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**

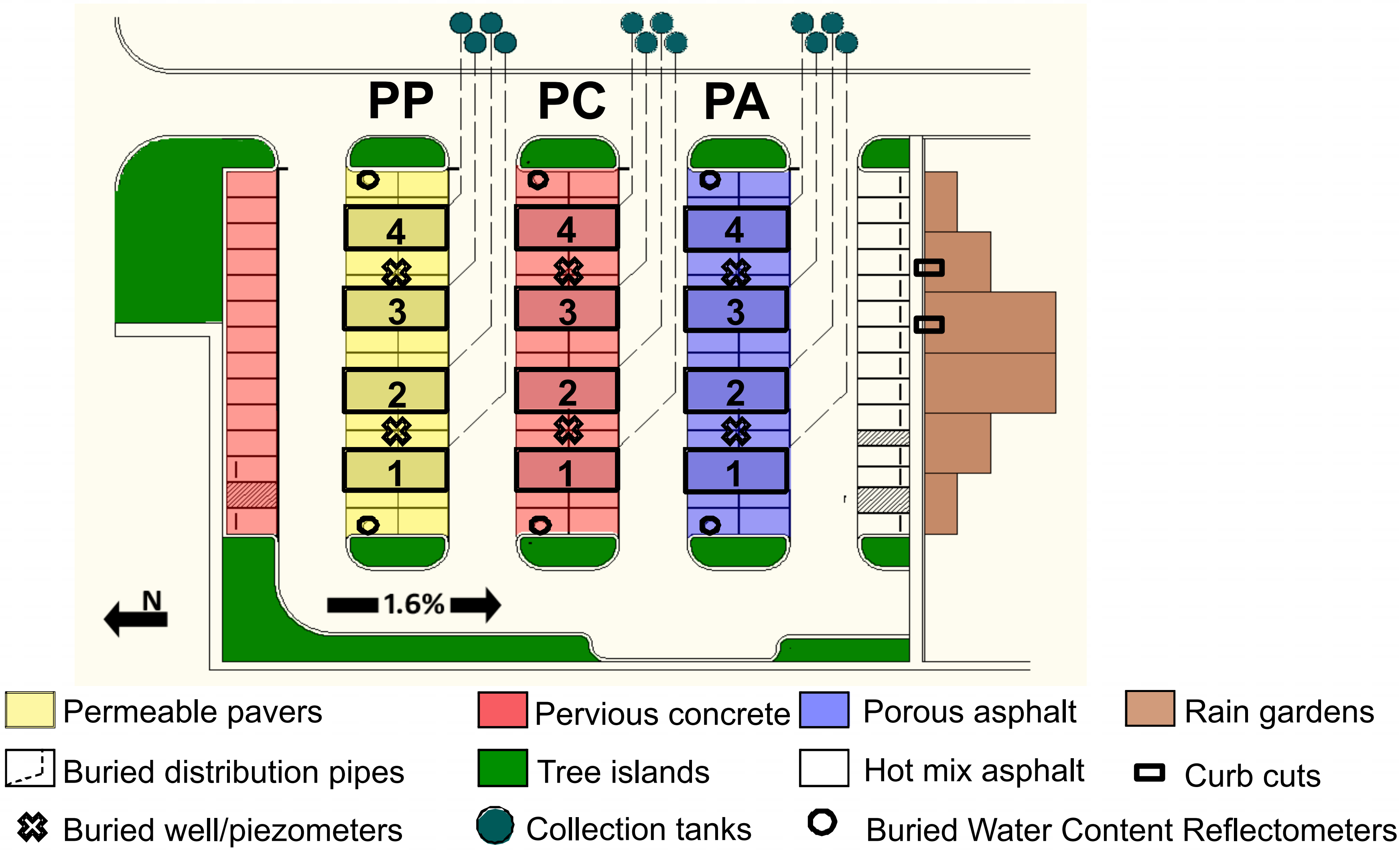
Roof runoff collection and use

Urban Water Research Facility
- **Swales**
- **Rain gardens**
- **Rainwater sampling**
- **Pipelines**

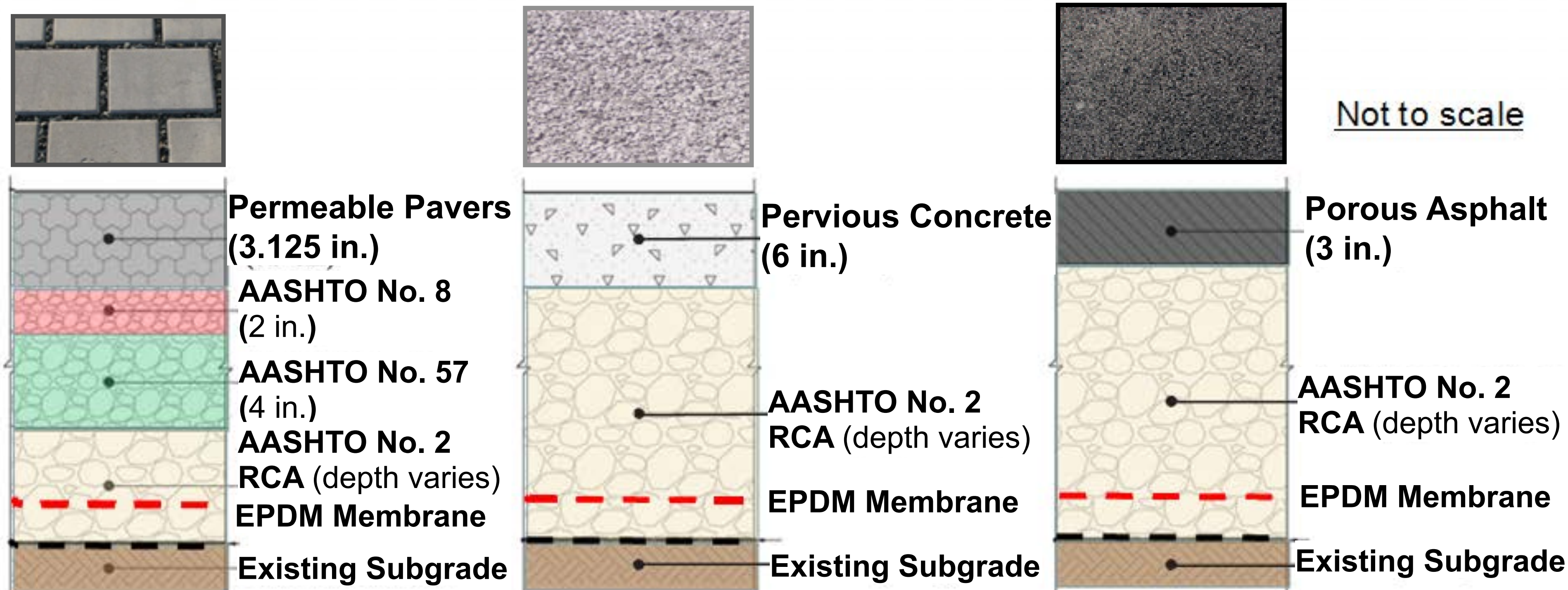
Permeable Pavement and Bioinfiltration Research and Demonstration Site

- 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.

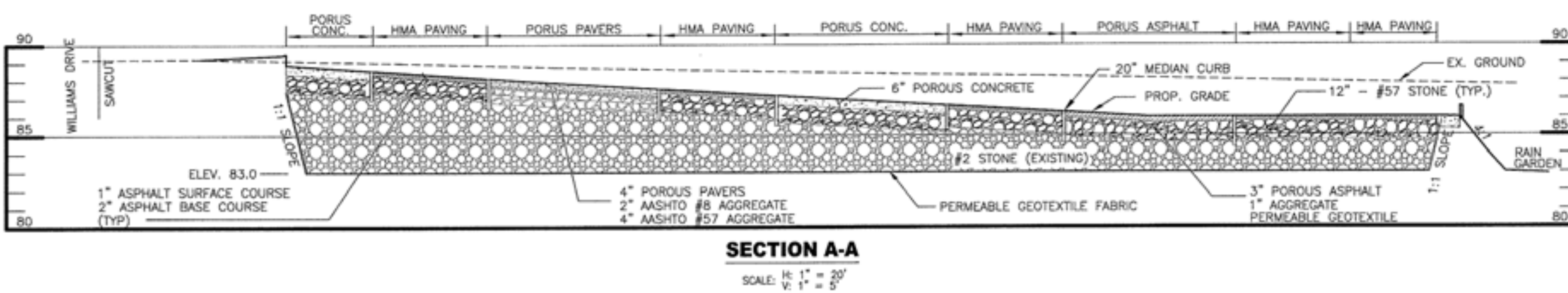


Vertical cross sections of permeable surfaces vary slightly from material to material.



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

RCA = Recycled Concrete Aggregate
Depth to EPDM Membrane ~ 16 in.



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

EPA United States Environmental Protection Agency

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)

EPHenry EcoPavers

East Penn Pavement Company

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

Weldon Concrete

Nova Crete, Inc.

Porous Concrete (PC)

Placing the porous asphalt (PA) took two days.

Stavola, Inc.

