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Permeable Pavement Research Highlights

Performance and effectiveness of permeable pavement systems

Michael Borst

Edison Environmental Center
Edison, New Jersey

Story Ave.
Louisville, Kentucky

Sietz Elementary School
Fort Riley, KS

Office of Research and Development
National Risk Management Research Laboratory
Water Supply and Water Resource Division
Urban Watershed Management Branch

Green Infrastructure Research

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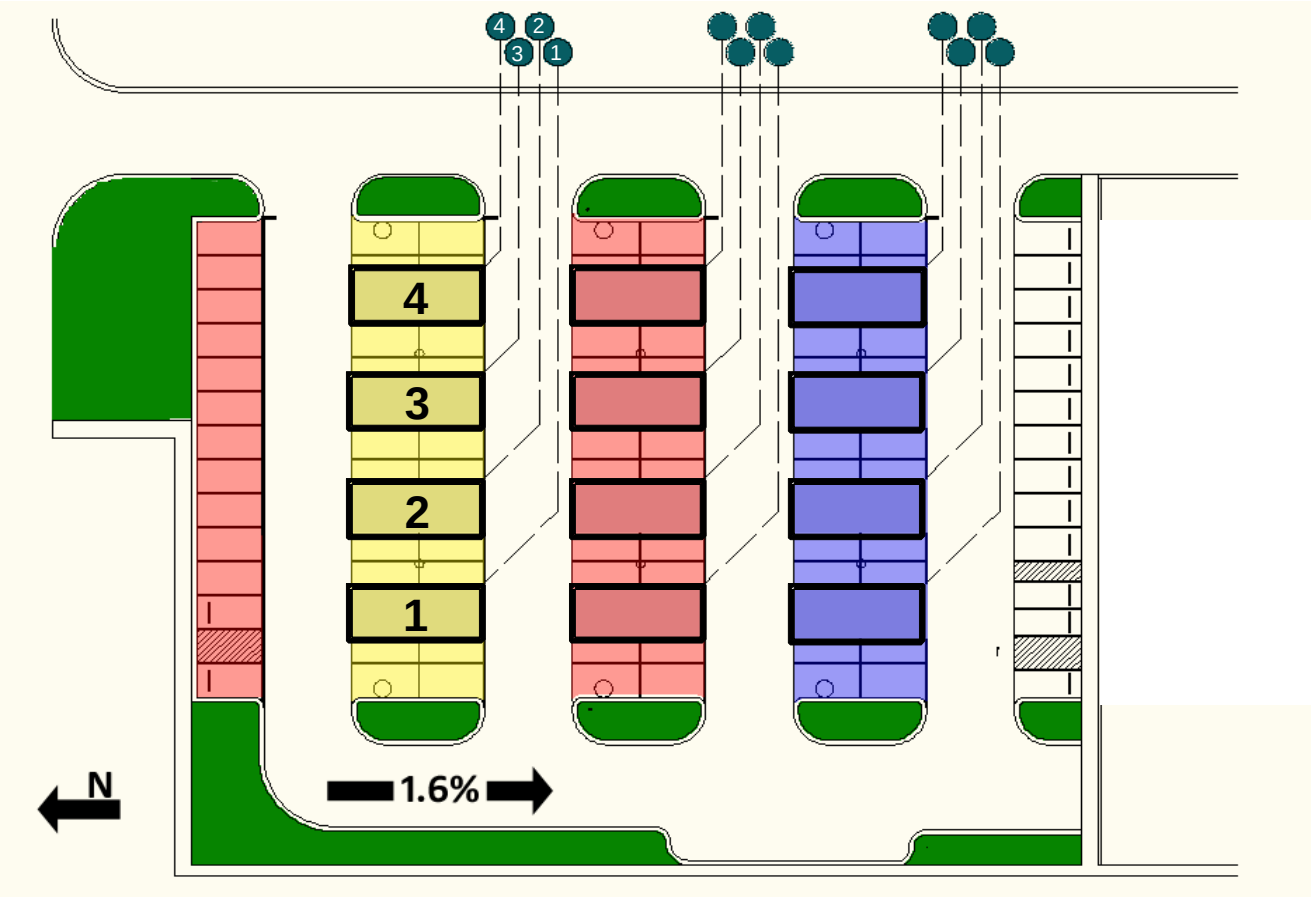
EPA designed and built a parking lot at the Edison Environmental Center.

The design at the EEC incorporated water quality monitoring capabilities.



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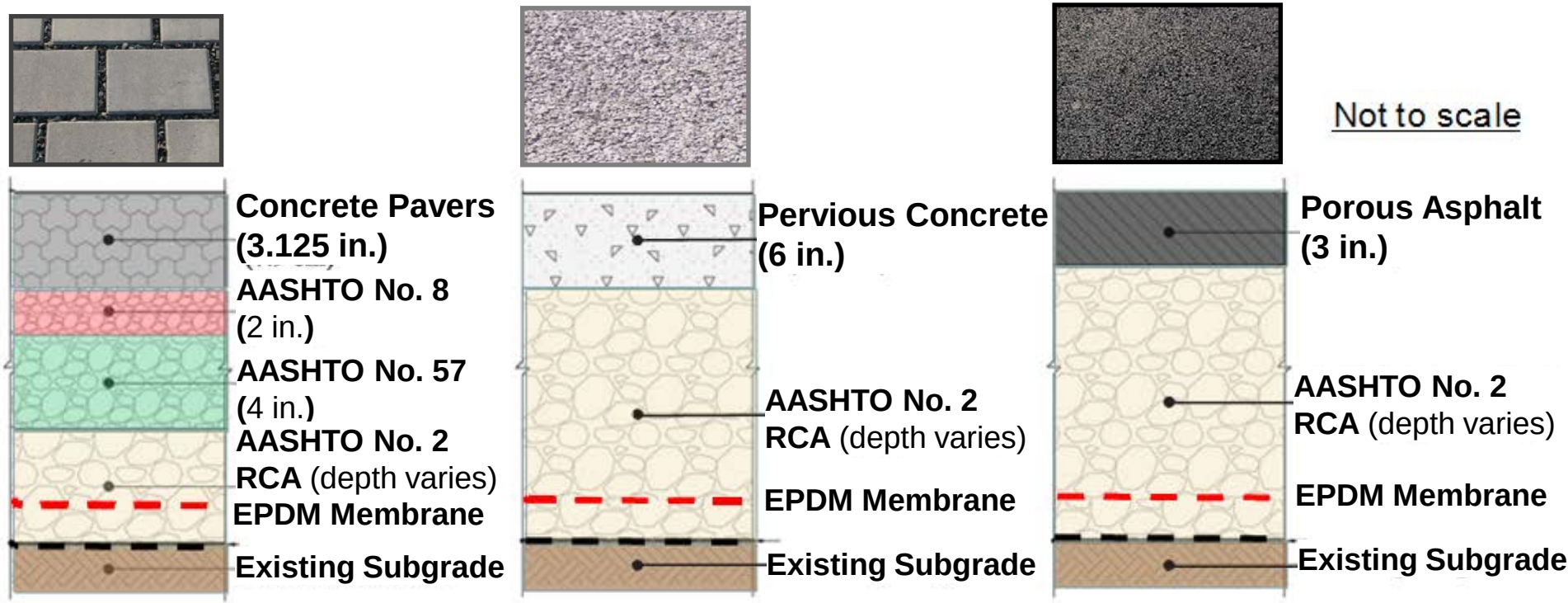
Vertical cross sections of permeable sections varied slightly from material to material.



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

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Four equally-sized and spaced lined sections collect infiltrating water from each monitored permeable surface with the balance infiltrating to the underlying soil.

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Infiltrate drains from the lined sections to 1,500-gallon tanks on the east side of the parking lot where we can collect samples.

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The tanks allow us to collect the entire runoff for rain events through ~38 mm.

- Published or in review
  - Chloride
  - Speciated nitrogen
  - Organic carbon
  - Phosphate
  - pH
  - Eh
- In production
  - SVOCs
  - Metals
  - Microbials

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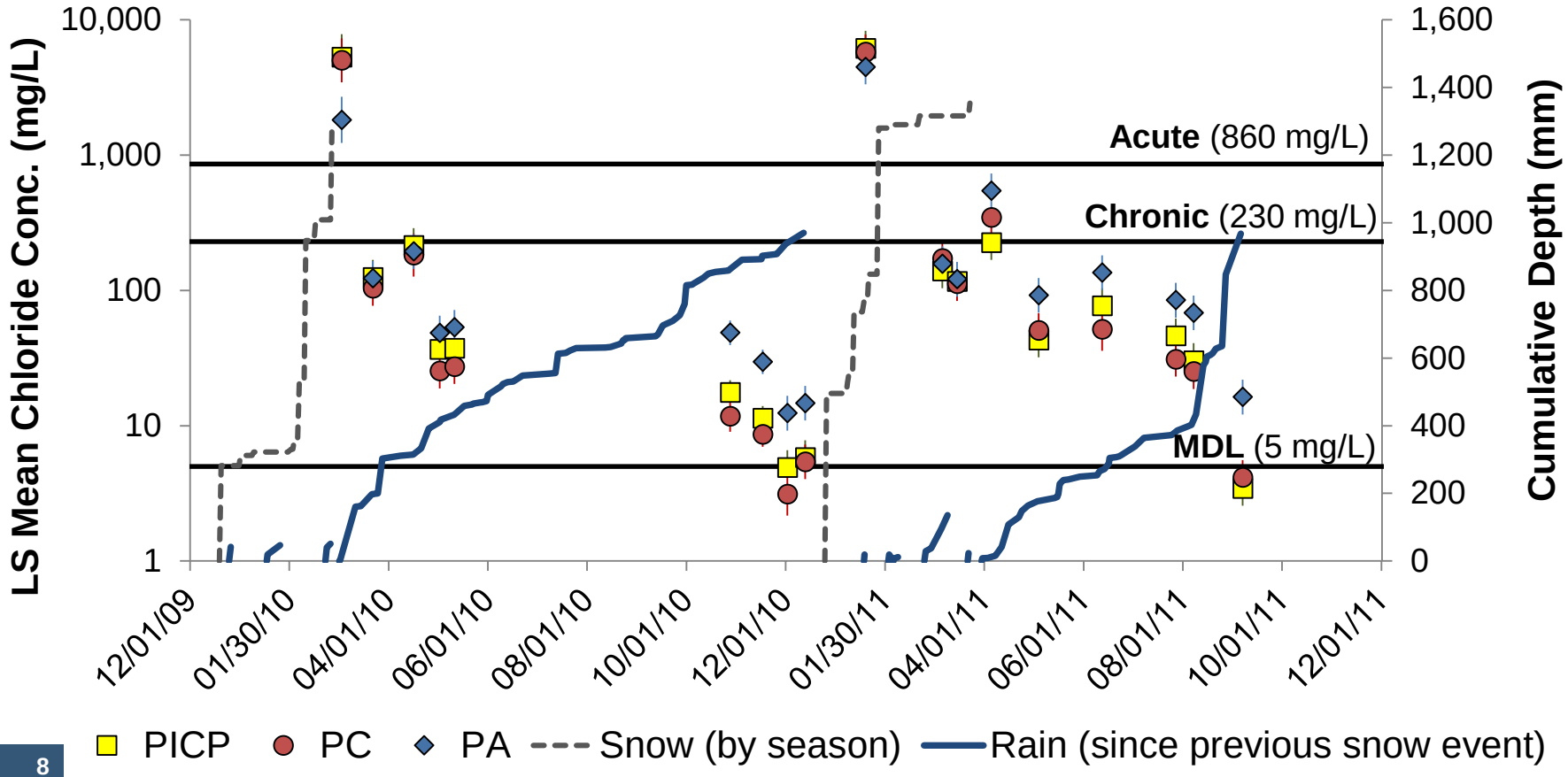
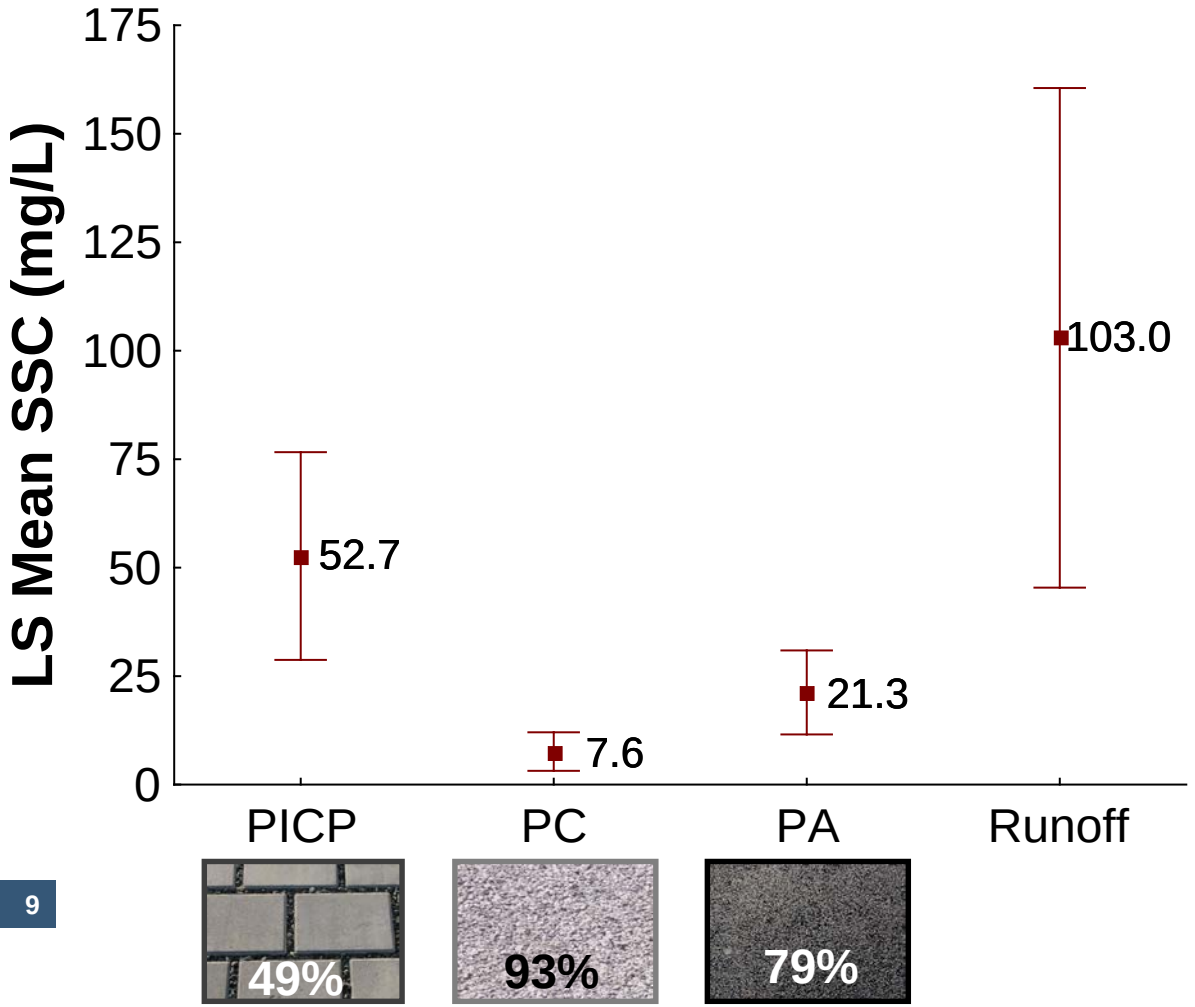
After winter salt application, chloride concentration decreases throughout the remainder of the year.



Bars represent 95% confidence intervals; snowfall data from NJ State Climatologist.
JAWRA 50(1) 29-41

All permeable surfaces reduced Suspended Solids Concentration (SSC) to different degrees.



