

Evaluating whether BMP and restoration investments improve stream condition at the watershed scale

Restoration research question addressed: Effectiveness of stormwater and stream restoration programs at the watershed/catchment scale

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Research Question and Hypotheses:

- Restoration research question addressed:
 - Effectiveness of stormwater and stream restoration programs at the watershed/catchment scale
- Project question:
 - Do watersheds with greater BMP-treated area show improved channel condition and altered baseflow nutrient chemistry?
- Hypotheses:
 - Watersheds with greater BMP-treated area and restoration extent will show higher stream channel integrity.
 - Streams with higher channel integrity will show lower baseflow nitrate and higher baseflow phosphate concentrations.



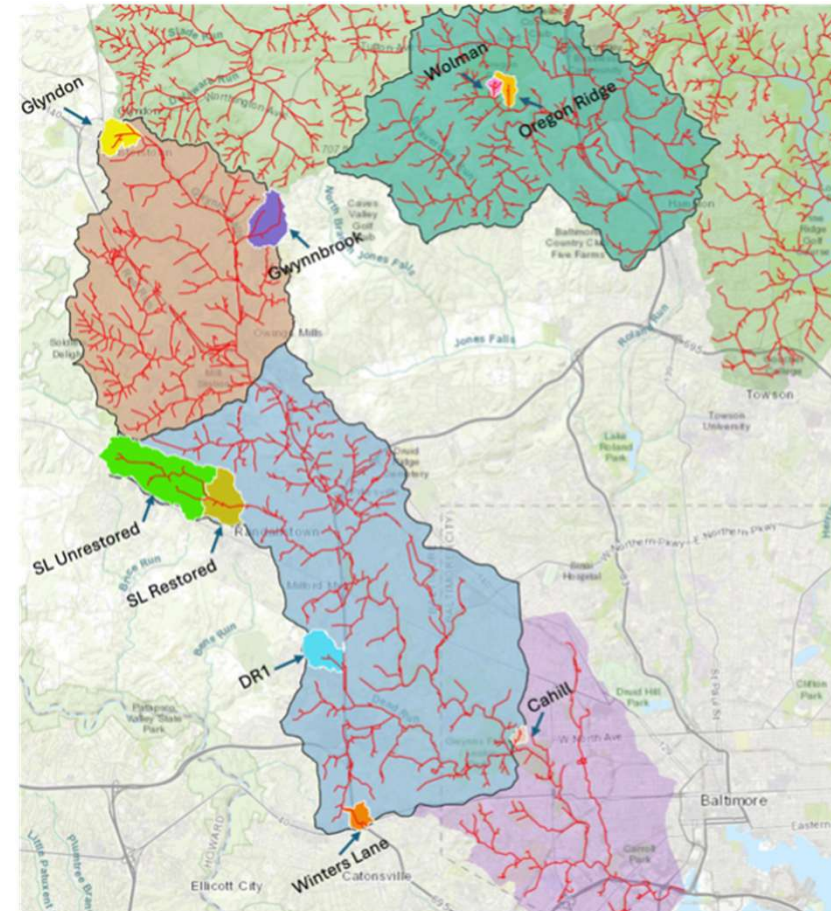
Watershed-scale BMP effectiveness is difficult to evaluate:

- At the watershed scale, responses may be shaped by:
 - Climate and rainfall patterns
 - Past and present land use
 - Existing geomorphic degradation
 - Best Management Practices (BMP) type, age, placement, and drainage area
 - Stream restoration history
- But: Stormwater BMPs and stream restoration projects are often evaluated individually.
- *Ultimately: Do restoration investments produce measurable watershed-scale improvements?*

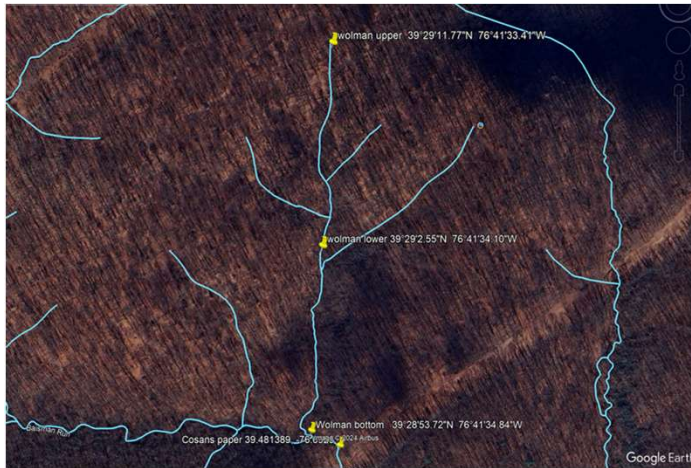


Methods: Nine watersheds in the Baltimore metropolitan area

- Forested reference, suburban, urban, restored, and unrestored watersheds:
 - Reference sites for expected natural channel condition.
 - Urban and suburban sites vary in impervious cover, BMP implementation, and stream restoration history.
- Study design:
 - 9 watersheds
 - 3 reaches per watershed
 - 3 sampling locations per reach
 - 81 sampling locations

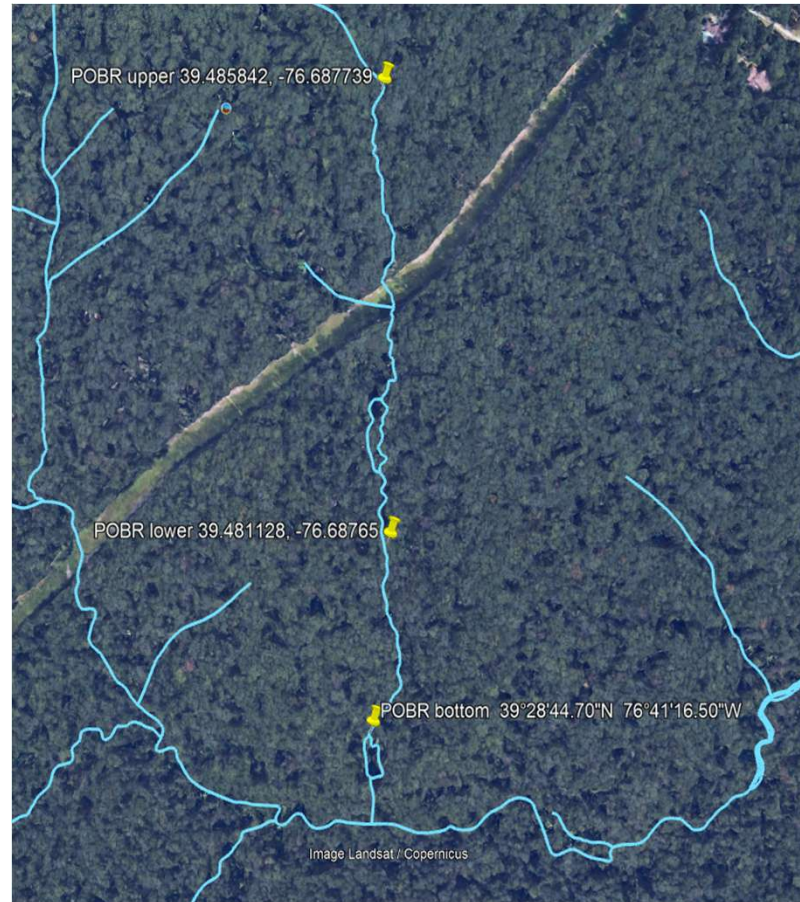


Two reference sites:

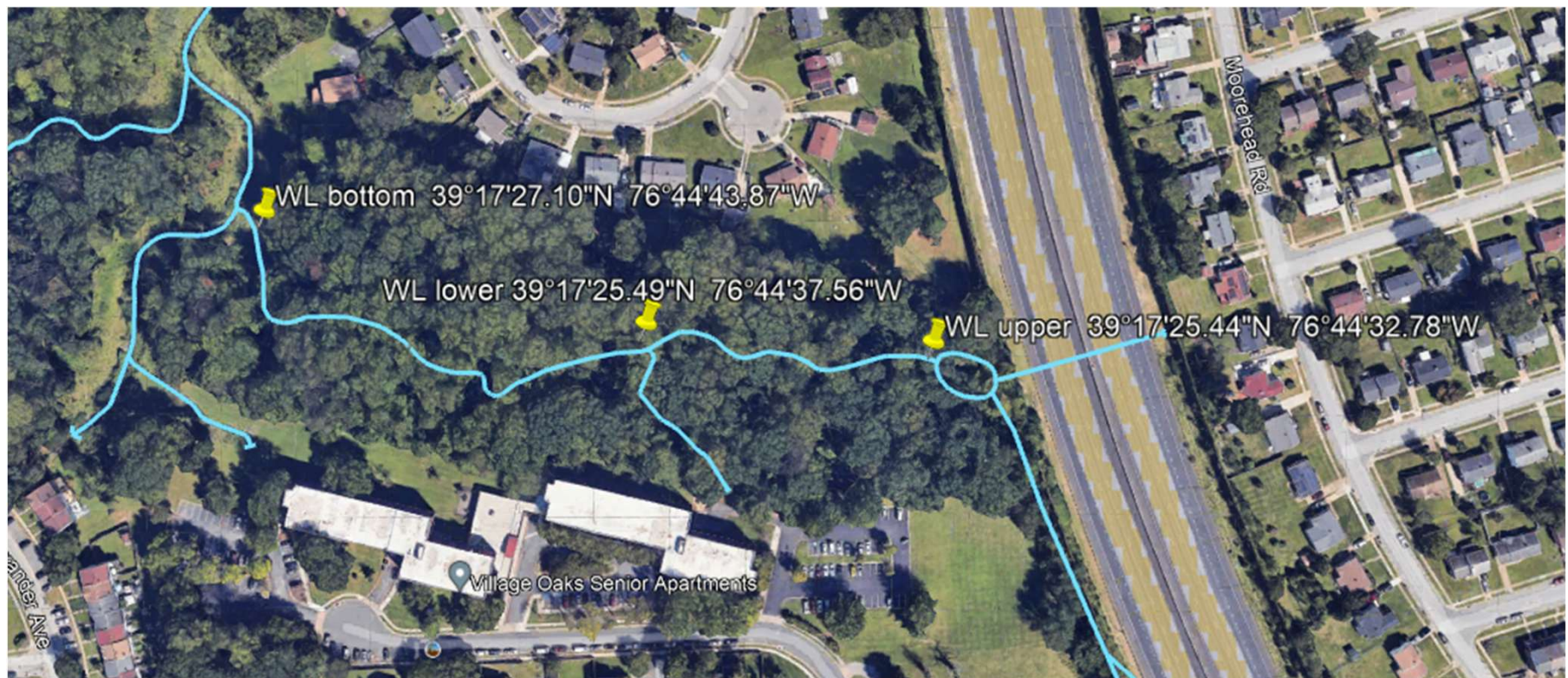


Pond Branch at Oregon Ridge, MD - 01583570

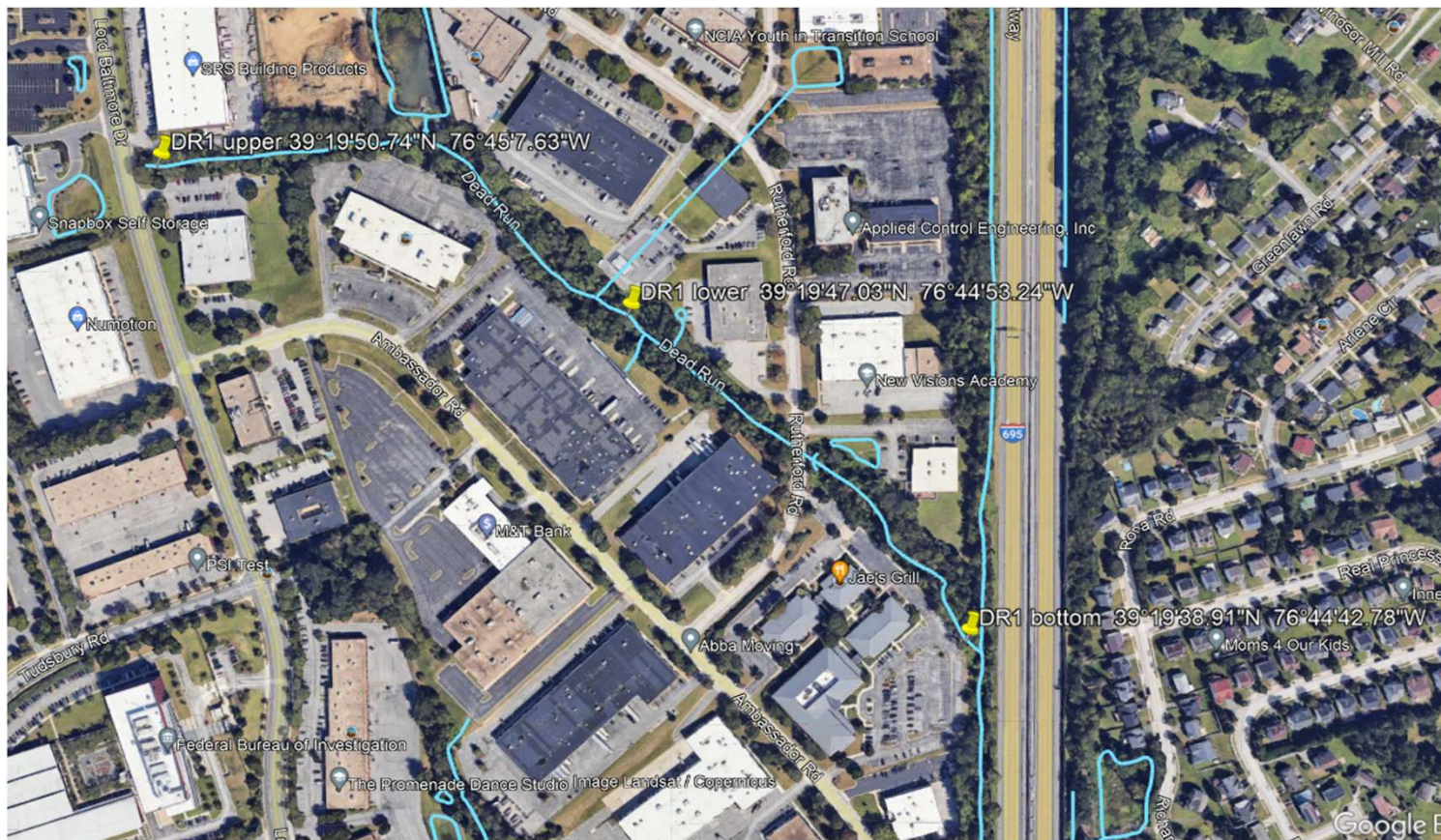
July 14, 2023 - July 13, 2024



Headwaters of Dead Run (DR5): High urban



Headwaters of Dead Run (DR1): High urban



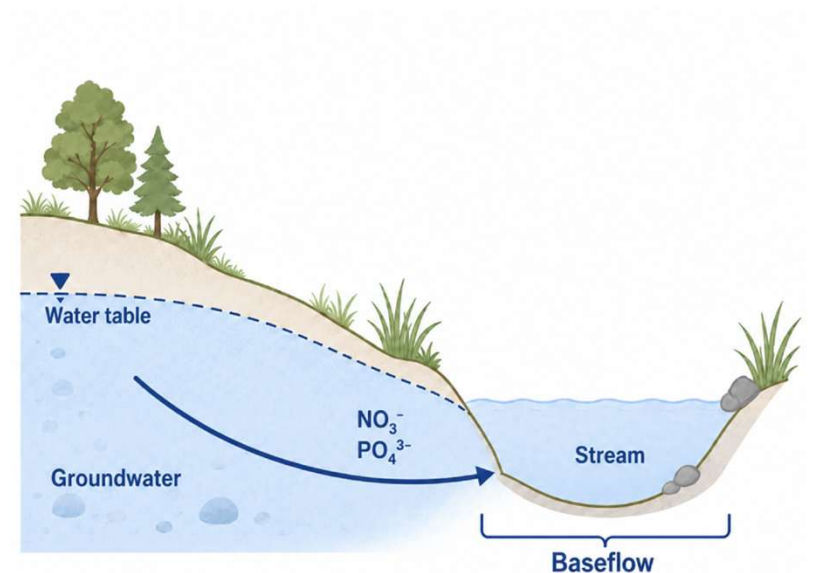
Methods: Geomorphic characterization

- Field measurements of channel depth:width as indicator of channel incision.
- Higher values indicate deeper, narrower channels.
- Compare with LiDAR-based assessments (Baker et al.)



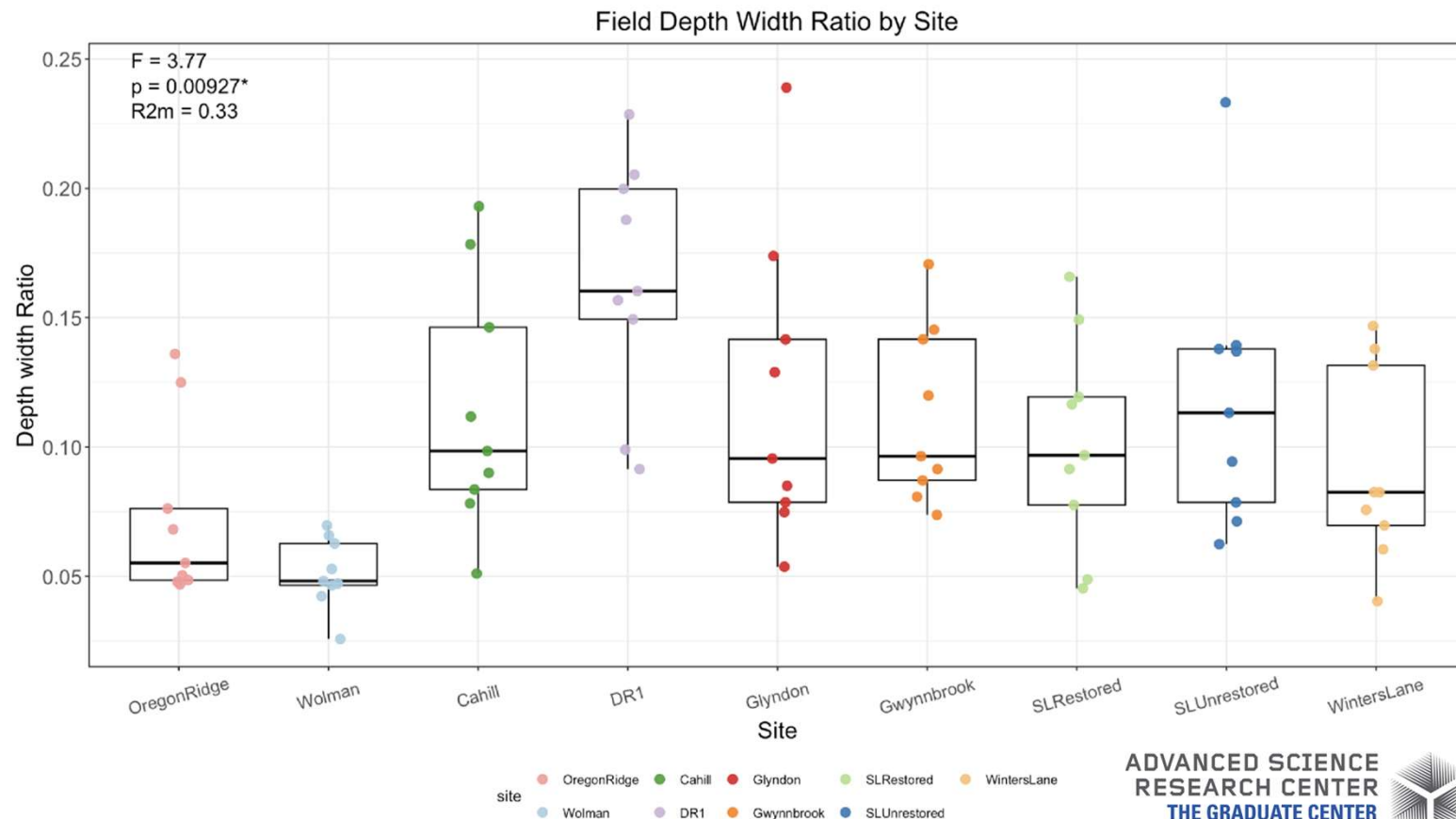
Methods: Baseflow stream sampling

- After 10 days of no rain, streamwater is dominated by groundwater (Welty et al. 2023).
- Baseflow sampling provides insight into spatial patterns of groundwater chemistry and watershed connectivity.
- Five sampling campaigns: July 2024, March 2025, April 2025, two in August 2025.
- Measurements of nitrate, phosphate, dissolved organic carbon in lab. In field measurements of temperature, conductivity, pH, turbidity.



