Research on Green Infrastructure At the USEPA

Michelle Simon, Ph.D., P.E.
United States Environmental Protection Agency

Minnesota Stormwater Seminar Series

January 21, 2021

Disclaimer

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Introduction

Michelle Simon, Ph.D. , P.E.

United States Environmental Protection Agency

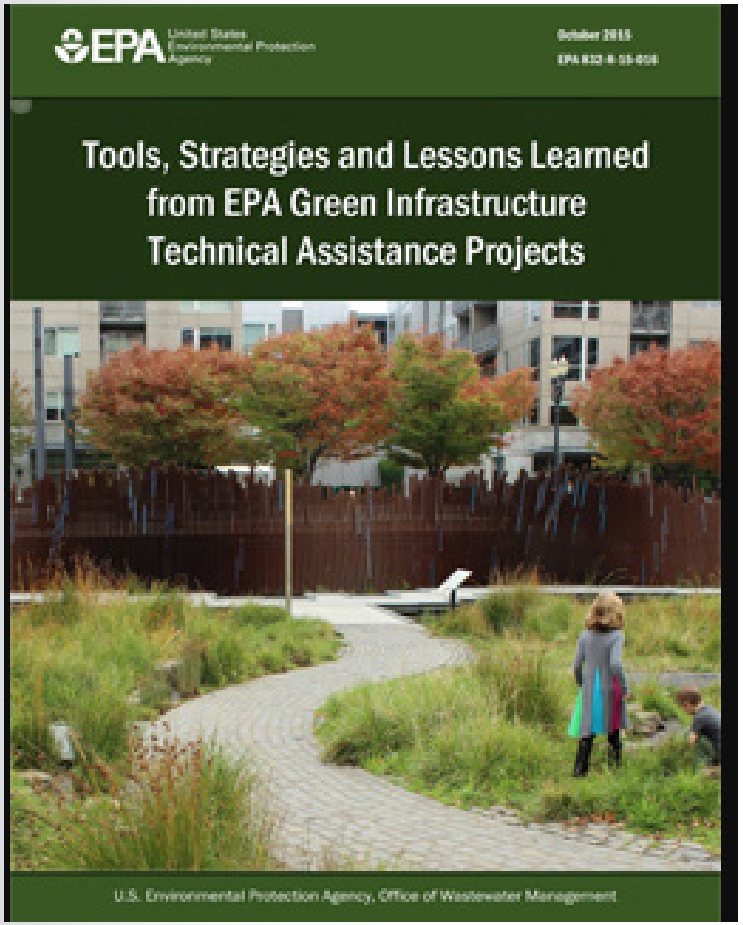
Cincinnati, OH

Simon.michelle@epa.gov

EPA Point of Contact for SWMM

Worked on Green Infrastructure since 2010

Talk Outline



Introduction

EPA's Stormwater Management Model (SWMM)

EPA's Green Infrastructure Empirical Research

EPA's Green Infrastructure Modeling Research

Summary

EPA ORD Green Infrastructure and SWMM Members

Jason Bernagros, bernagros.jason@epa.gov

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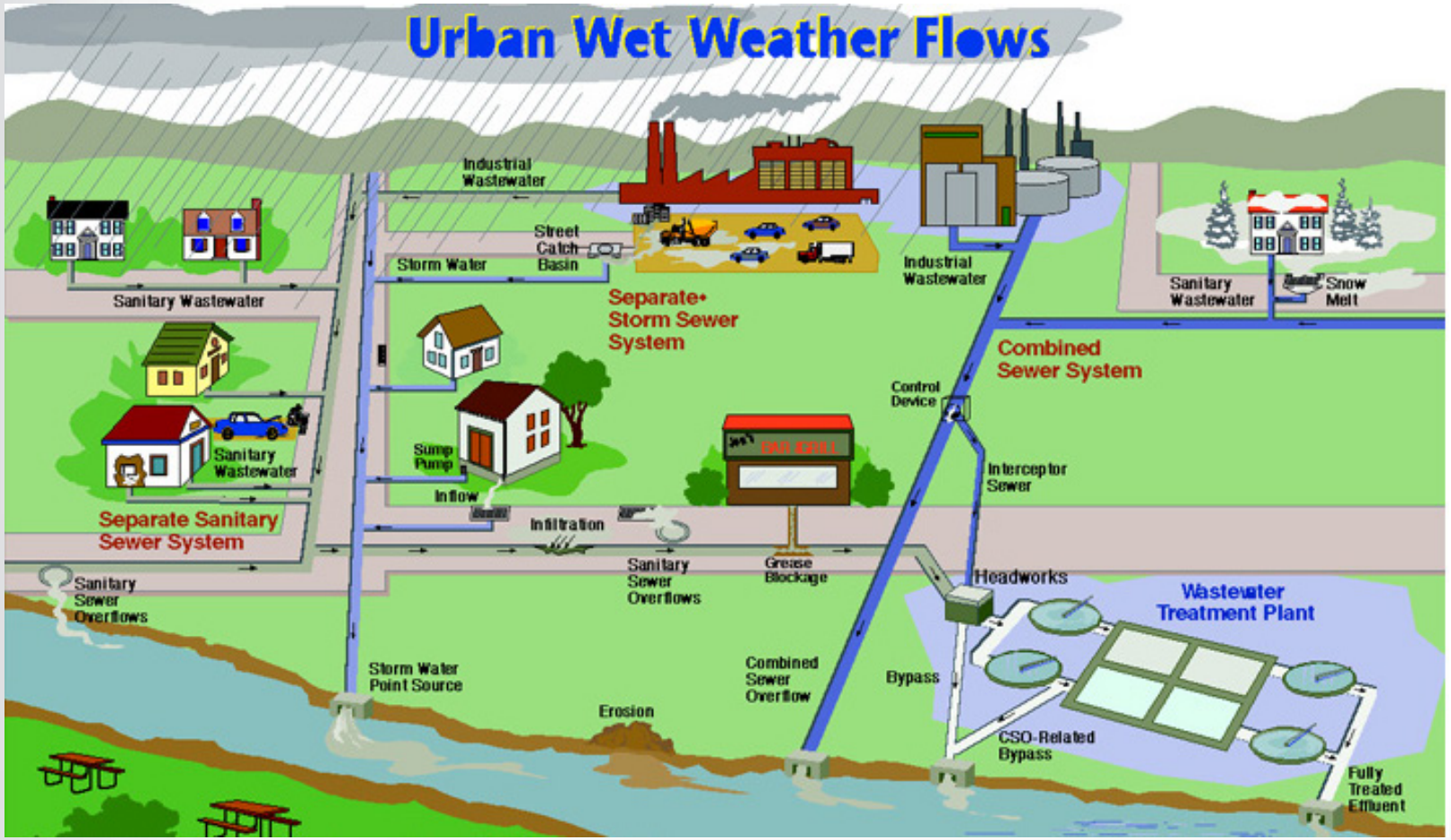
Michelle Simon, simon.michelle@epa.gov

Michael Tryby, tryby.michael@epa.gov

What is SWMM?

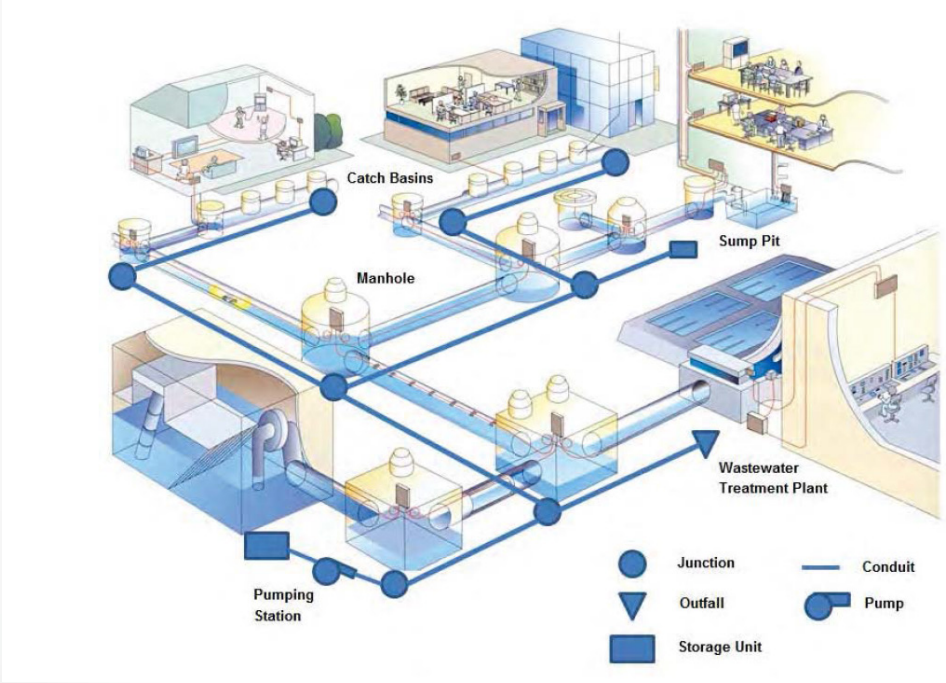
https://www.epa.gov/water-research/storm-water-management-model-swmm



SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

Lew Rossman (retired), Michelle Simon, Michael Tryby, Katherine Ratliff

EPA Stormwater Management Model

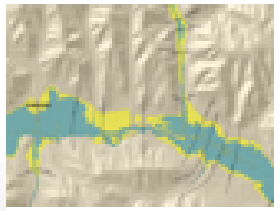


Why we need SWMM (CSO, MS4, TMDL, NPDES)

Design and sizing of drainage system.

Control of combined and sanitary sewer overflows.

Modeling Inflow & Infiltration in sanitary sewer systems.

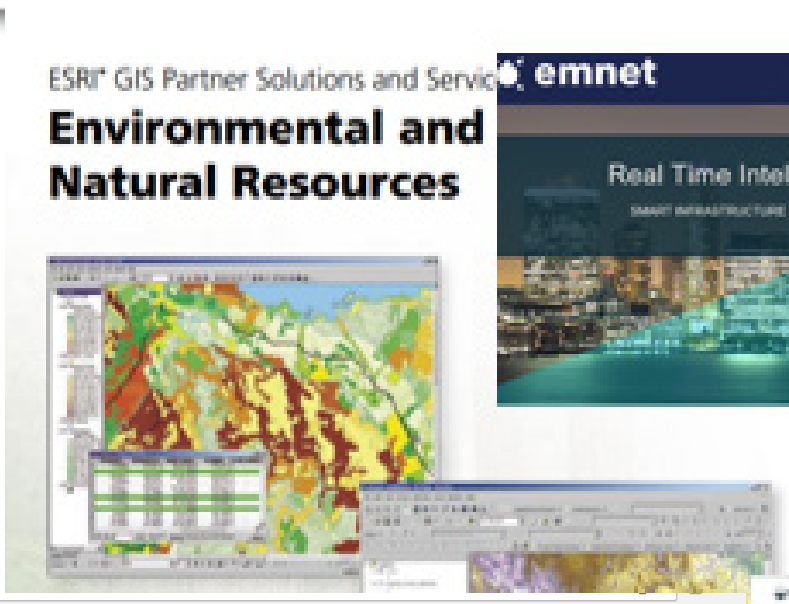


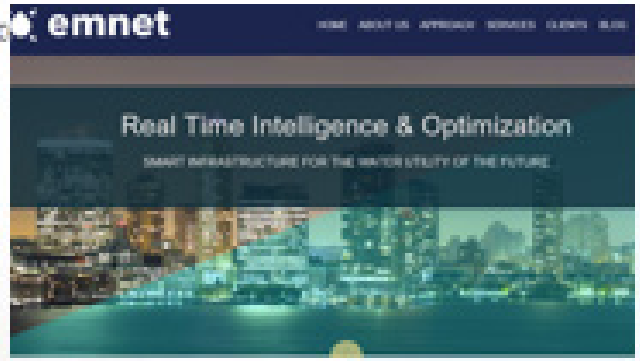
Generating non-point source pollutant loadings for waste load allocation studies.