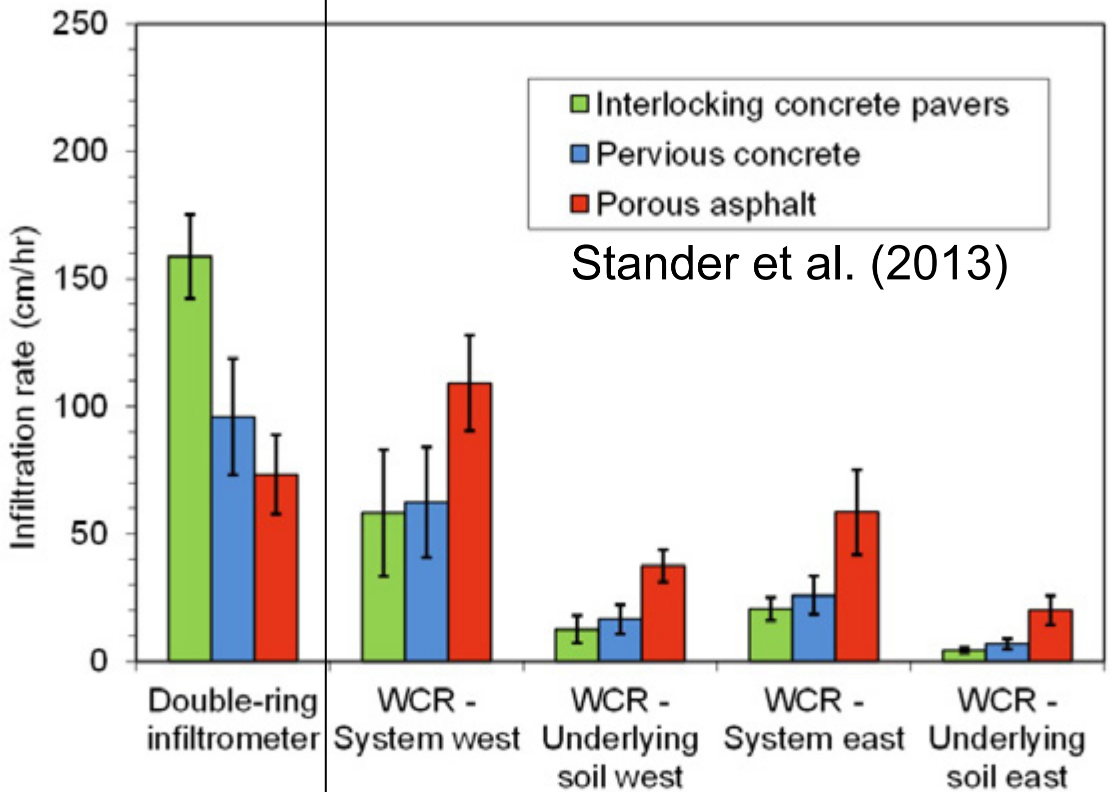
Stavola, Inc.

Permeable Surfaces during Rain

Results

- Infiltration Testing
- Water Quality

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

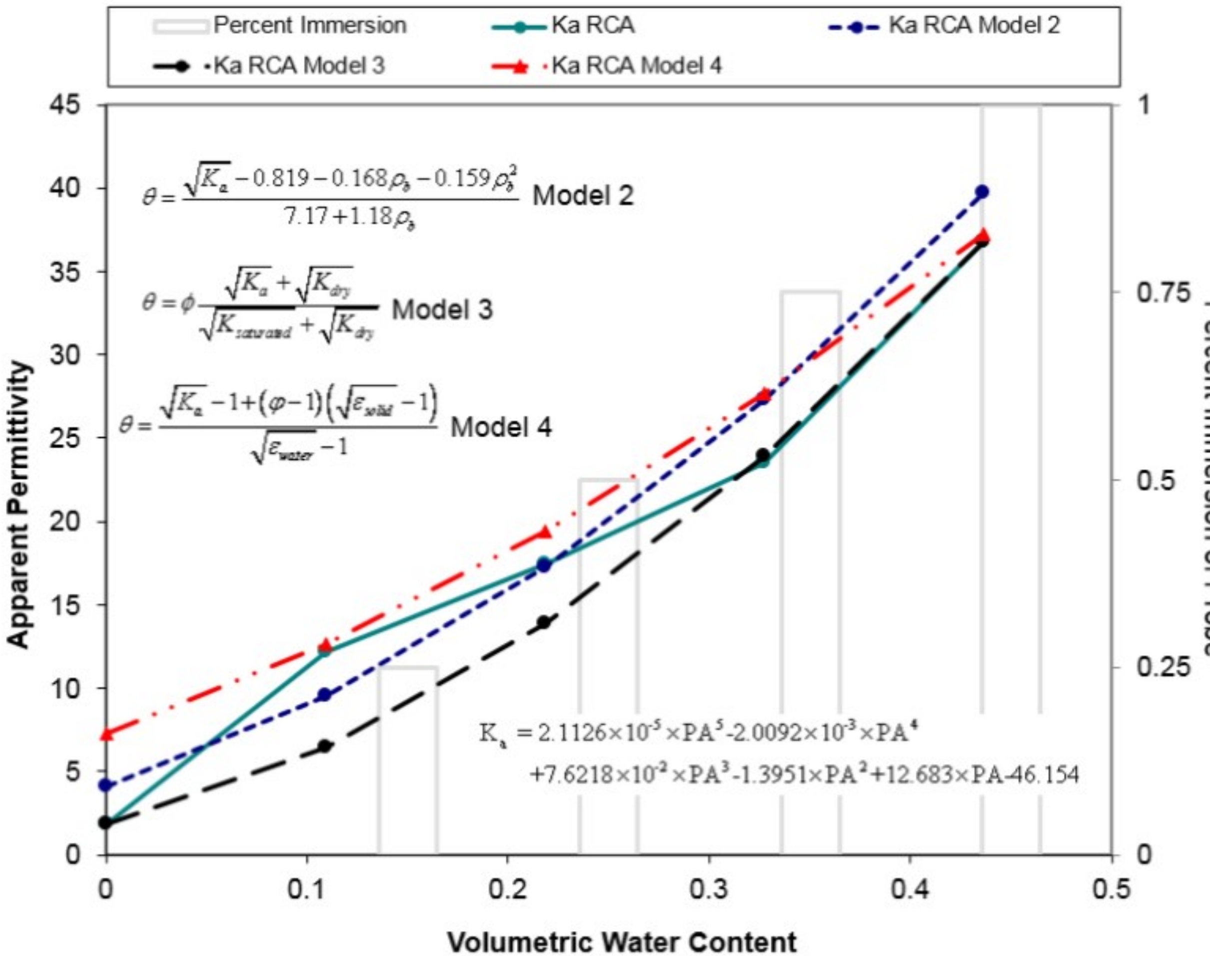


Pre-construction infiltration test

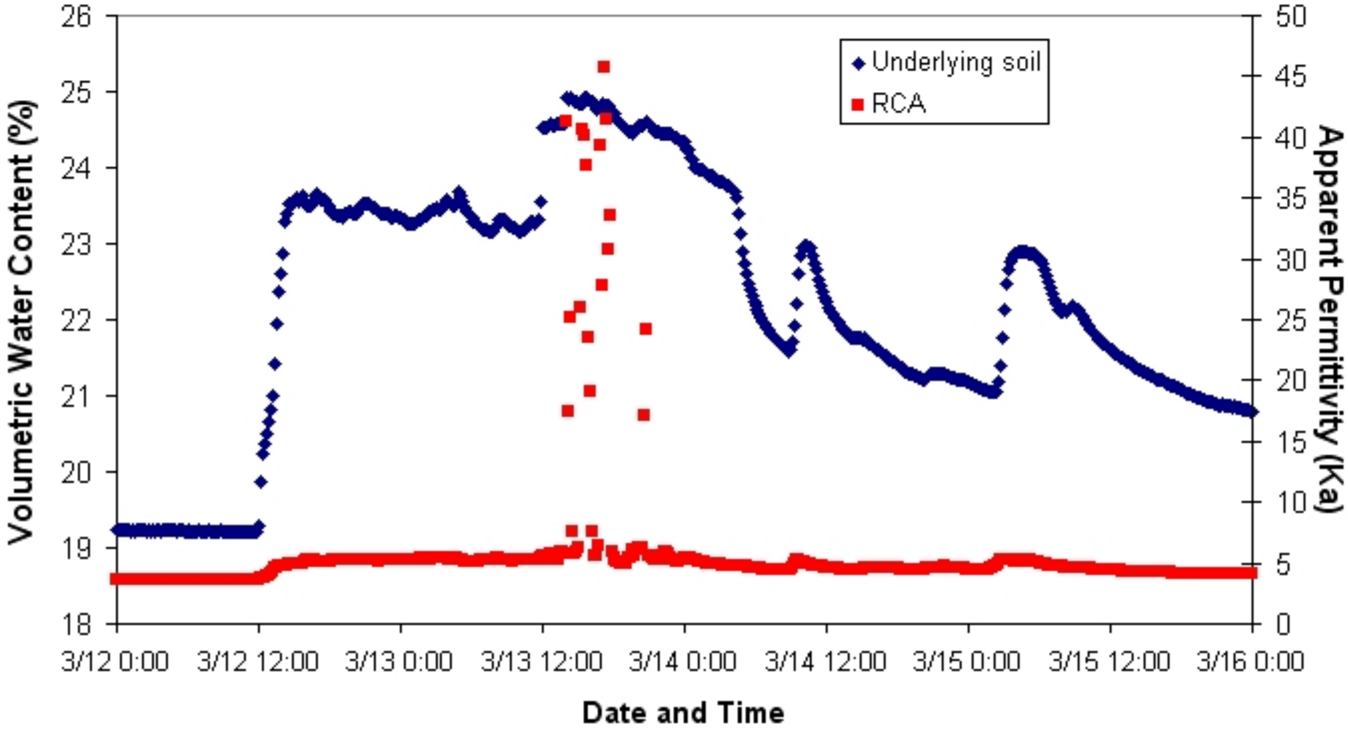
Post-construction soil moisture measurements

