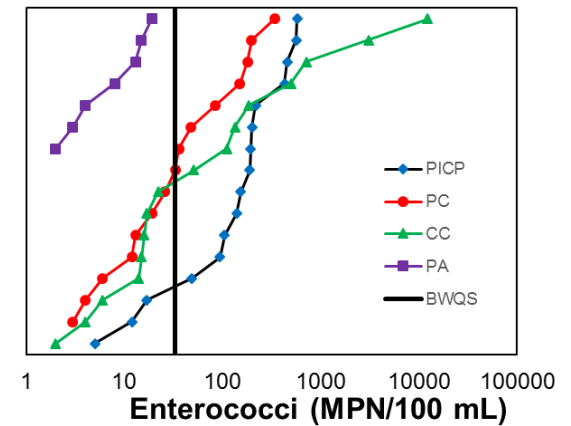
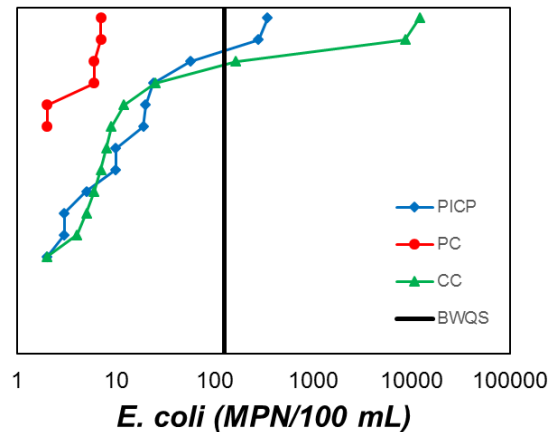
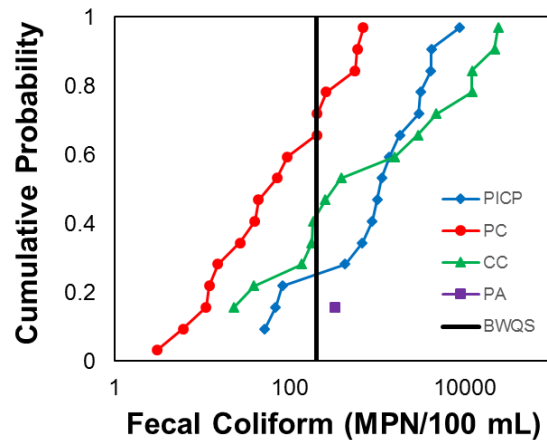


Observation of Semi-Volatile Organics Compounds in Permeable Pavement Infiltrate

- Data range is from February, 2010 – April, 2013.
- Most chemicals below detection with 42 never observed and 12 < 10% observation frequency.
- Only 22 chemicals had > 10% observation frequency.
- Trend for 22 chemical observed in porous asphalt infiltrate: greater observation of low molecular weight (LMW) SVOCs and lesser observation of high molecular weight (HMW) SVOCs.
- No such trend observed for PICP or pervious concrete infiltrate.
- Porous asphalt is source for LMW SVOC and sink for HMW SVOC.

O'Connor (2017)