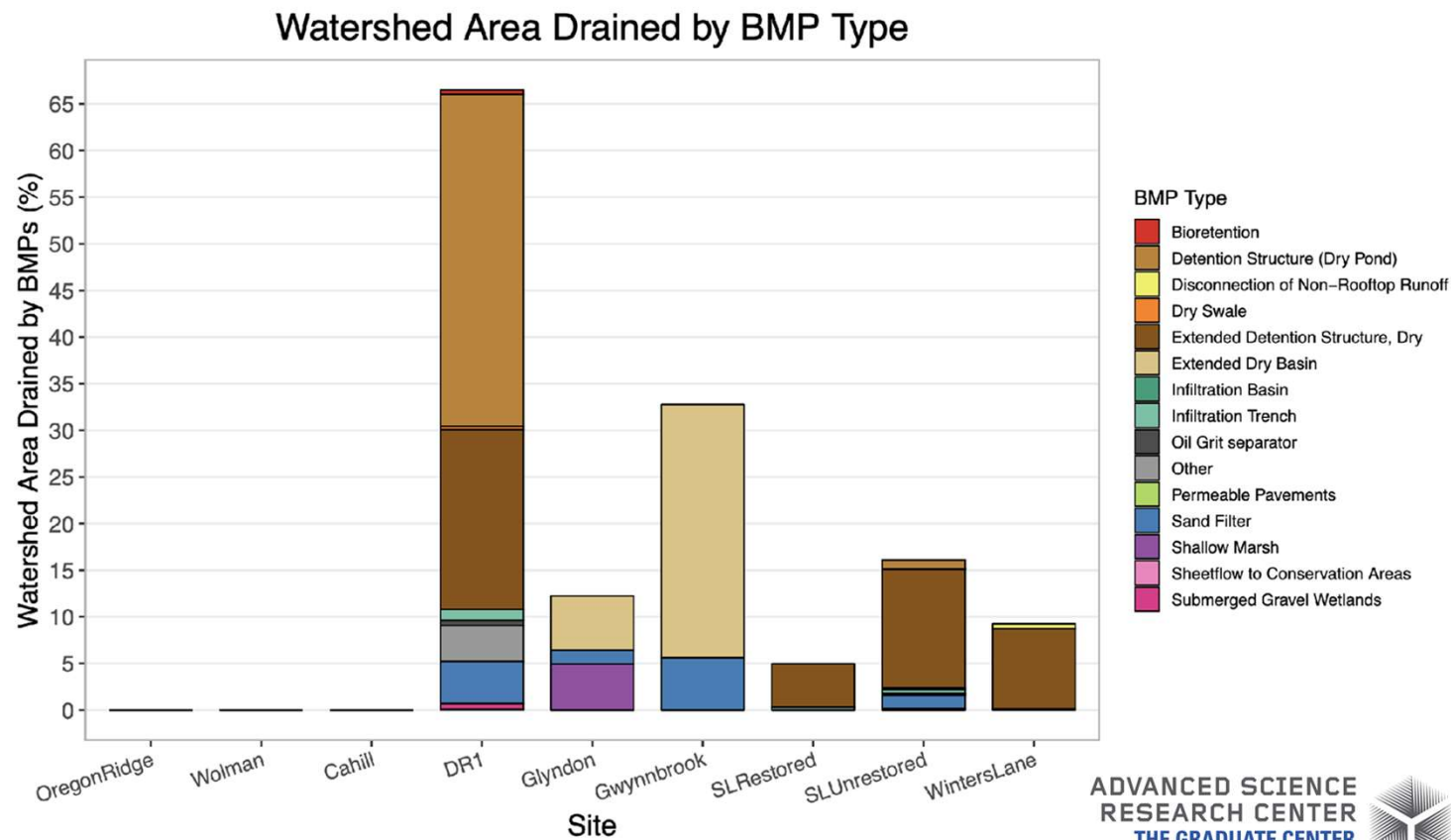
Results: Geomorphic characterization shows urban streams more incised than forest reference streams

- Big difference between reference and urban sites.
- No differences among urban sites.
- Focus on DR1 (lots of BMPs) versus Winters Lane (few BMPs).
- Also compare Glyndon and Gwynnbrook, both in headwaters of Gwynns Falls.



Results: Wide variation in the nature and extent of BMPs among our study watersheds

- Particular focus on DR1 (lots of BMPs) versus Winters Lane (few BMPs). Both are in the headwaters of Dead Run watershed.
- Also compare Glyndon and Gwynnbrook, both in headwaters of Gwynns Falls.



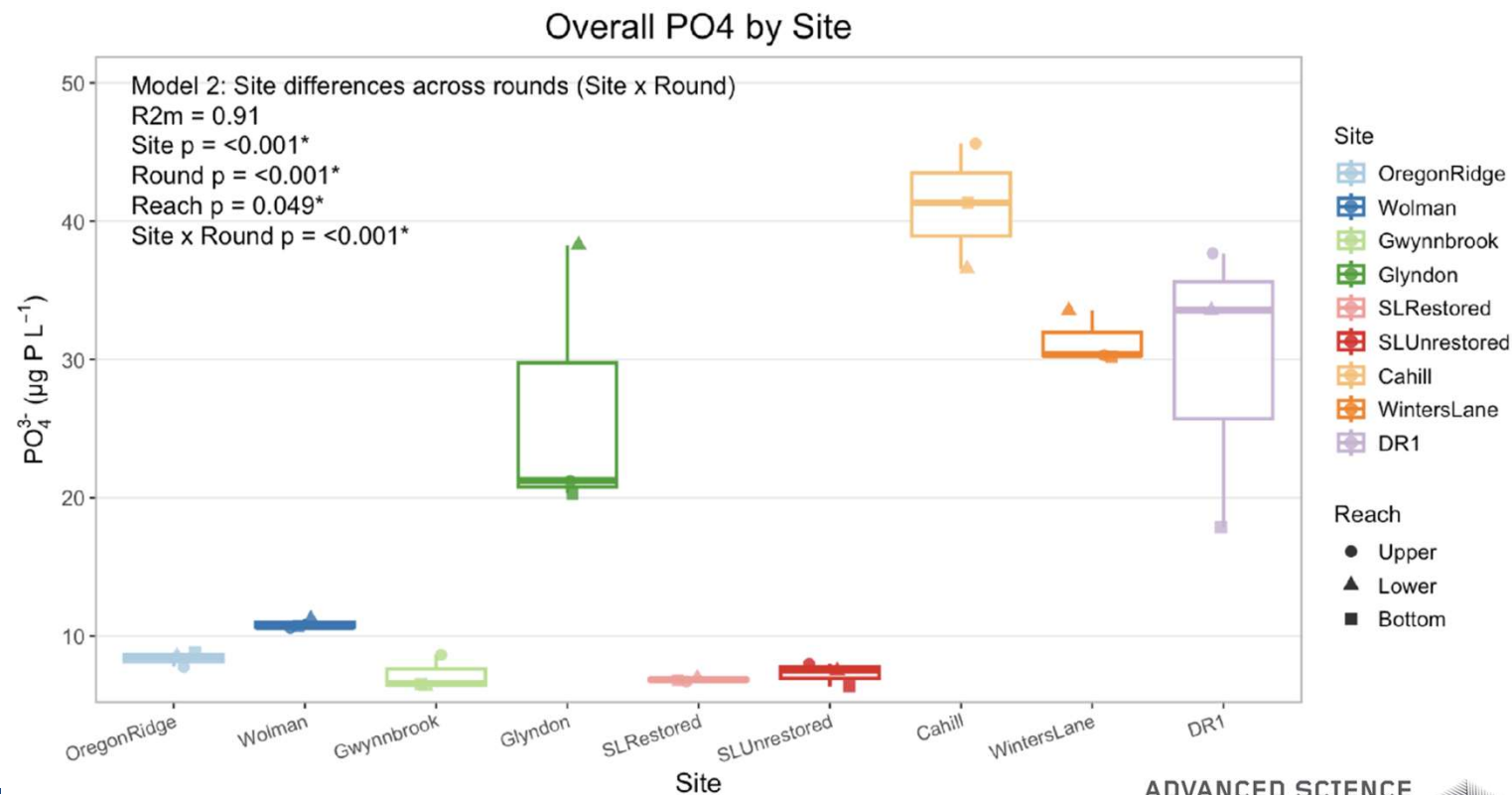
Results: Stream chemistry shows marked differences between urban and forest reference streams

- Nitrate concentrations very low in forest reference sites.
- Some differences among the urban sites, e.g., low concentrations at Scotts Level.
- Big differences between Glyndon and Gwynnbrook.
- No relationships between nitrate and BMPs or geomorphic condition.



Results: Stream chemistry shows marked differences between urban and forest reference streams

- Phosphate concentrations more variable than nitrate.
- Some urban sites have very low phosphate (e.g., Scotts Level, Gwynnbrook).
- No relationships between phosphate and BMPs or geomorphic condition.



Conclusions: BMPs do not appear to improve geomorphic condition or water quality at the watershed scale

- We do not see strong relationships between BMP coverage and channel condition or baseflow nutrient chemistry.
- Weak relationships do not necessarily mean BMPs have no value:
 - Do we need to pay more attention to location and other factors? Watershed response depends on placement, design, age, drainage area, restoration history, existing channel degradation, and legacy land use effects.
 - The BMPs in many of our watersheds are older and not “state-of-the-art.”
 - Would these urban streams be in much worse condition if the BMPs had not been implemented?
 - BMPs have been shown to be highly effective in carefully planned new developments.
 - For already degraded streams, retrofit BMPs may need to be paired with more targeted channel or watershed interventions.
 - For water quality, highly localized sources may dominate over BMP effects, e.g., Glyndon versus Gwynnbrook.

Future work: BMP location may help explain weak watershed-scale relationships

- Percent watershed treated may be an inadequate indicator of BMP effectiveness. Location matters! We will more analysis of relationships between BMP location and geomorphic condition.
- Focus on variation among reaches within each stream. BMP influence on stream condition may be easier to “see” at this scale.
- More focused comparison of restored and unrestored streams and reaches.
- More detailed comparisons of LiDAR-based estimates of stream geomorphic condition and stream chemistry.
- Look for possible “hotspot” sources of nutrients in our streams.



Funding and acknowledgments:

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Award #23848 - 2024 to 2026

Research Foundation of CUNY, Advanced Science Research Center
Chesapeake Bay Trust Pooled Monitoring Initiative

The Pooled Monitoring Initiative funds applied science to advance restoration research for cumulative impacts, comparative effectiveness of stormwater practices, pollutants of emerging concern, and trade-offs with new research questions added annually.

Acknowledgments

Chesapeake Bay Trust

Pooled Monitoring Initiative partners
CUNY Advanced Science Research Center

Baltimore Ecosystem Study

UMBC/CUERE

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Andrew Miller



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RESEARCH CENTER
THE GRADUATE CENTER
CITY UNIVERSITY OF NEW YORK



TRANSLATION SLIDES

What are the take home points?
What does this mean for me?

Translation Slides by Ari Engelberg,
Maryland Department of Natural
Resources.



WHAT DOES THIS MEAN FOR ME?

1. Stream baseflow chemistry not significantly correlated to BMP implementation at the watershed scale
 - Is there actually no impact of BMPs on baseflow nutrient concentrations in these watersheds or...
 - Is this an artifact of the experimental design? For example, maybe we need greater spatiotemporal resolution of baseflow samples to capture impacts of BMPs on nutrient levels?
2. Channel geomorphic condition negatively correlated to % BMP in watershed
 - Is that result because of the BMPs or something else? E.g., could it be due to autocorrelation between the amount of BMPs and % urbanization in the study watersheds
1. Either way, it seems like you can't expect significant improvements in baseflow chemistry and stream geomorphology to occur in highly urbanized watershed as a result of BMP retrofits.



WHAT DOES THIS MEAN FOR ME?