Water content reflectometer (WCR) installation

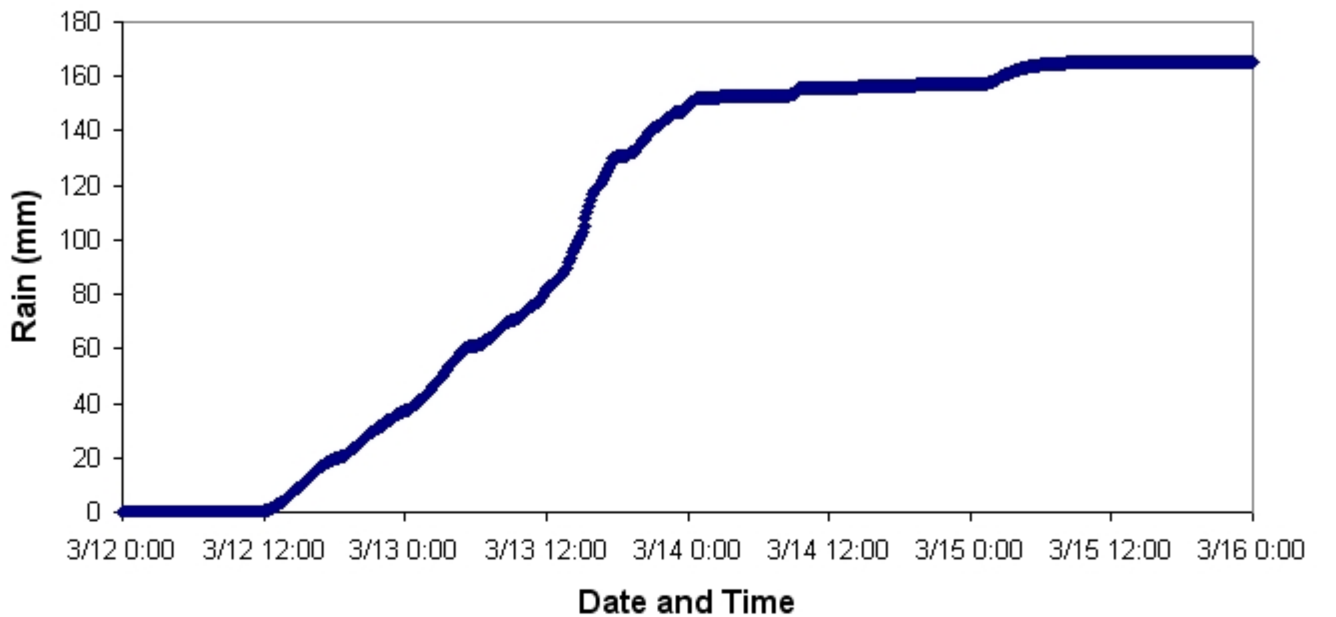
Calibration of Water Content Reflectometers in Large Aggregate



Stander et al. (2013)



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)

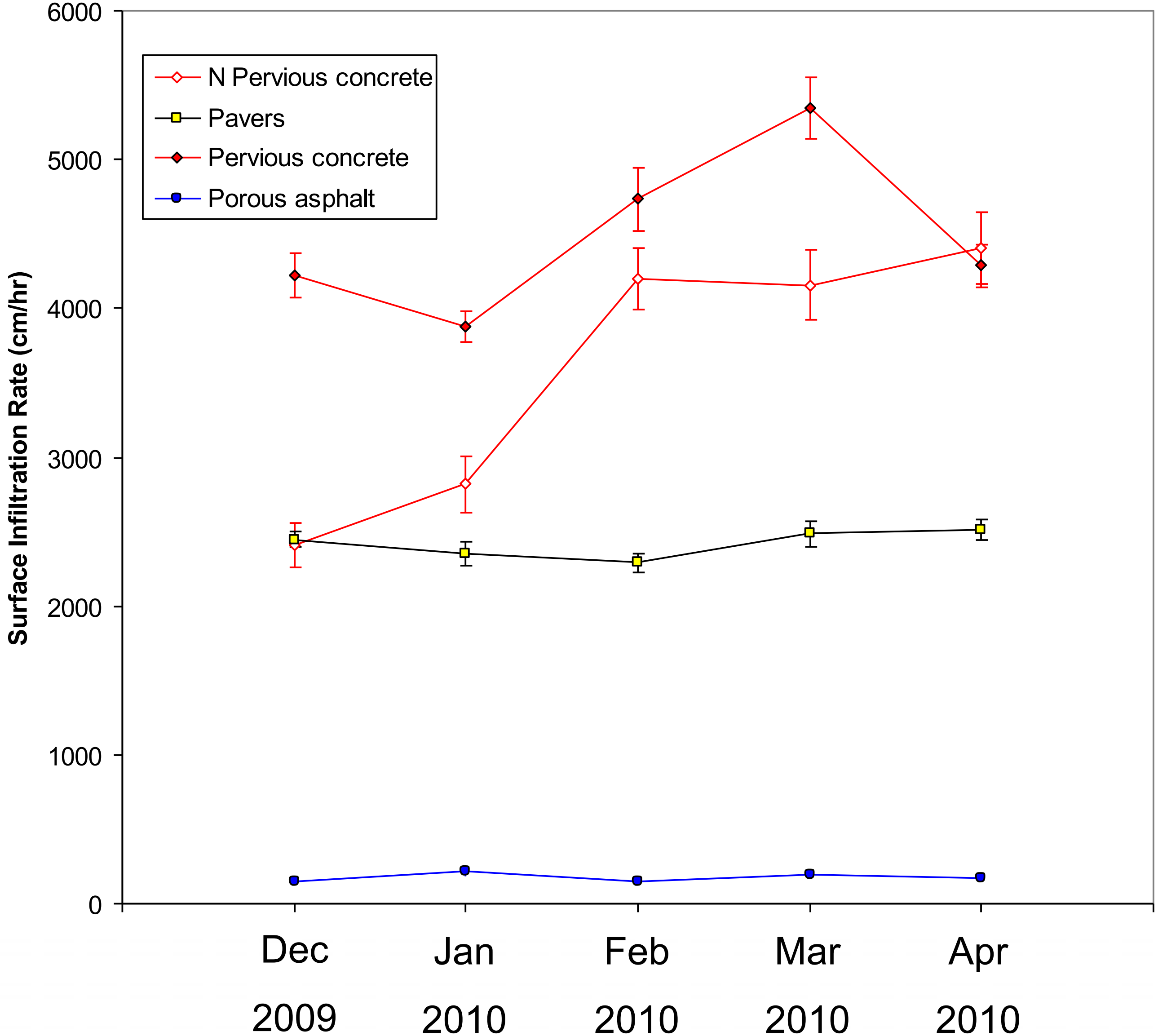
Initial Surface Infiltration Rates

Modified ASTM C1701 apparatus

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

EPA (2010)

Surface Infiltration Rates



EPA (2010)

United States Environmental Protection Agency

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:

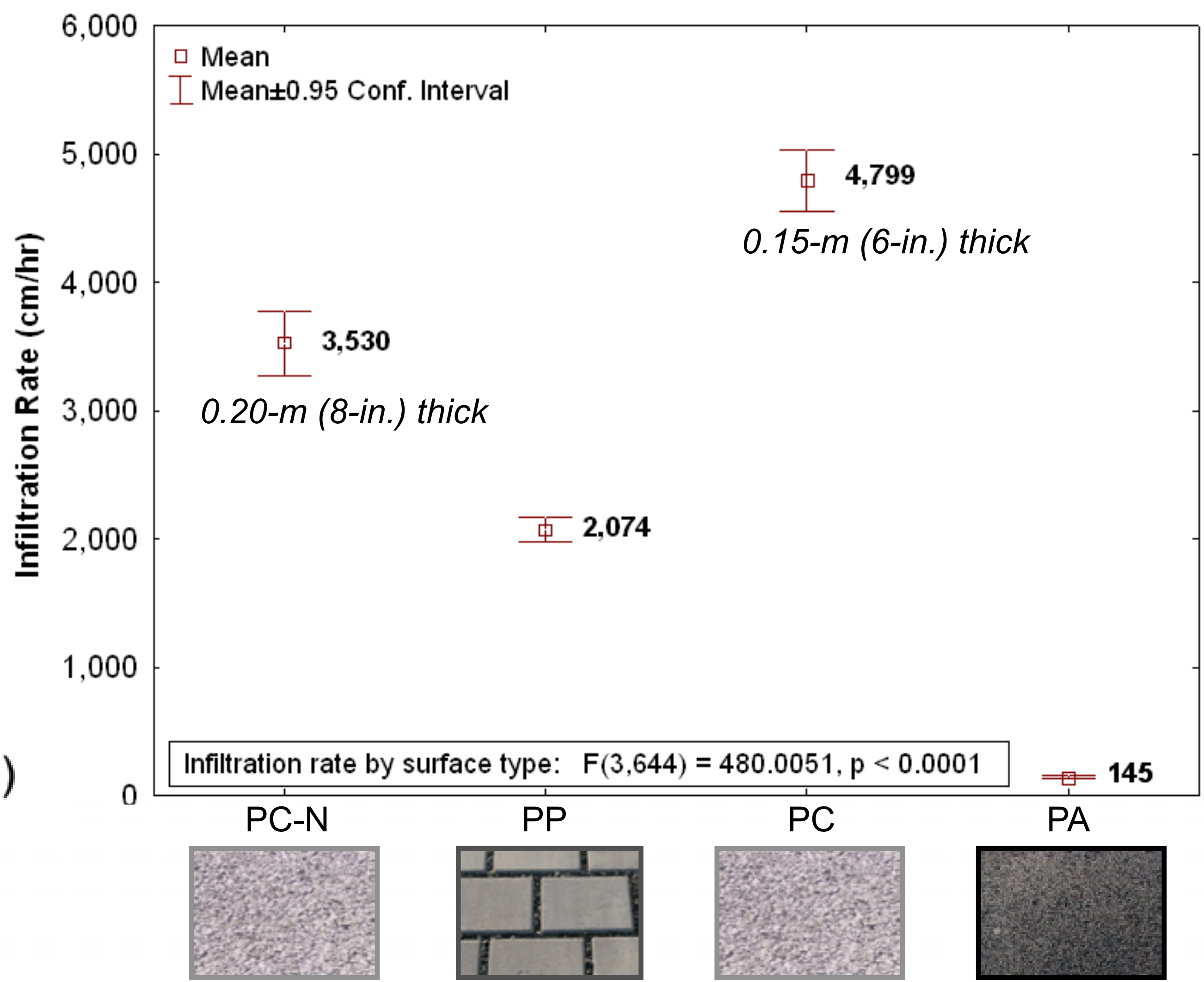
(1) how the seal was achieved between the ring and the surface;
(2) added temperature measurements of surface and water.