Date Range:
1/26/2010 – 6/4/2013

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

Mean
Mean±0.95 Conf. Interval

Note: NSQD TSS commercial median 98 mg/L

Note: Preliminary Data

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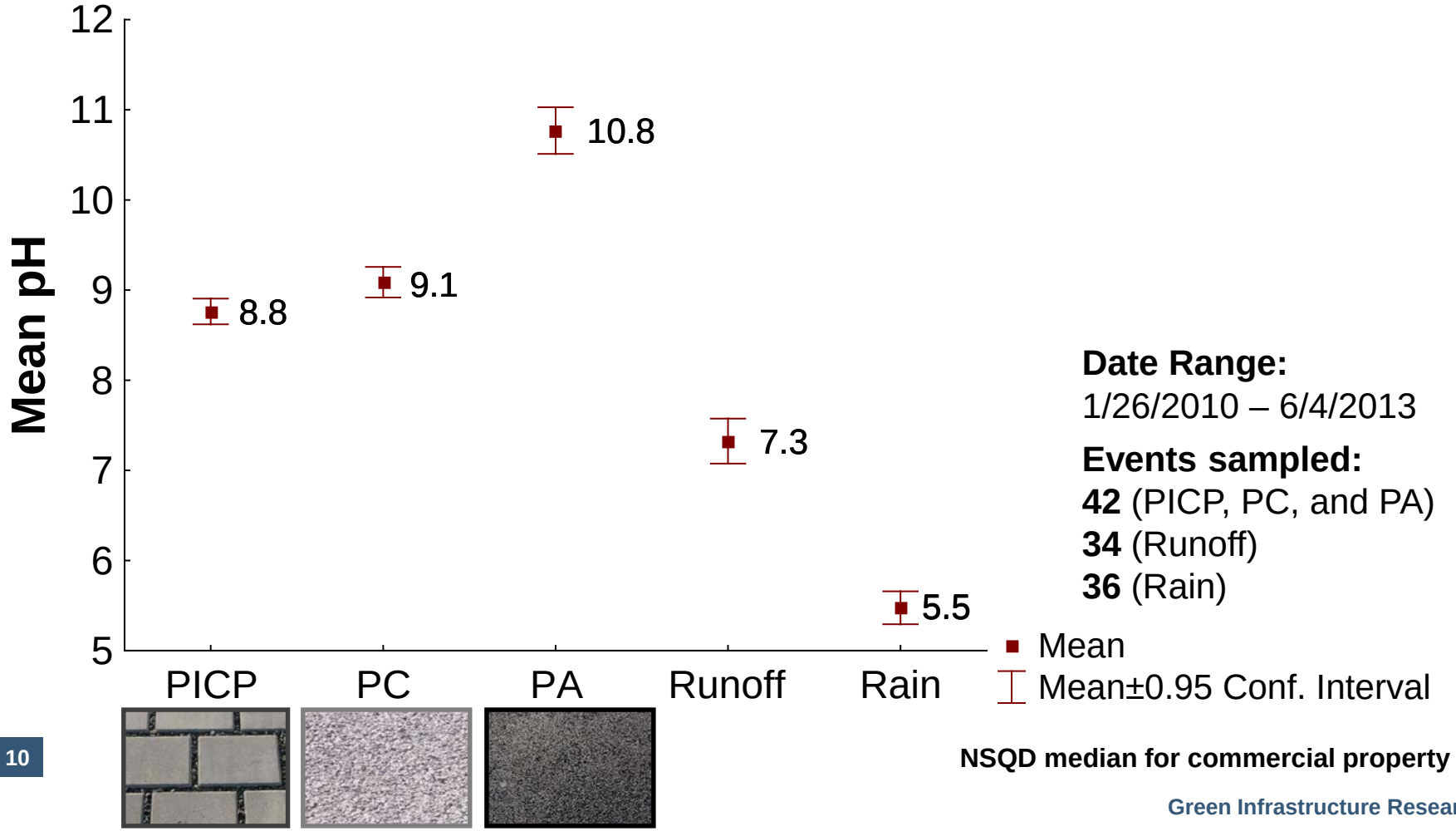
Acidic rainfall is buffered by all pavement surfaces, and PA exfiltrate is surprisingly basic.



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

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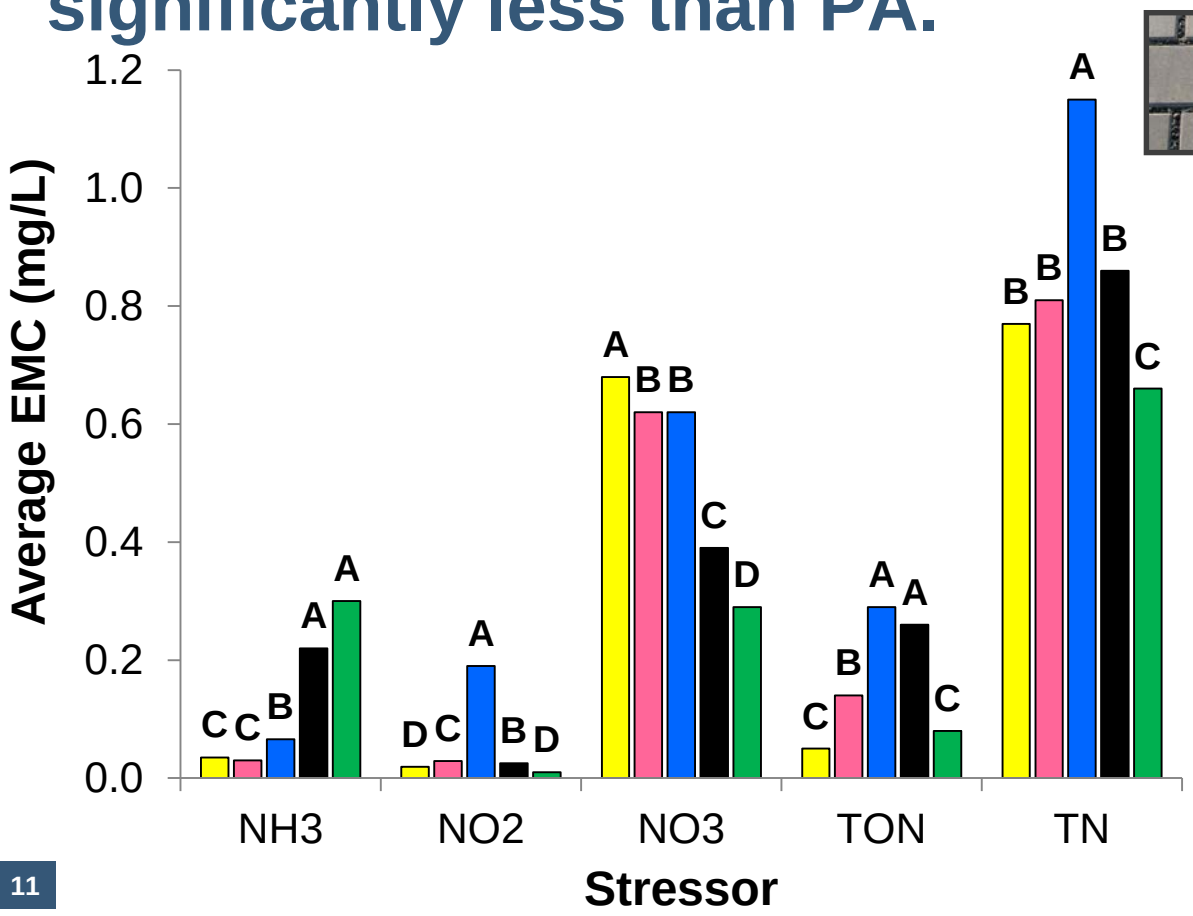
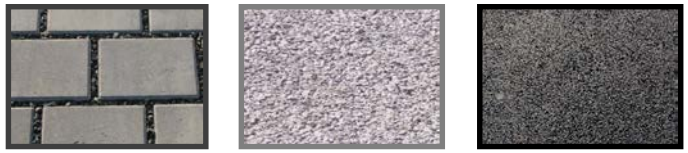
TN concentrations in PICP, PC, and runoff were not significantly different, but all three were significantly less than PA.





PICP PC PA

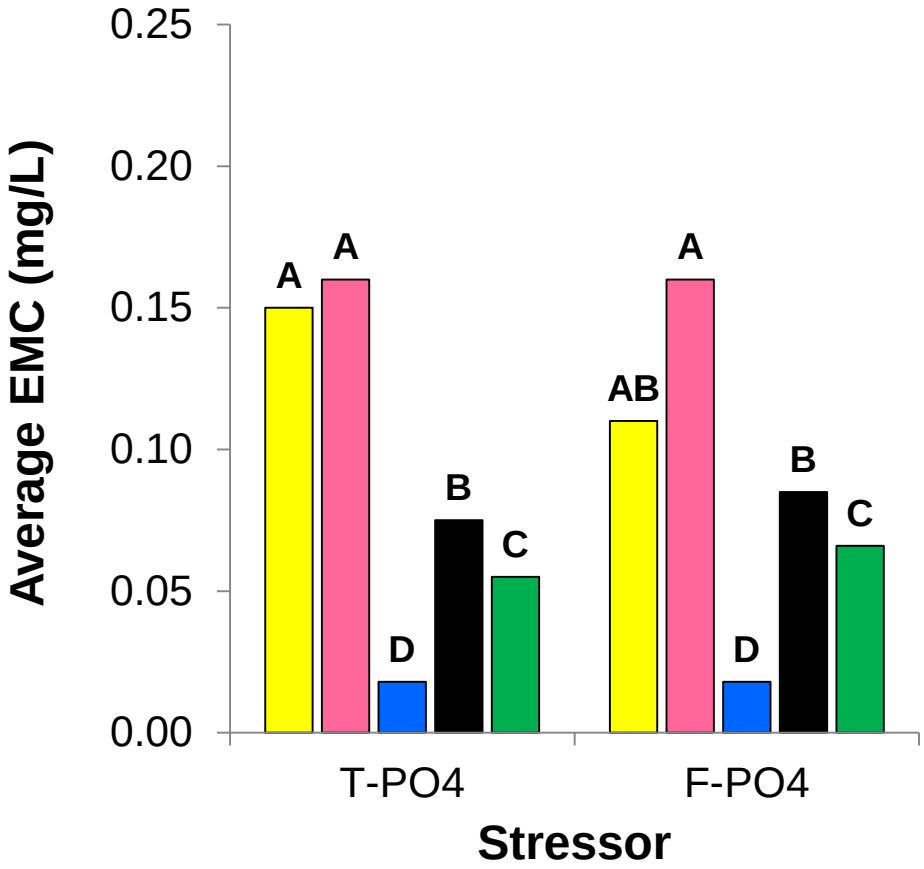
RO RAIN

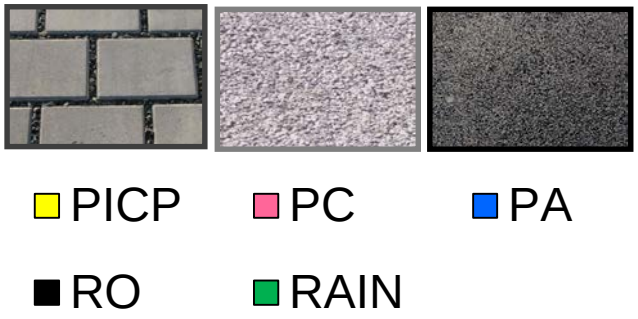
Date Range:
10/28/2010 – 9/7/2011

Events sampled:
13 (PICP, PC, and PA)
12 (Runoff and Rain)

NSDQ median NH3 0.5 mg/L
median NO3-2 0.6 mg/L
median TKN 1.6 mg/L

Total phosphate concentrations in PICP and PC were significantly larger than in the runoff, and all were significantly larger than PA.

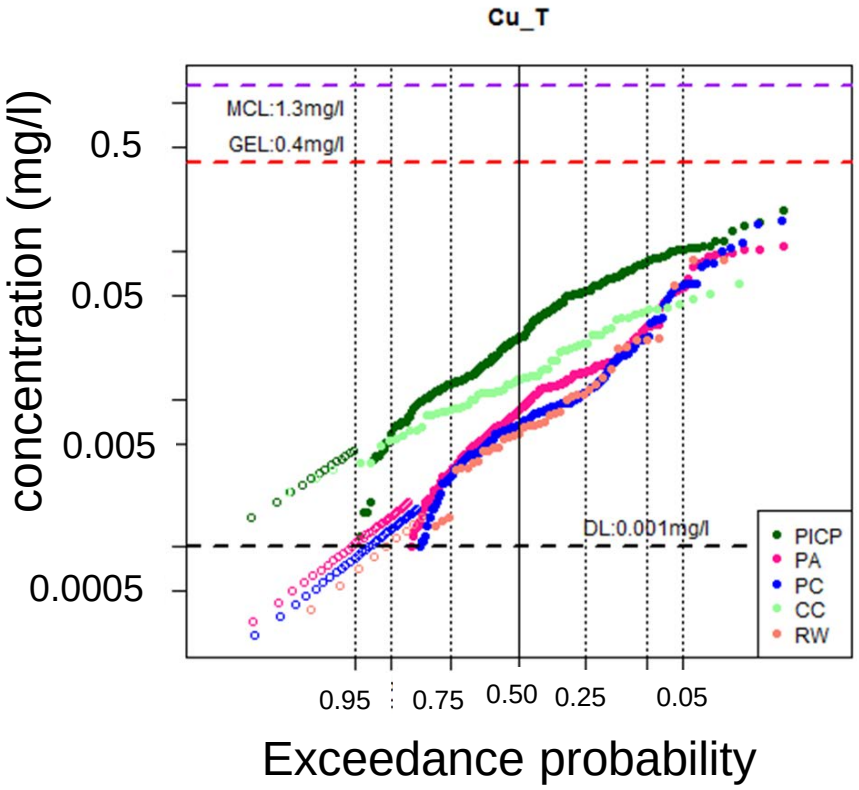


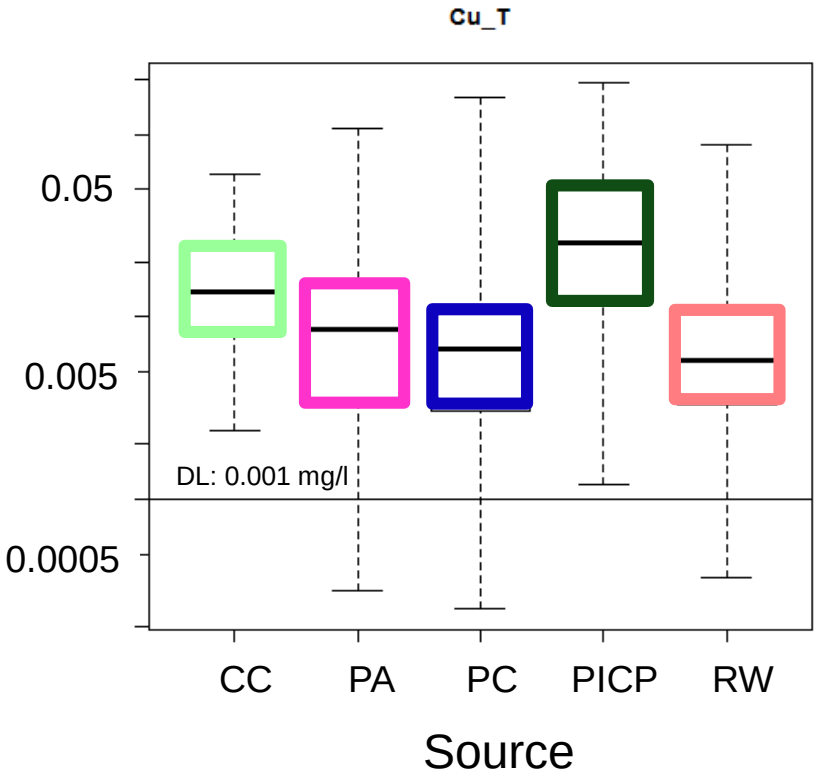


Date Range:
10/28/2010 – 9/7/2011

Events sampled:
13 (PICP, PC, and PA)
12 (Runoff and Rain)

The concentration of priority-pollutant metals were generally less than the groundwater discharge limit.