What do I take from this if I am a practitioner:

Targeted siting and design of BMPs will be critical to achieving water quality uplift at the watershed scale. These improvements won't be realized without holistic planning.

What do I take from this if I am a regulator:

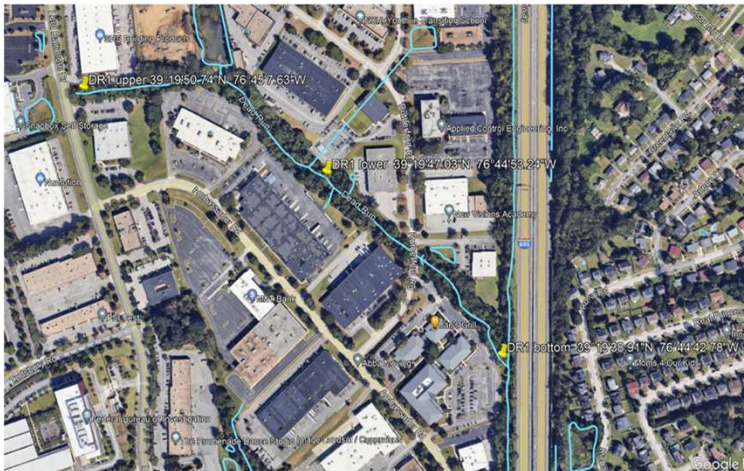
See above comment, also, this type of monitoring approach should be considered for wider adoption. For example, pre-post restoration baseflow chemistry sampling of stream restorations. There is likely more to learn here through this type of cost-effective sampling approach.



Q&A: DR1 versus Winters Lane

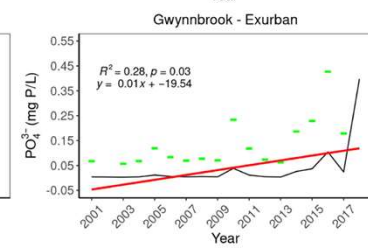
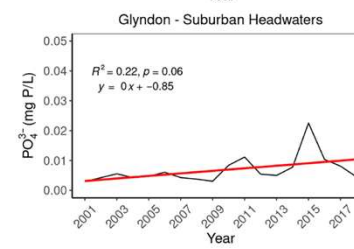
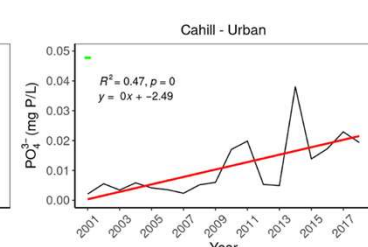
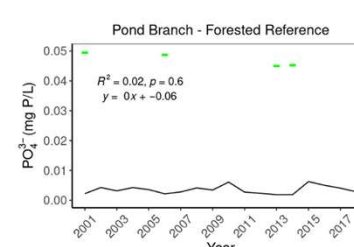
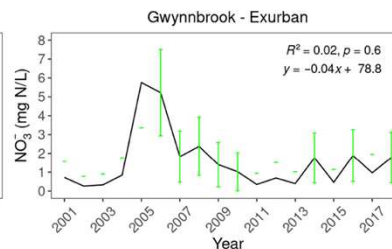
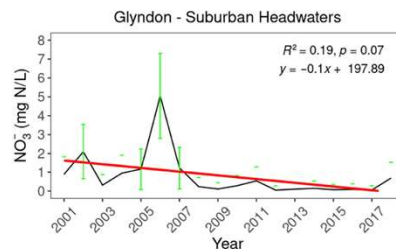
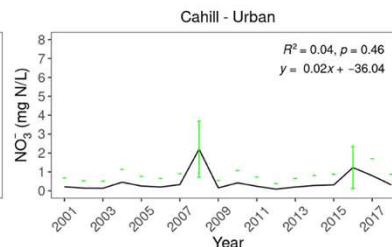
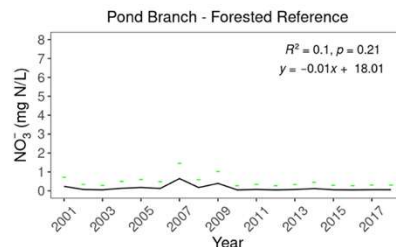
Stability despite similar incision measurements

- DR1 has extensive development and substantially greater BMP coverage than Winters Lane.
- The incision measurements do not clearly distinguish the two streams.
- Winters Lane shows visible signs of active erosion, including bare and collapsing banks and unstable trees.
- DR1 is not pristine, but it appears comparatively stable and does not show the same visible evidence of active erosion.
- This suggests that stability may be an important measure of BMP success, even when the channel has not returned to reference condition.



Q&A: Long-Term Changes in Stream Chemistry

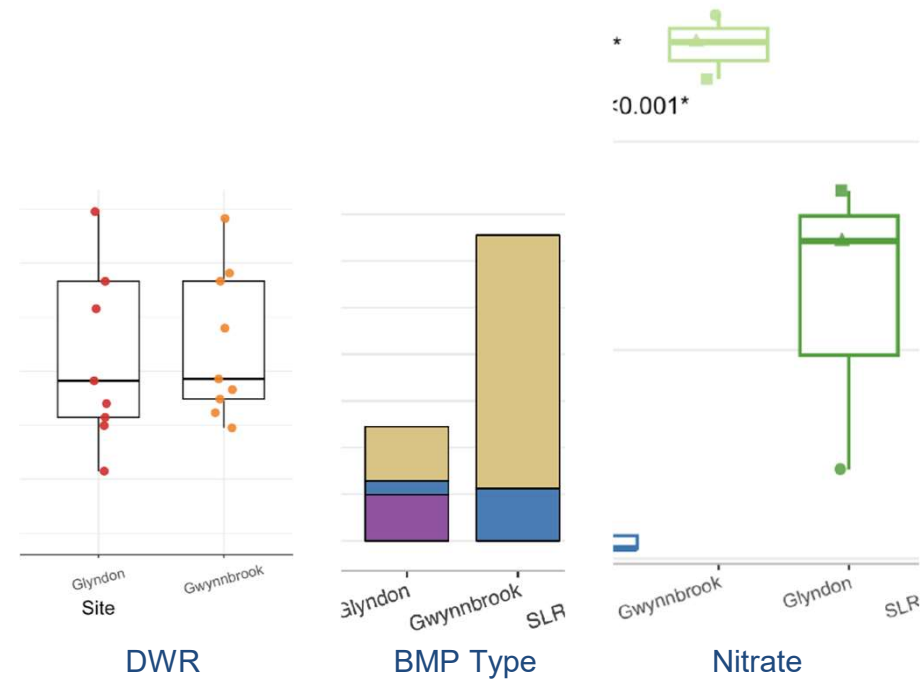
- Long-term monitoring shows that nutrient trajectories differ among watersheds.
- Nitrate declined at some sites
- Phosphate increased at some sites
- Some changes were linked to water-table depth and hydrologic connectivity.
- The synoptic study compares watersheds across sampling rounds.
- Long-term monitoring captures gradual change within each watershed.
- BMP effects may become clearer over time.



Q&A: Local nutrient sources and watershed chemistry

Glyndon and Gwynnbrook: why chemistry varies so strongly among apparently comparable watersheds?

- The two watersheds have similar geomorphic condition.
- Their BMP coverage and BMP types differ.
- Glyndon has much higher nitrate concentrations.
- A localized nutrient source may be influencing Glyndon.
- Local sources may mask broader BMP effects.



Q&A: Temporal Processes

BMP and restoration effectiveness should be evaluated over time, not only through a single geomorphic or chemistry assessment.

Possible components:

- Repeat site photographs
- Periodic rapid visual assessments
- Repeated synoptic chemistry sampling
- Updated LiDAR comparisons
- Selection of monitoring locations based on LiDAR change detection

Q&A: Could the BMP database be incomplete or outdated?

BMP data source and limitations

- BMP records came from the Baltimore County NPDES database.
- The database was reviewed recently.
- Some BMPs may still be missing from the available records.
- Many recorded BMPs are older designs.
- We used the best available county data and welcome updated records.

BMP Source: <https://www.baltimorecountymd.gov/departments/information-technology/gis/data-download>



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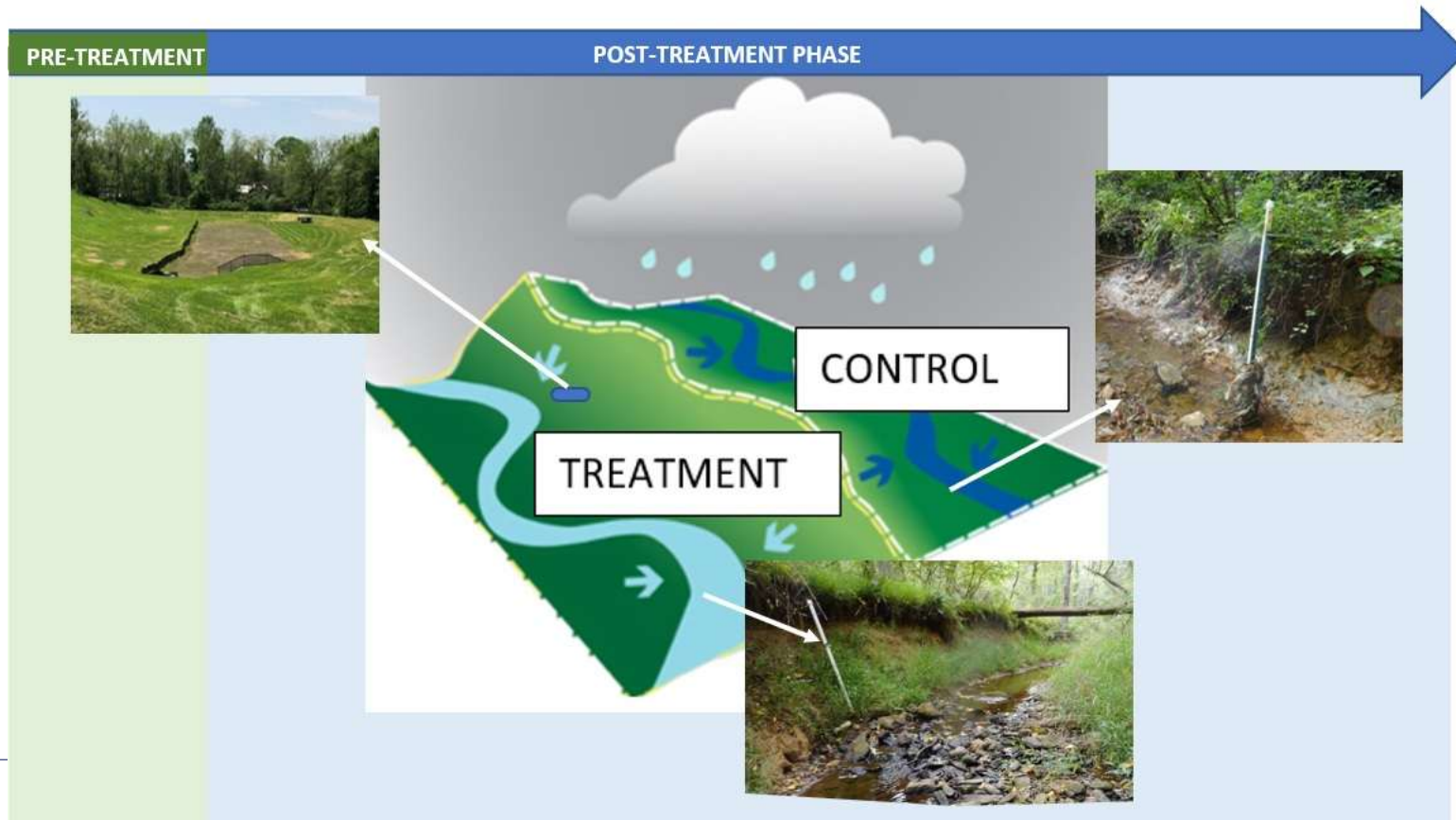
The Long-Term Effects of BMP Implementation on Stream Channel Stability in Urban Watersheds