Brown and Borst (2014)

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

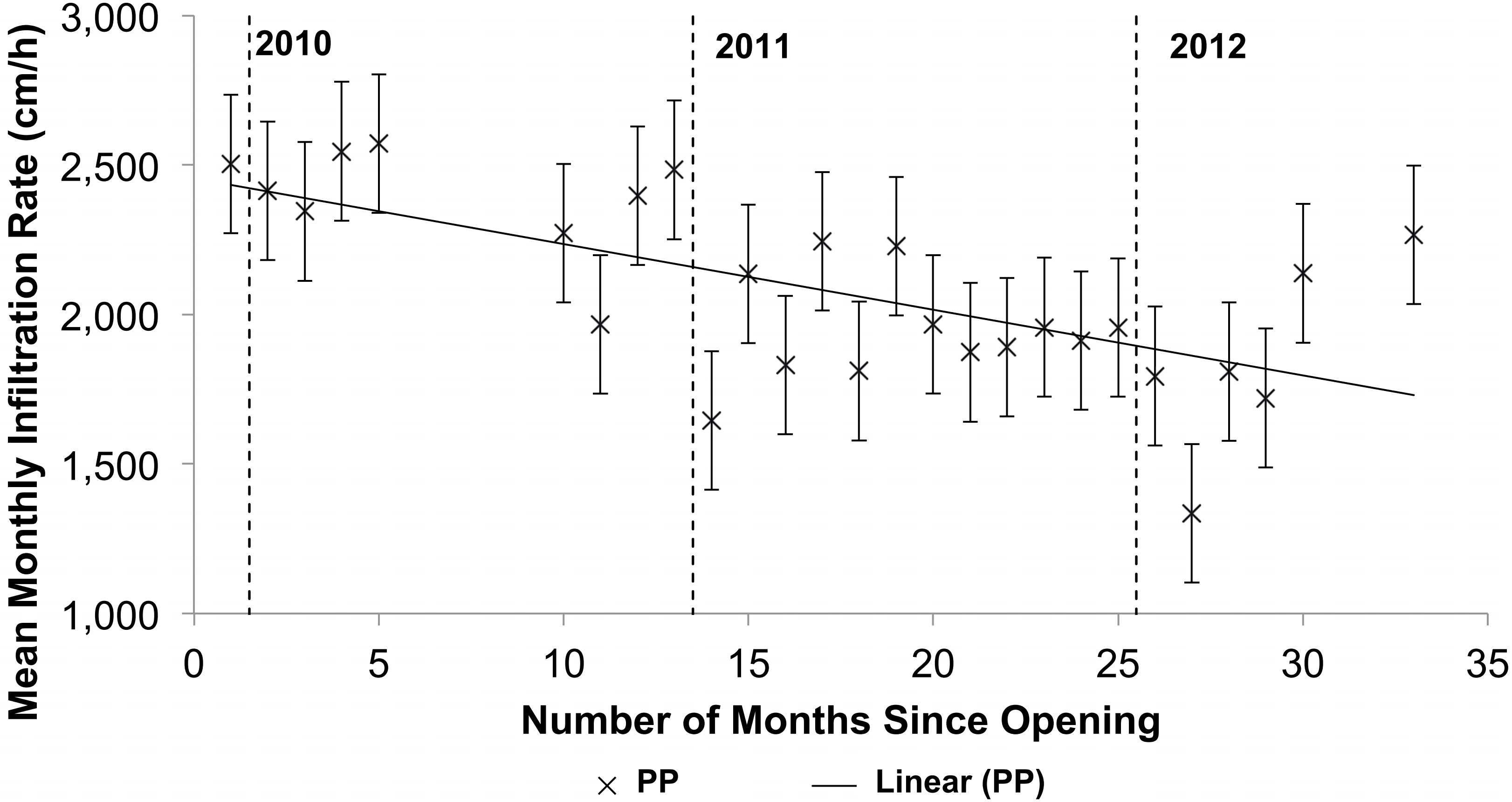
100-year, 5-minute rainfall intensity

- 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.

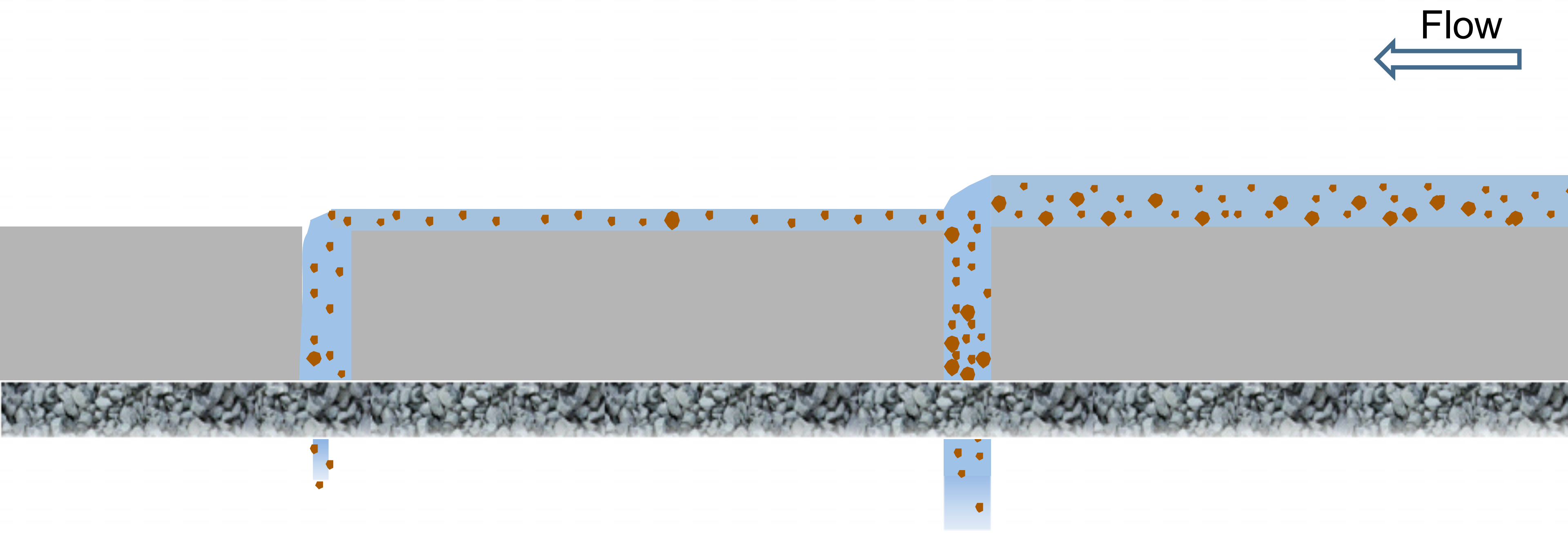


Error bars represent standard error.