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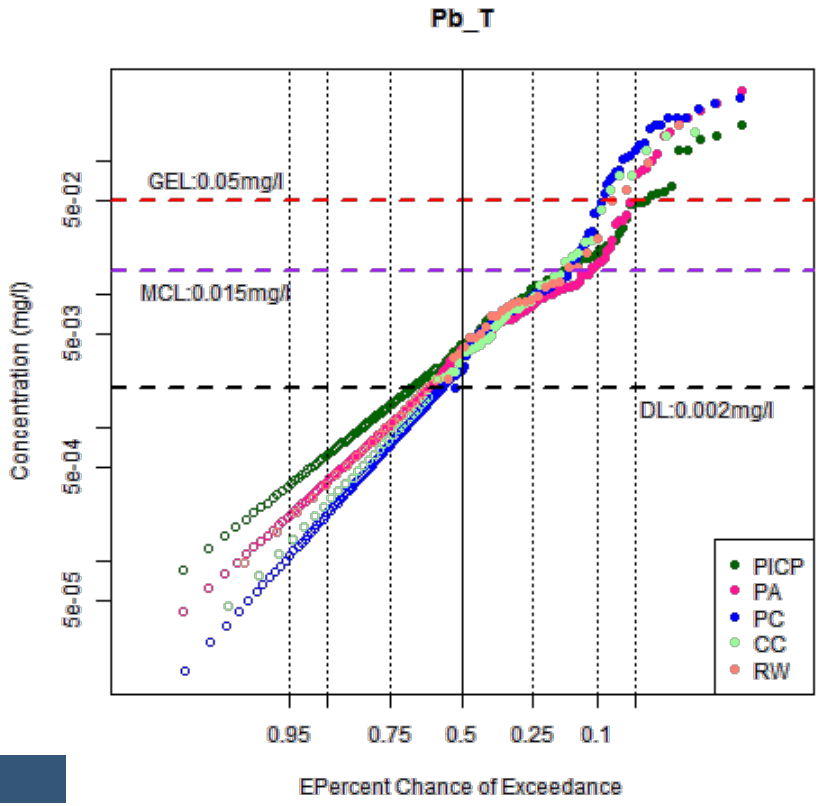
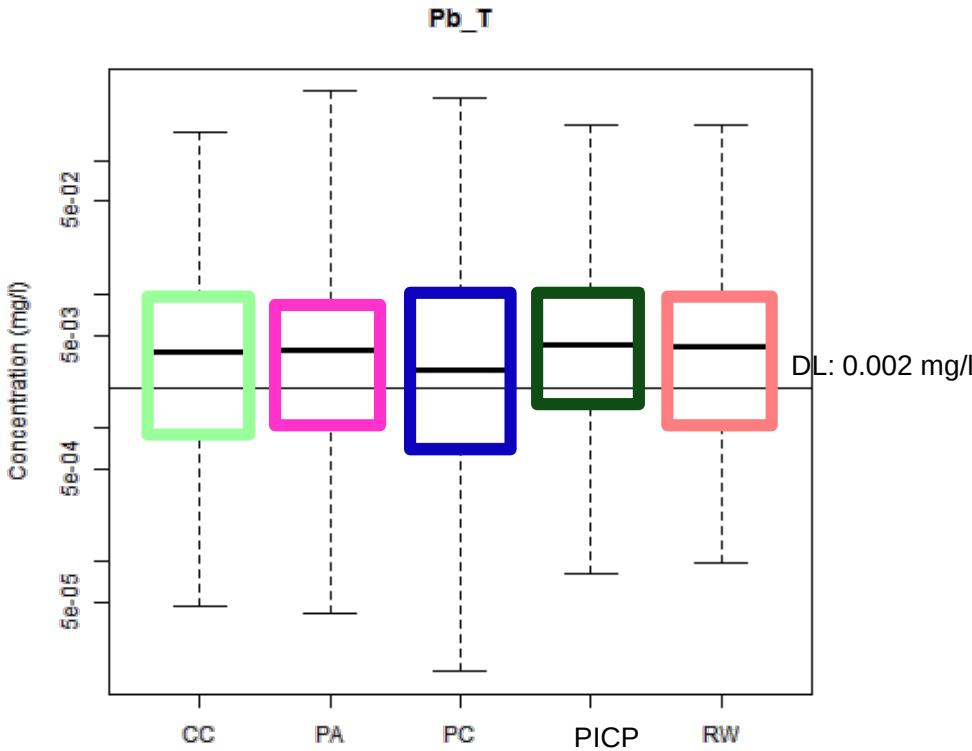
Total lead concentration does not differ across sources and sometimes exceeds regulatory limits.





The most popular question is about infiltration rates.

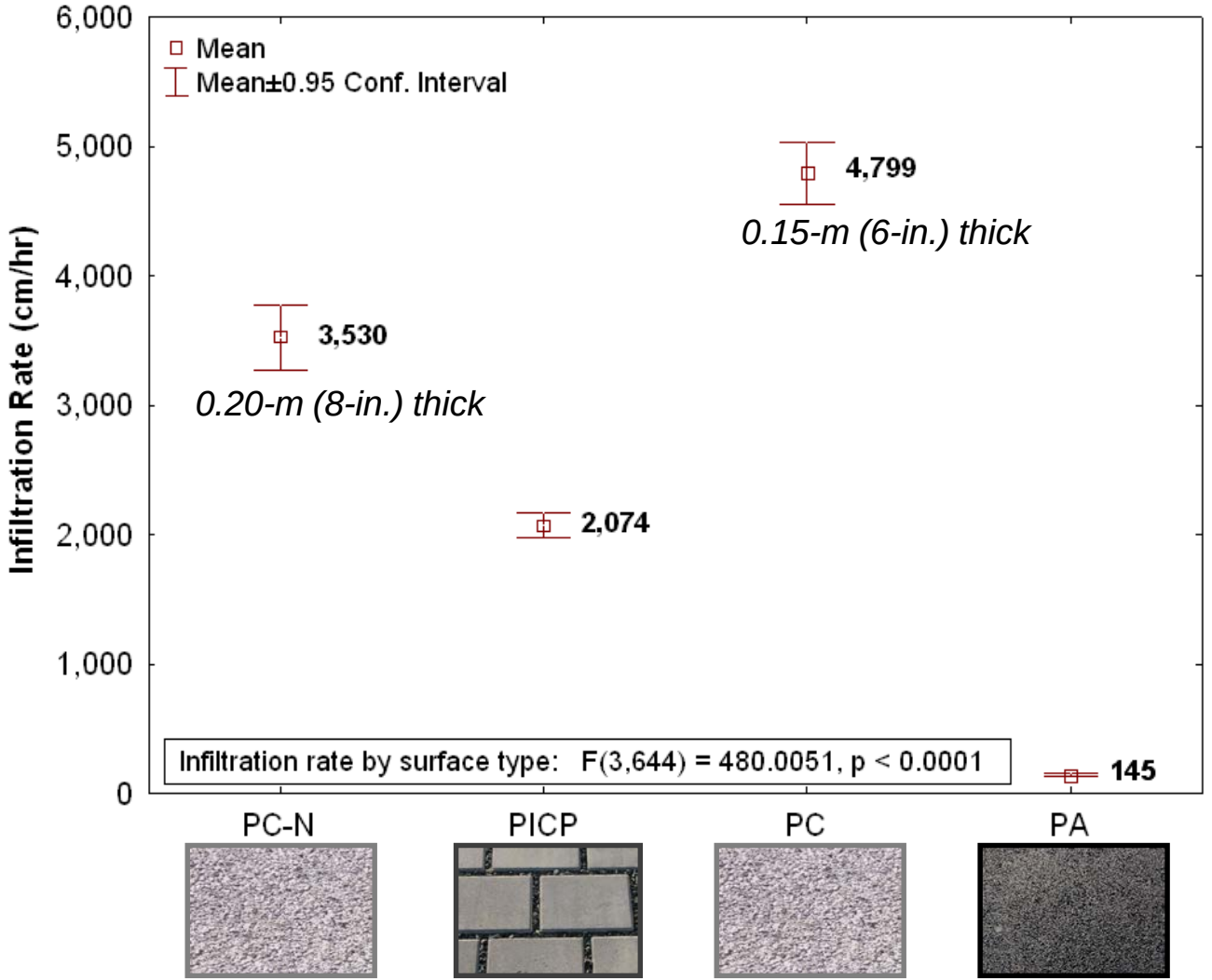
We measured infiltration rate at three randomly selected locations on each half of each surface monthly.

Modified ASTM C1701 apparatus

The infiltration rate varies among the four tested surfaces, but all surfaces are sufficient to handle maximum expected direct rainfall rates.

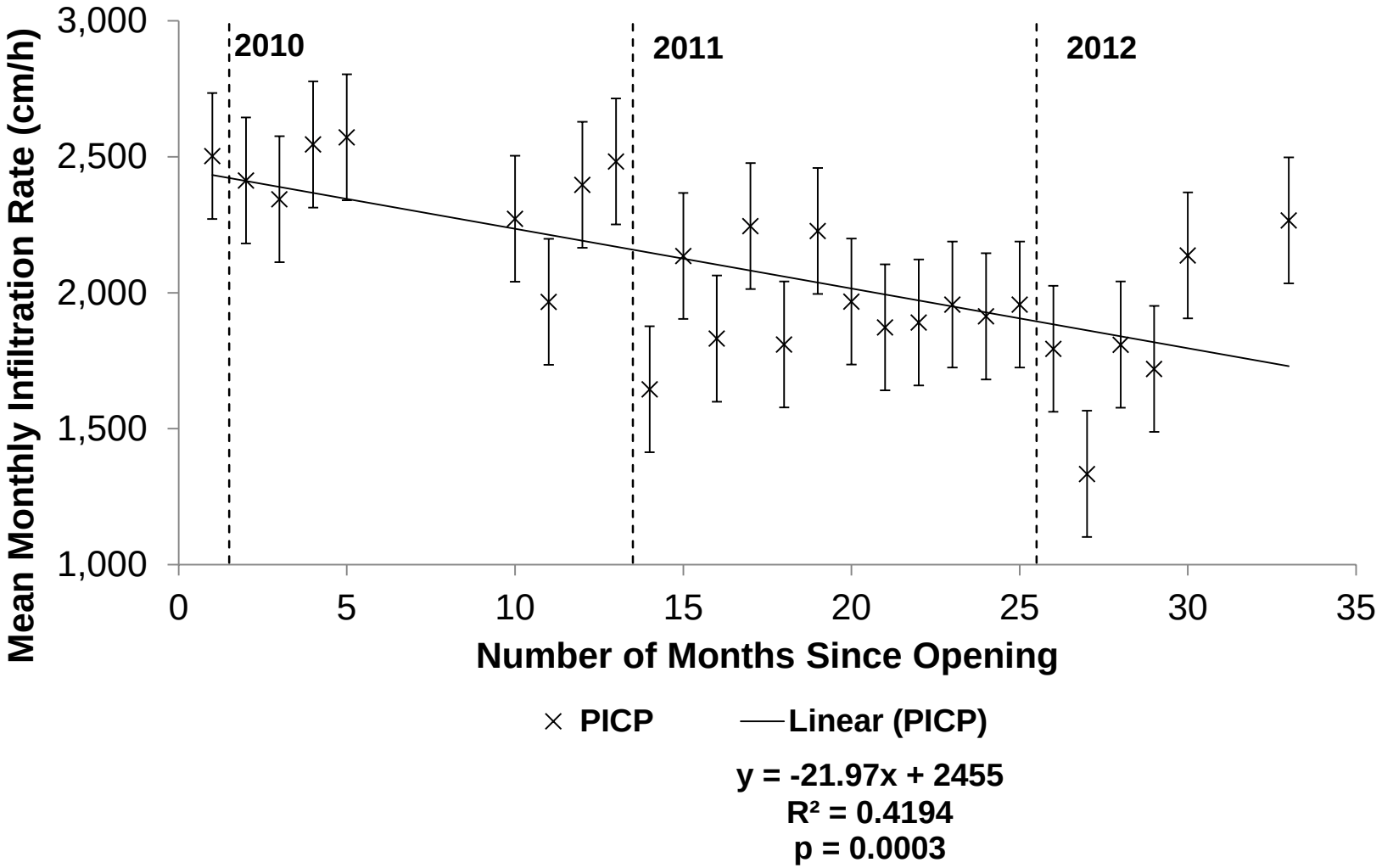
100-year, 5-minute rainfall intensity

• Edison, NJ
20.8 cm/hr (8.2 in/hr)



J. Hydrol. Eng. DOI: 10.1061

Infiltration decreased with age for the three surfaces that received run-on from driving lane.



Bars represent standard error.

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Surface results:

- The three surfaces have very large infiltration rates.
- Clogging progresses from upgradient to downgradient.
- Microtopography partly determines clogging pathway.
- 5 to 7% of the captured water evaporates through the surfaces.

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

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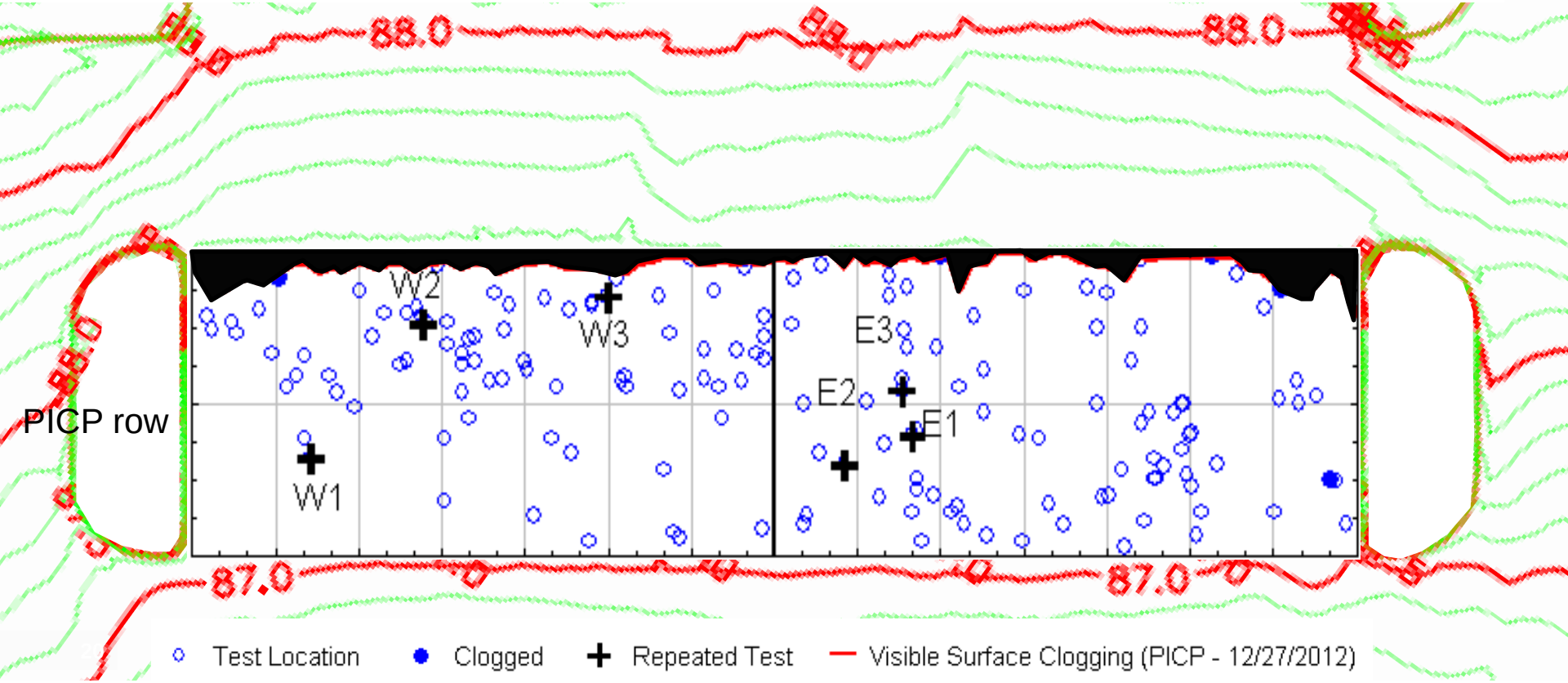
The surface clogging progression varied because of microtopography.



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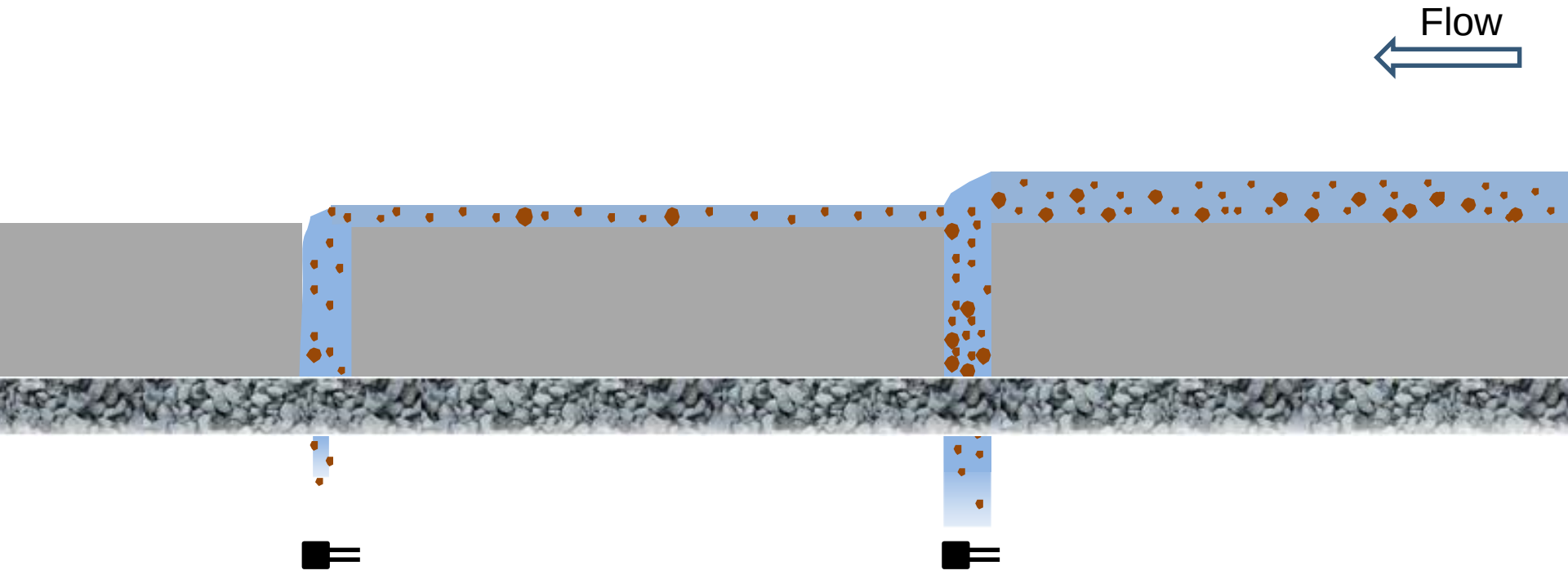
We developed a working hypothesis of the mechanics of the clogging processes.