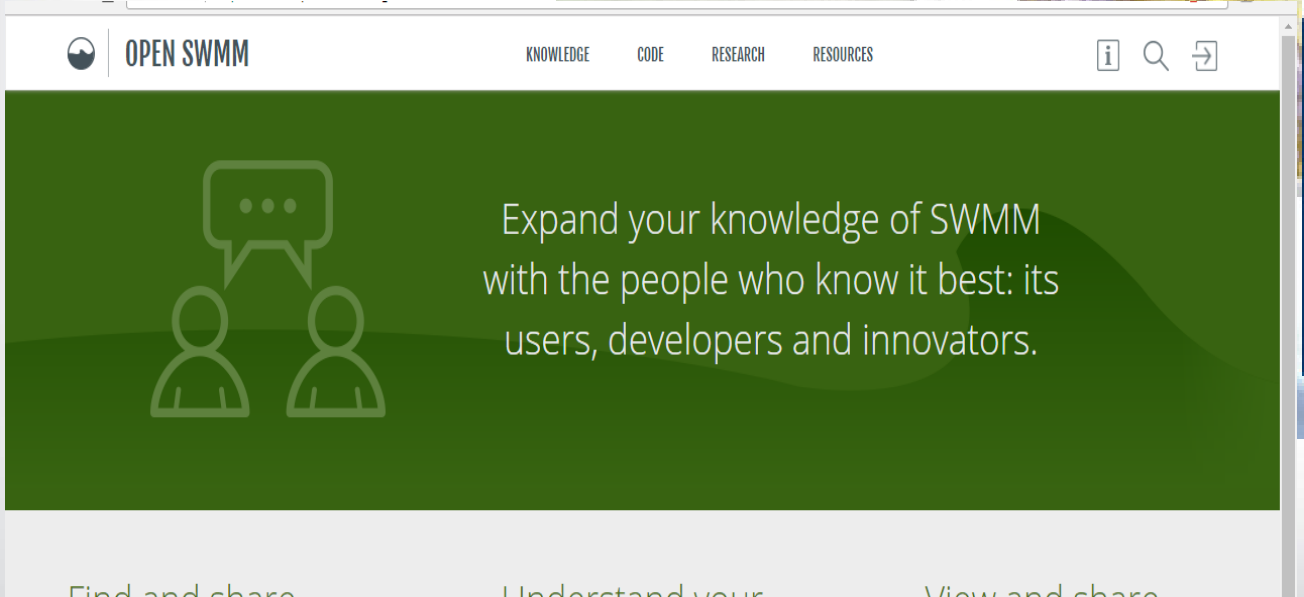
Evaluating green infrastructure.

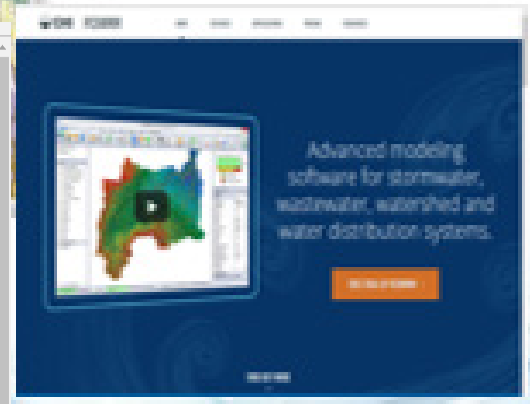
SWMM – Many stakeholders

Downloaded >30,000 annually







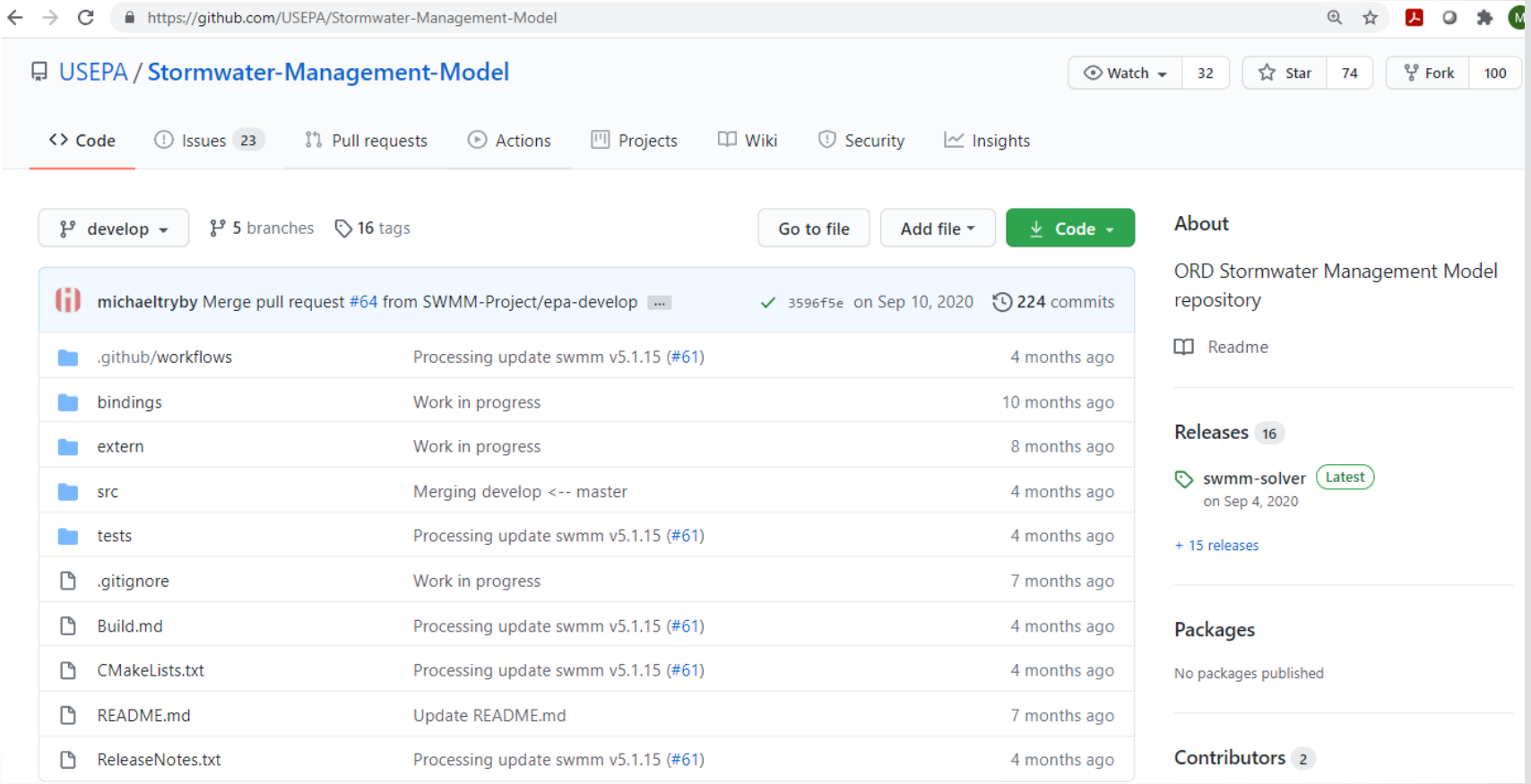


Regulators
Communities,
Utilities,
Private industry,
Consultants,
Academia

Open Community Development

https://github.com/USEPA/Stormwater-Management-Model

SWMM 5.1.015 July 2020



Jay Garland, Nichole Brinkman, Greater Cincinnati Water Works

Using SWMM to calculate COVID detection

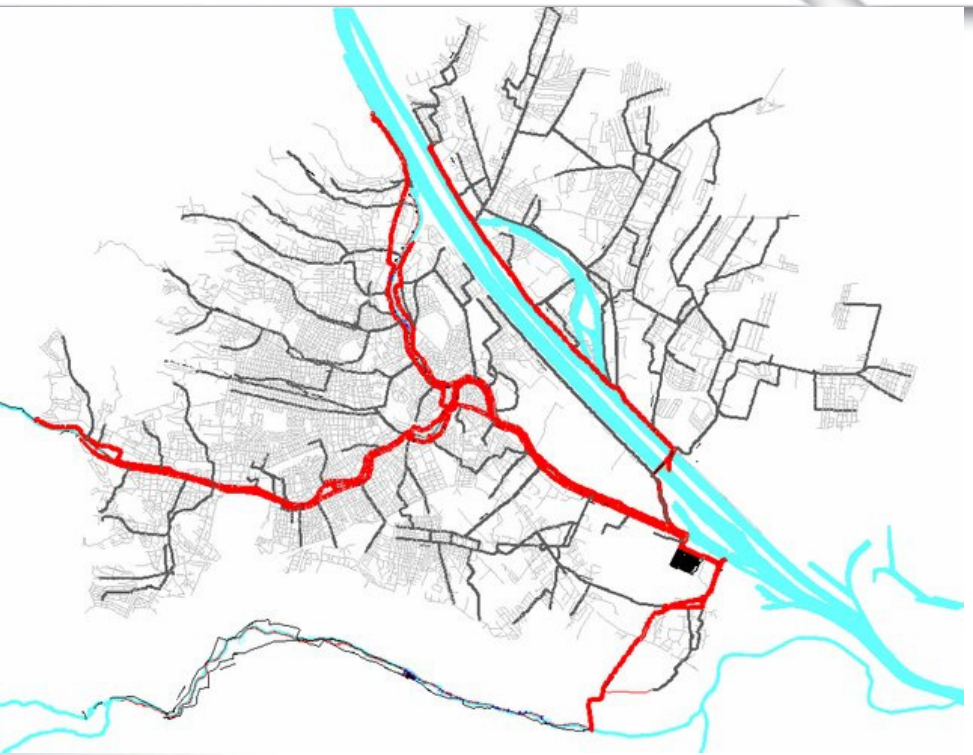


Figure: Fuchs, L. and T. Beeneken. (2004). Development and Implementation of Real-Time Control Strategy for the Sewer System of Vienna City. 6th International Conference on Urban Drainage Modeling – Volume 2

Estimated kinetic parameters of SAR-CoV-2 attenuation in wastewater at ambient temperature

Time to 99.9% reduction (hours)	Half-Life, $t_{1/2}$ (hours)	Mean Lifetime, τ (hours)	Decay constant, λ
48	4.82	6.95	0.143
72	7.22	10.4	0.096

From Hart & Halden (2020) informed by Gundy et al. 2009

https://www.epa.gov/water-research/water-research-webinar-series

https://www.epa.gov/coronavirus

Olga E. Hart, Rolf U. Halden, 2020
Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges, Science of The Total Environment, Volume 730, 2020
https://doi.org/10.1016/j.scitotenv.2020.138875

Michelle Simon, Michael Tryby

Ground-truthing SWMM, Hydrology

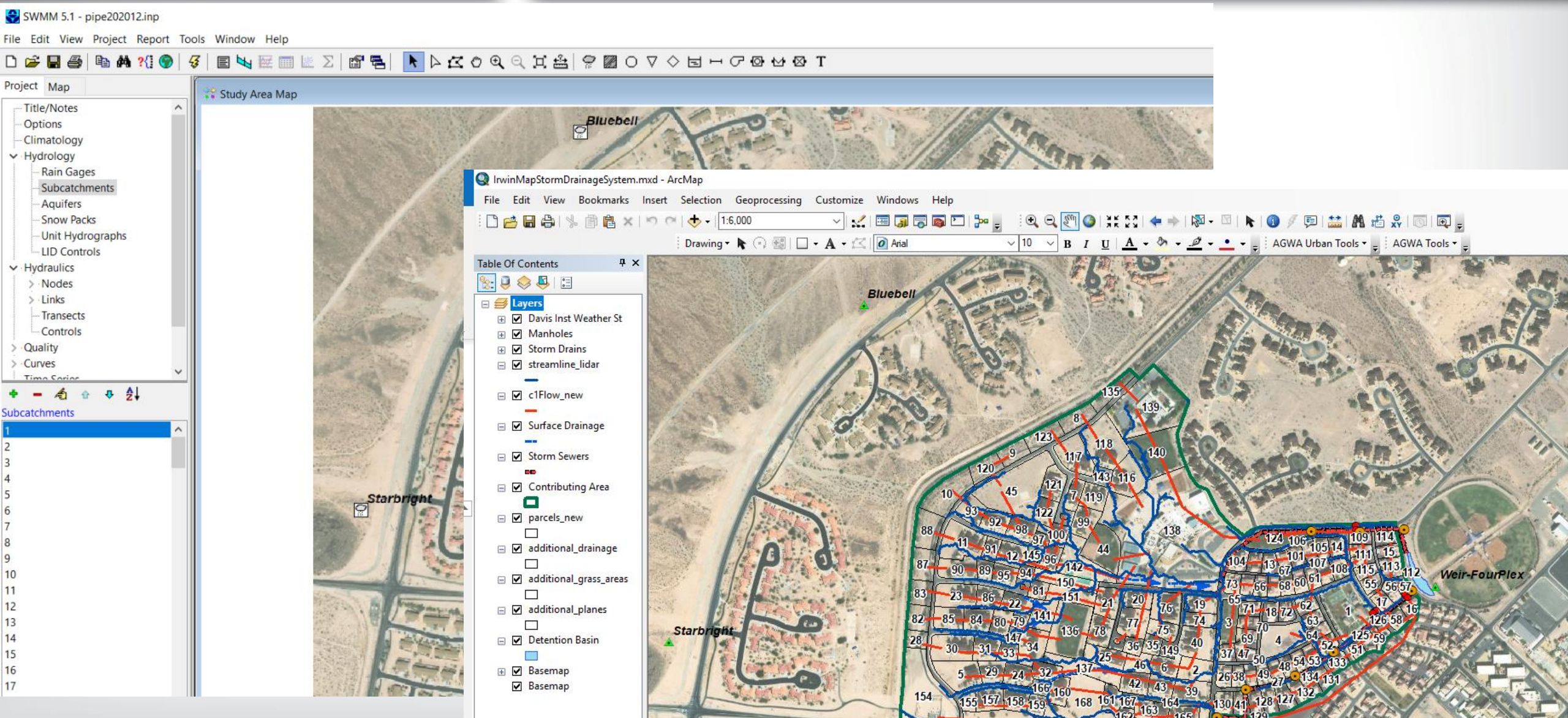
Metric	Average	Range
Nash-Sutcliffe Efficiencies, NSE	0.81	0.55 to 0.99
Percent, Bias, PBIAS	-9%	-74 to 21%
Ratio of Root Mean Square Error to Standard Deviation of measured Values, RSR	0.485	0.18 to 1.11
Index of Agreement, d	0.94	0.85 to 1.00
Percent Magnitude of Peak, %	-9%	-48 to 97%

Bioretention
Bioswale
Green Roof
Permeable Pavement
(Infiltration Trench)

Michelle Platz, Michelle Simon, Michael Tryby. (2020). "Testing of Storm Water Management Model Low Impact Development Modules." *Journal of the American Water Resources Association (JAWRA)*. https://doi.org/10.1111/1752-1688.12832 .