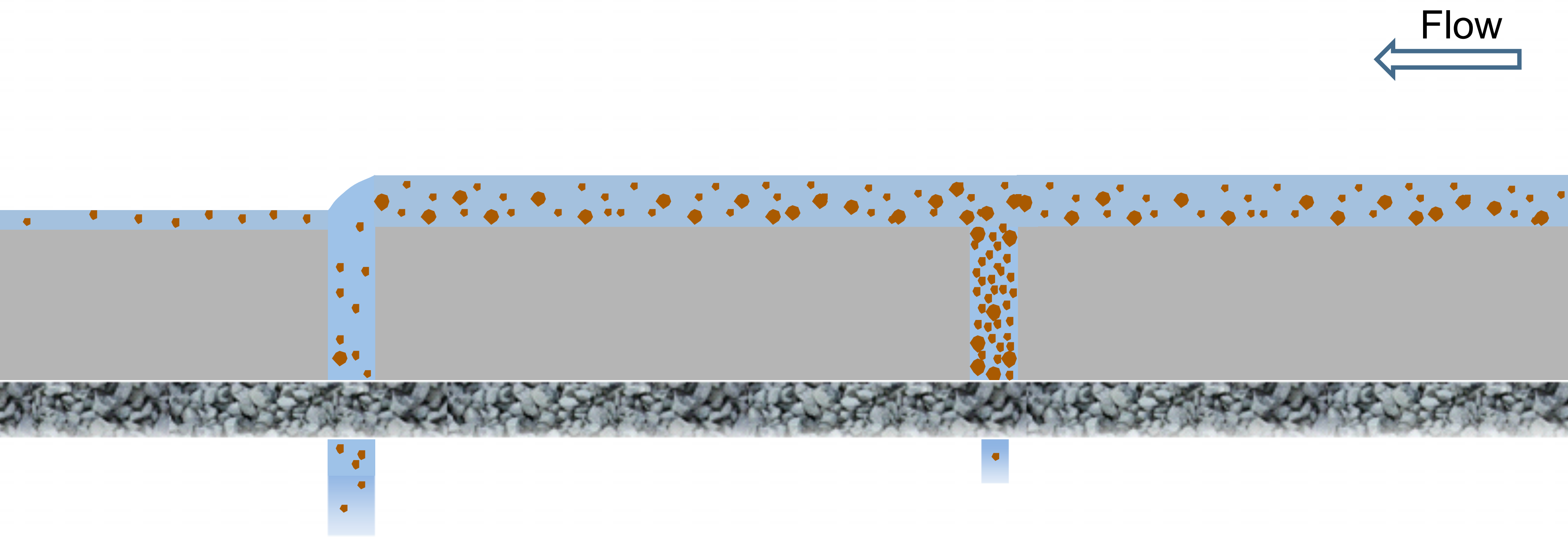
y = -21.97x + 2455
$R^2 = 0.4194$
p = 0.0003

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.



United States Environmental Protection Agency

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

No sediment

Sediment

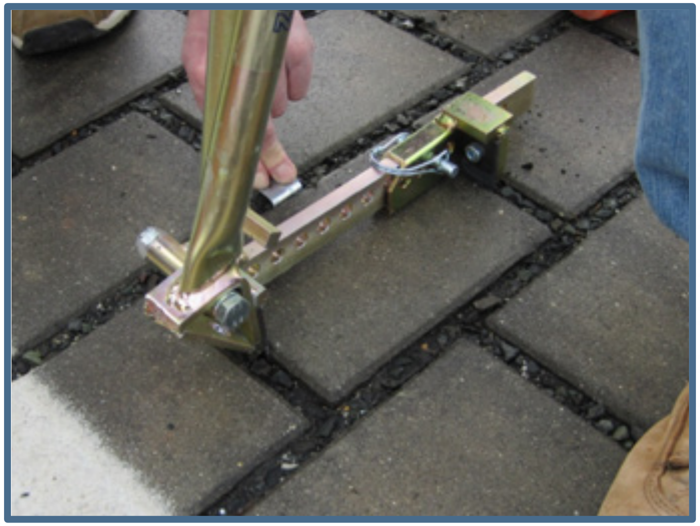
Permeable Interlocking Concrete Pavers Immediately after Installation

Inspection of porous asphalt supports proposed mechanism.

After installation

After use

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



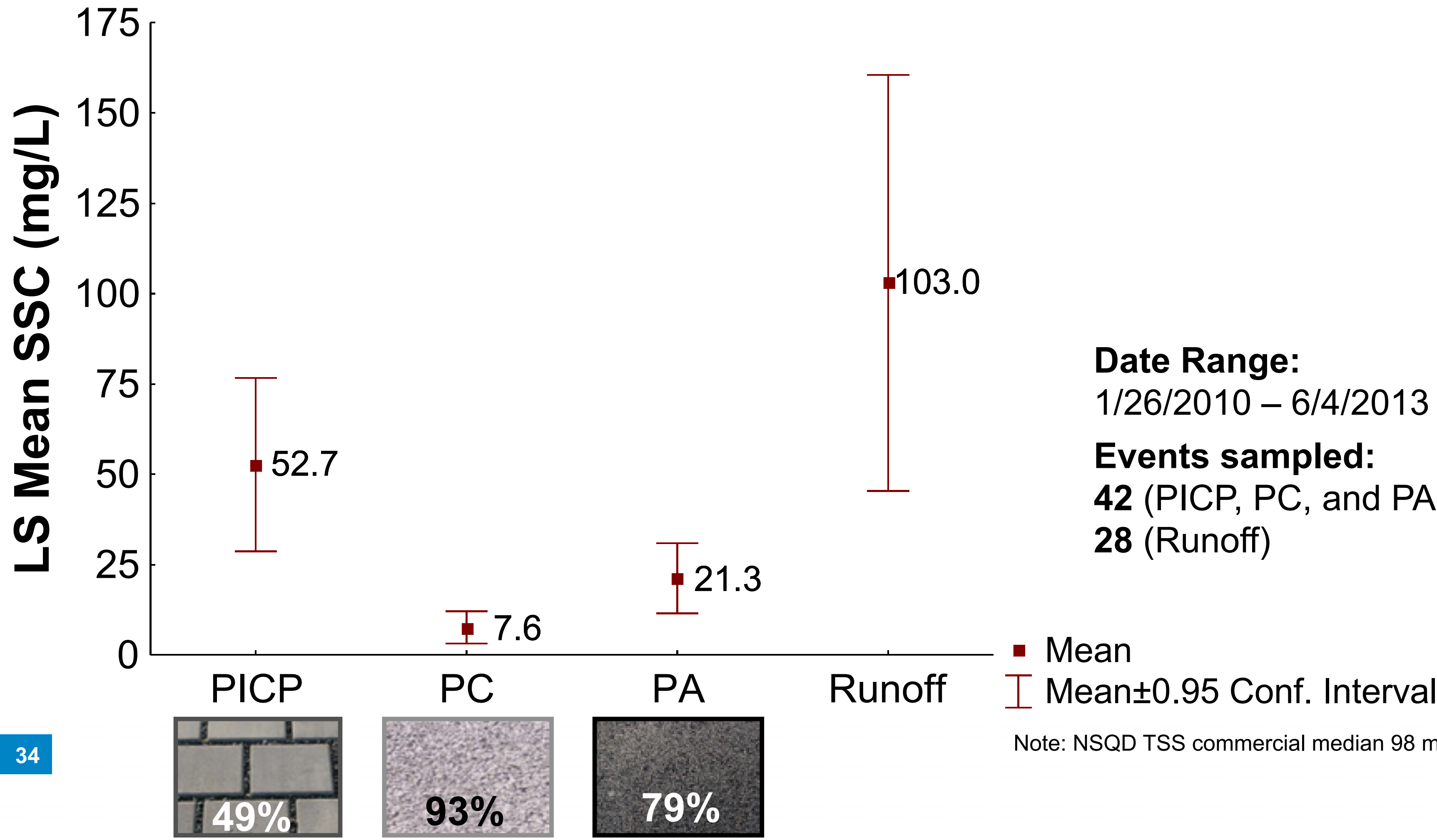
With aggregate between the pavers, most fines are trapped in the top 20 mm.

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).



Date Range:
1/26/2010 – 6/4/2013

Events sampled:
42 (PICP, PC, and PA)
28 (Runoff)