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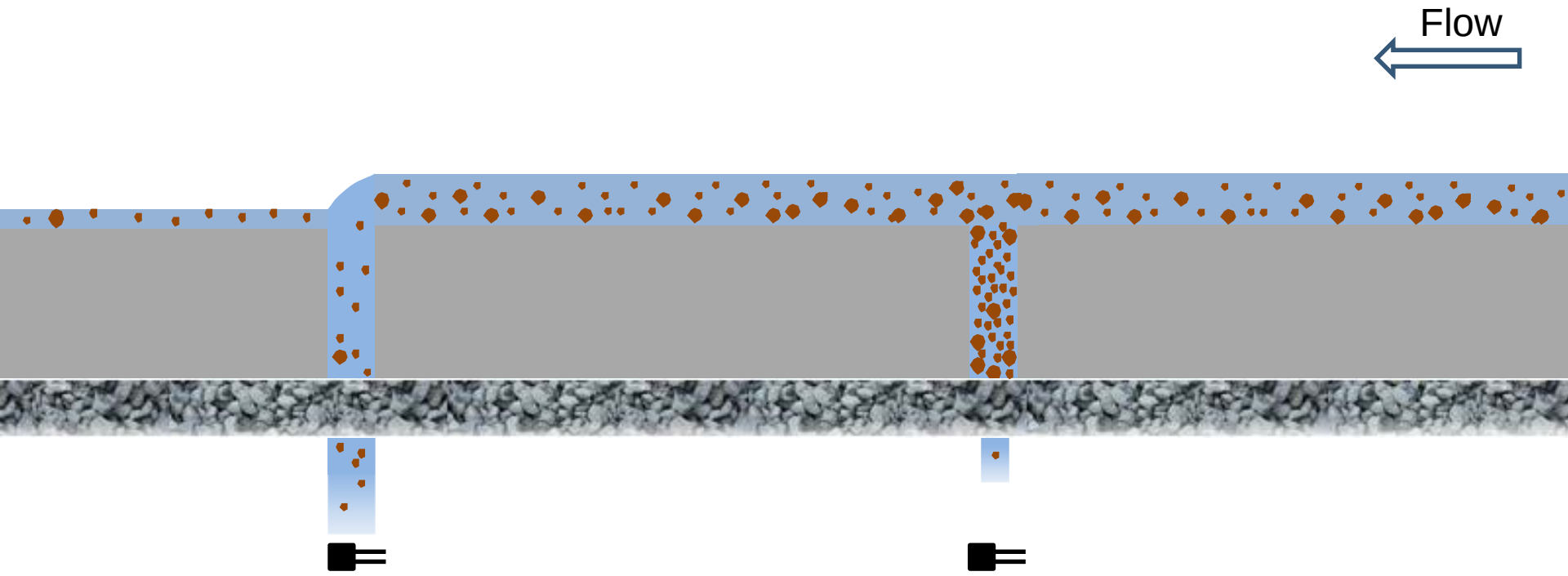
As gaps fill with sediment, the location of the primary infiltration moves downgradient.



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 it recurred.

Is structural failure coupled with chloride?

WYOMING ANALYTICAL LABORATORIES, INC.

May 06, 2014

Analytical Report

Wt.%, as Received Basis

Customer ID	Water Soluble Mg
119176 Permeable Concrete Core Sample "EPA" 0-2"	0.017
119176 Permeable Concrete Core Sample "EPA" 3-4"	< 0.001
119176 Permeable Concrete Core Sample "EPA" 5-6"	0.006
119177 Permeable Concrete Sample "Trump F" Sample A	0.051
119177 Permeable Concrete Sample "Trump F" Sample B	0.149

Analysis in Accordance with ASTM C-1218 and X-Ray Fluorescence Spectrometry (XRF)

Charles R. Wilson
Division Manager

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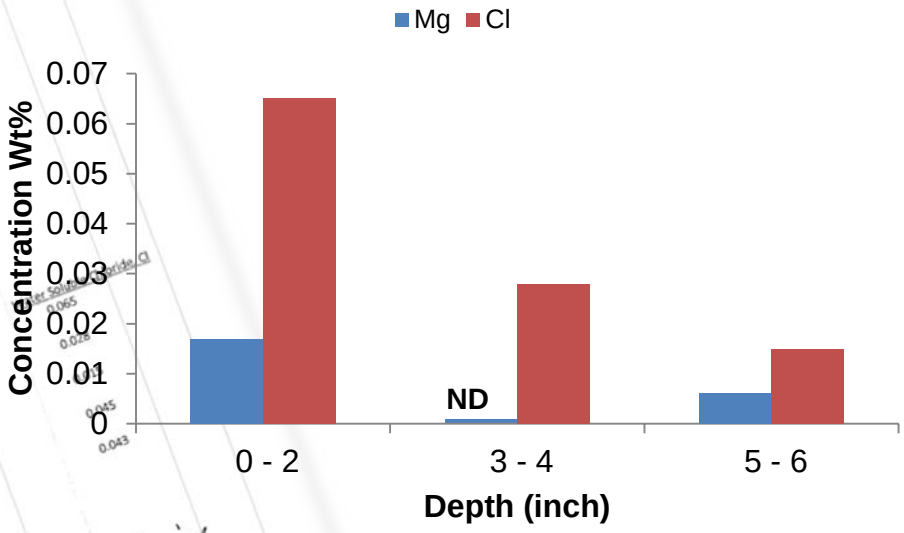

NRMCA revised O&M guidance (2015)

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

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Although the surface had disaggregated, there was still substantial material remaining.

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We have replaced the porous concrete sections with pavers.

Belgard Eco Dublin

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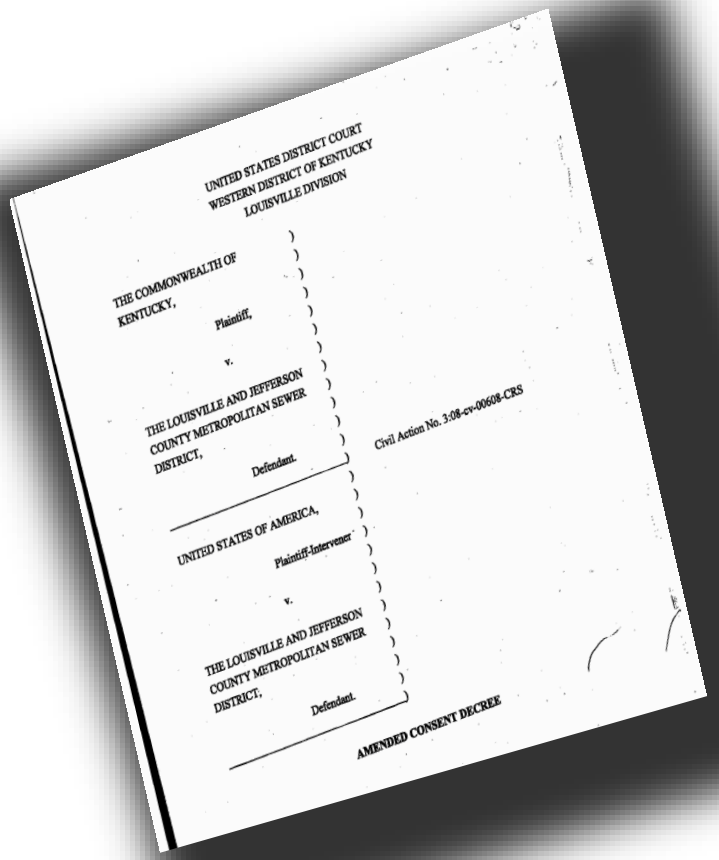
In 2011, Louisville MSD installed permeable pavement strips in parking lanes near the catch basins in the Butchertown section of Louisville.

In-Street Application

Louisville, Kentucky



UNITED STATES DISTRICT COURT
WESTERN DISTRICT OF KENTUCKY
LOUISVILLE DIVISION

THE COMMONWEALTH OF KENTUCKY,
Plaintiff,
v.
THE LOUISVILLE AND JEFFERSON COUNTY METROPOLITAN SEWER DISTRICT,
Defendant.
Civil Action No. 3:08-cv-00608-CRS

UNITED STATES OF AMERICA,
Plaintiff-Intervenor
v.
THE LOUISVILLE AND JEFFERSON COUNTY METROPOLITAN SEWER DISTRICT,
Defendant.

AMENDED CONSENT DECREE

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There are large variation in native soil infiltration rates at small geographic scales.

Measurement location	Expected rate from "nearby" geotechnical survey 4.3 cm/hr			
	Control 19G		Control 19H	
	Infiltration rate (cm/hr)	**USDA soil texture classification** (% sand/silt/clay)	**Infiltration rate** (cm/hr)	**USDA soil texture classification** (% sand/silt/clay)
Upgradient	0.114	Sandy Loam (58/34/8)	0.258	Sandy Loam (55/36/9)
Middle	0.108	Loam (50/33/17)	0.780	Silt Loam (35/50/15)
Downgradient	0.012	Silty Clay Loam (18/52/30)	0.096	Sandy Loam (62/25/13)
Average	0.078		0.378	

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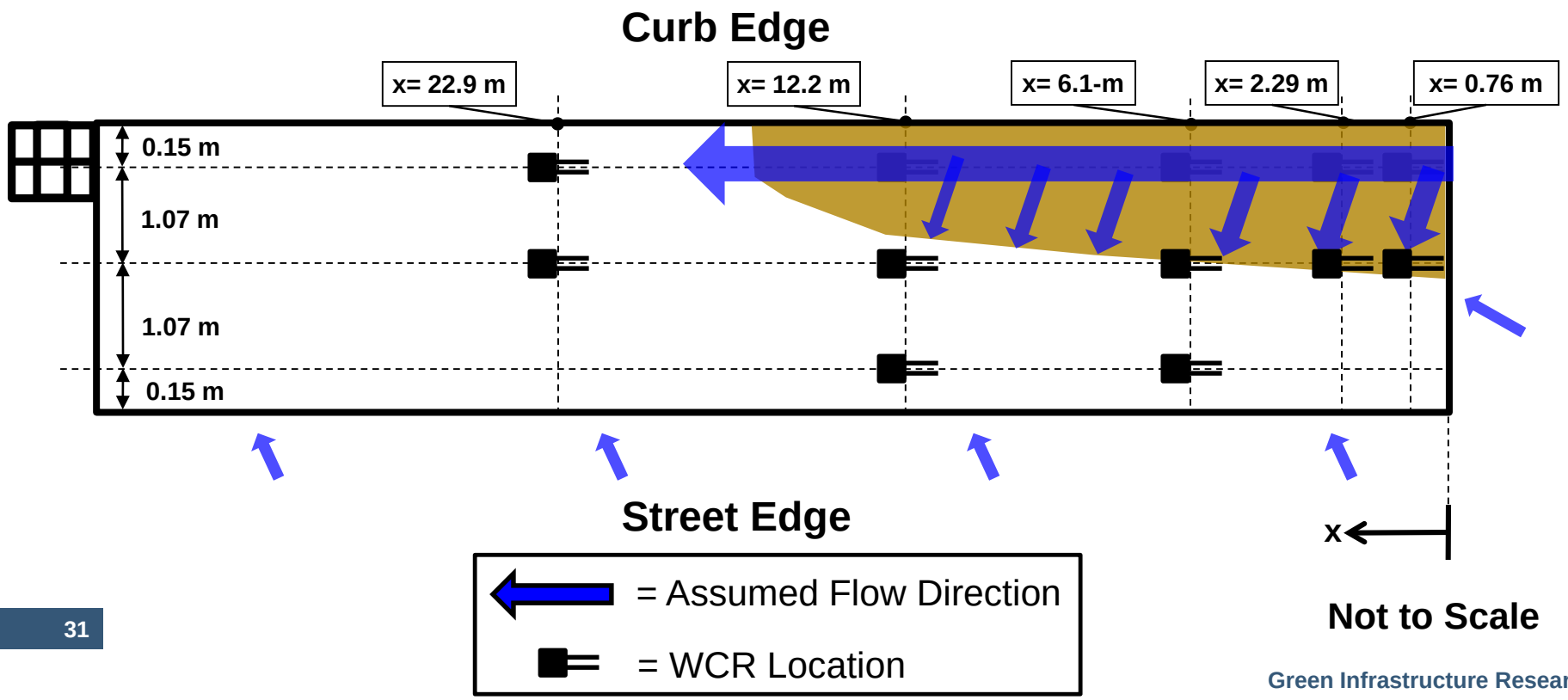
In this curb and gutter system, we expected concentrated flow along the curb to transport and deposit sediment from the drainage area.



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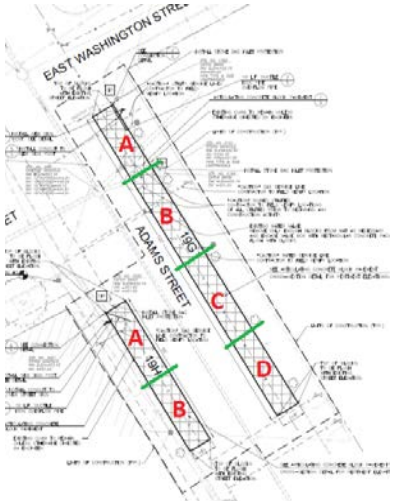
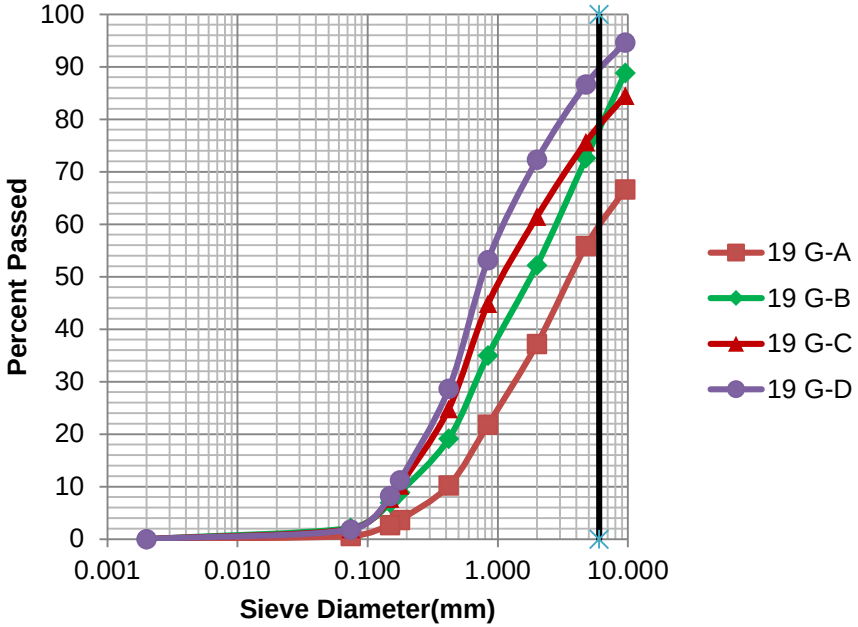
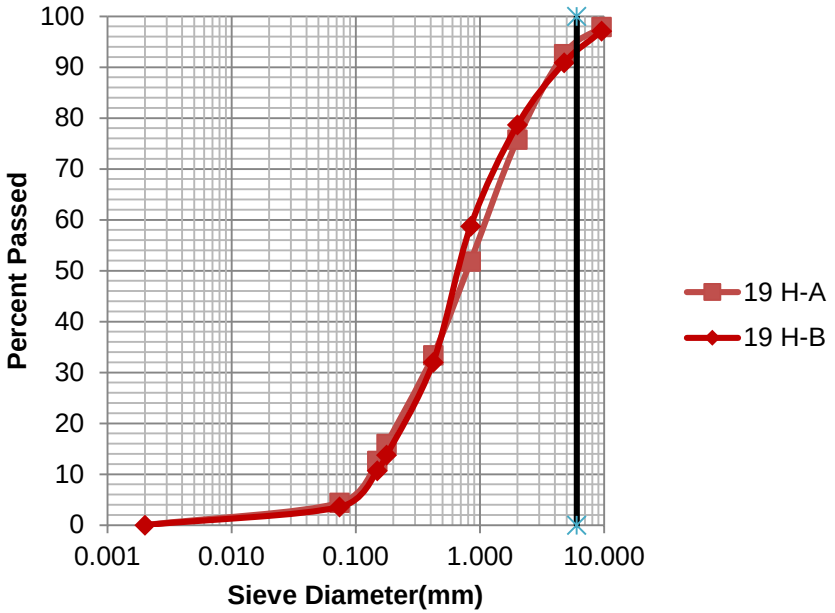
Recovered sediment particle size analysis shows initial accumulation of fines in the upgradient sections.