Michelle Simon, Steve Kraemer, USDA, UC-Riverside, UofArizona

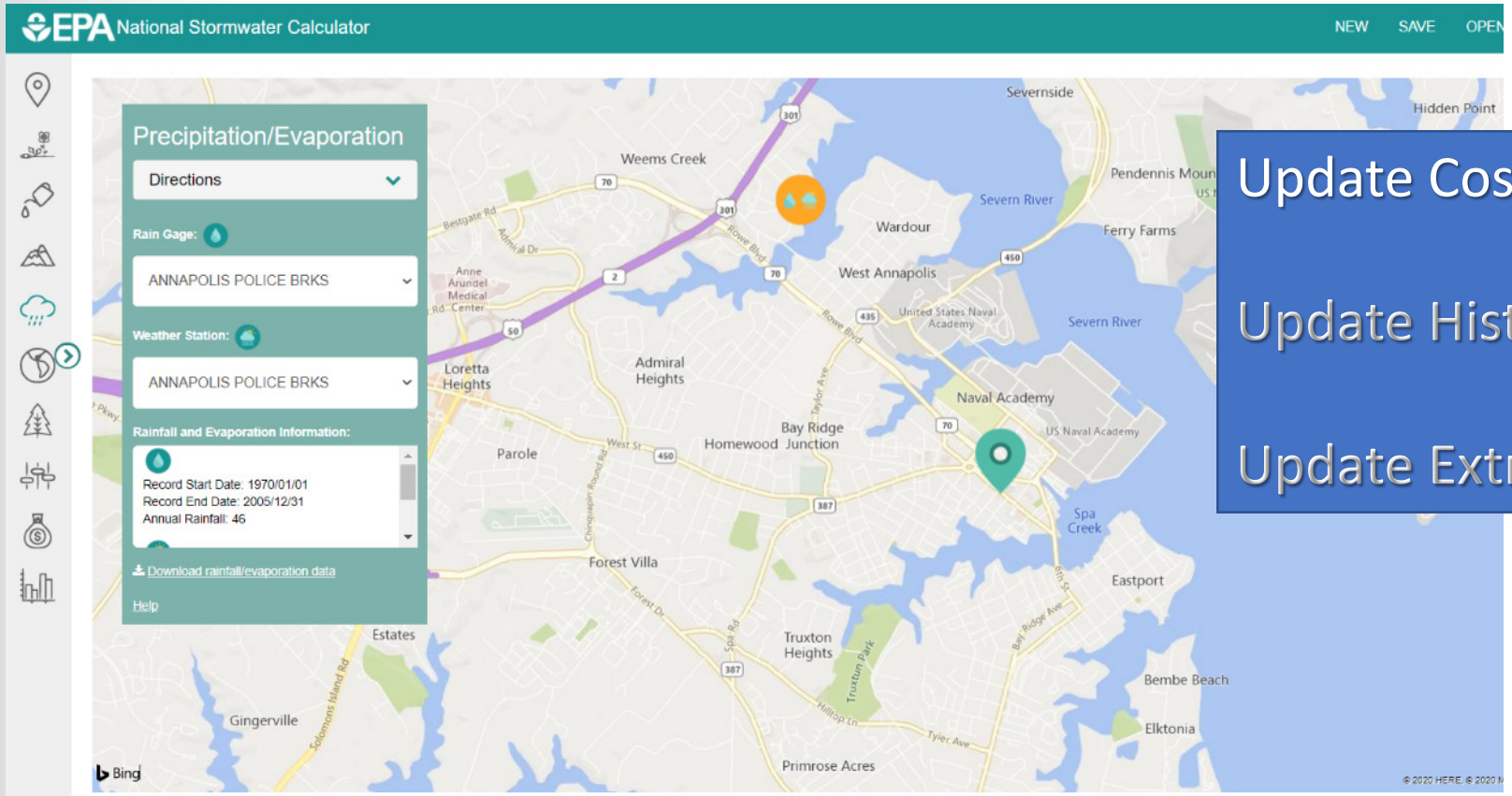
Comparing SWMM to AGWA Urban Tool



Lew Rossman (retired), Jason Bernagros, Michelle Simon

EPA Stormwater Calculator

https://www.epa.gov/water-research/national-stormwater-calculator



Update Cost Data from BLS

Update Historical Meteorological Data to 2019

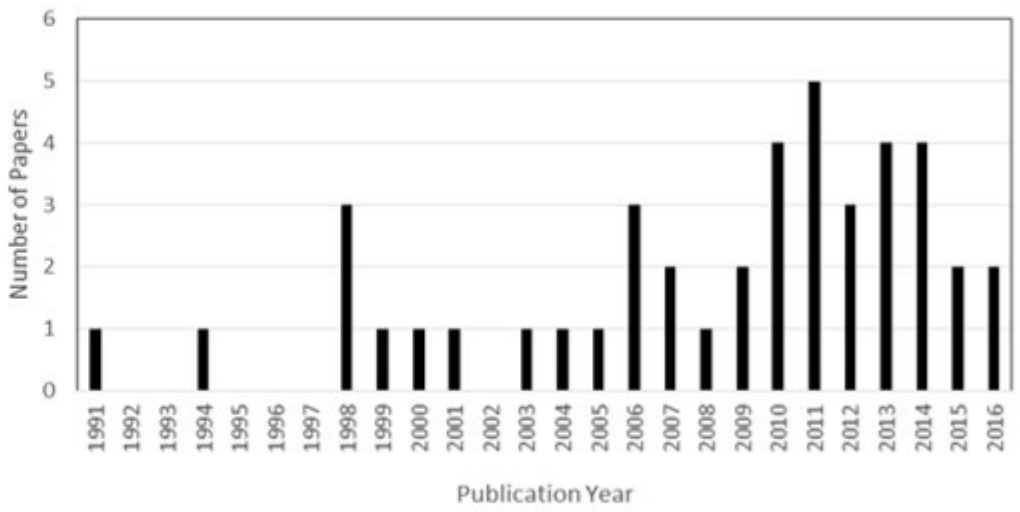
Update Extreme Event Data from CREAT 3.0

Bernagros, J.; D. Pankani; S.D. Struck; M.E. Deerhake. (2021). "Estimating Regionalized Planning Costs of Green Infrastructure and Low-Impact Development Stormwater Practices: Updates to the US Environmental Protection Agency's National Stormwater Calculator. Volume 7 Issue 2
https://doi.org/10.1061/JSWBAY.0000934

Washoff in SWMM

Washoff is the process of erosion or solution of constituents from a subcatchment surface during a period of runoff.

- **Exponential** $W = C_1 q^{C_2} B$
- **Rating Curve** $W = C_1 Q^{C_2}$
  - W = washoff load (mass/hour)
  - C_1 = washoff coefficient
  - C_2 = washoff exponent
  - q = runoff rate per unit area (inches/hour or mm/hour)
  - B = pollutant buildup in mass units
- **Event Mean**
  - C_1 = pollutant concentration (mass/L)
  - C_2 = 1



Papers with the terms 'Stormwater' and 'Washoff' published each year in the ISI Web of Science Database (43 total).