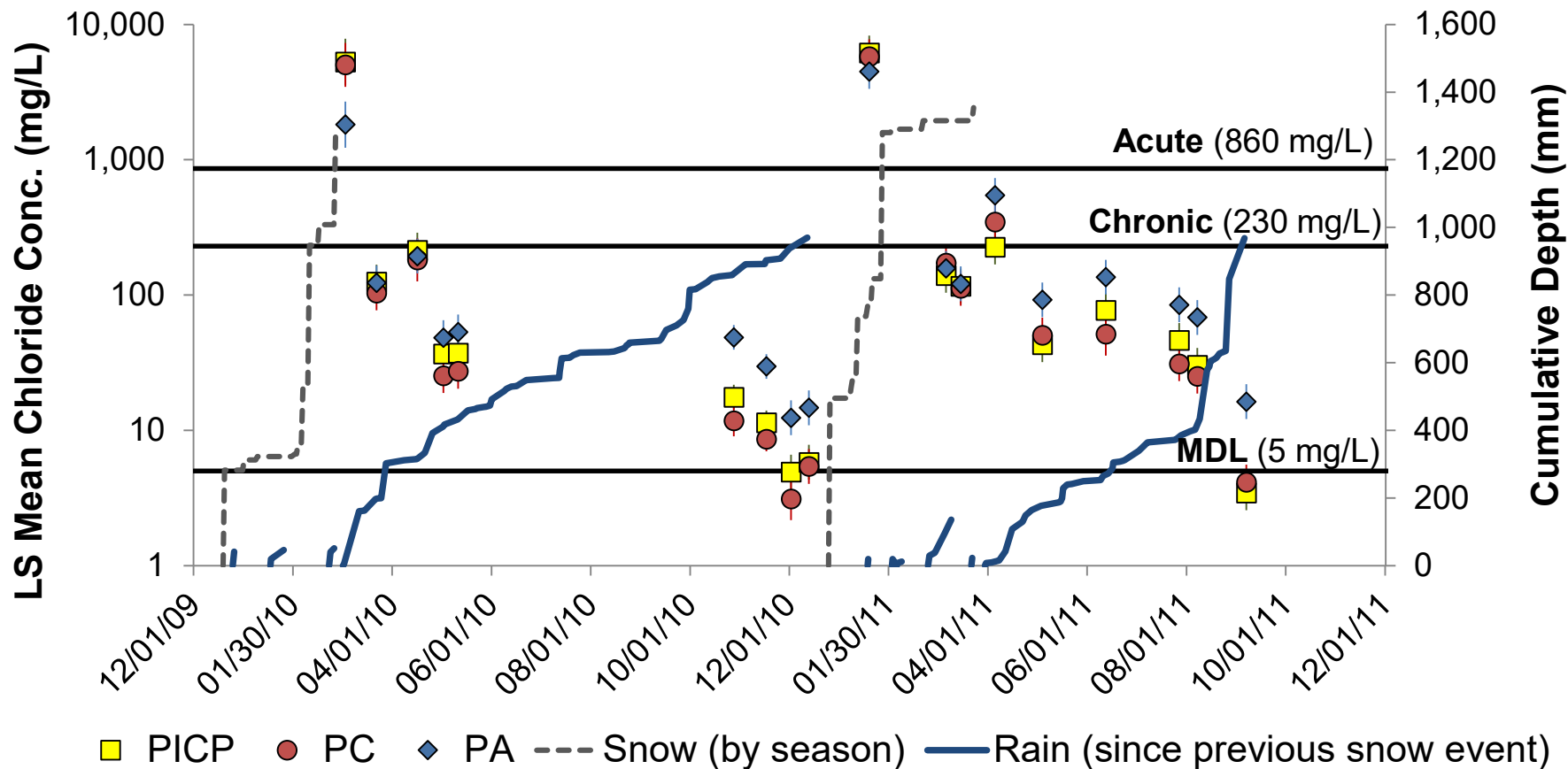
Observation of Microbial Pathogenic Indicator Organisms in Permeable Pavement Infiltrate



Potential Source of High pH in Porous Asphalt Infiltrate

- Asphalt emulsions are suspected cause of high pH.
- Specifications for porous asphalt called for asphalt mix between 4.0% and 4.5% asphalt and addition of a liquid anti-stripping agent.
- Anionic emulsions have pH range of 10 to 12 (Transportation Research Board, 2006) which is range of pH observations for the PA infiltrate.
- Alternatively asphalt emulsions can be cationic with correspondingly acidic pH (e.g., pH 1 to 4) (Transportation Research Board, 2006).

Winter salt application leads to observed chloride concentrations with annual rainfall.



Chloride from Deicing Salts

- Chloride concentrations of infiltrate exceeded acute toxicity for freshwater aquatic life (>860 mg/l) in rain events immediately following salt application.
- Chloride concentrations exceeding detection limit (> 5 mg/l) throughout remainder of the year, but did not exceed chronic toxicity threshold (>230 mg/l) after April.
- Porous Asphalt had the slowest release, chloride persisted at larger concentrations in samples collected after April.
- Annually, mean infiltrate concentration observed was largest for the PA pavement.