Mar. – May 2012
(9 in. cum. rainfall)



Dec. 2011 – May 2012
(19 in. cum. rainfall)

Data source:
Amirhossein Ehsaei –
University of Louisville

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We ran some flume experiments to test the hypothesized mechanisms and influences.

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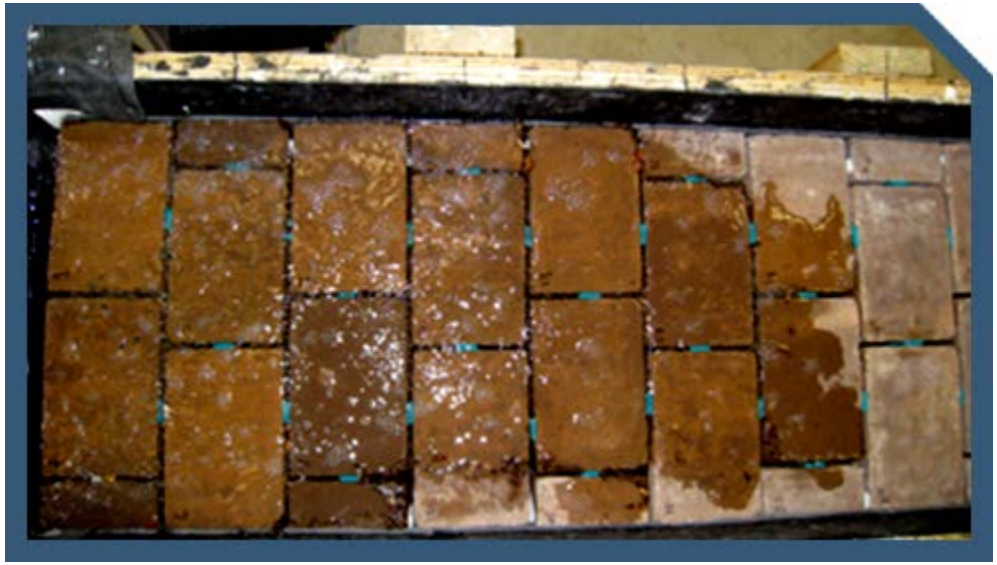
Flume tests show the progressive infiltration of the runoff that leads to the clogging.



Photos: Amir Ehsaei
University of Louisville

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The flume tests are showing the same general pattern of accumulated sediment as observed in the field.

Inorganic material near up gradient edge

Organic material near down gradient edge

Photos: Amir Ehsaei
University of Louisville

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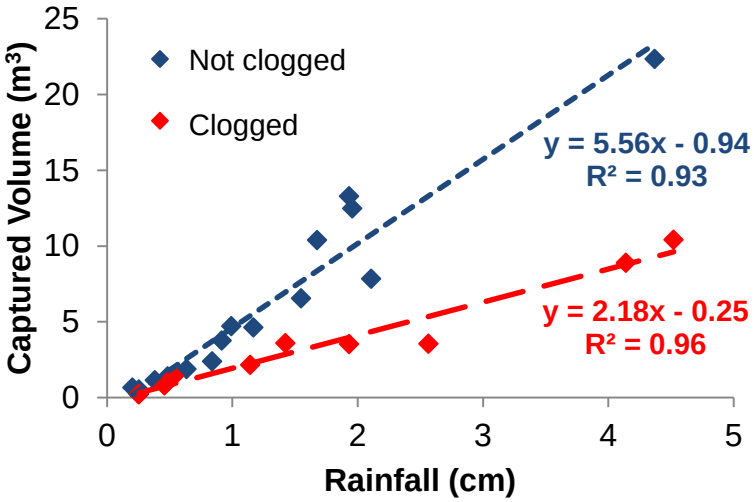
Findings:

- There are very large variations in soil hydraulic conductivity at small spatial scales.
- Clogged does not mean sealed.
- Embedded instruments can be used monitor the clogging progression.
- Clogging distance is proportional to rainfall depth and not time.
- Static volumetric design may cause oversized stormwater controls.



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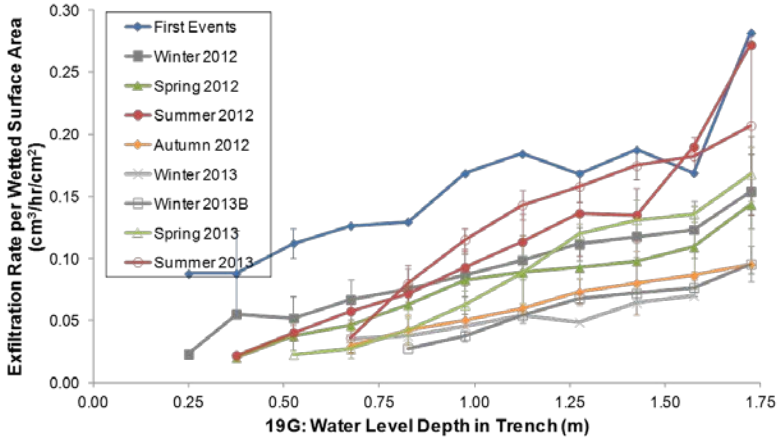
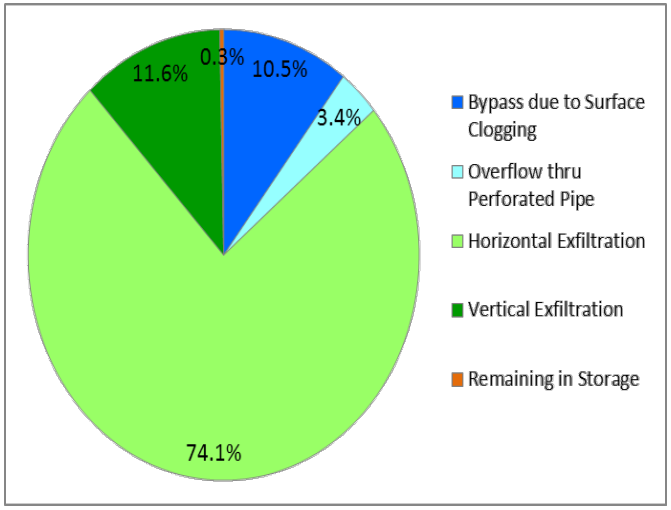
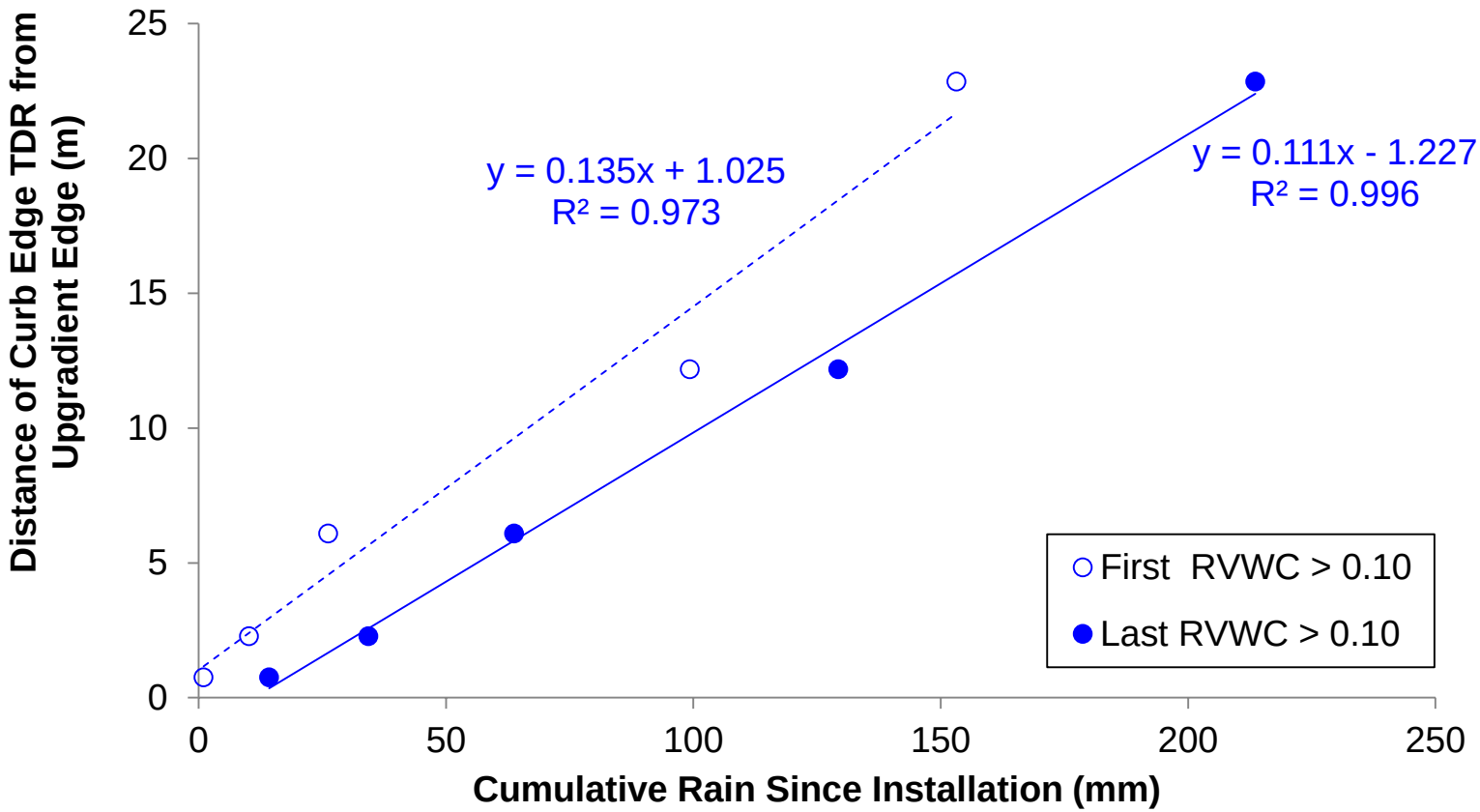
Findings:

- Exfiltration rates vary with age.
- Exfiltration rates vary with water depth and constant hydraulic flux is not representative of exfiltration processes.
- Much of the exfiltration occurs through the sides.
- SCM geometry is important.





Installed instruments can be used to determine the control's longitudinal clogging rate.



Control Louisville 19G
Response threshold 0.10 RVWC
The initial clogging rate was about 0.123 m per mm (10 ft per inch) of rain.

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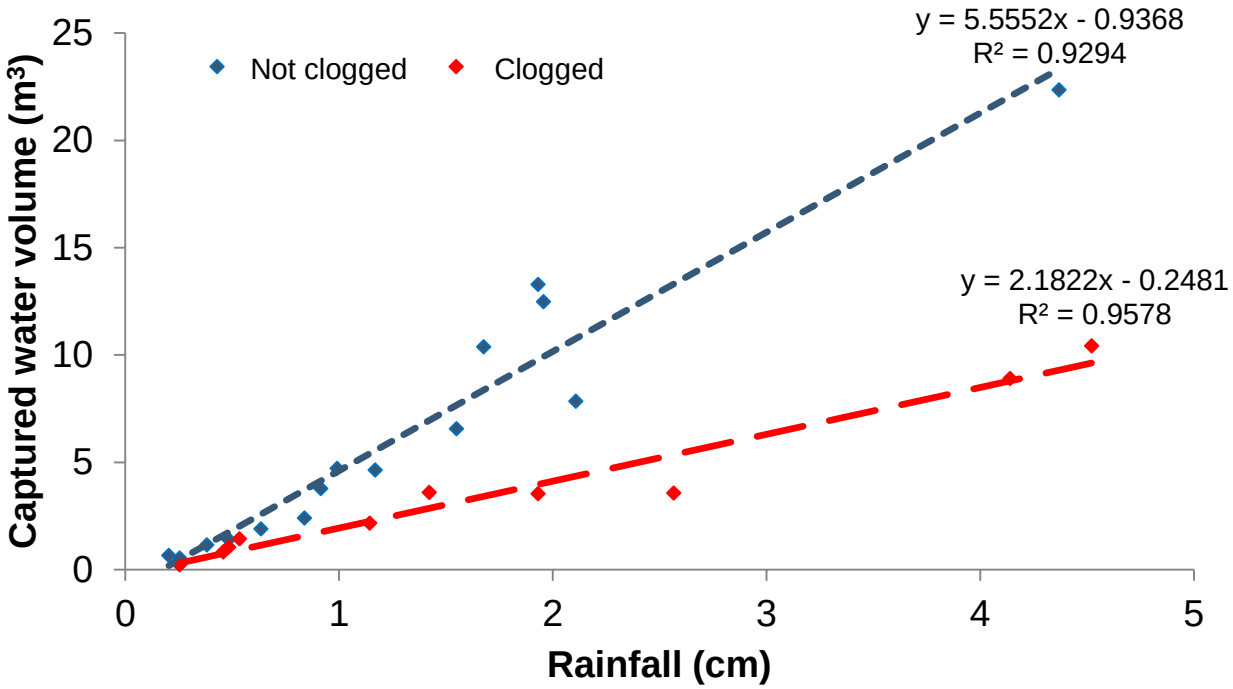
Even when clogged, the surface is not sealed.



Louisville control 19H
Level data at 1-minute intervals
Rainfall data at 5-minute intervals MSD gauge TR05

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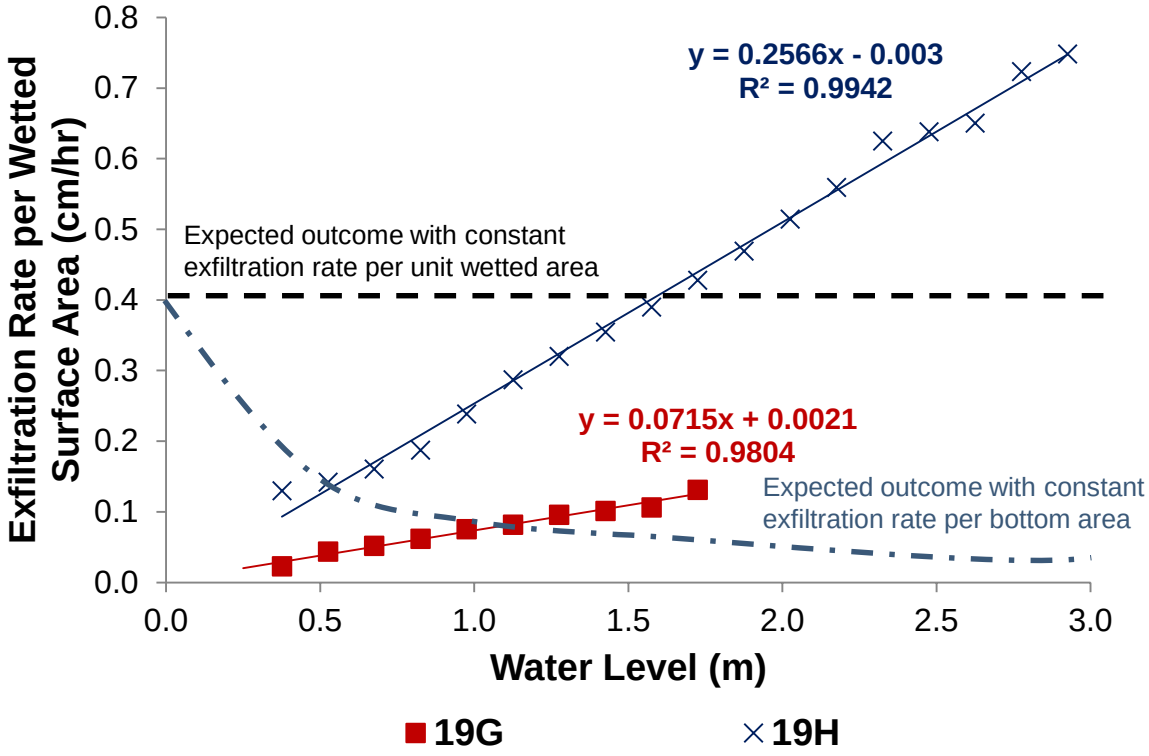
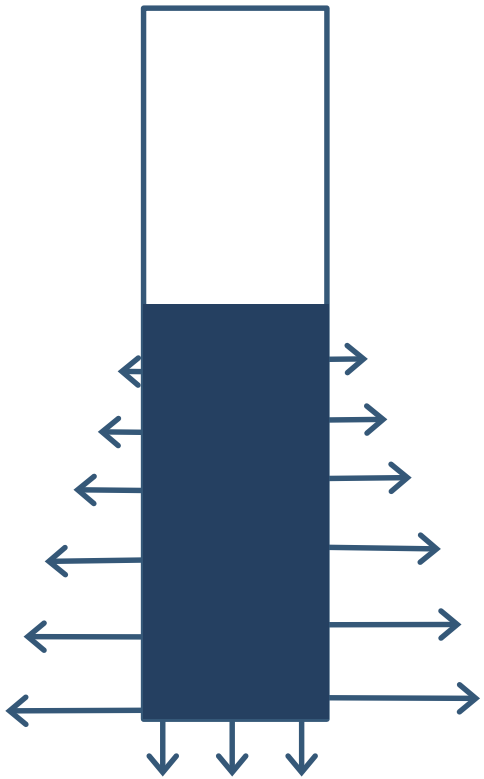
Constant exfiltration across wetted perimeter or base is not supported by the measurements.