Lisa Fraley-McNeal, CWP
Byron Madigan, Carroll County
Deb Caraco, CWP
Sami Khan, CWP
Bill Stack, CWP

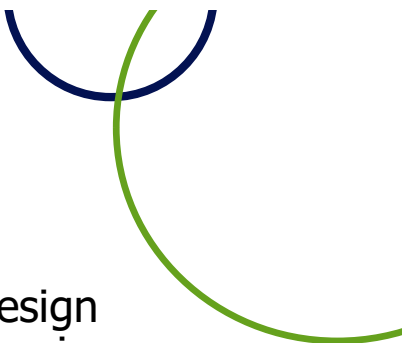
Chesapeake Bay Trust Pooled Monitoring Forum
June 18, 2026

Research Question

What is the effectiveness of stormwater best management practices (BMPs) at the catchment scale?



Hypotheses

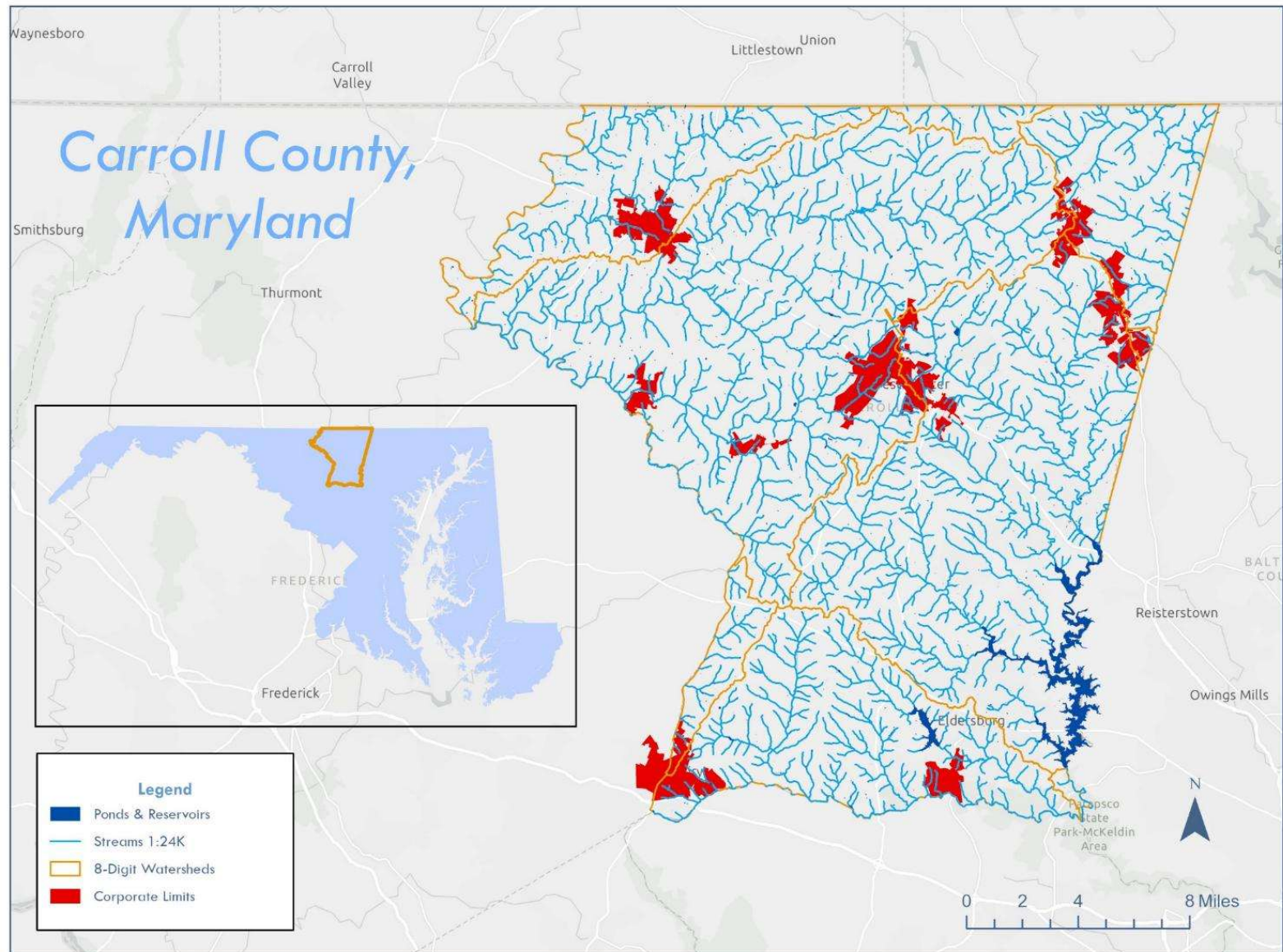


H1: The implementation of BMPs retrofitted to meet Carroll County's sand filter design standard will modify the runoff response from the watershed (hydrograph) resulting in a reduction in the magnitude, duration, and frequency of erosive flow rates that meet and or exceed MDE performance standards for stream channel protection.

H2: The implementation of these BMPs will create hydraulic conditions that lead to self-recovery of channel stability.

- a. The bank erosion rate in treatment reaches will be lower than the control reaches due to reduction in magnitude, duration, and frequency in flows that contribute to bank erosion.
- b. The treatment reaches will be aggrading due to the reduction in magnitude, duration, and frequency in flows resulting in sediment deposition on the streambed.

H3: The implementation of these BMPs will decrease sediment loadings downstream because of reduced bank erosion rates.



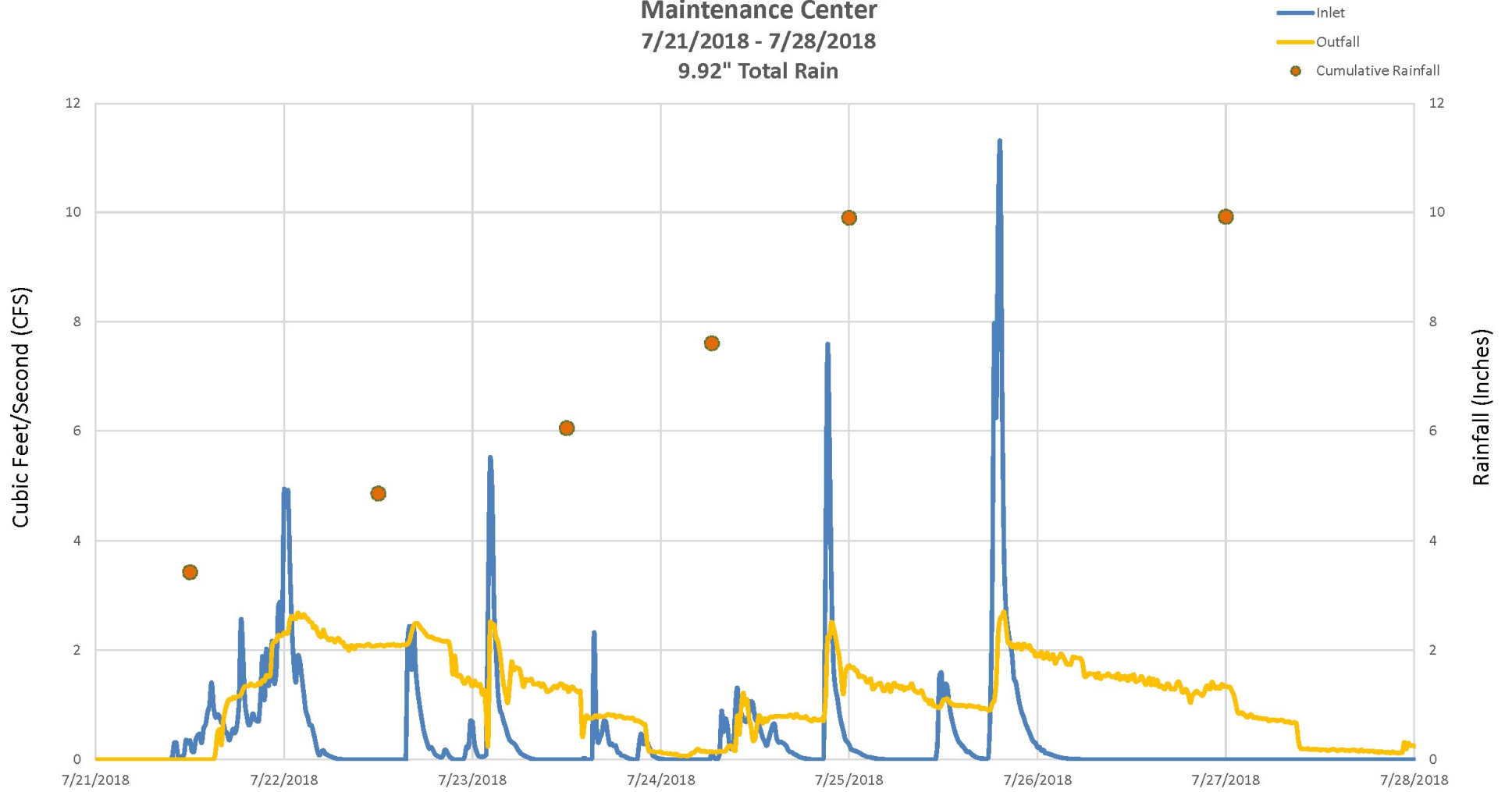
Carroll County Sand Filter Design

Unique Design Characteristics

- No Riser - all design flows through sand control
- Drop Structures and Level Pipes
 - Turbulent to laminar flow
- Total Capture of 2 year storm, “difference in 10 year runoff volume”
 - Direct runoff difference – Meadow and Impervious
- Sand layer seeded w/ MDE mix
 - Prevents cracking/short circuiting of filter