Note: NSQD TSS commercial median 98 mg/L

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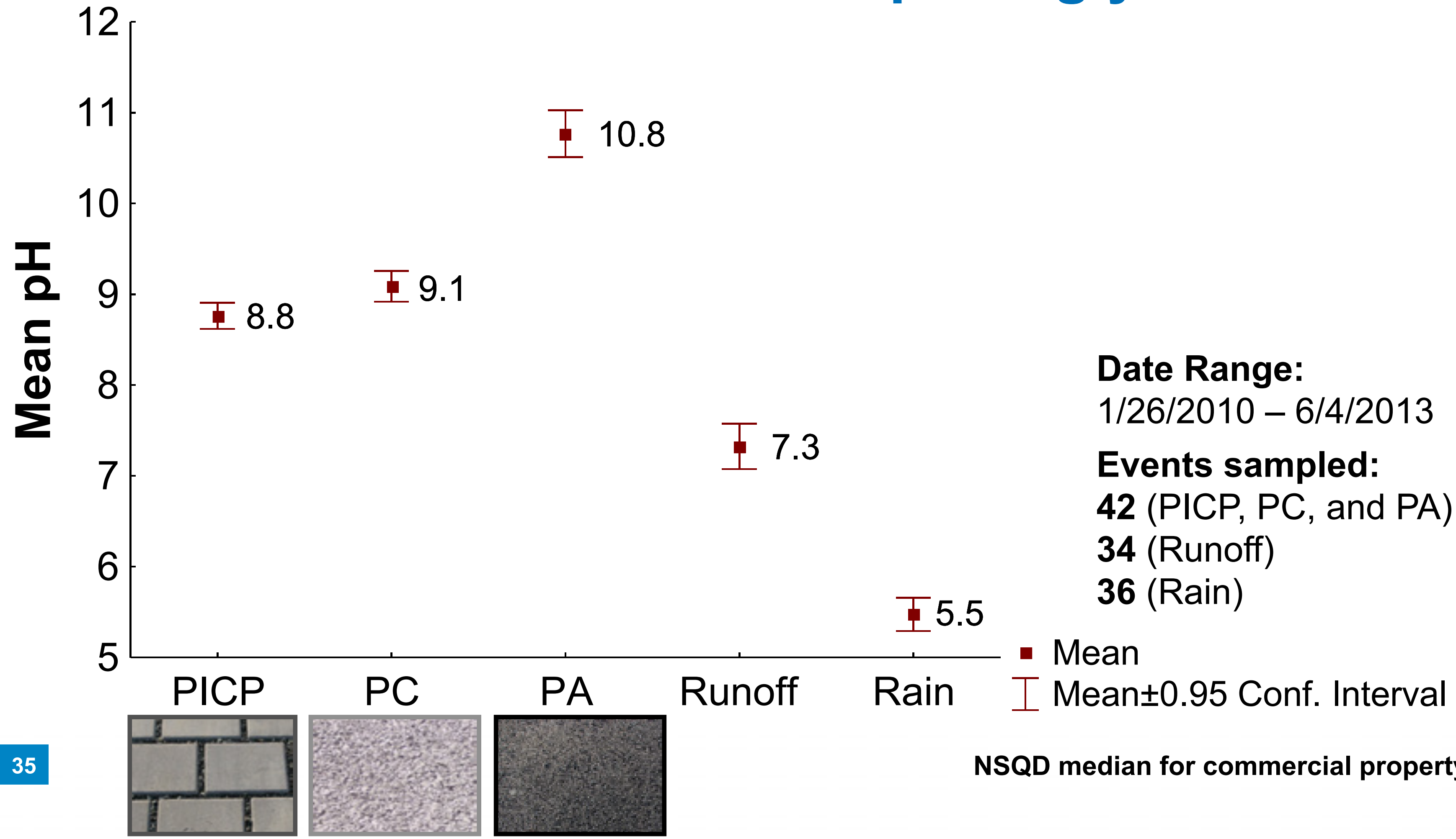
Note: Preliminary Data

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

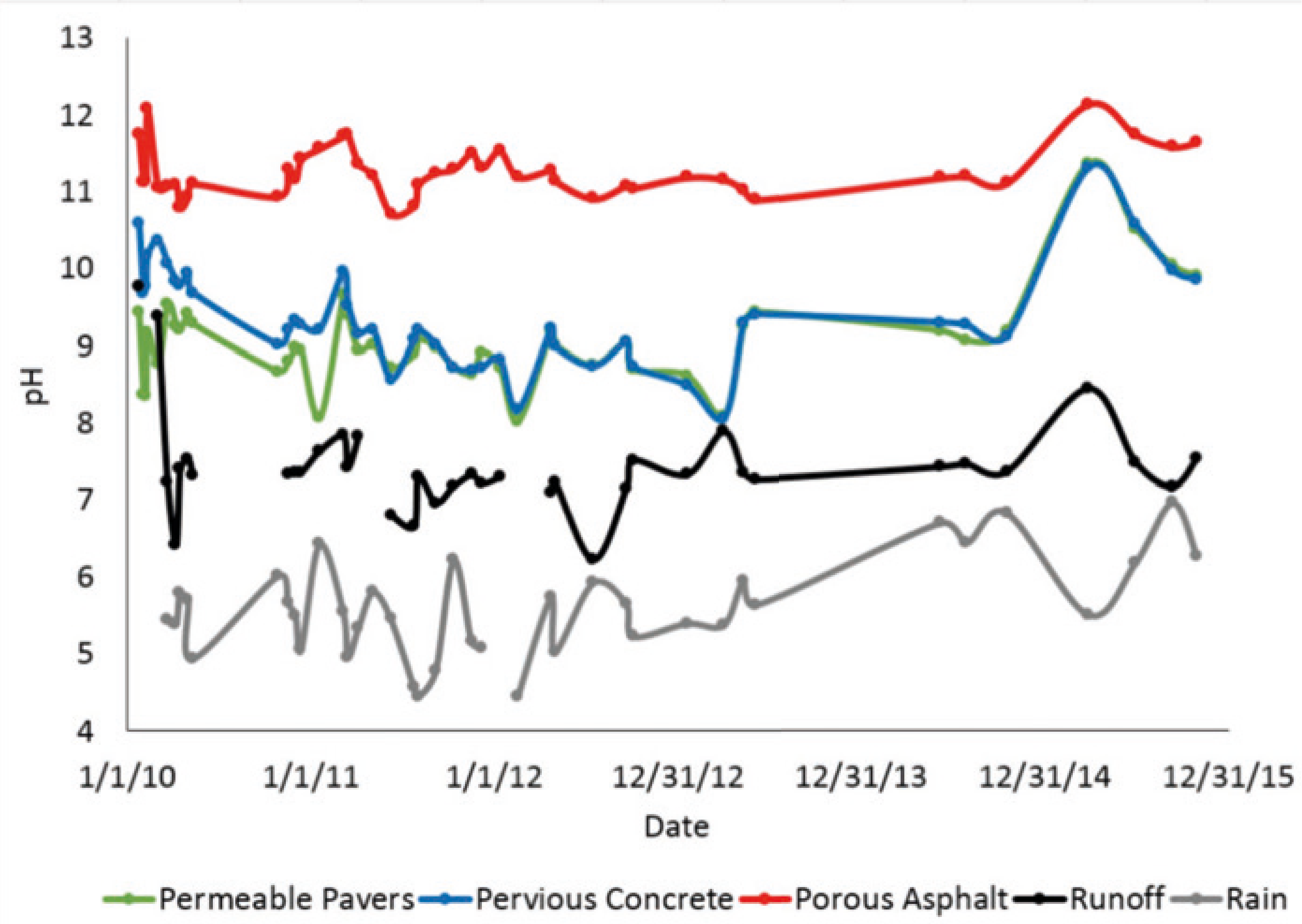


Date Range:
1/26/2010 – 6/4/2013

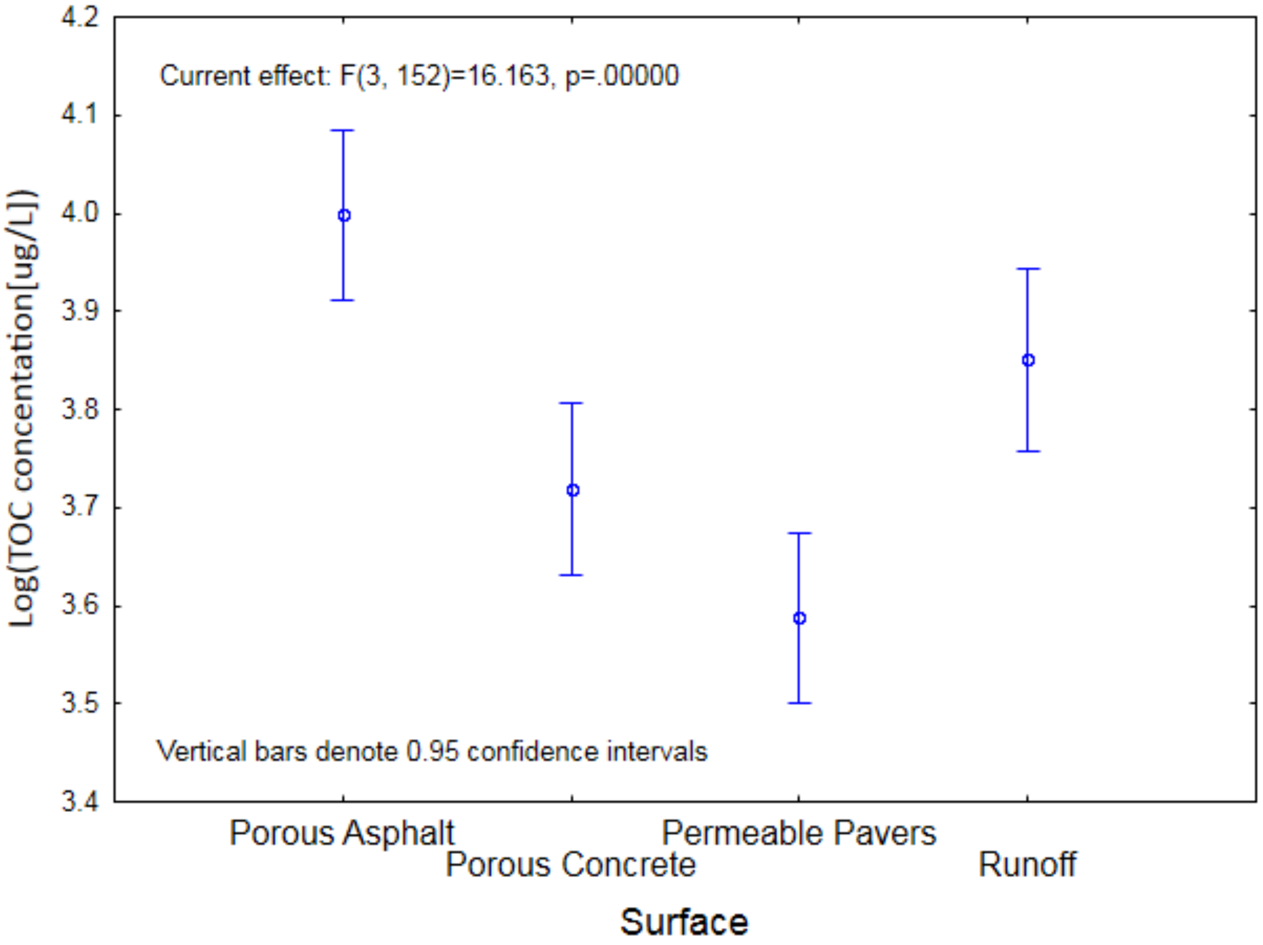
Events sampled:
42 (PICP, PC, and PA)
34 (Runoff)
36 (Rain)