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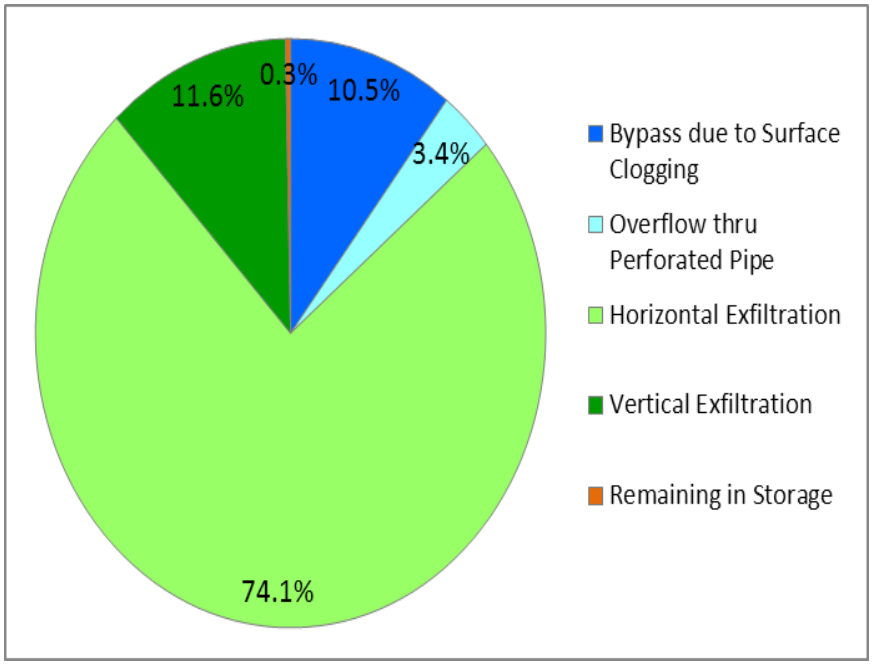
Modeling the fate of runoff showed that most of the captured water exfiltrated laterally through the side walls.

Subsurface flow patterns and interactions with groundwater will be the emphasis of near-term studies in KY and KS.

Flow patterns will also be investigated in Philadelphia under the NCER cooperative agreements.



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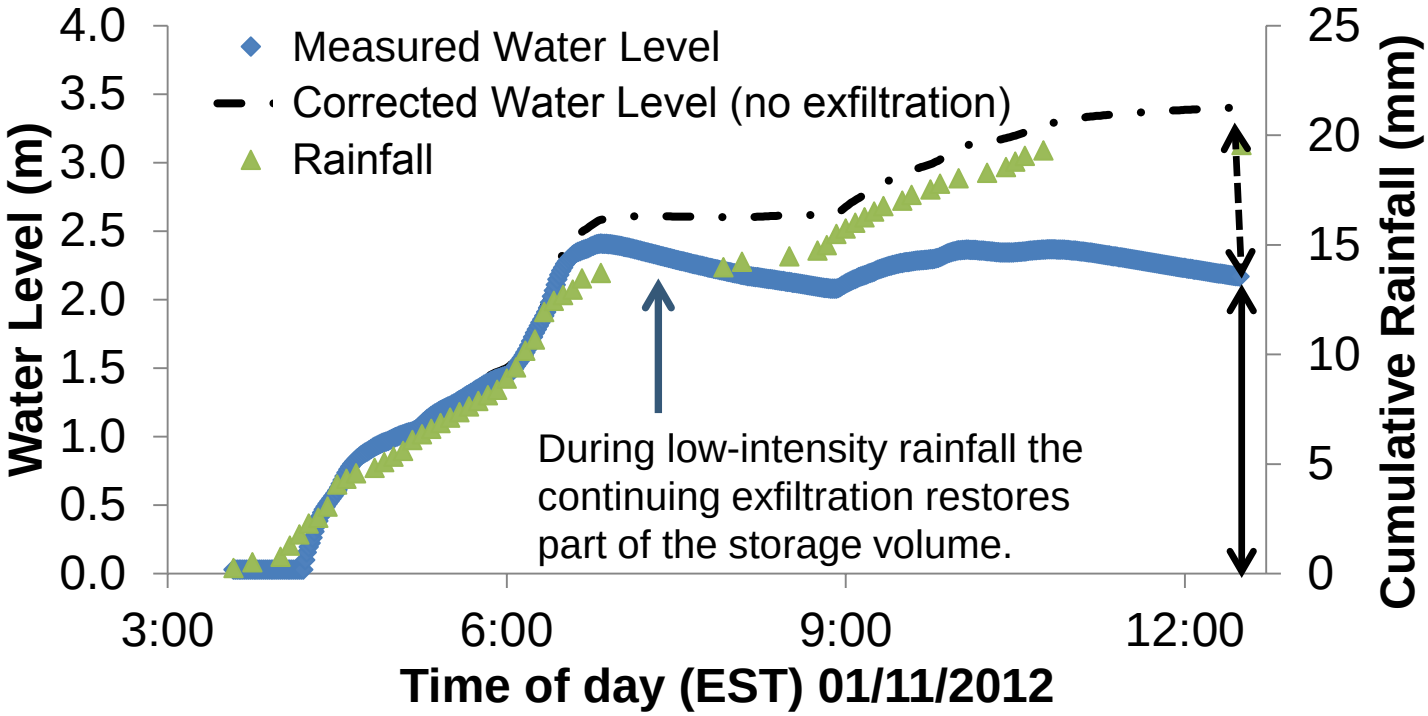
Intra-event exfiltration can be significant



Static sizing criterion may significantly oversize the SCM.

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Maintenance:

- Multiple techniques were implemented.
- Each technique increased surface infiltration capacity, but did not always restore baseline conditions.
- Longevity of the restored infiltration capacity varied.
- Results are probably product specific.

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We have costs for maintenance activities undertaken to date but have concerns about scaling.

Cost of initial maintenance techniques			
Method	Cost ($)	Area maintained (ft^2)	Unit cost ($/ ft^2)
Sweeping	370	960	0.385
Air jetting & brush	921	1,400	0.658

Note: We expect some economy of scale to produce lower unit costs when additional controls are built.

Sweeping was only done to control 19G. Fixed mobilization / demobilization costs may skew unit cost estimate

Data source: URS

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Research at Fort Riley ….

Photo: Chris Otto

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Research at the K-5 school includes interaction with the STEM program

Photo: Maria Childs, Fort Riley Public Affairs

https://www.army.mil/article/174165/fort_riley_students_go_beyond_the_classroom_to_learn_science_of_water

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Monitoring Clogging of the Permeable Pavement

- Previous EPA research provides a foundation for predicting the clogging mechanism and progression.
- This site is providing us an opportunity for confirmatory monitoring, evaluation of alternate instrumentation to determine maintenance time, confirmation that the clogging depends on rainfall, and evaluation of maintenance practices.

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Standing water generally indicates that it is (past) time for maintenance.

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Although clear on the surface, the pathways are clogged at deeper layers.

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The solids are very fine-grained

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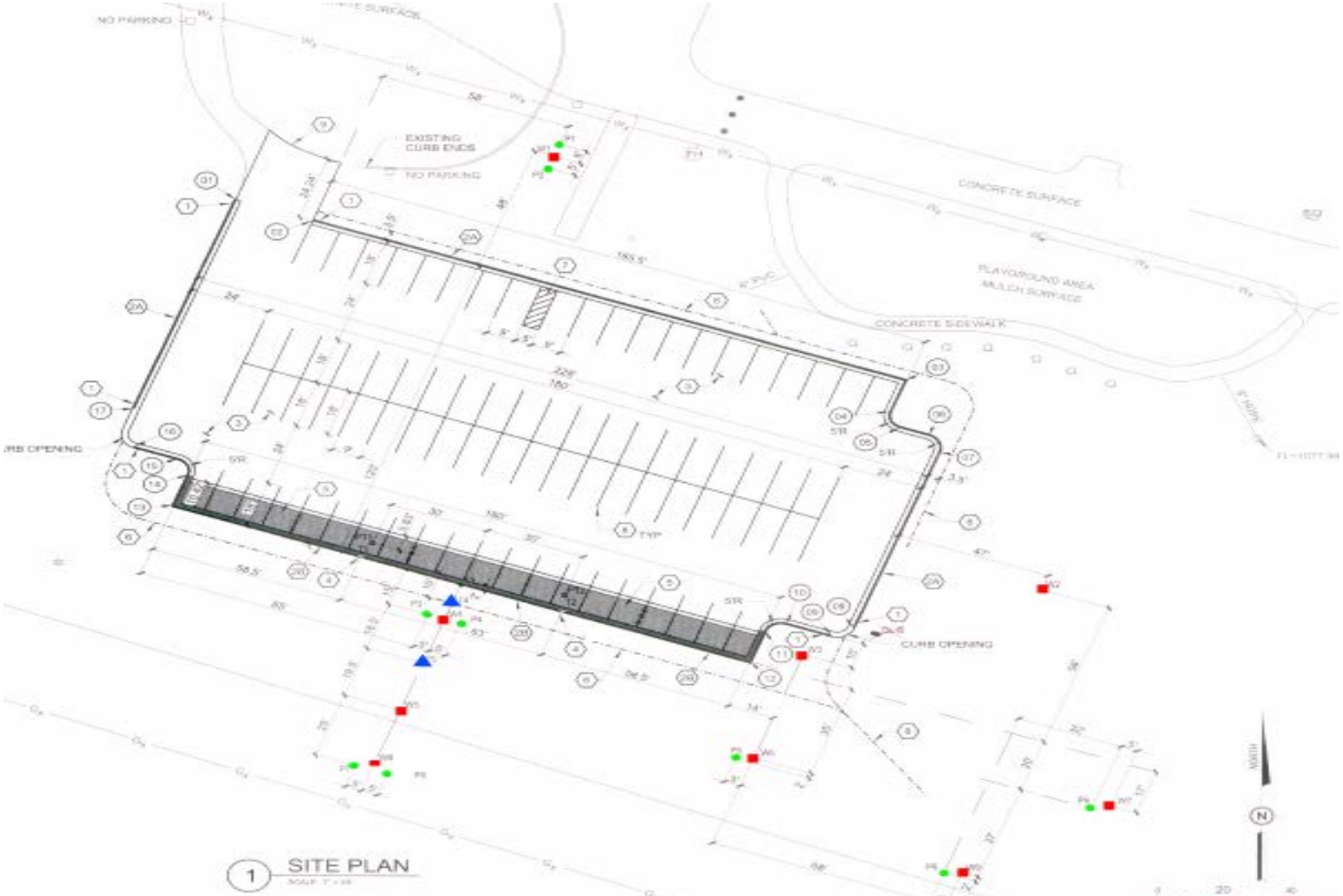
Near field subsurface monitoring.



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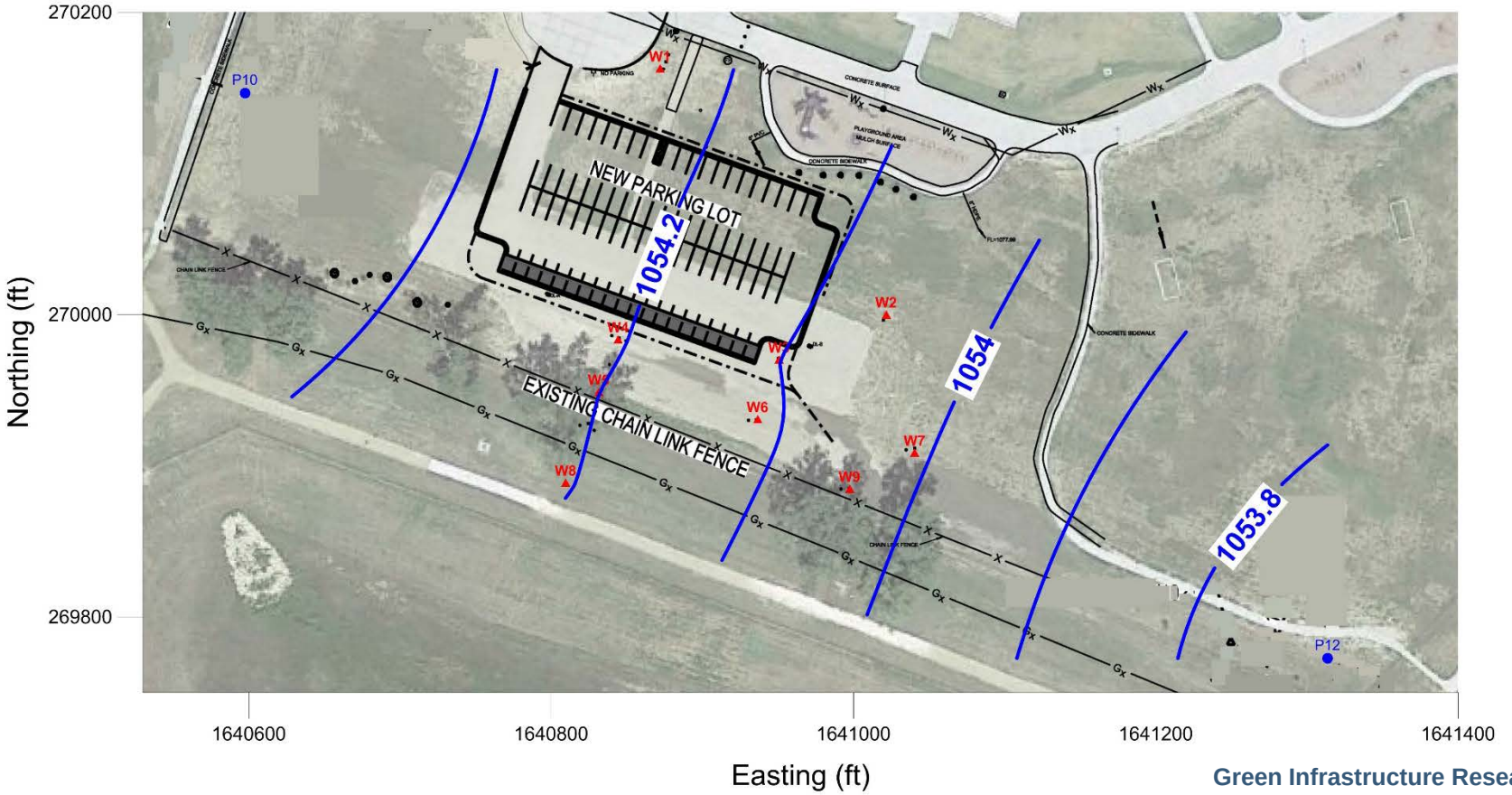
Water Table Elevation
August 31, 2015