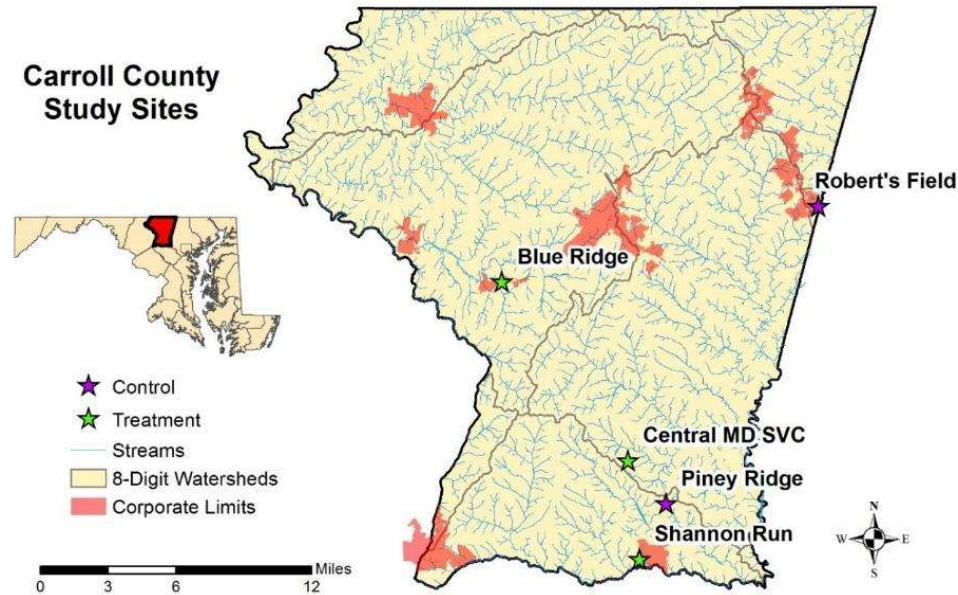
Maintenance Center
7/21/2018 - 7/28/2018
9.92" Total Rain



Monitoring Locations

Pre-Treatment Monitoring
November 2016 – October 2017

Post-Treatment Monitoring
October 2018 – June 2026

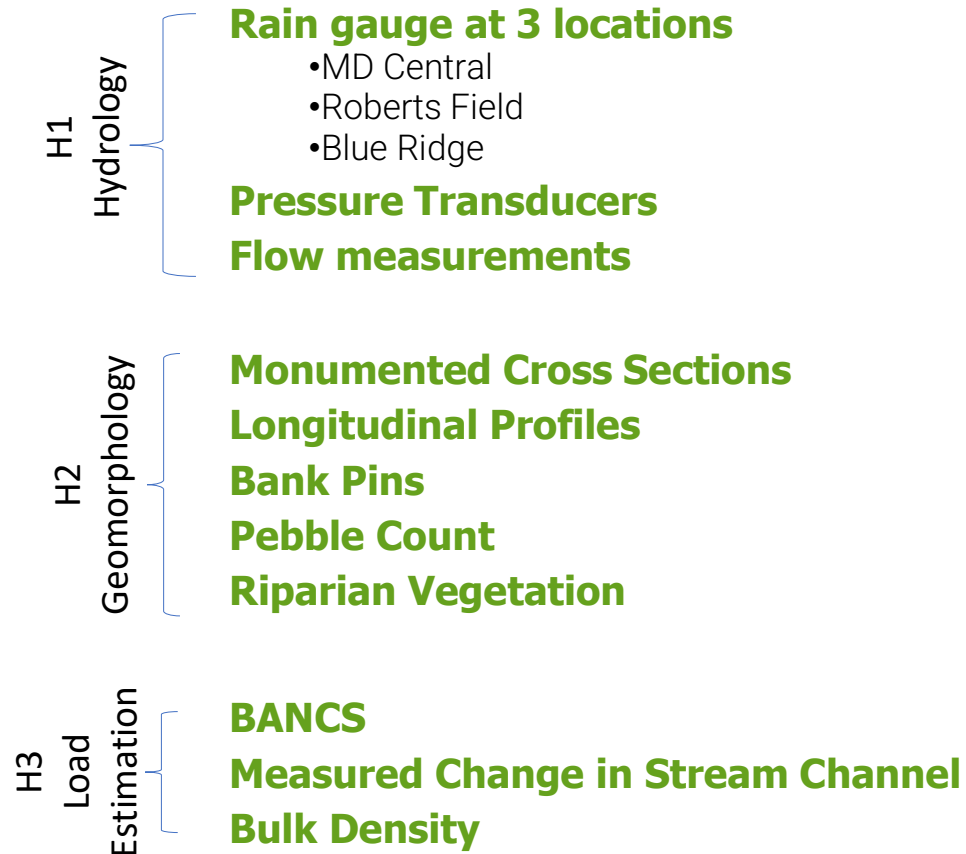


Study Site	Treatment or Control	Drainage Area (ac)	Impervious Cover (%)	Study Reach Length (ft)	Existing BMP Type	Retrofit Type
Blue Ridge ¹	Treatment	33.6	26.9%	145	Retention	Sand Filter
Central MD SVC ¹	Treatment	91.7	31.3%	325	Detention	Sand Filter
Robert's Field ¹	Control	28.8	37.4%	157	Extended Detention	N/A
Shannon Run	Treatment	209	20%	366	Retention	Wet Pond
Piney Ridge	Control	91.1	36.1%	559	Retention	N/A

¹ Rain gauge located at site.

Ponds were originally designed for 2- and 10-year management. At the treatment sites, the ponds were retrofitted to provide channel protection volume.

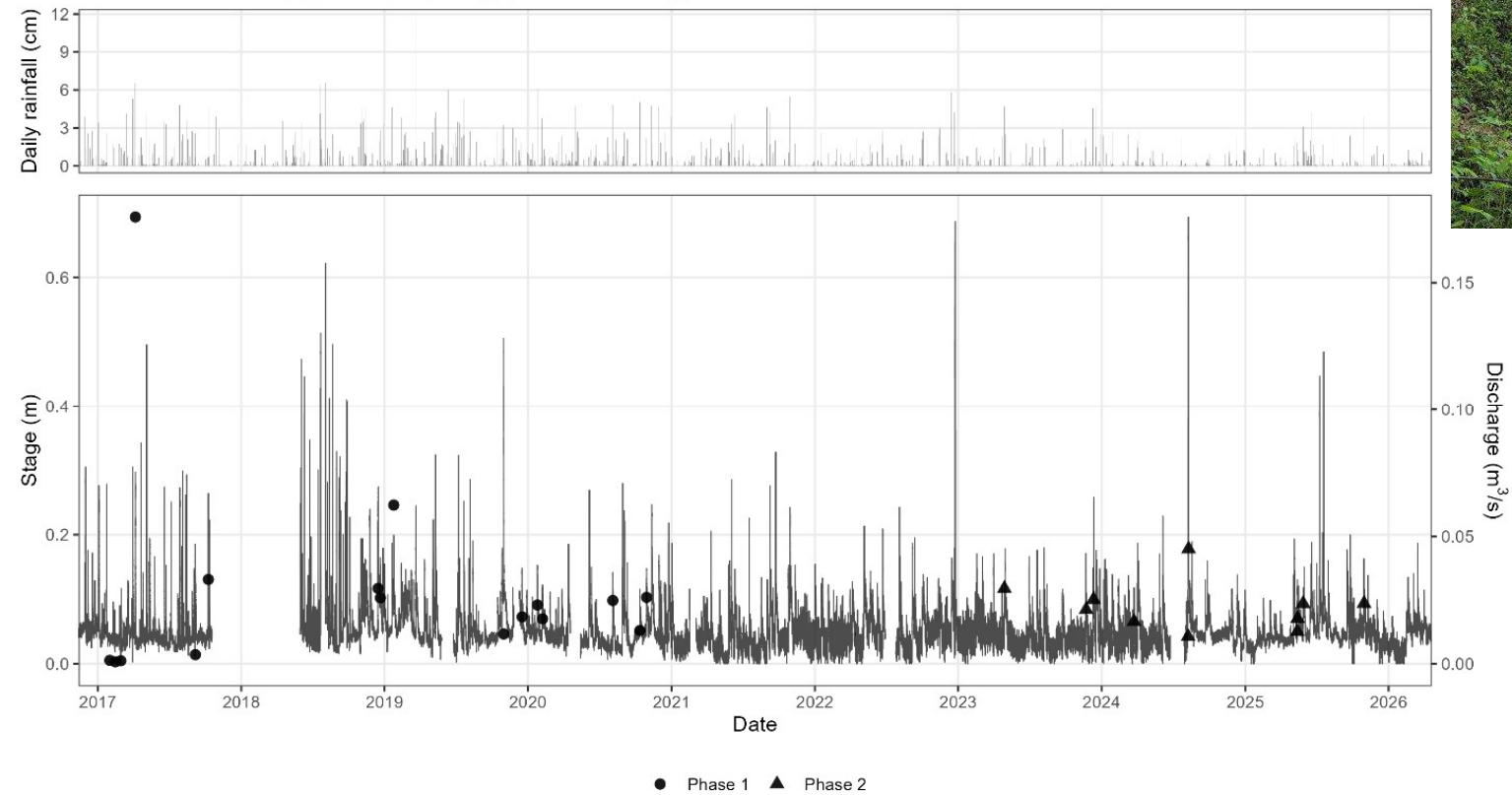
Monitoring Methods



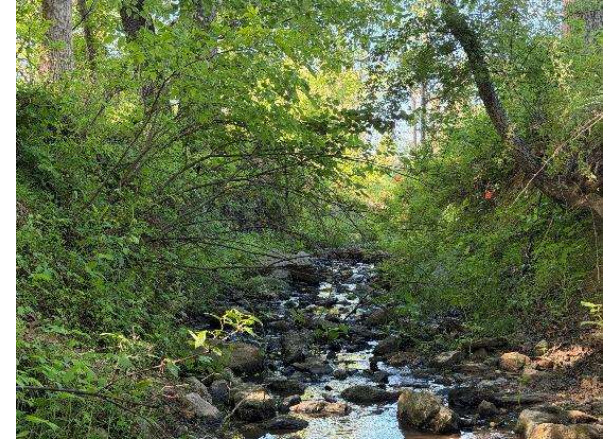
H1: Hydrology

Central Maryland Service Center Treatment Site

Central MD SVC (T) - Rainfall, Stage, and Discharge



Note: Negative stage values were excluded from the plot for visualization purposes.