Disaggregation of Pervious Concrete



Large portions of the pervious concrete disaggregated. The problem first became apparent about 18 months after pouring concrete. It was repaired by the contractor in May 2011, but has recurred more extensively in 2014.



National Ready Mixed Concrete Association (NRMCA) revised O&M guidance (2015).

“Deicing chemicals should not be used on any type of concrete in the first year.”



**Pervious Concrete
Pavement Maintenance
and Operations Guide**

Replacement Surface (2016): Pavers, Compliant with Americans with Disabilities Act (ADA)

Narrower gap



Other Findings

- Cumulative evaporation for PICP was 3.9–5.8%, PC 6.5–7.6% and PA 2.4–5.6% (Brown and Borst 2015).
- Temperature of Surfaces

Media	Mean Temperature (° C)	Maximum Temperature (° C)
PICP	15.8	57.5
PC	15.6	44.7
PA	16.1	58.1
Hot Mix Asphalt	19.7	78.3
Unvegetated Soil	14.5	35.2
Air	13.3	40.6

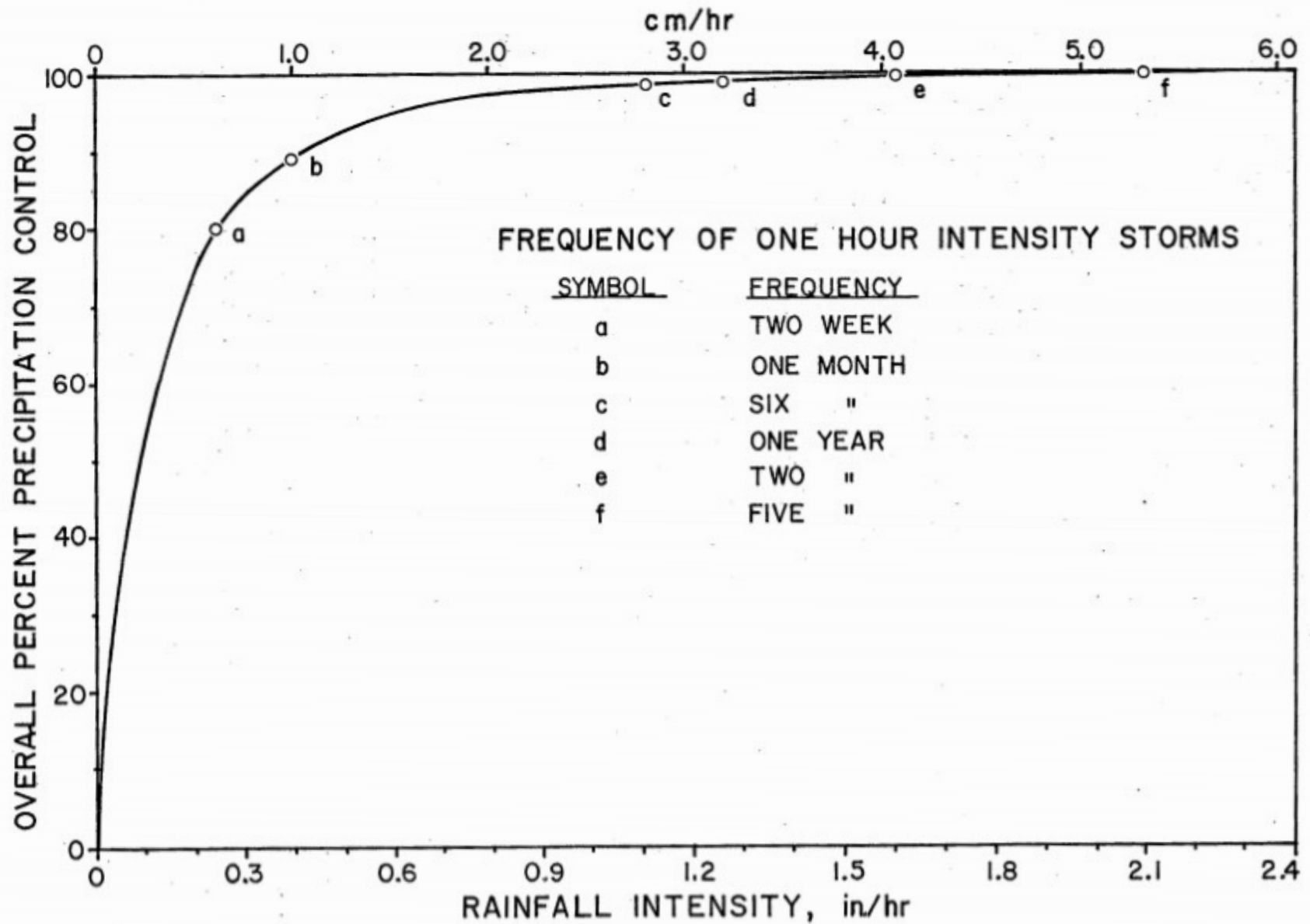


Figure I-2. Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972)

Journal Articles

- E. Stander, A. A. Rowe, M. Borst and T. P. O'Connor (2013). "Novel Use of Time Domain Reflectometry in Infiltration-Based Low Impact Development Practices." Journal of Irrigation and Drainage Engineering (JIDE), Vol 139, No. 8, pp. 625–634 ([http://dx.doi.org/10.1061/\(ASCE\)IR.1943-4774.0000595](http://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000595)).
- Brown, R. and Borst, M. (2013). "Assessment of Clogging Dynamics in Permeable Pavement Systems with Time Domain Reflectometers." J. Environ. Eng., 139(10), 1255–1265. ([http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)EE.1943-7870.0000734](http://ascelibrary.org/doi/abs/10.1061/(ASCE)EE.1943-7870.0000734))
- Brown, R.A., and M. Borst. (2014). "Evaluation of surface infiltration testing procedures in permeable pavement systems." J. Environ. Eng., , 140(3), 04014001. ([http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)EE.1943-7870.0000808](http://ascelibrary.org/doi/abs/10.1061/(ASCE)EE.1943-7870.0000808))