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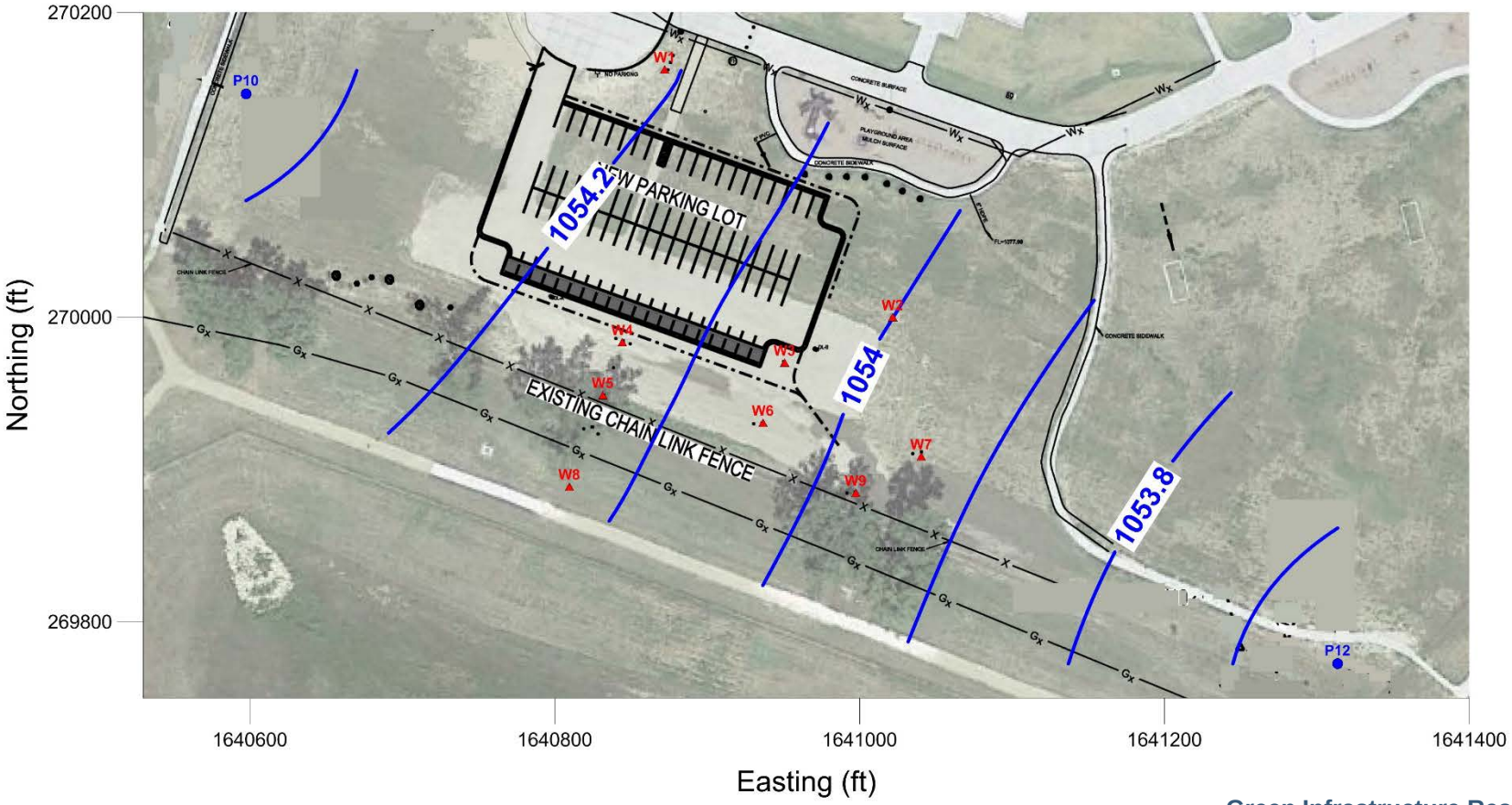
Water Table Elevation
September 2, 2015



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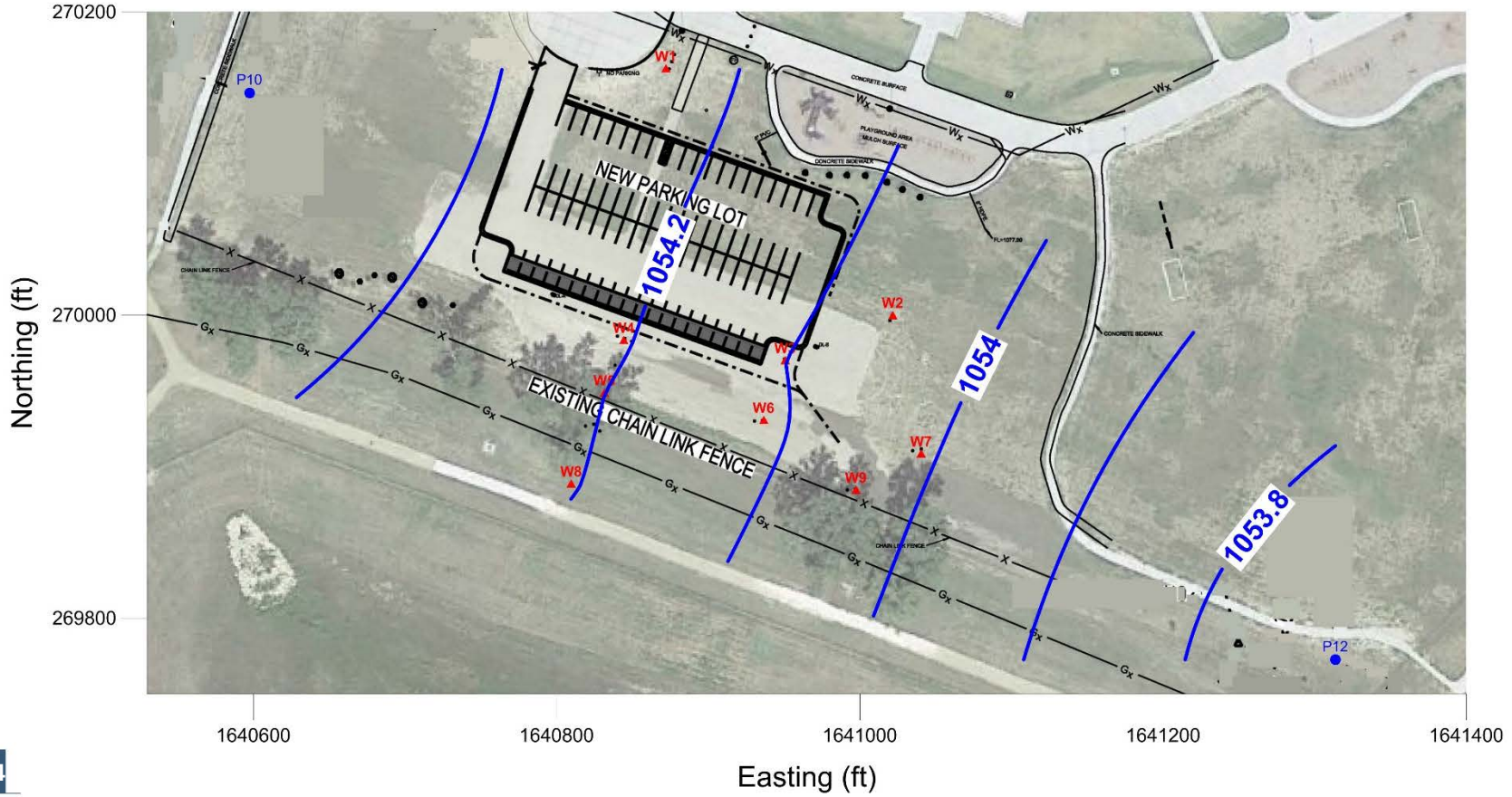
Water Table Elevation
August 31, 2015



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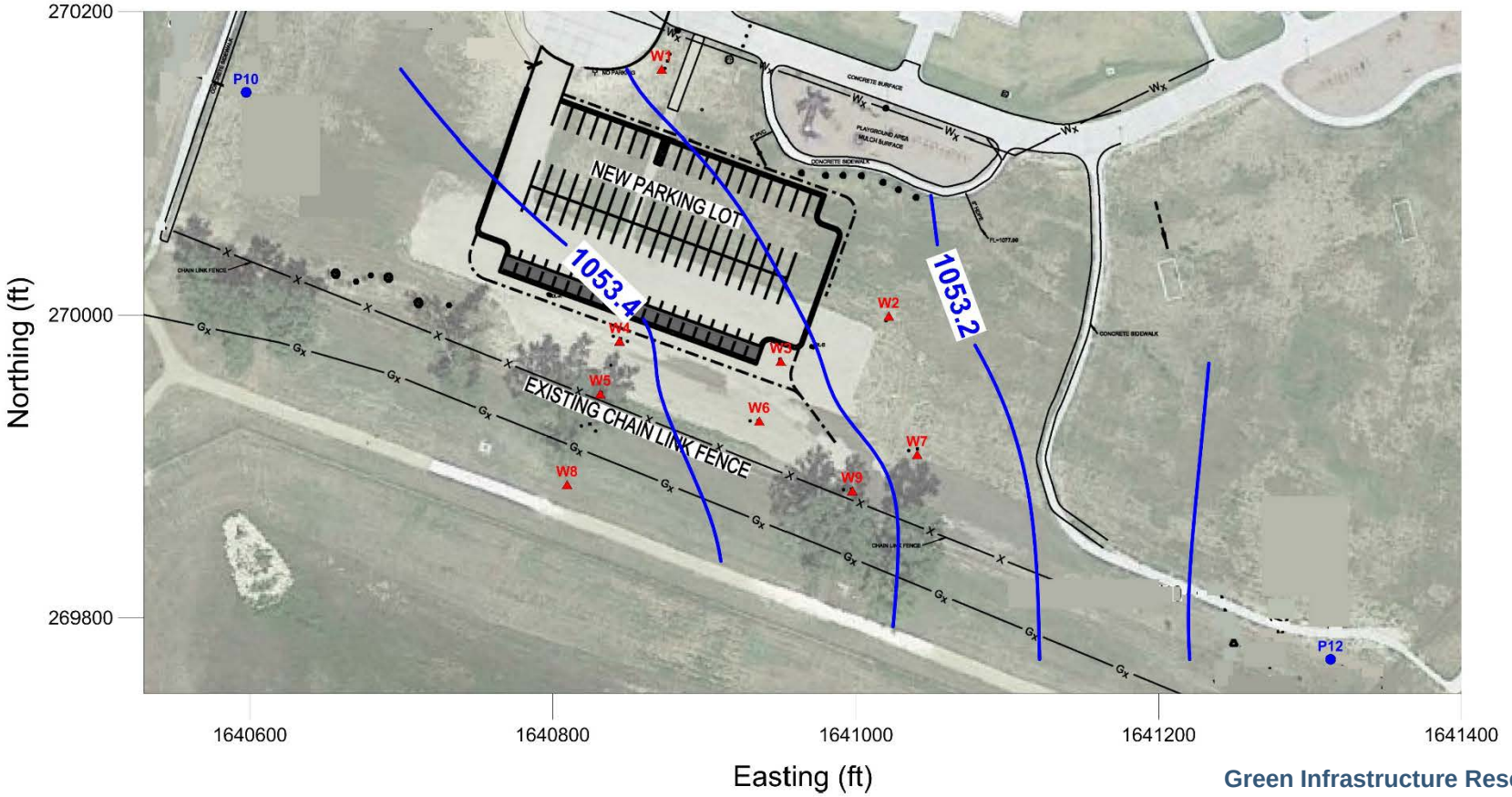
Water Table Elevation
November 30, 2015



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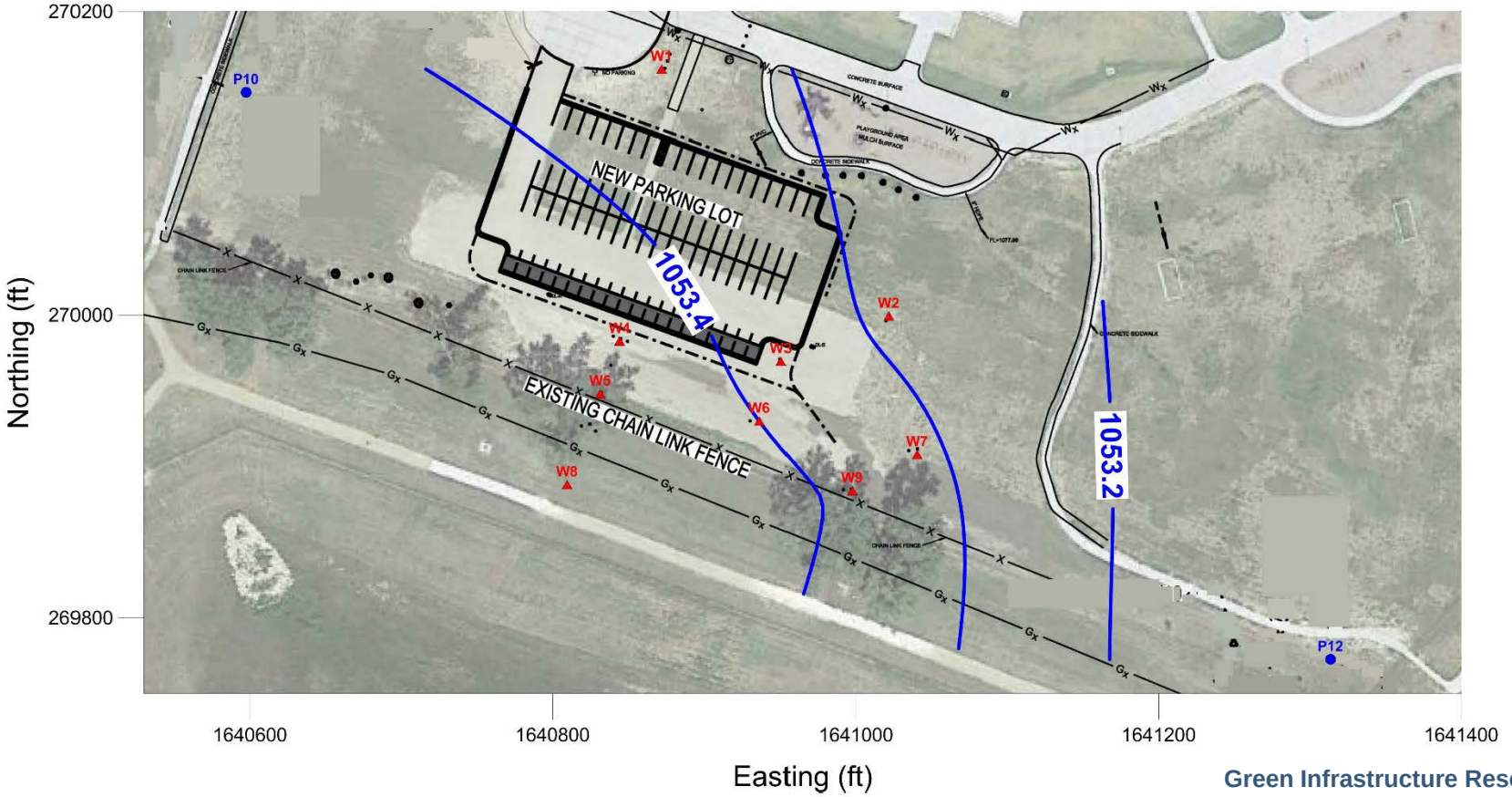
Water Table Elevation
December 1, 2015



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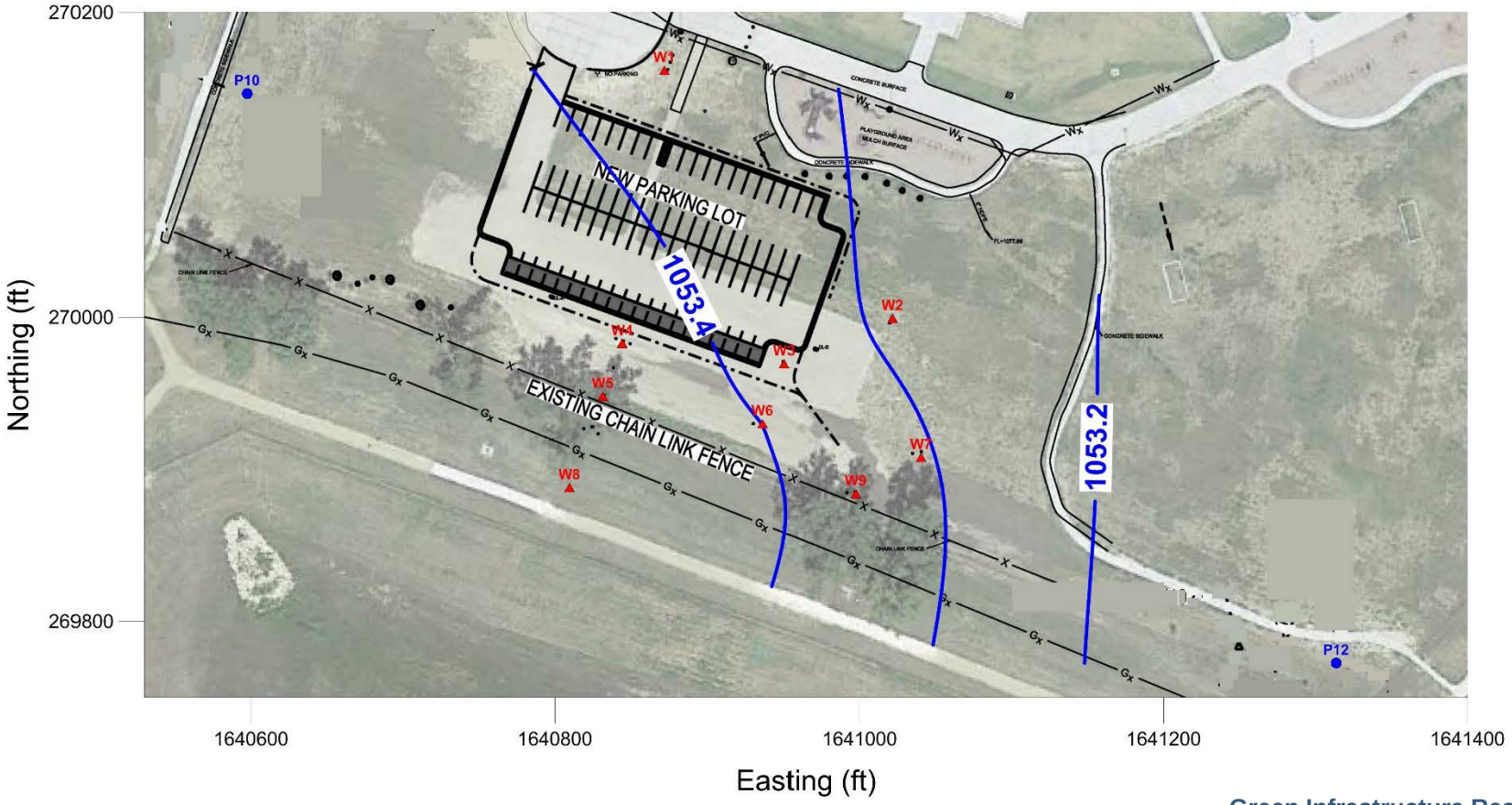
Water Table Elevation
December 2, 2015