H1: Hydrology

Flow Measurement and Calculations

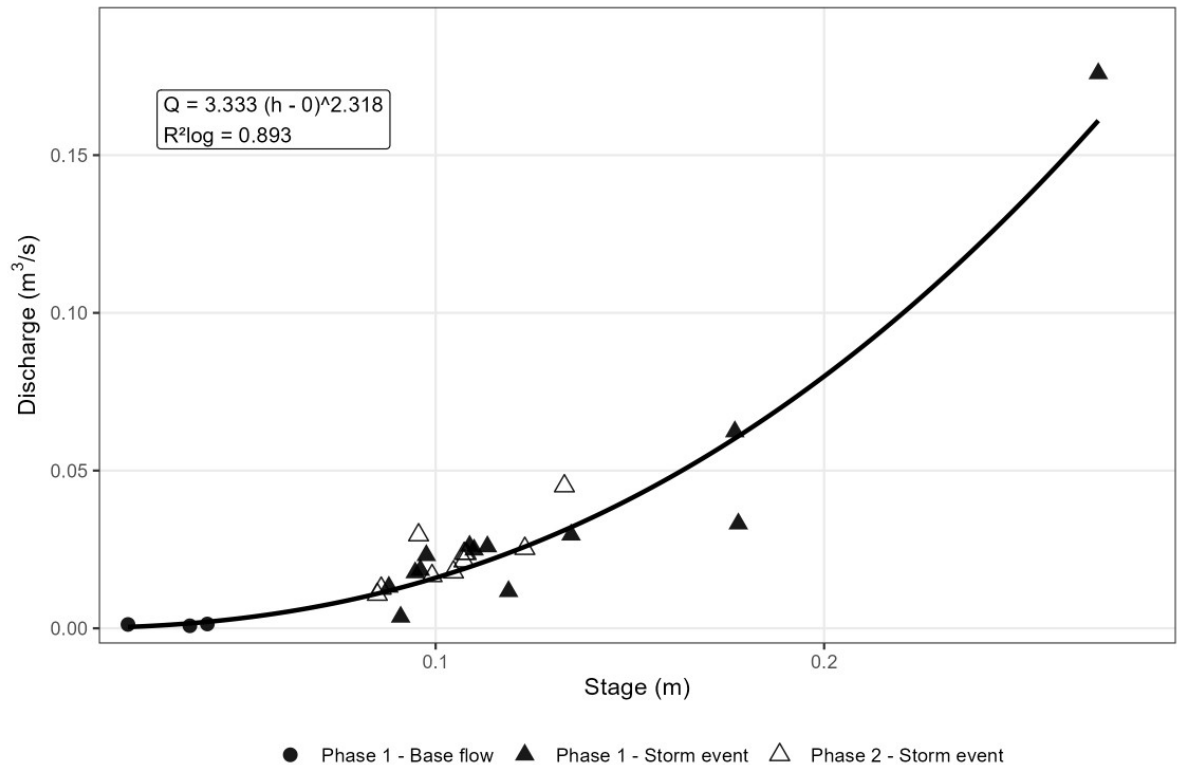
Measurement Changes

- Additional barometric pressure transducers in late 2024
- 2 x-sections measured per reach (down from 3)

Re-Evaluate Stage-Discharge Curves

- Add new “Phase 2” data to initial stage-discharge curves.
- Do we need a new curve based on:
 - Additional observations (improvement), or
 - Channel geometry changes
 - Possible revised methodology for flows beyond the range of the curve.

Central MD SVC (T) - Rating Curve



Rating curve was constructed using Phase 1 discharge measurements.

H1: Hydrology

Preliminary Post-Pre Comparisons

Paired Watershed/ mBACI Approach

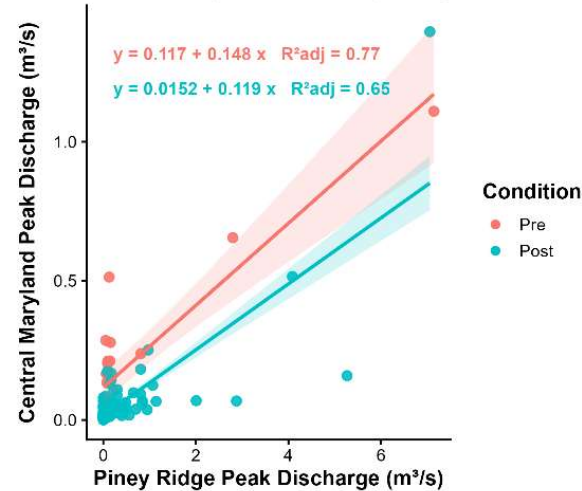
- Compared both Discharge and flow volume relationships between Control and Treatment Sites.
- In Phase 2, continued to add data to these evaluations.

Key questions:

- Does the improvement from Treatment sites persist over time?
- Do the new data strengthen or weaken the original conclusions?

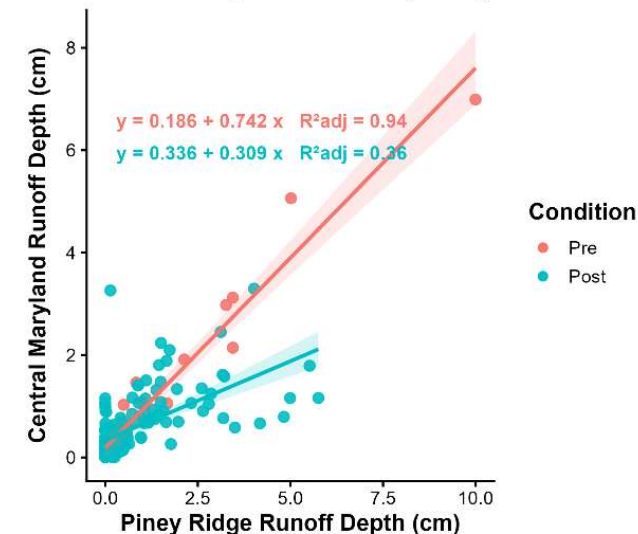
Peak Discharge Comparison

Central Maryland vs Piney Ridge



Runoff Volume Comparison

Central Maryland vs Piney Ridge



H2: Geomorphology

Shannon Run (Treatment)

May 2025



November
2016

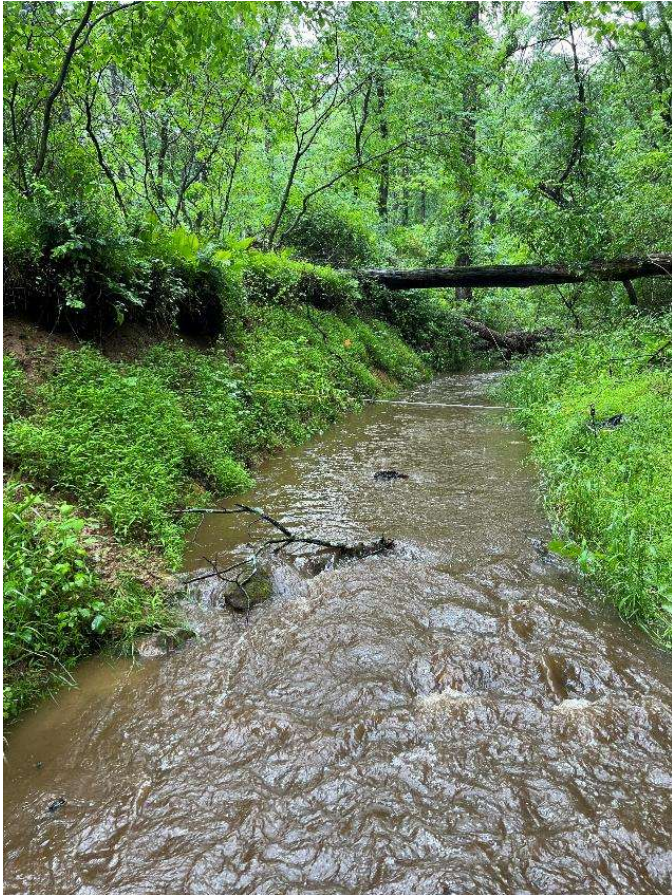


May 2020

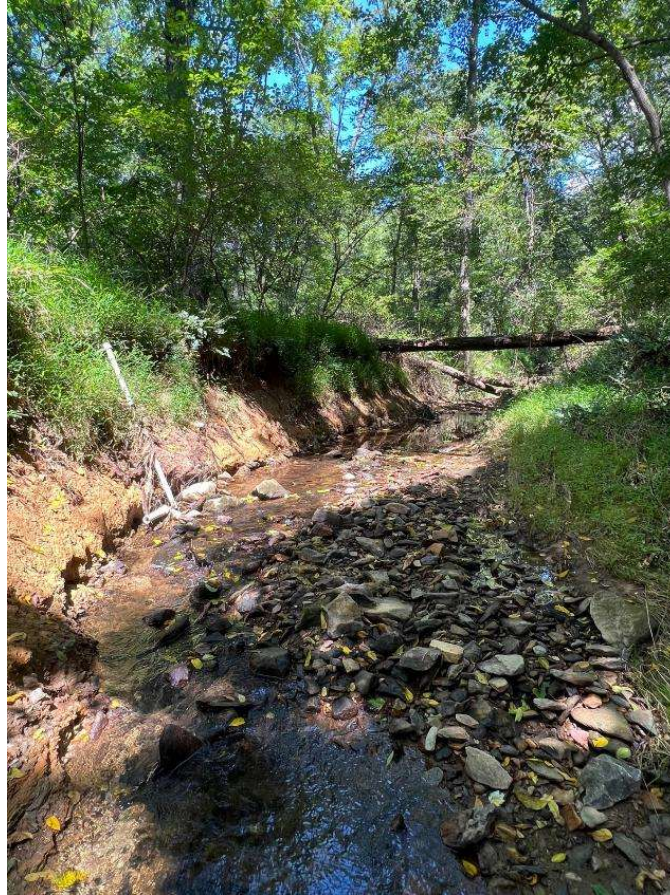


H2: Geomorphology

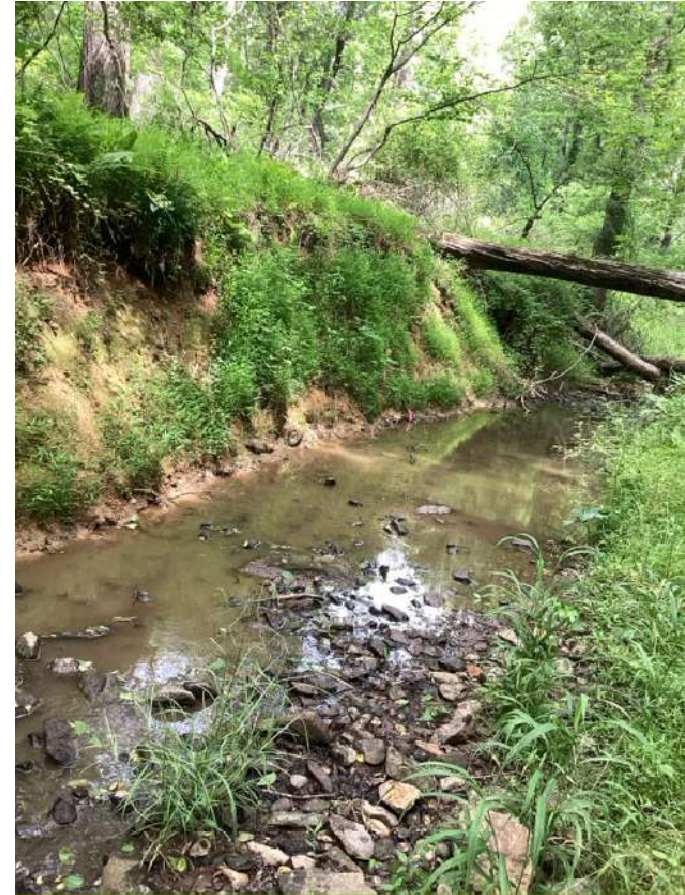
Shannon Run (Treatment)