Slide from Anne Mikelonis and Katherine Ratliff

Examples of EPA GI Study Locations

Permeable Pavement Studies

Edison Environmental Center
Edison, NJ

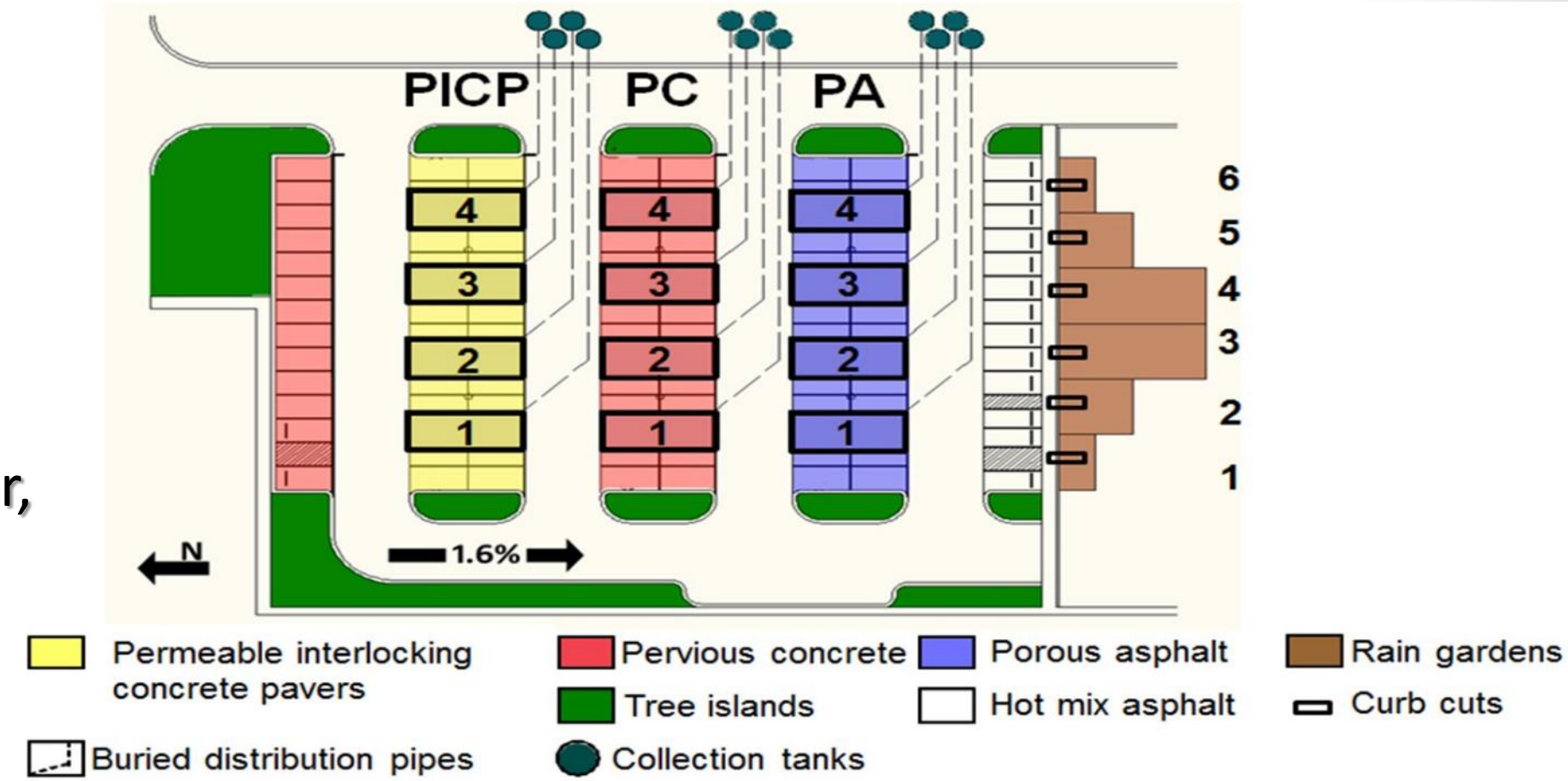
Story Avenue
Louisville, KY

Sietz Elementary School
Fort Riley, KS

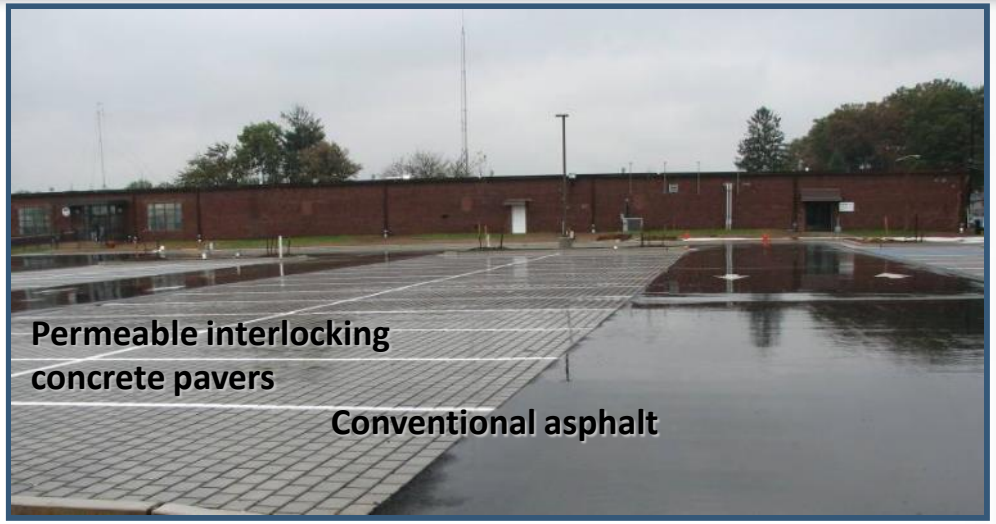
Edison, NJ Permeable Parking Lots

2010 to present

Michael Borst,
Thomas O'Connor
Ariamalar Selvakumar,
+ many more



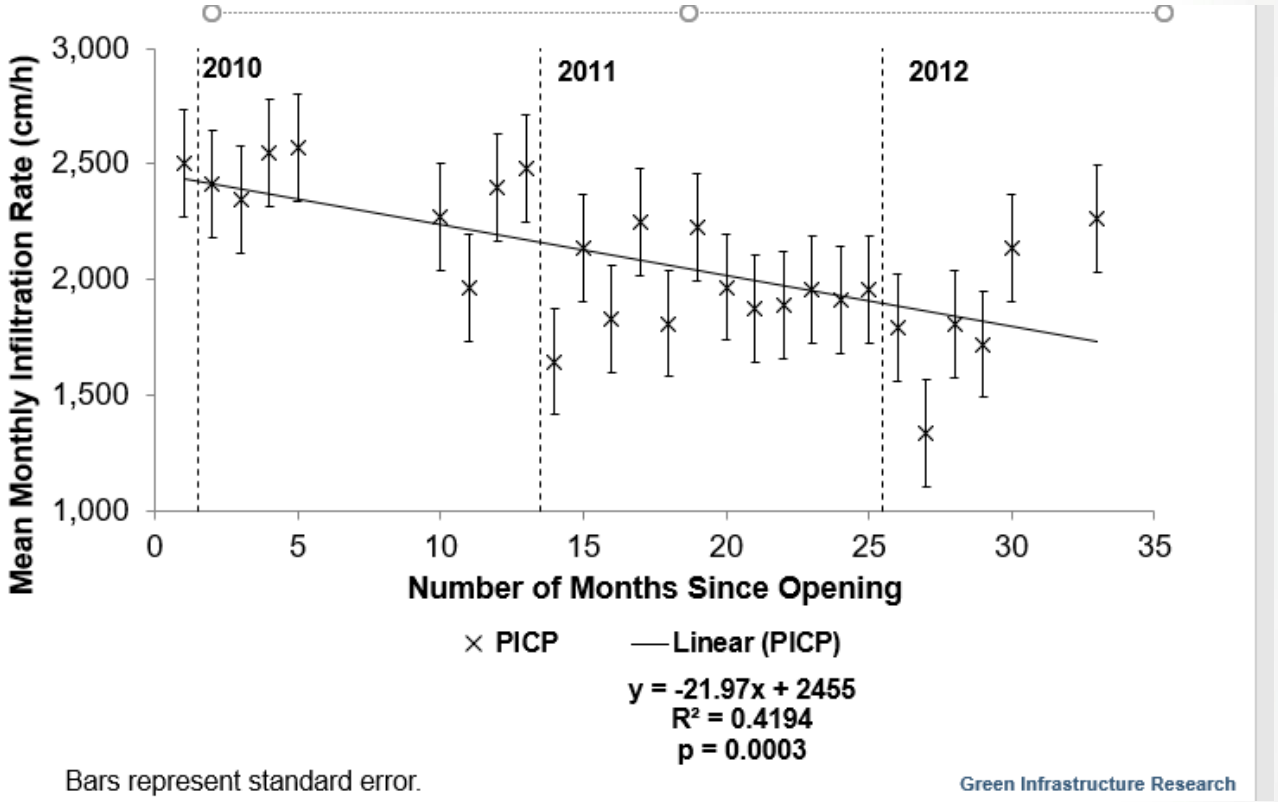
Permeable Pavement



Michael Borst, Thomas O'Connor

Infiltration

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



Razzaghmanesh, M. and M. Borst (2019). "Monitoring the performance of urban green infrastructure using a tensiometer approach." Science of the Total Environment 651: 2535-2545.

Brown, R. A. and M. Borst (2015). "Evaluation of Surface and Subsurface Processes in Permeable Pavement Infiltration Trenches." Journal of Hydrologic Engineering **20**(2): 12.

Brown, R. A. and M. Borst (2014). "Evaluation of Surface Infiltration Testing Procedures in Permeable Pavement Systems." Journal of Environmental Engineering 140(3): 12.

Ahmed, F. and M. Borst (2019). "Monitoring infiltration rates with time domain reflectometers." Water Environment Research 91(12): 1638-1649.

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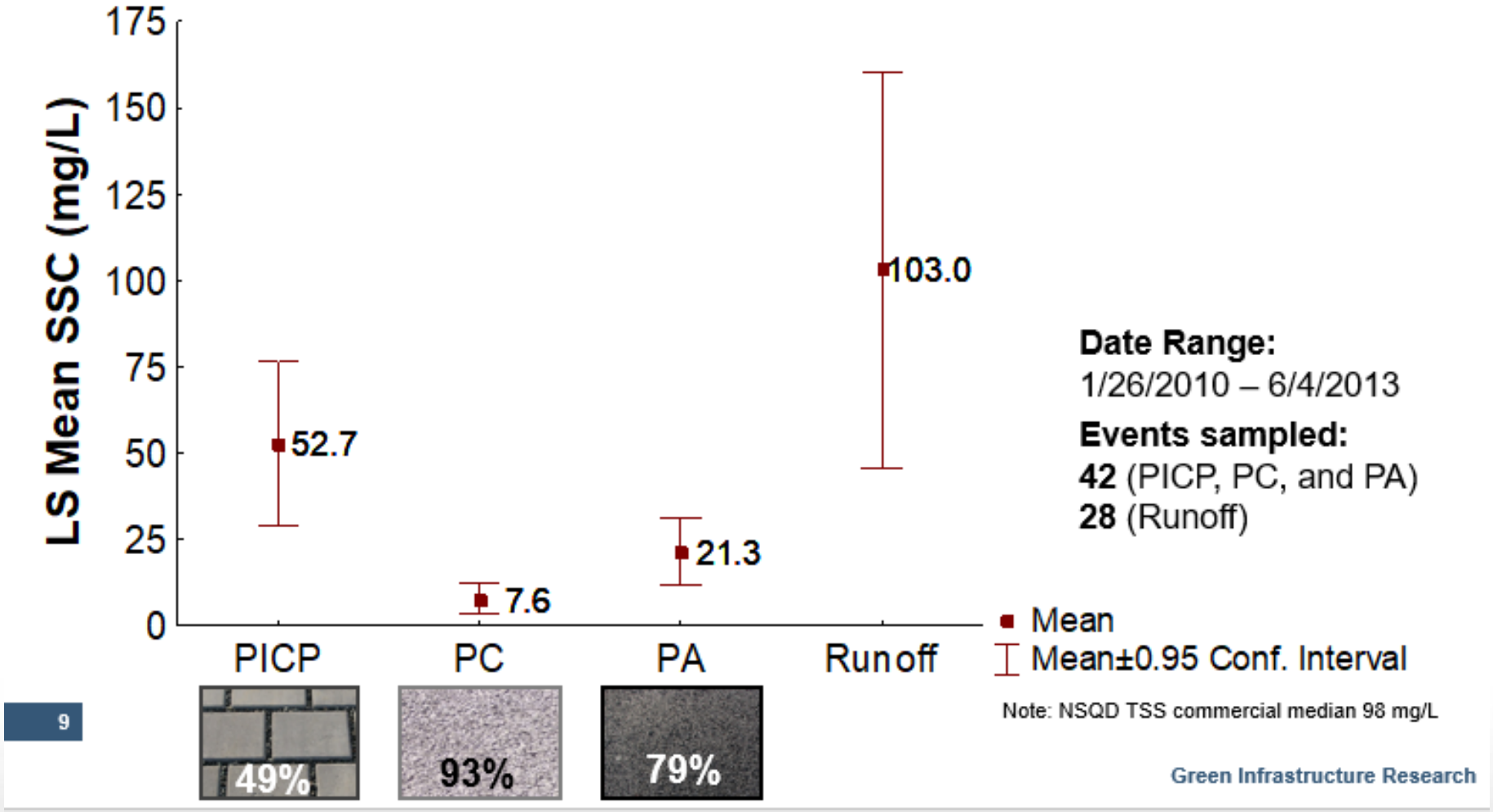
Water Quality – Suspended Solids

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



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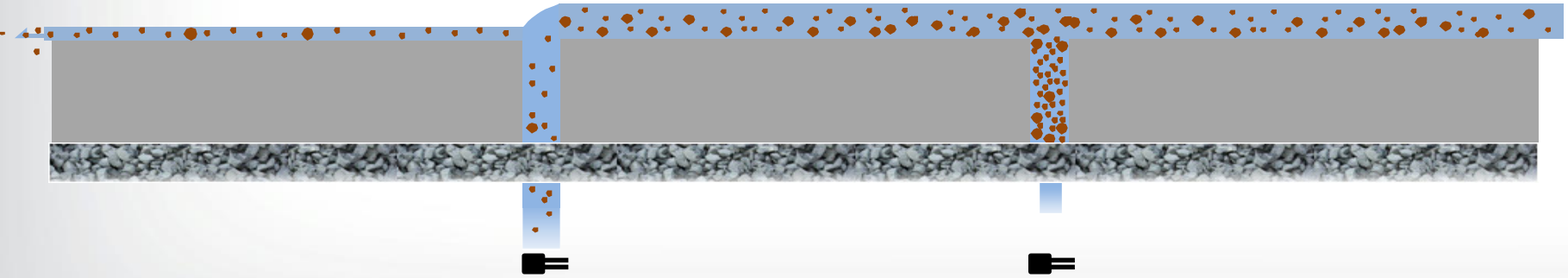
Water Quality – Solids/Clogging

Razzaghmanesh, M. and M. Borst (2018). "Investigation clogging dynamic of permeable pavement systems using embedded sensors." Journal of Hydrology 557: 887-896.

Brown, R. A. and M. Borst (2013). "Assessment of Clogging Dynamics in Permeable Pavement Systems with Time Domain Reflectometers." Journal of Environmental Engineering 139(10): 1255-1265.

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.