NSQD median for commercial property 7.3

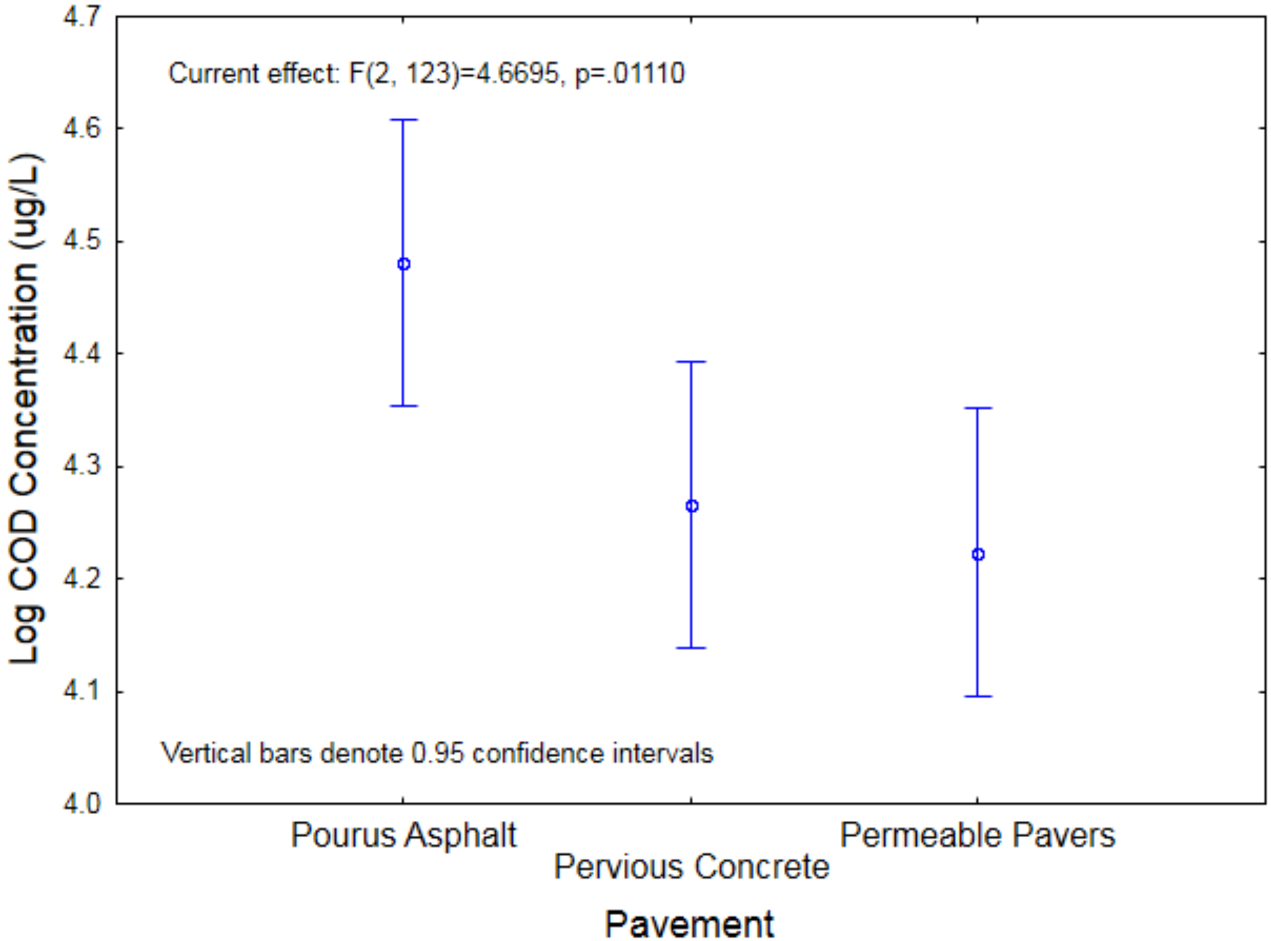
Mean pH per surface per sampling event over time



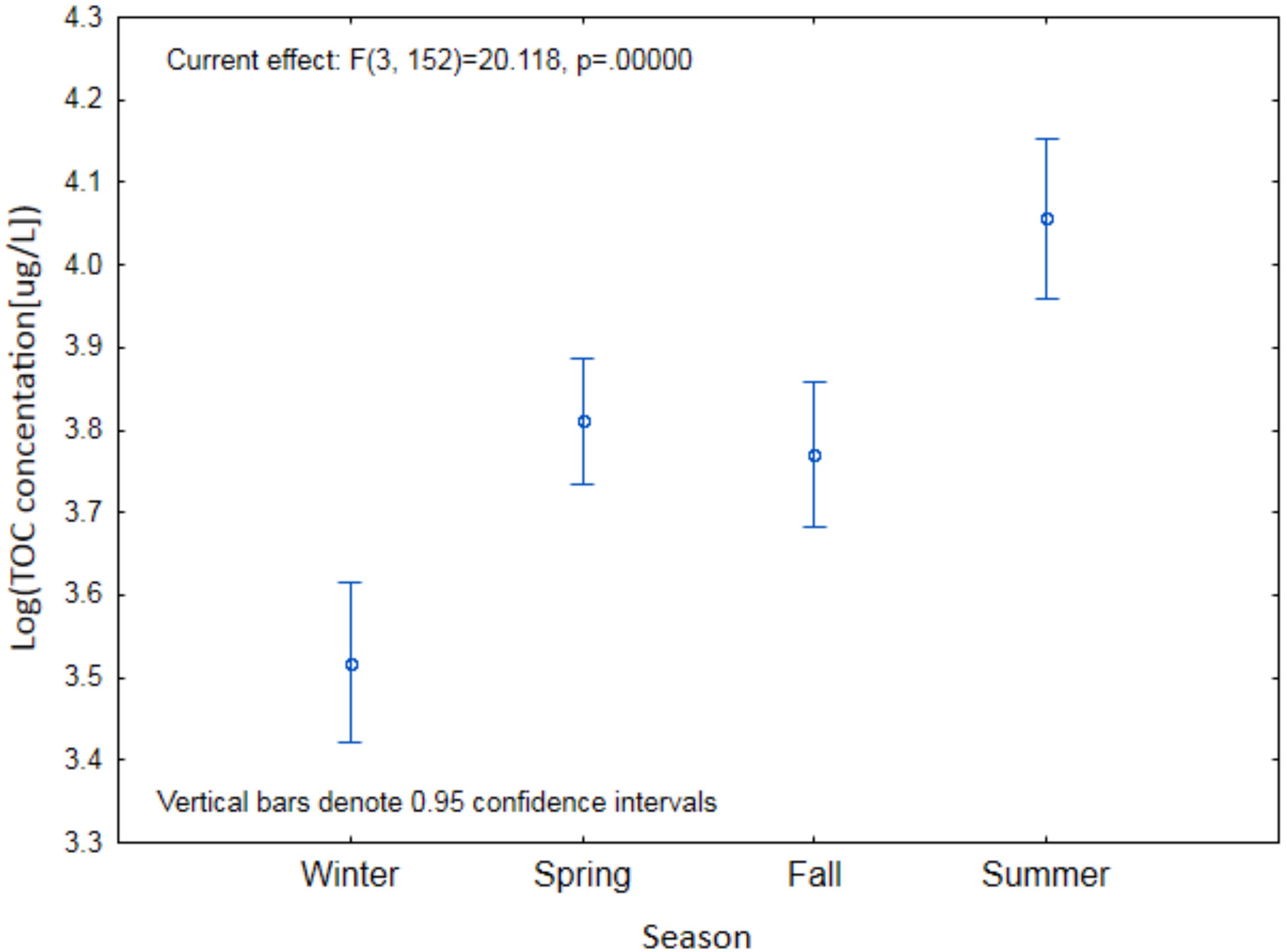
One-way ANOVA Type of Pavement Effect on Log Total Organic Carbon (TOC)