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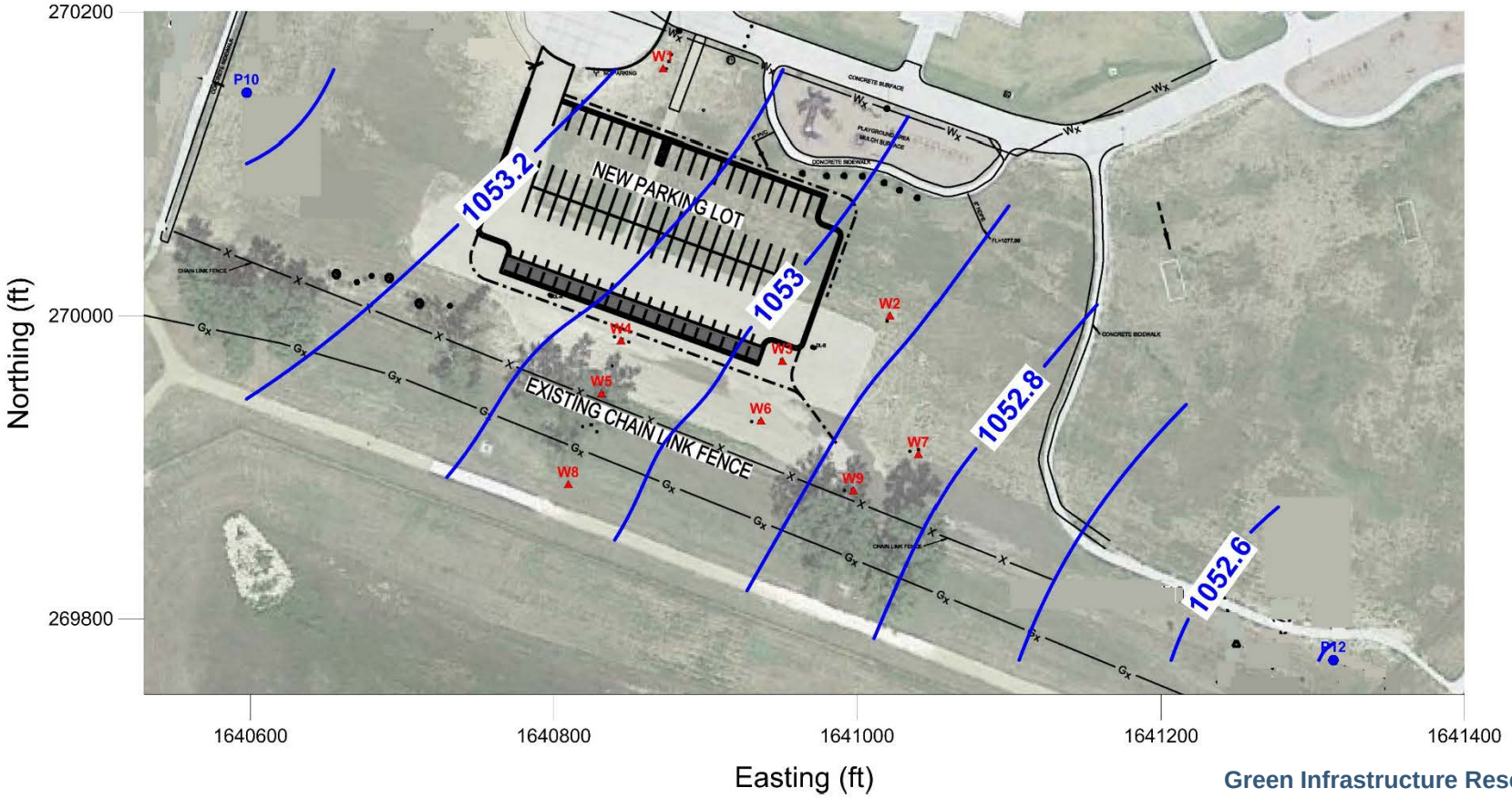
Water Table Elevation
February 17, 2016



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Water Table Elevation
April 4, 2016

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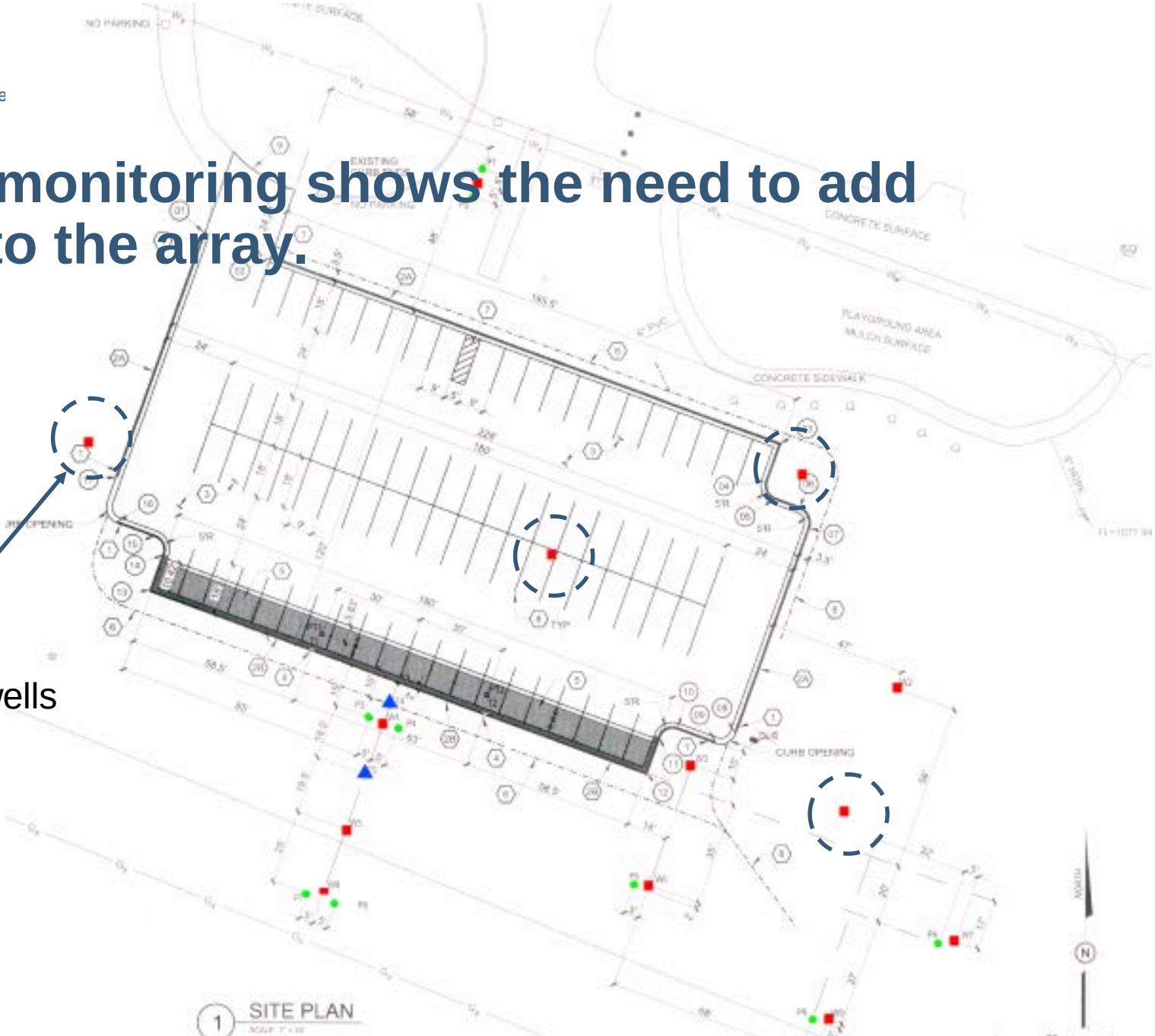
Initial monitoring shows the need to add wells to the array.



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Interaction of Captured Water with the Groundwater

- Collecting runoff and infiltrating in a concentrated area should affect the groundwater hydrology – so we are monitoring near-field groundwater levels.
- Infiltrating the runoff water will affect groundwater chemistry. We are testing for this as well.
- We are also documenting water chemistry during the vadose zone migration.

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Analytes of interest

Field analysis	Laboratory analysis	
pH	ICP-OES Total Metals	Iodide
Temperature	ICP-OES Dissolved Metals	Phosphate
Dissolved Oxygen	ICP-MS Total Metals	Sulfate
Specific Conductivity	Total Nitrogen	O, H Stable isotopes of water
ORP	Nitrate + Nitrite	DOC
Alkalinity	Ammonia	DIC
Dissolved Ferrous Iron	Bicarbonate	Low level volatile organic compounds‡
Dissolved Sulfide	Bromide	Organic compounds (SVOC)‡
Turbidity	Chloride	
TDS	Fluoride	

‡ Region 7 is assisting with collecting and analyzing these samples.

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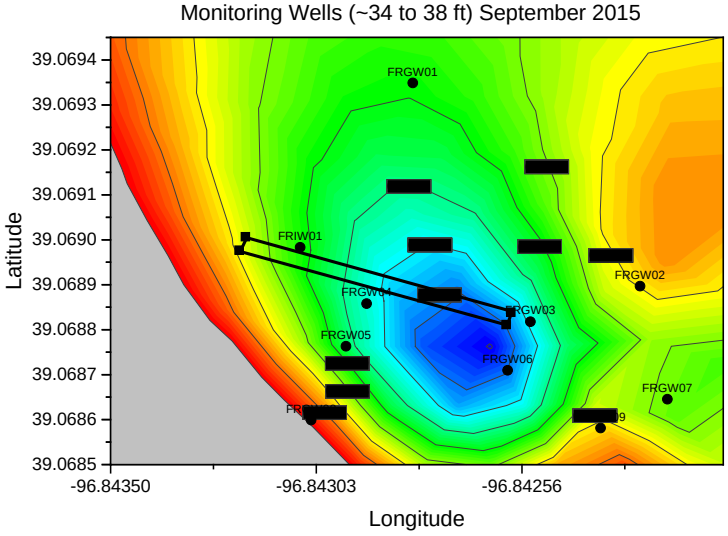
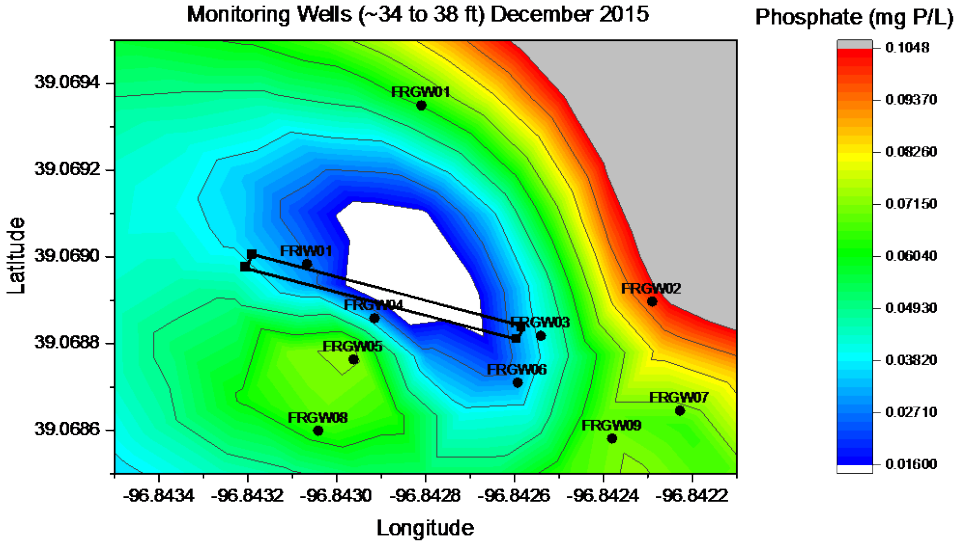
Early indicators suggest that the infiltrating water alters the subsurface phosphate





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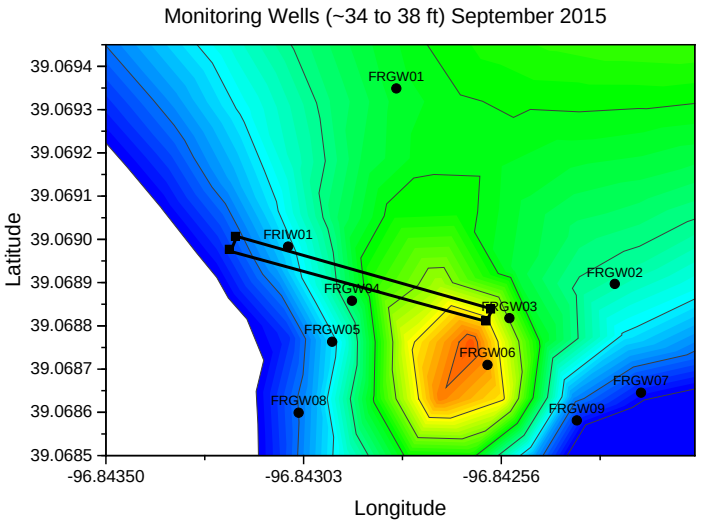
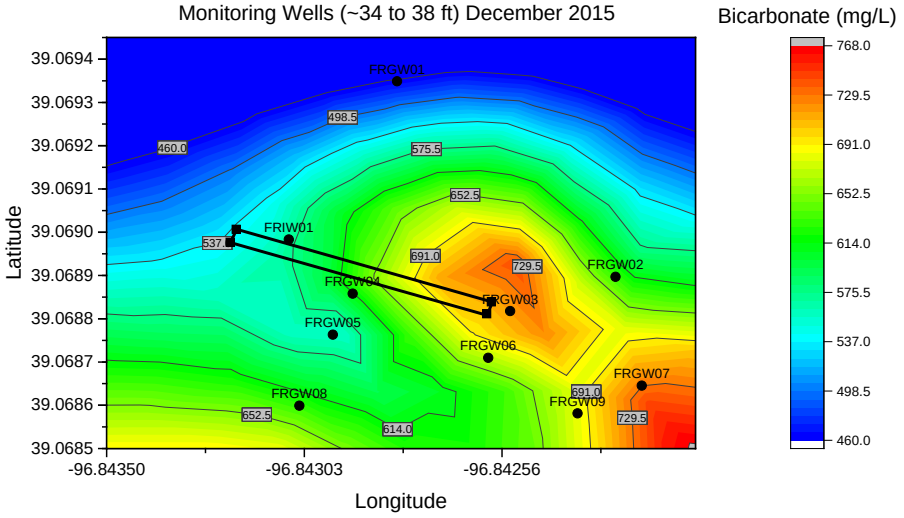
It appears that the exfiltrate carries carbonate from the aggregate.

September 2015



December 2015



34 to 38 ft BGL

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Office of Research and Development
National Risk Management Research Laboratory
Water Supply and Water Resource Division
Urban Watershed Management Branch

Green Infrastructure Research