Large response

Medium response

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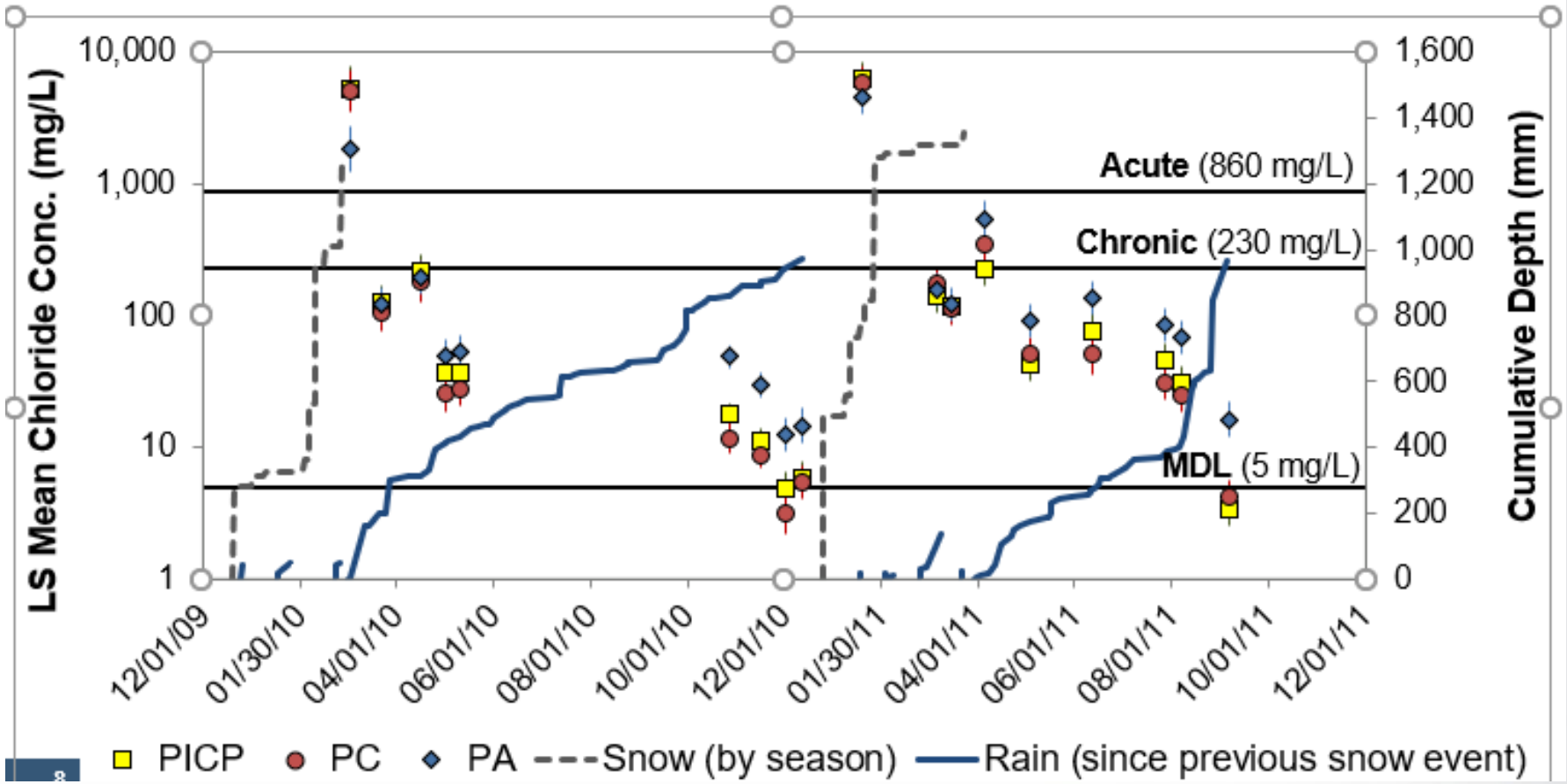
Water Quality - Chlorides

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

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.



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

Porous Concrete Raveling

Pervious Concrete Pavement Maintenance and Operations Guide

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

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.

25

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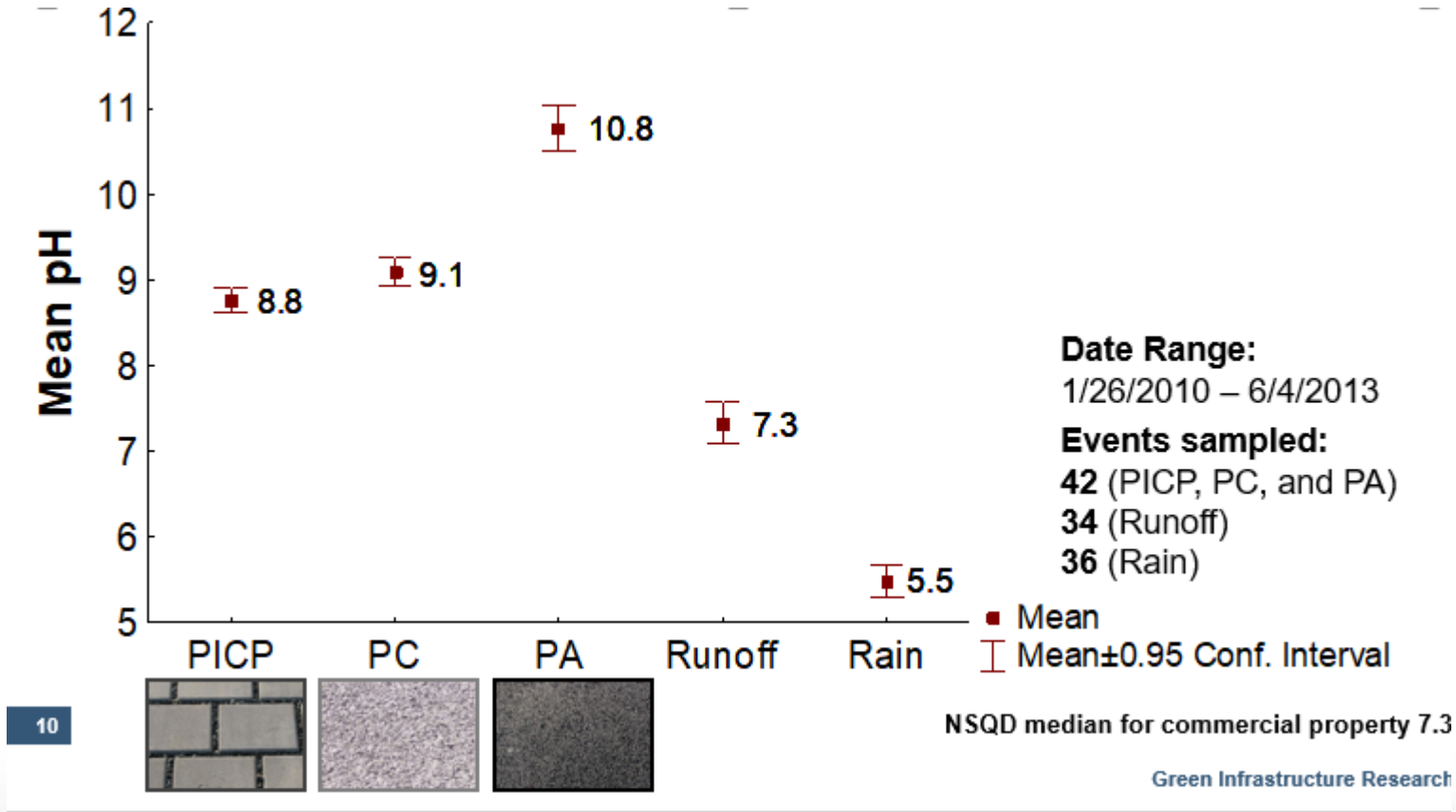
Water Quality - pH

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



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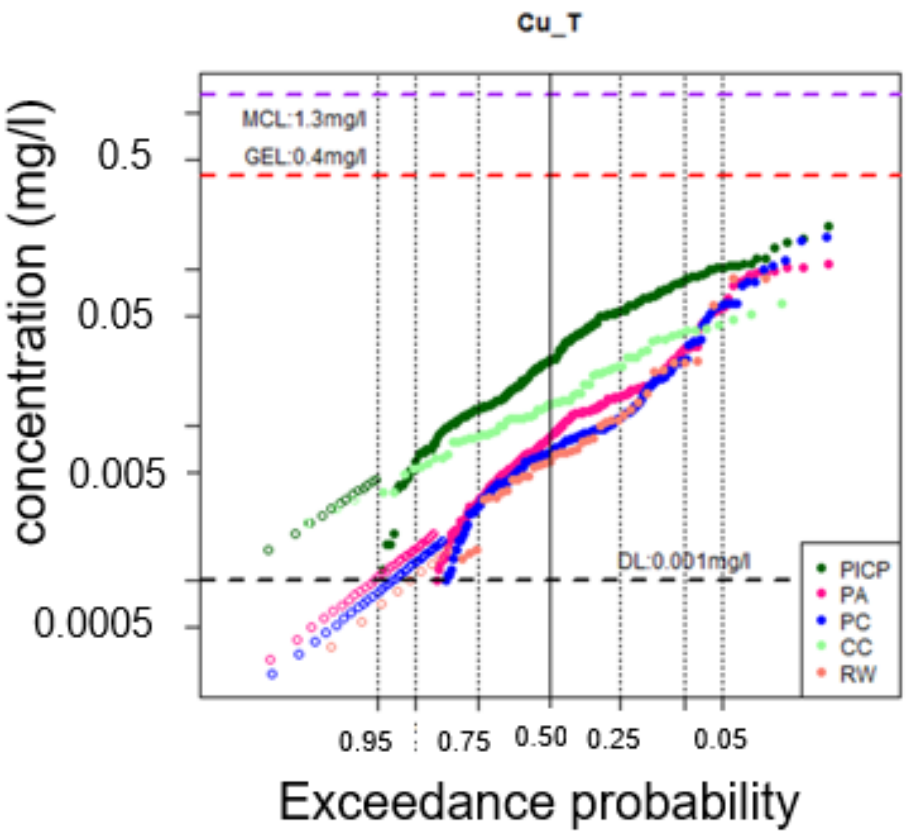
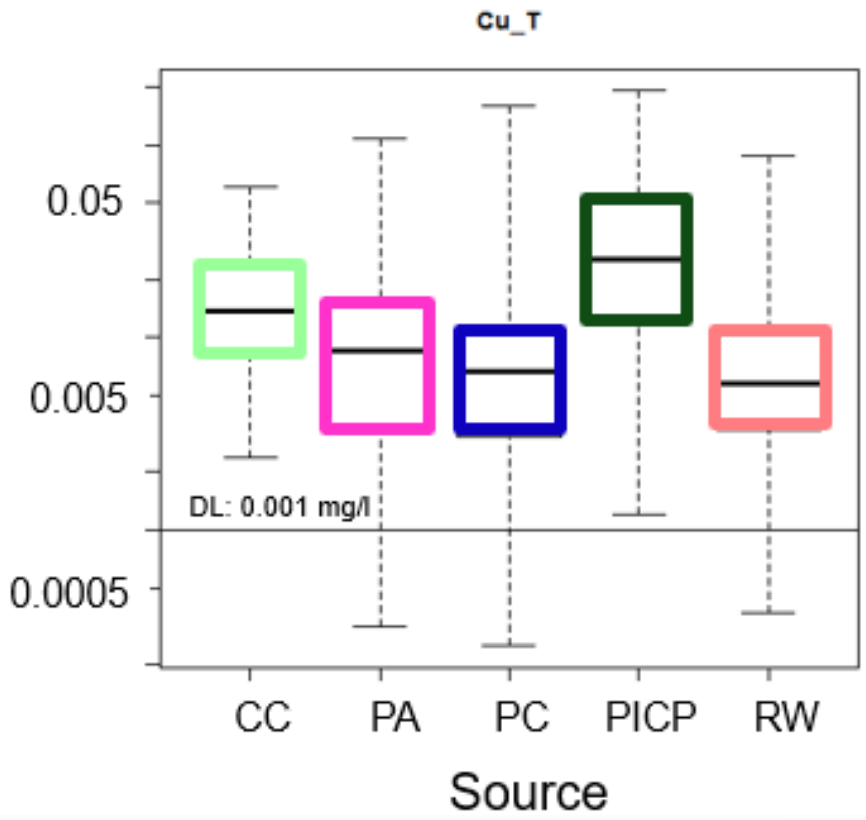
Water Quality – Priority Pollutant Metals