- Borst, M., and R.A. Brown. (2014). "Chloride released from three permeable pavement surfaces after winter salt application." Journal of the American Water Resources Association, 50(1), 29-41. (<http://onlinelibrary.wiley.com/doi/10.1111/jawr.12132/epdf>)
- Brown, R.A., and M. Borst. (2015). "Quantifying evaporation in a permeable pavement system." Hydrological Processes, 29(9), 2100–2111. (<http://onlinelibrary.wiley.com/doi/10.1002/hyp.10359/pdf>)
- Brown, R.A., and M. Borst. (2015). "Nutrient infiltrate concentrations from three permeable pavement types." Journal of Environmental Management, 164, 74-85 (doi:10.1016/j.jenvman.2015.08.038)
- O'Connor, Thomas P. (2017) "Detection of semi-volatile organic compounds in permeable pavement infiltrate" American Society of Civil Engineering's Journal of Sustainable Water in the Built Environment, Vol. 3, No. 2, May, 2017 (on-line 2/16/2017). (doi: <http://ascelibrary.org/doi/abs/10.1061/JSWBAY.0000822>)
- Selvakumar, Ariamalar and Thomas P. O'Connor "Indicator Organism Detection in Infiltrates from Permeable Pavement Parking Lots at the Edison Environmental Center, New Jersey" Water Environment Research, Vol. 90, No. 1, January, 2018, pp. 21-29 (DOI: <https://doi.org/10.2175/106143017X14902968254575>)

EPA Reports

- EPA (1977) “Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume II: Cost Assessment and Impacts” (EPA-600/2-77-064b)
<http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300003OL.txt>
- EPA (2010) “Surface Infiltration Rates of Permeable Surfaces: Six Month Update (November 2009 through April 2010)” U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, Report No. EPA/600/R-10/083, June, 2010. (<http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1008CH4.txt>)

Other Resources

- NRC (2009). “Urban Stormwater Management in the United States” National Research Council (NRC). Washington, D.C., The National Academies (http://www.nap.edu/openbook.php?record_id=12465)
- Transportation Research Board (2006) Asphalt Emulsion Technology, Circular No. E-C102.
(<http://onlinepubs.trb.org/onlinepubs/circulars/ec102.pdf>)

Questions?