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



One-way ANOVA Seasonal Effect on Log TOC

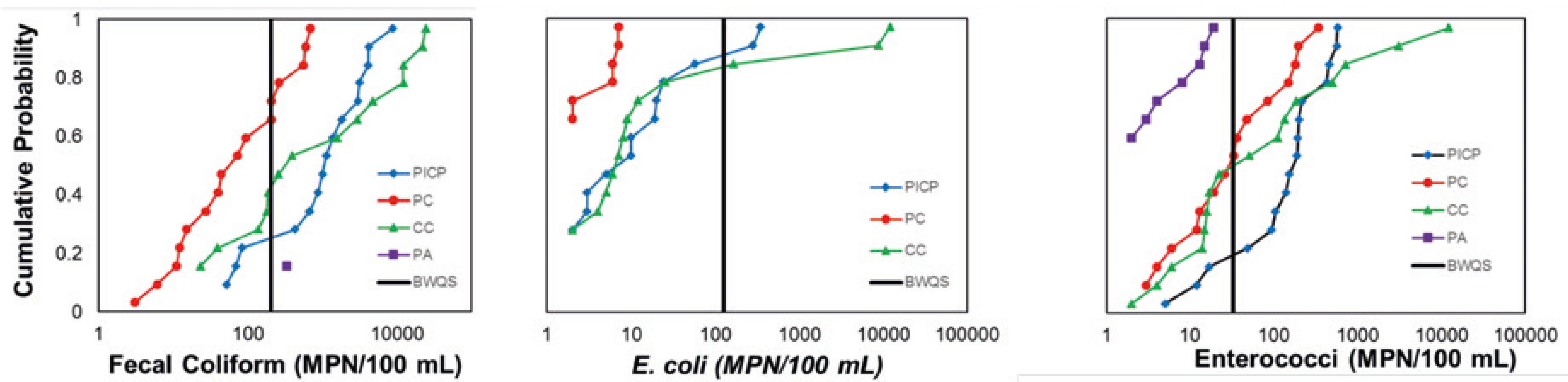


Observation of Semi-Volatile Organics Compounds in Permeable Pavement Infiltrate

- 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



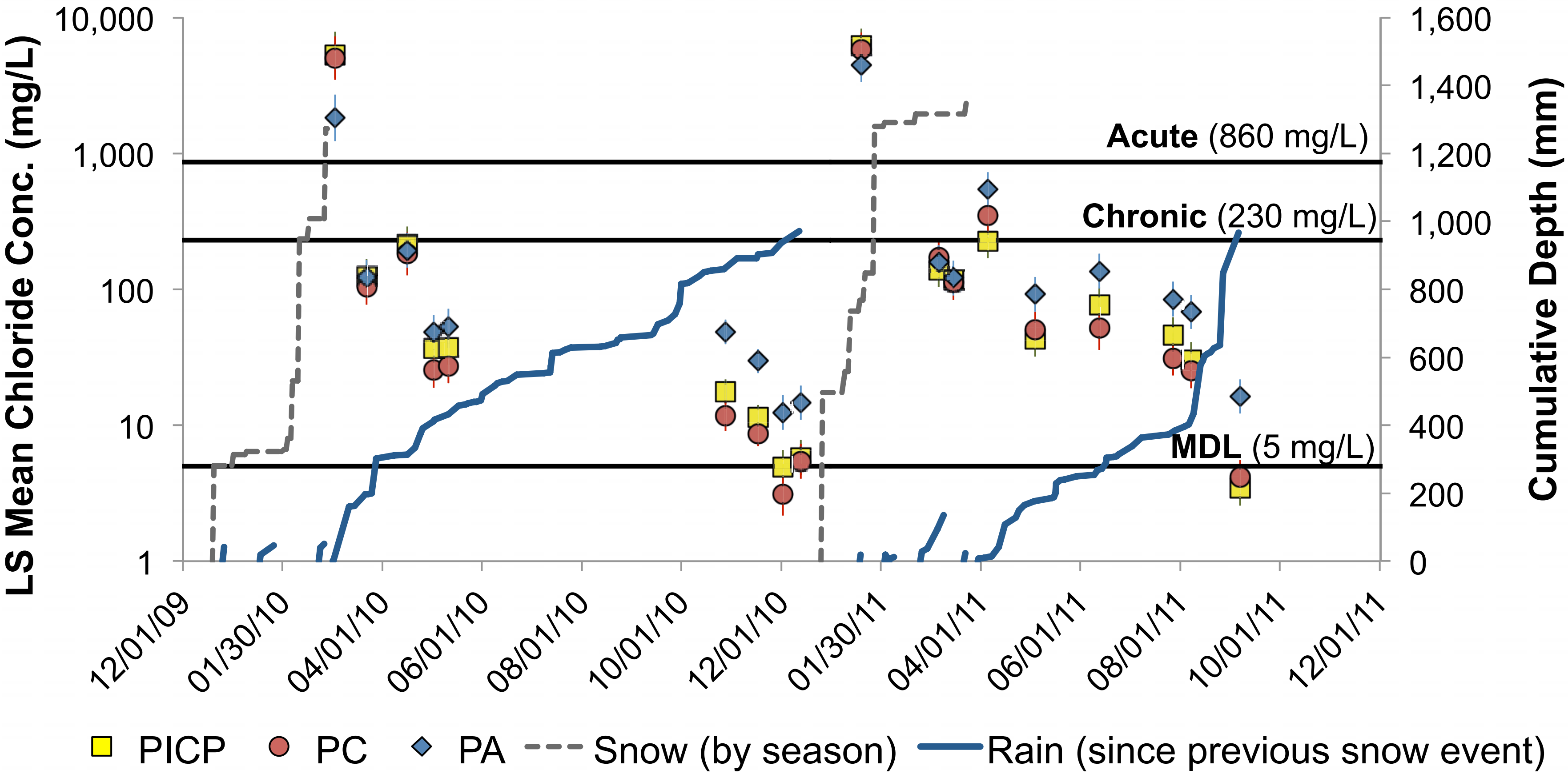
Selvakumar and O'Connor (2018)

United States Environmental Protection Agency

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.



Bars represent 95% confidence intervals; snowfall data from NJ State Climatologist.

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.

Borst and Brown (2014).

EPA United States Environmental Protection Agency

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."

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

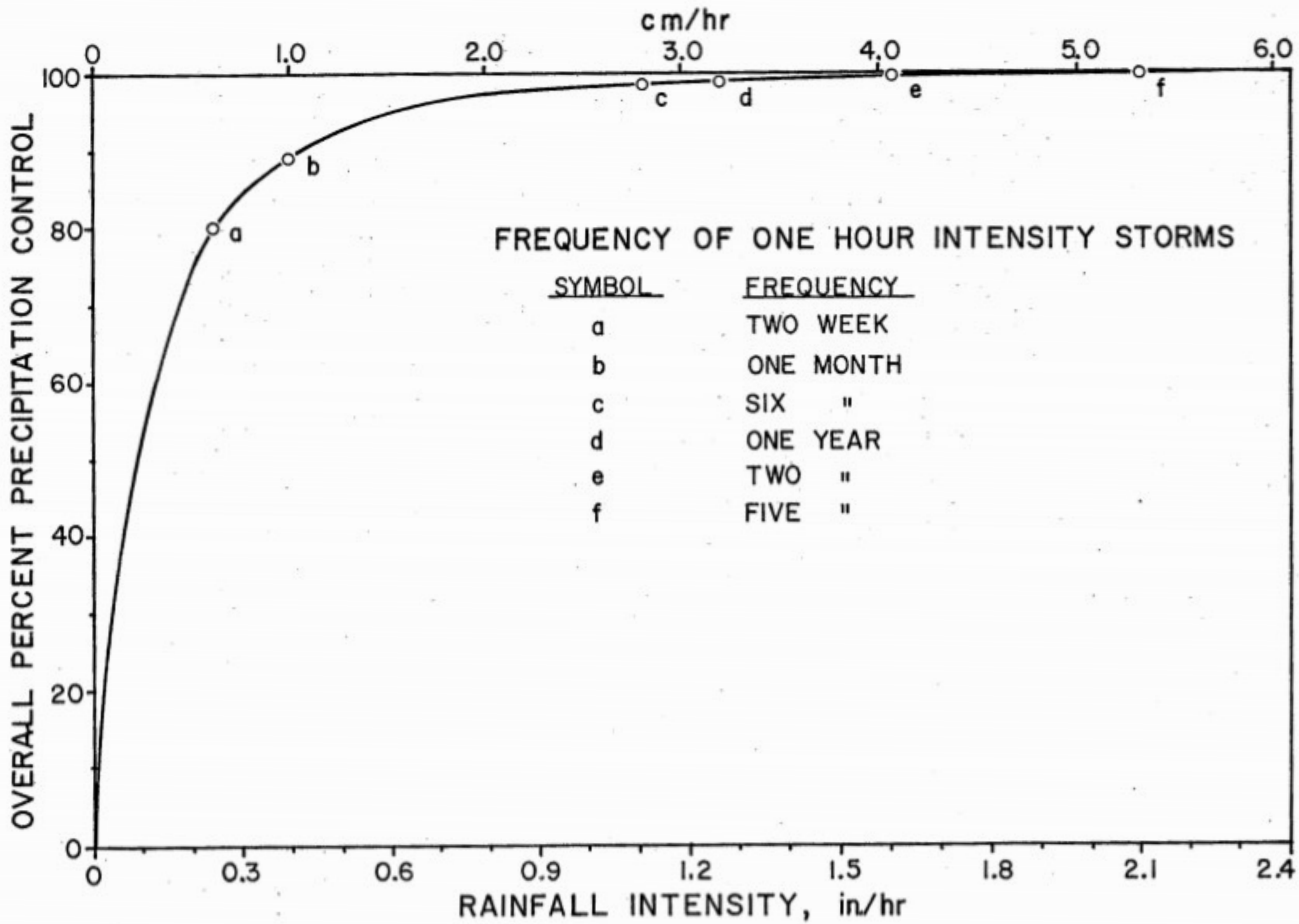


Figure I-2. Overall Percent Precipitation Control vs Rainfall Intensity – Atlanta, GA (1948-1972)

EPA (1977)

Journal Articles

United States Environmental Protection Agency

- 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).
- 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)
- 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)
- 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)

EPA United States Environmental Protection Agency

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?