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



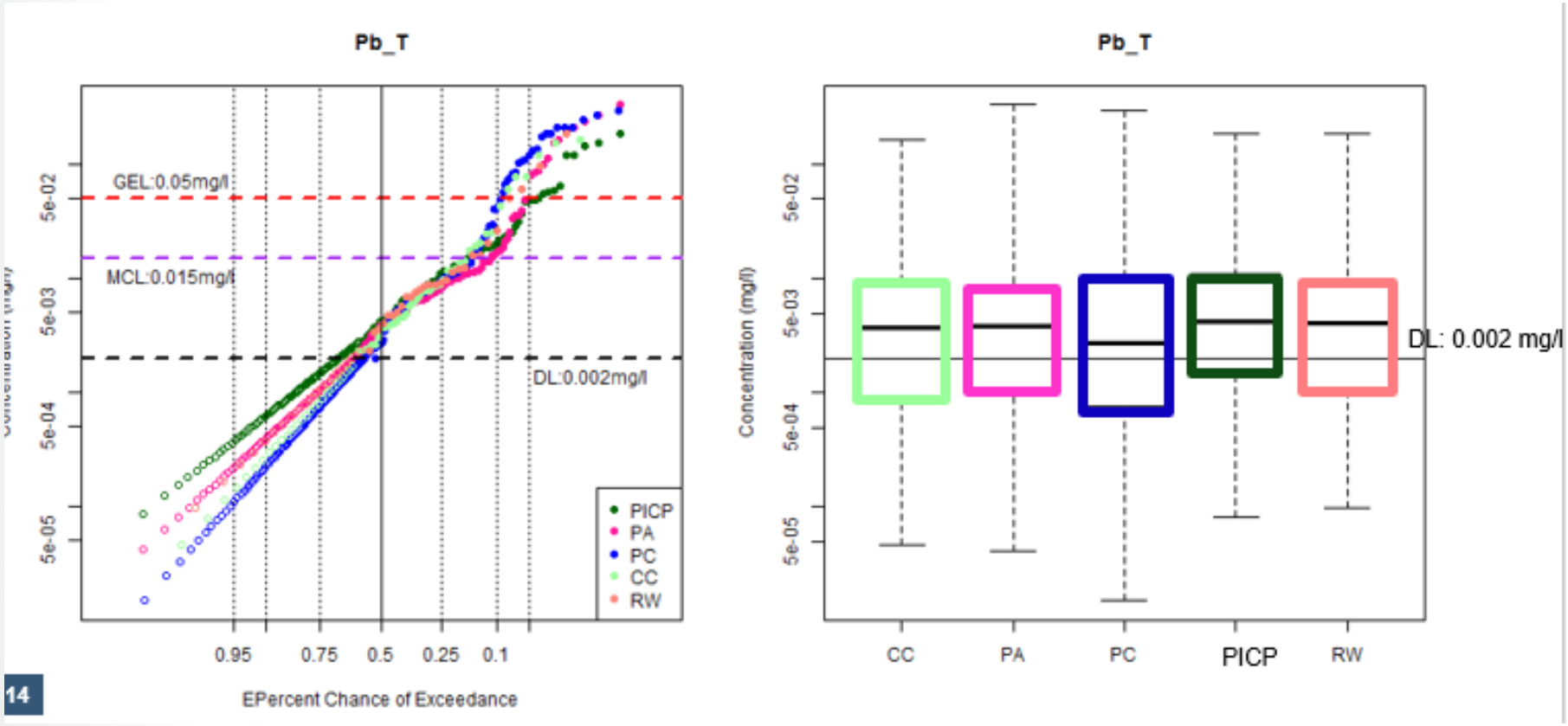


Liu, J. Y. and M. Borst (2018). "Performances of metal concentrations from three permeable pavement infiltrates." Water Research 136: 41-53.

Michael Borst, Thomas O'Connor

Water Quality – Lead

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

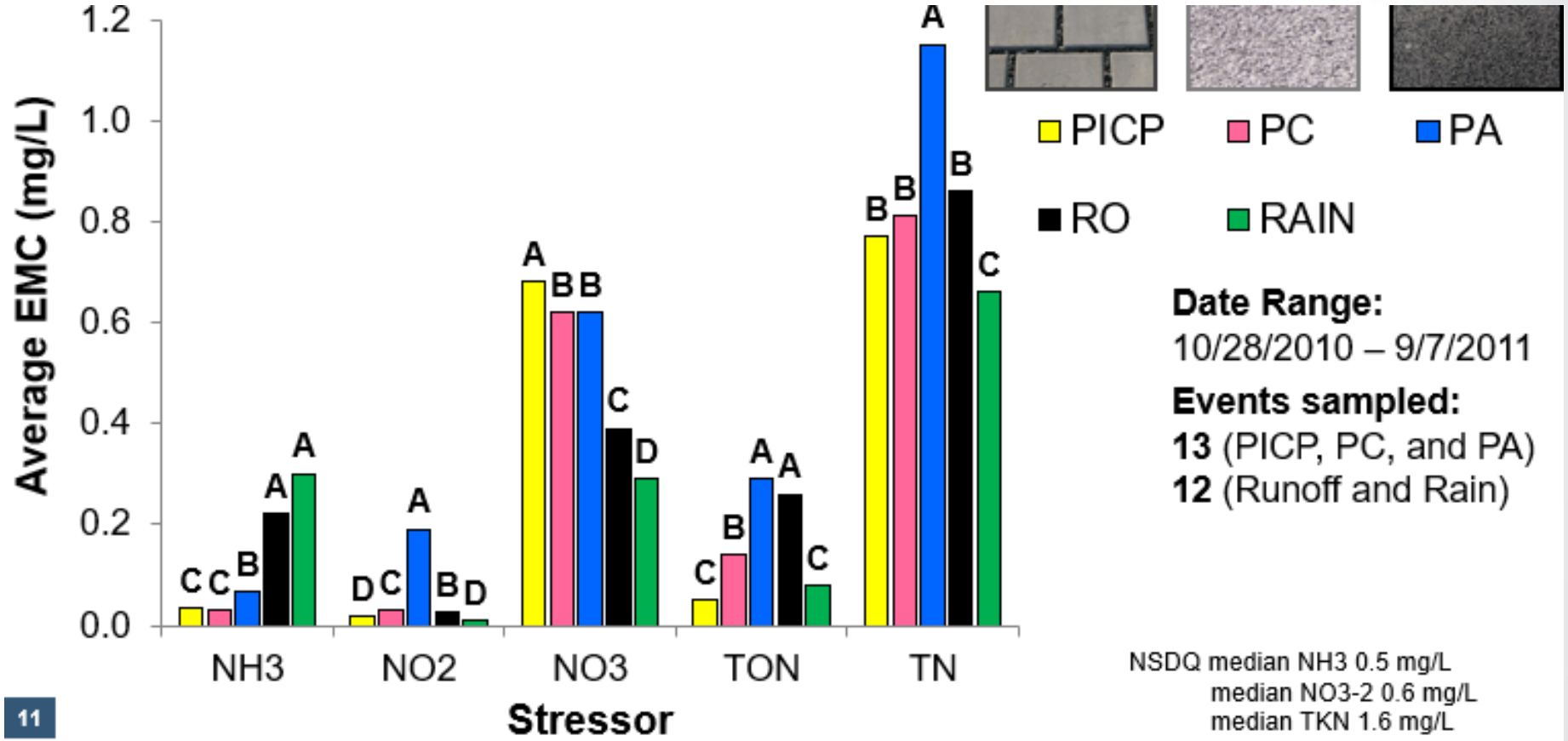


Michael Borst, Thomas O'Connor

Waster Quality - Nutrient

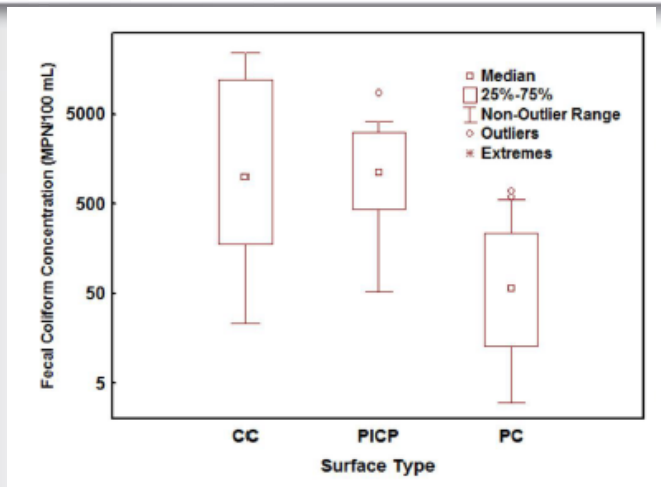
TN concentrations in PICP, PC, and runoff were not significantly different, but all three were significantly less than PA.

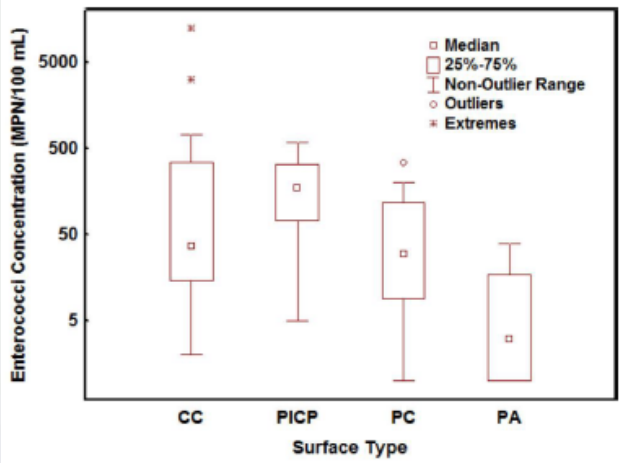
Brown, R. A. and M. Borst (2015). "Nutrient infiltrate concentrations from three permeable pavement types." Journal of Environmental Management 164: 74-85.



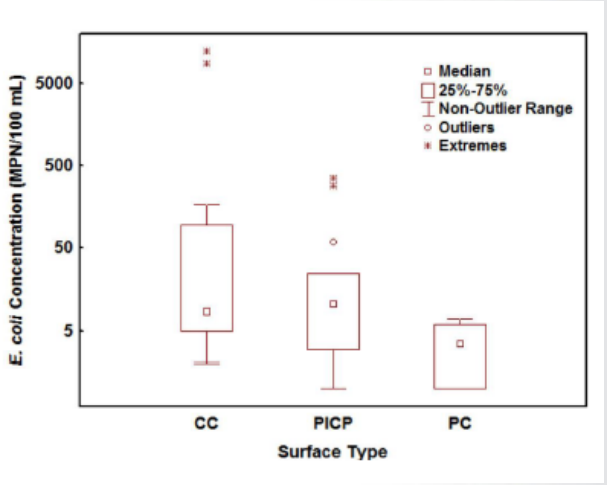
Ariamalar Selvakumar, Thomas O'Connor

Permeable Pavement – Bacteria





Organism	Surface Type	Concentration Reduction (%)
Fecal Coliform	PICP	0
	PC	93
	PA	94
Enterococci	PICP	0
	PC	62
	PA	100
E. coli	PICP	39
	PC	100
	PA	100



Selvakumar, A. and T. P. O'Connor (2018). "Organism Detection in Permeable Pavement Parking Lot Infiltrates at the Edison Environmental Center, New Jersey." Water Environment Research **90**(1): 21-29.

Anne Mikelonis, Katherine Ratliff

Spore and Long Lasting Radionuclides

Research Approach

LAB

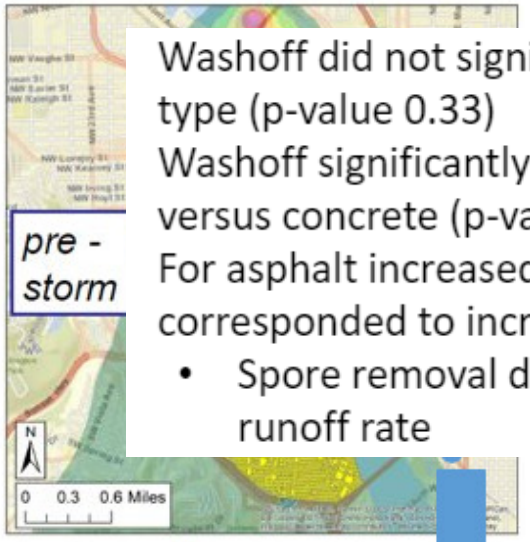
26 ft. Indoor Rainfall Simulator

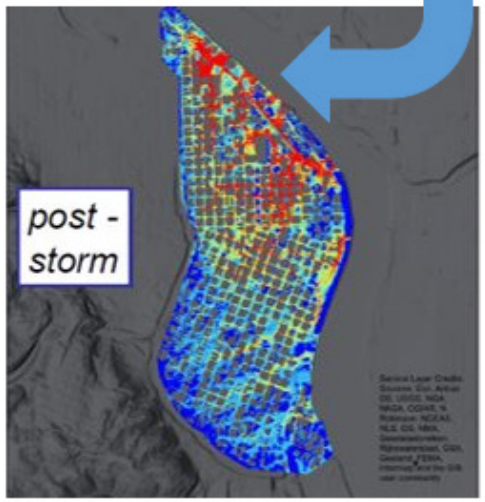
Portable Rainfall Simulator

FIELD

Autosamplers with cell phone activated sample triggering

MODELING





Washoff did not significantly vary by spore type (p-value 0.33)

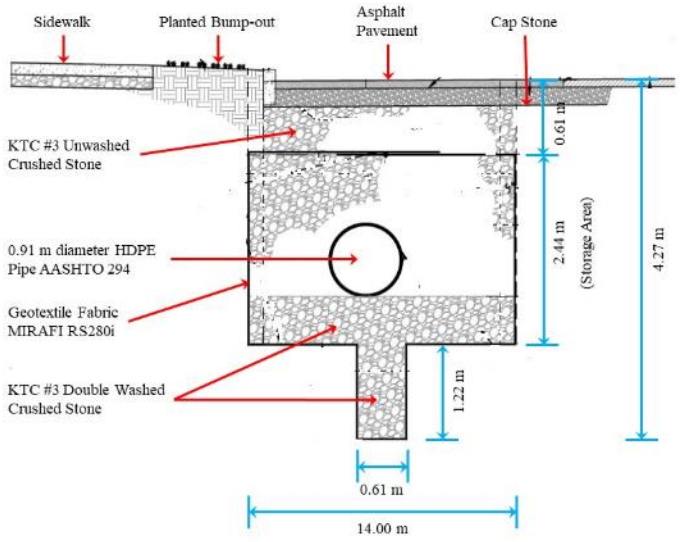
Washoff significantly varied for asphalt versus concrete (p-value 0.034)

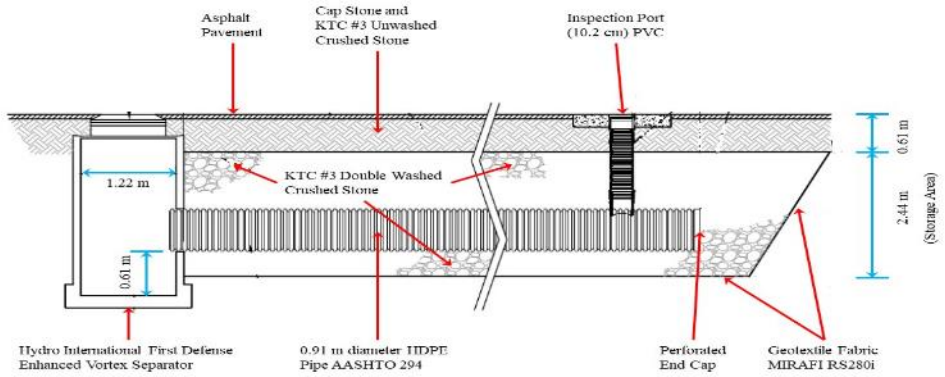
For asphalt increased removal of spores corresponded to increased kinetic energy

- Spore removal did not correlate with runoff rate

Douglas Beak, Steven Acree, Michael Borst, Randall Ross, Jessica Brumley

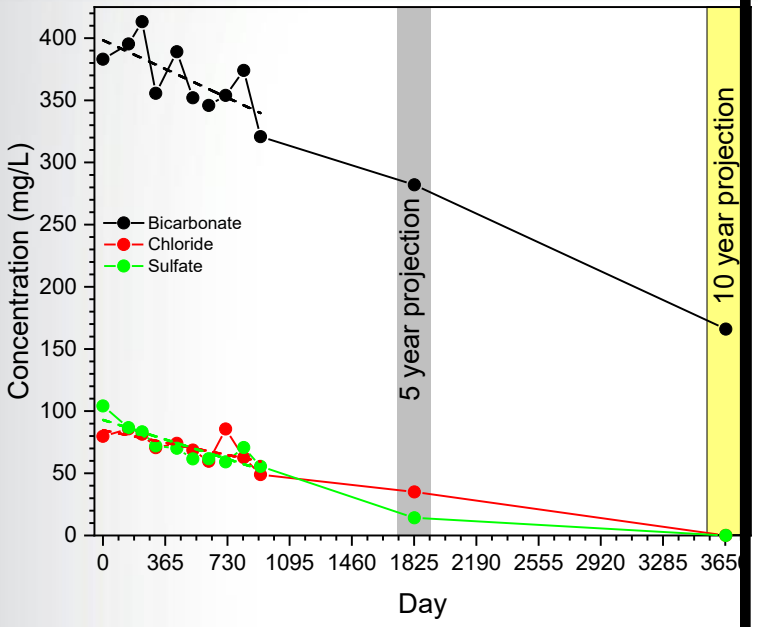
GW Impacts – Louisville, KY

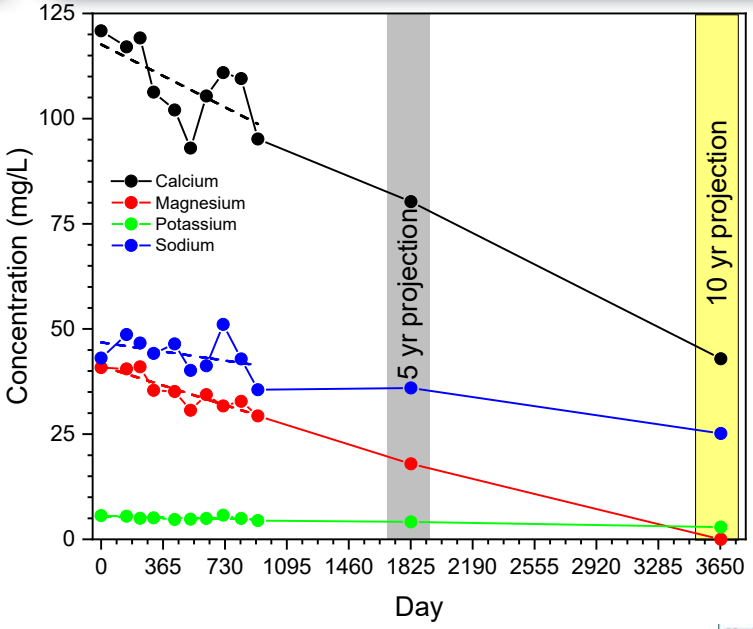


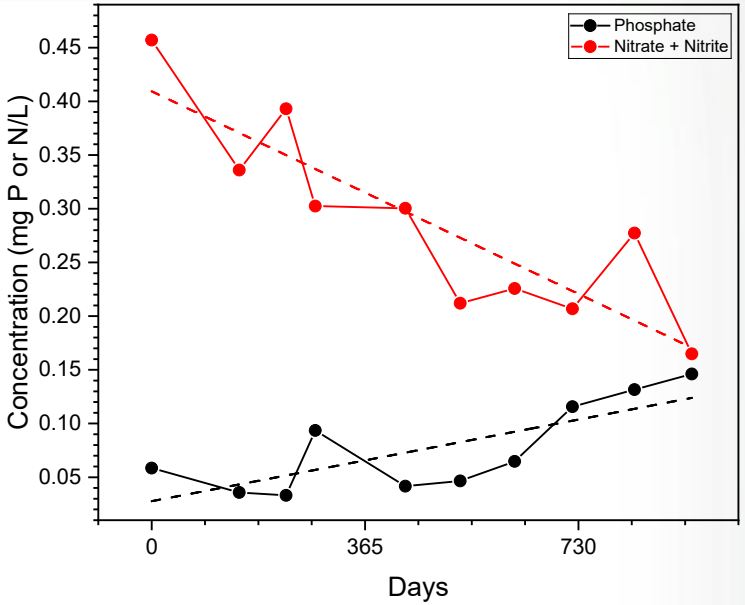


Douglas Beak, Steven Acree, Michael Borst, Randall Ross, Jessica Brumley

Groundwater Impacts







Major anion/ cation chemistry impacts

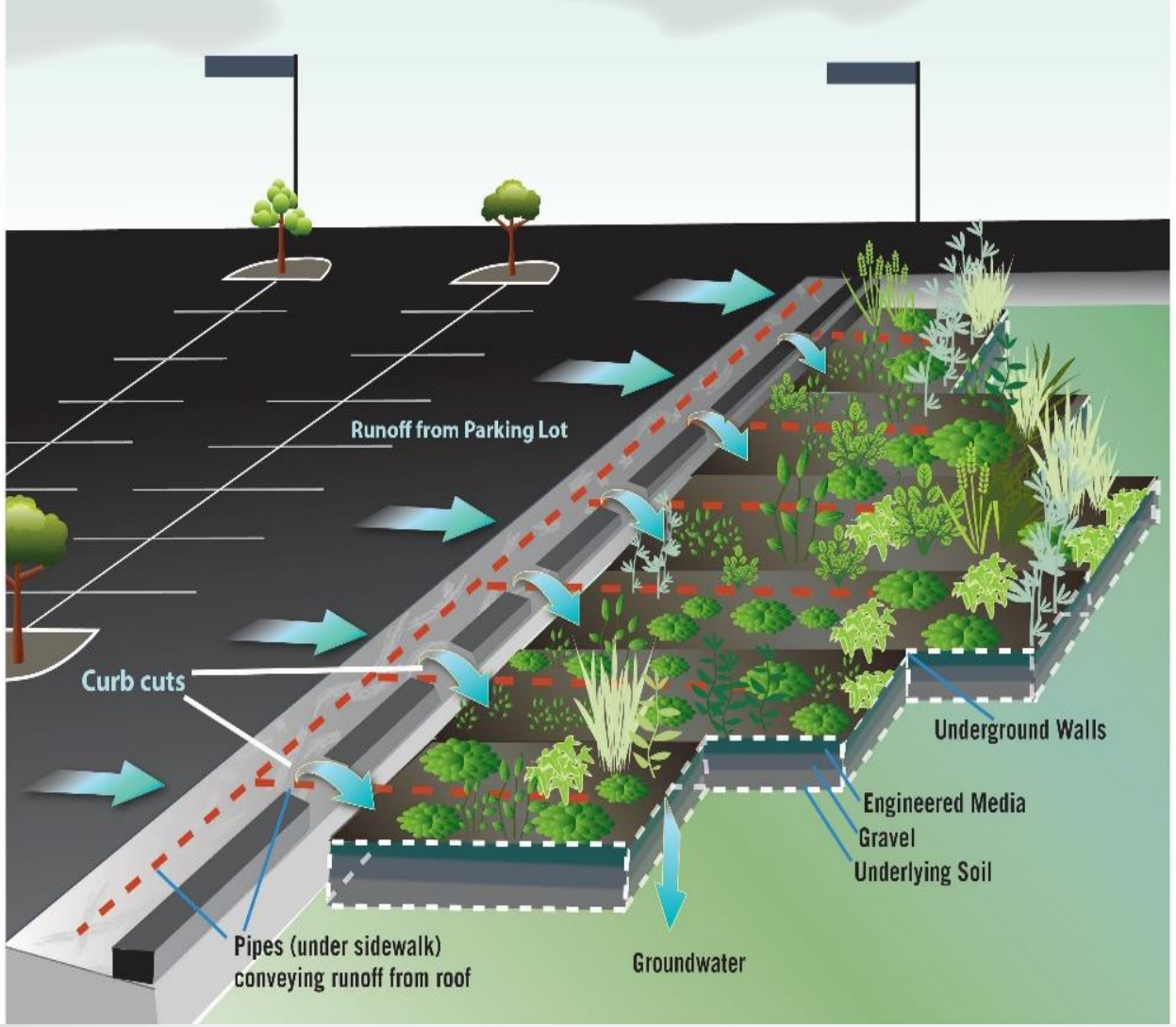
- Dilution of most major anions and cations were observed with time
- It is unknown how long this dilution trend will continue
- Dilution is causing a gradual shift for a Ca-HCO_3 type water towards a Na-HCO_3 type water.

Nutrients

- Phosphate concentrations are significantly increasing with time
- Nitrate + nitrite concentrations are significantly decreasing with time

Thomas O'Connor, Michael Borst

Rain Gardens



In federal and state rain garden manuals, sizing criteria as a fraction of the impervious area draining to the rain garden varies widely, leaving designers with differing guidance.

EPA Science in Action: Rain Gardens at EPA's Edison Environmental Center

Brown, R. A., T. P. O'Connor, and M. Borst. (2015). "Divergent vegetation growth patterns relative to bioinfiltration size and plant placement." Journal of Sustainable Water in the Built Environment, 1(3), 04015001.

O'Connor, T. P. and M. Amin. (2015). "Rainwater collection and management from roofs at the Edison Environmental Center." Journal of Sustainable Water in the Built Environment, 1(1), 04014001.

Michelle Simon, Richard Field (retired) , KCMO MSD, Tetra Tech, UMKS

Installation of Rain Gardens at KC, MO

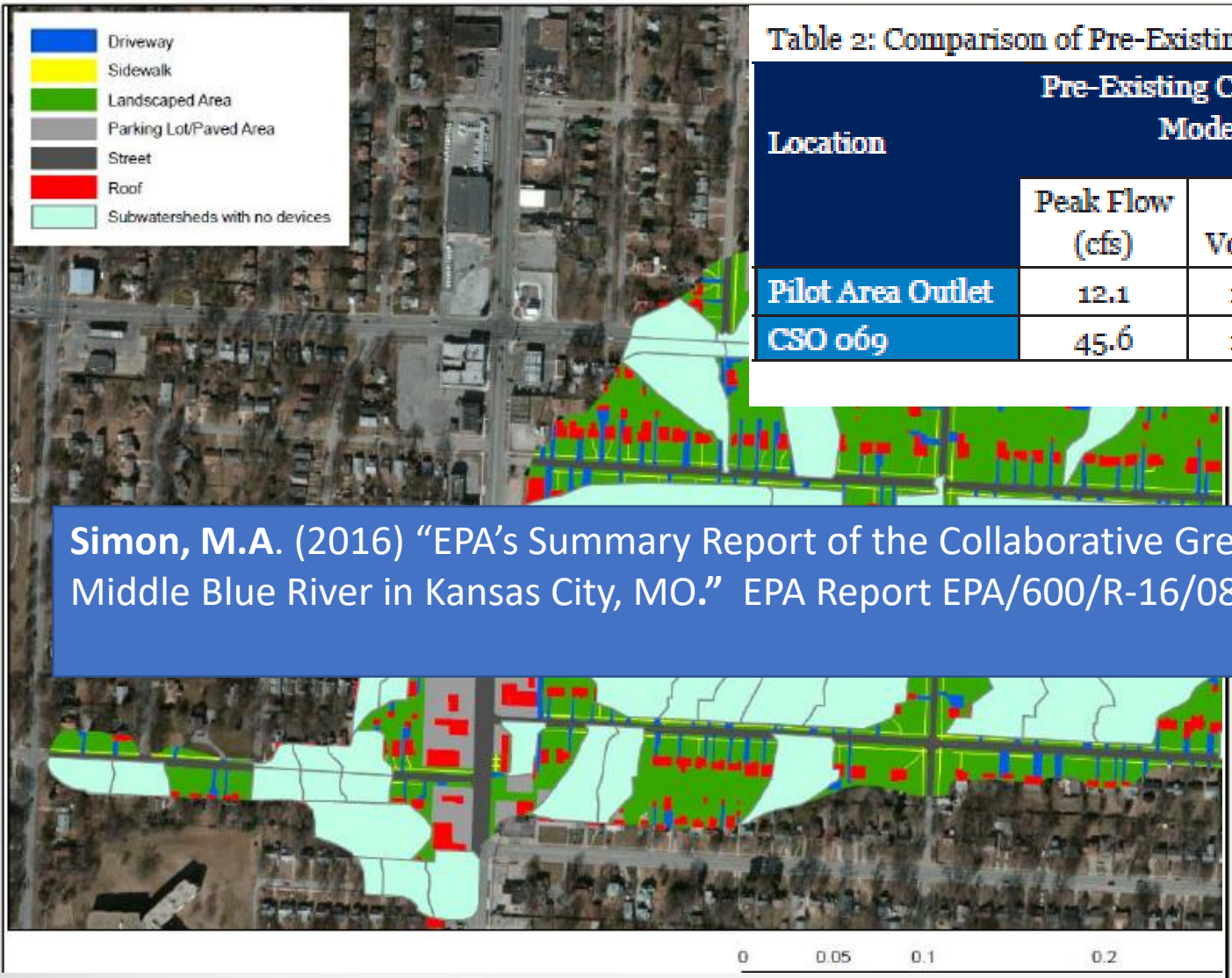
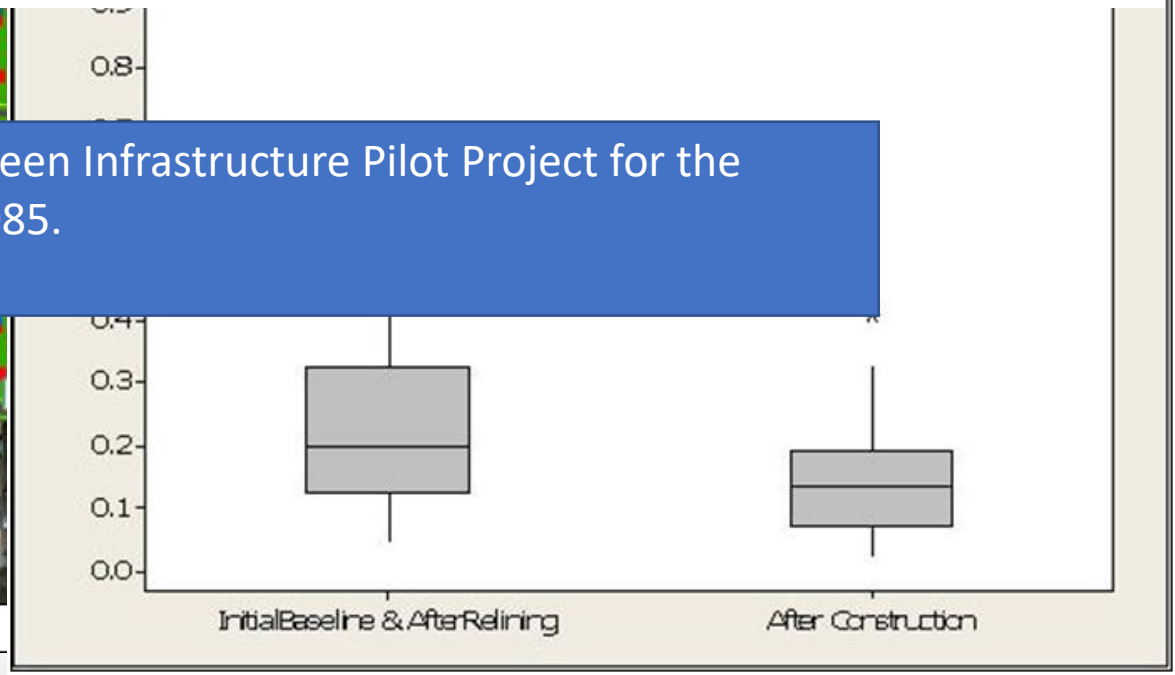


Table 2: Comparison of Pre-Existing Conditions and Calibrated BMP Model Results

Location	Pre-Existing Conditions Model		Calibrated BMP Model		Difference	
	Peak Flow (cfs)	Total Volume (cf)	Peak Flow (cfs)	Total Volume (cf)	Peak Flow (%)	Total Volume (%)
Pilot Area Outlet	12.1	108,600	2.9	69,600	-76.0	-35.9
CSO 069	45.6	184,000	30.9	133,000	-32.2	-27.8



Simon, M.A. (2016) "EPA's Summary Report of the Collaborative Green Infrastructure Pilot Project for the Middle Blue River in Kansas City, MO." EPA Report EPA/600/R-16/085.

https://www.kcwater.us/programs/green-stormwater-infrastructure-gsi/

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Tree Boxes

Ahmed, F. and M. Borst (2020). "Tree box performance in exfiltrating stormwater runoff." Water Environment Research 92(1): 106-114.

Ahmed, F. and M. Borst (2019). "Monitoring infiltration rates with time domain reflectometers." Water Environment Research 91(12): 1638-1649.

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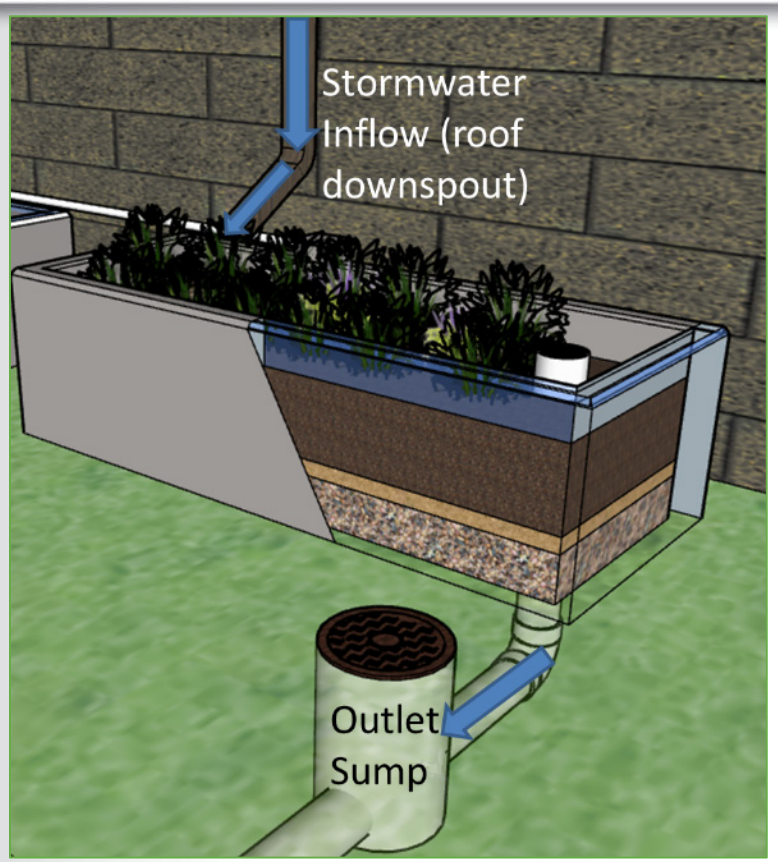
Planters

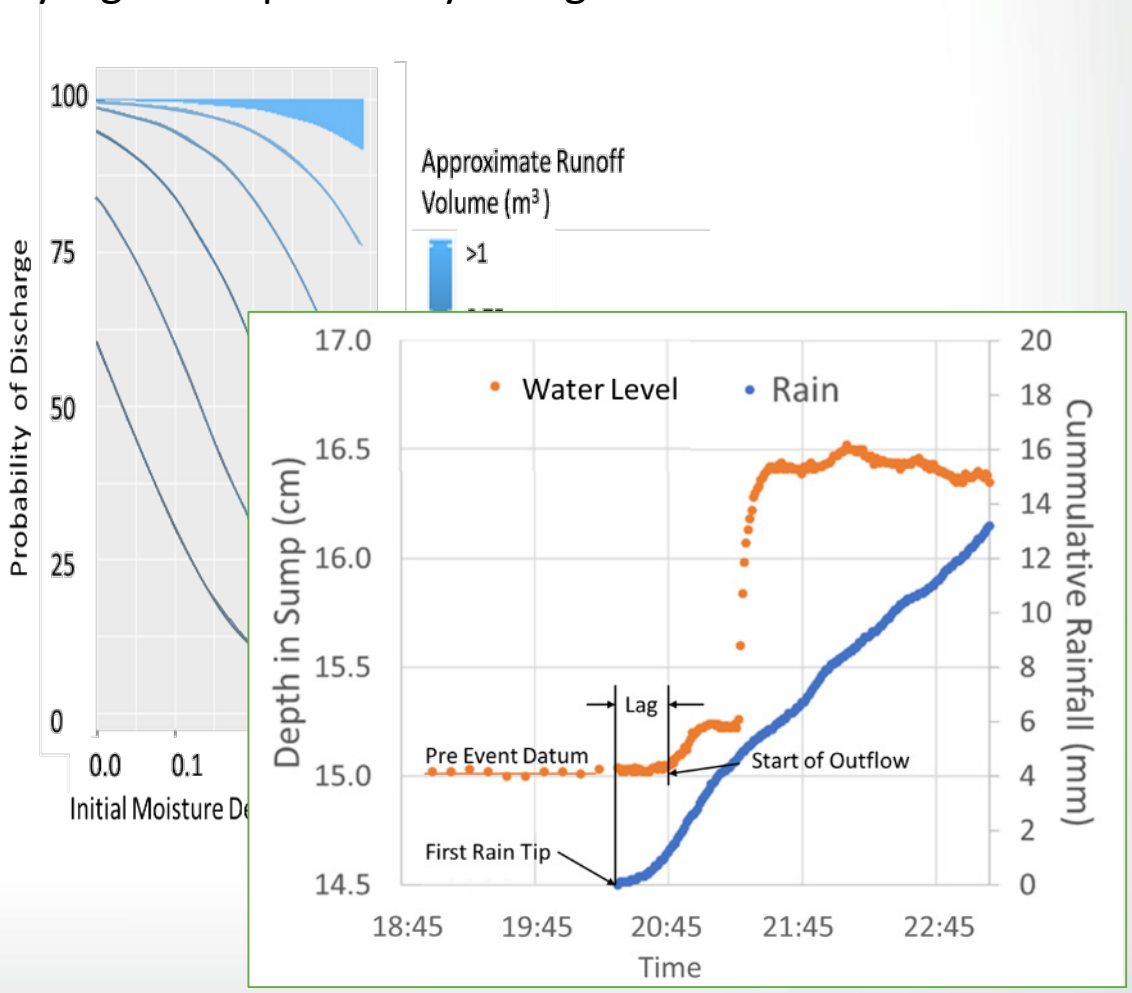


Nissen, K. A., M. Borst and E. Fassman-Beck. (2021). "Bioretention planter performance measured by lag and capture." Hydrological Processes: 9.

Planters completely captured 40% of storms

Controlling variables

- Approximate runoff volume
- Initial moisture deficit (based on pre-event and saturated conditions



Conclusions

We are constantly improving SWMM and our understanding of GI

We have compared SWMM Results to Empirical Data for Hydrology

- Bioretention
- Bioswale
- Green Roof
- Permeable Pavement
- (Infiltration Trench)

We are now looking at water quality

- Permeable Pavements
- Rain Gardens
- Tree Boxes and Planters

Thank-you

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