May 2025



August 2025
(after riser low-flow orifice clog)



June 2026

H2: Geomorphology

Control Sites



**Piney Ridge
May 2026**

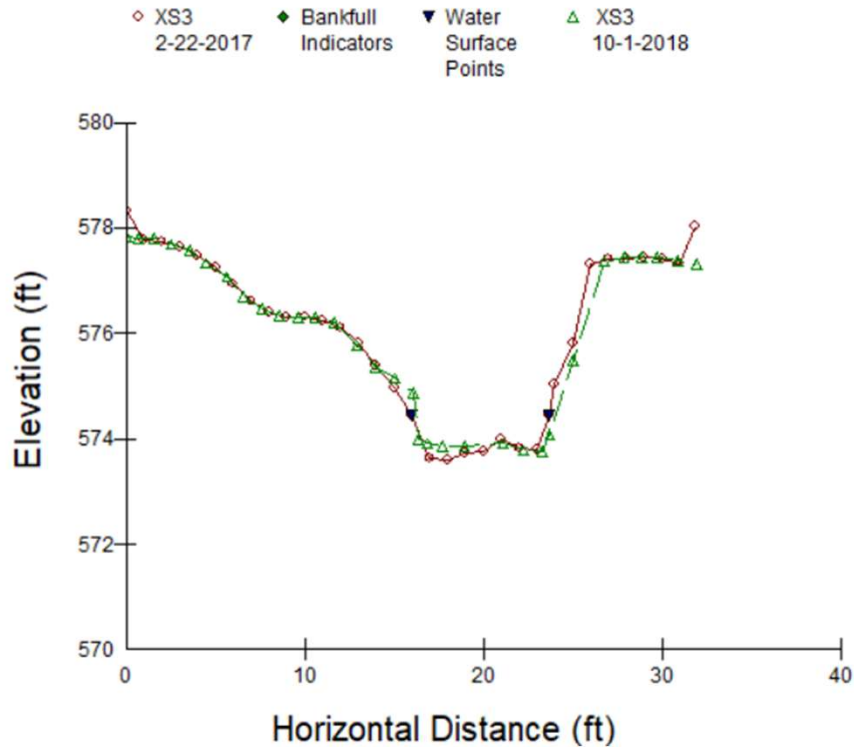


**Robert's Field
July 2024**

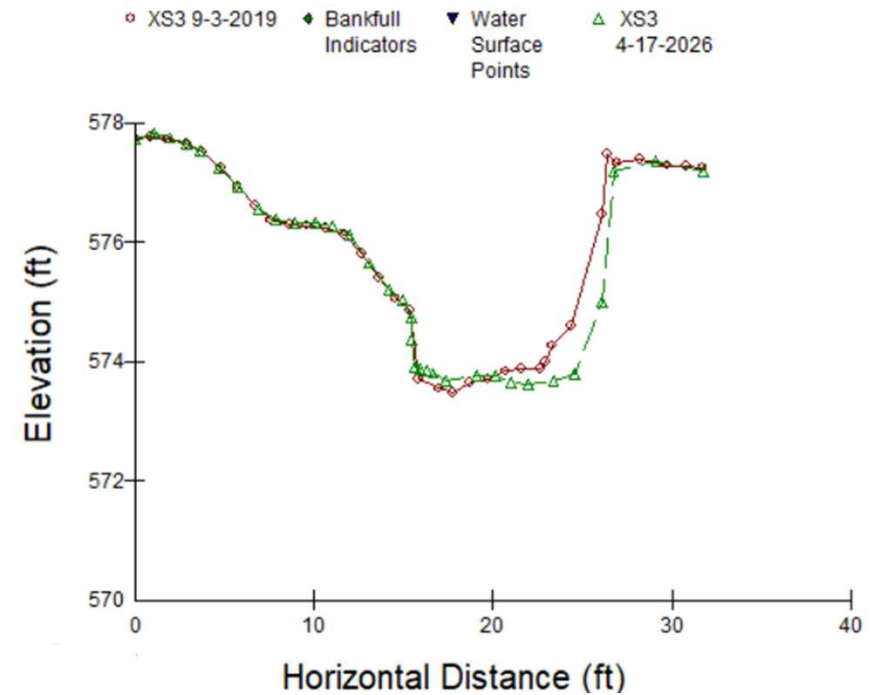
H2: Geomorphology

Cross Section Surveys

**Piney Ridge XS3 (C)
Pretreatment**



**Piney Ridge XS3 (C)
Posttreatment**



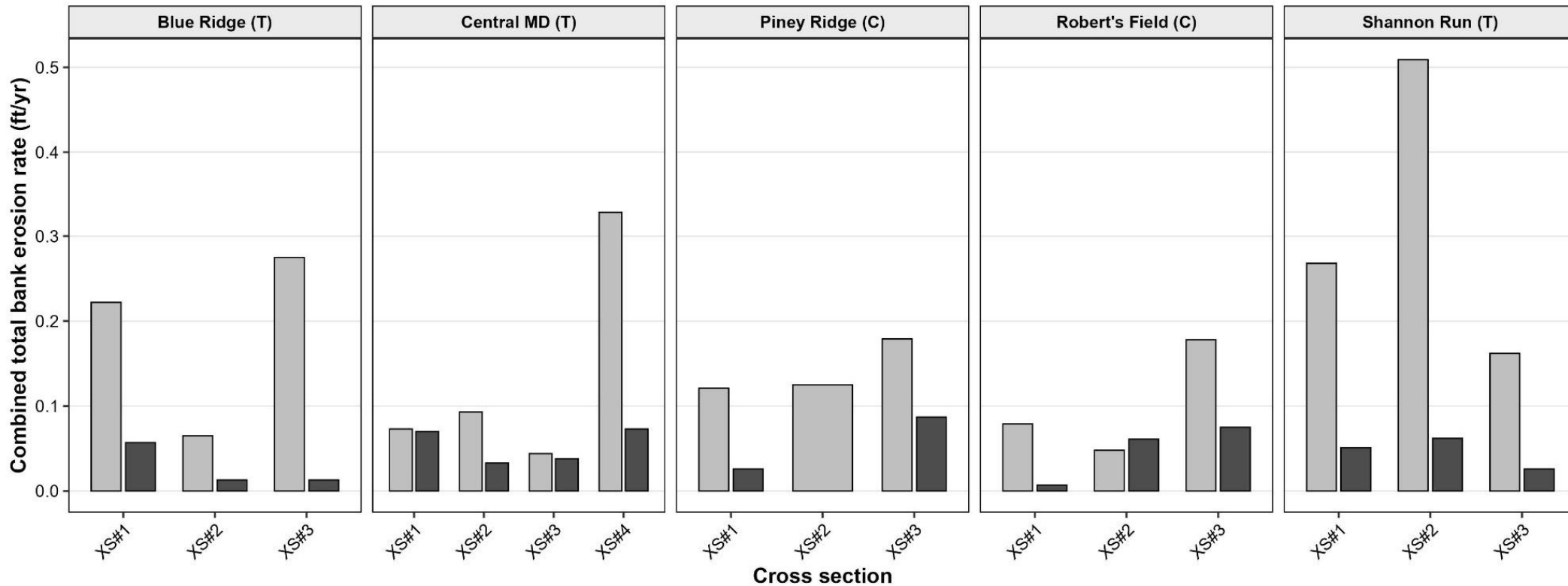
H2: Geomorphology

Bank Erosion Rates – Cross-Sections

Pre- and Post-Treatment Bank Erosion Rates by Cross-Section

Each bar represents one cross-section; T = treatment, C = control

Analysis Period  Pre-Treatment  Post-Treatment



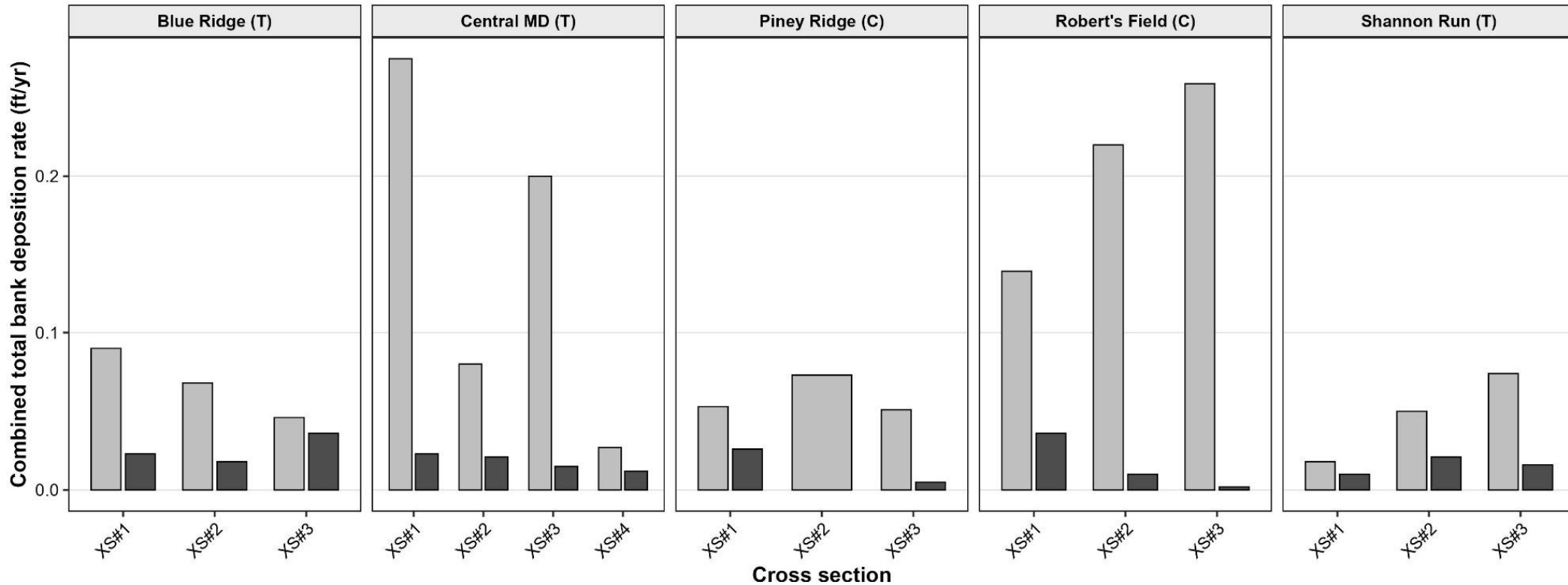
H2: Geomorphology

Bank Deposition Rates – Cross-Sections

Pre- and Post-Treatment Bank Deposition Rates by Cross-Section

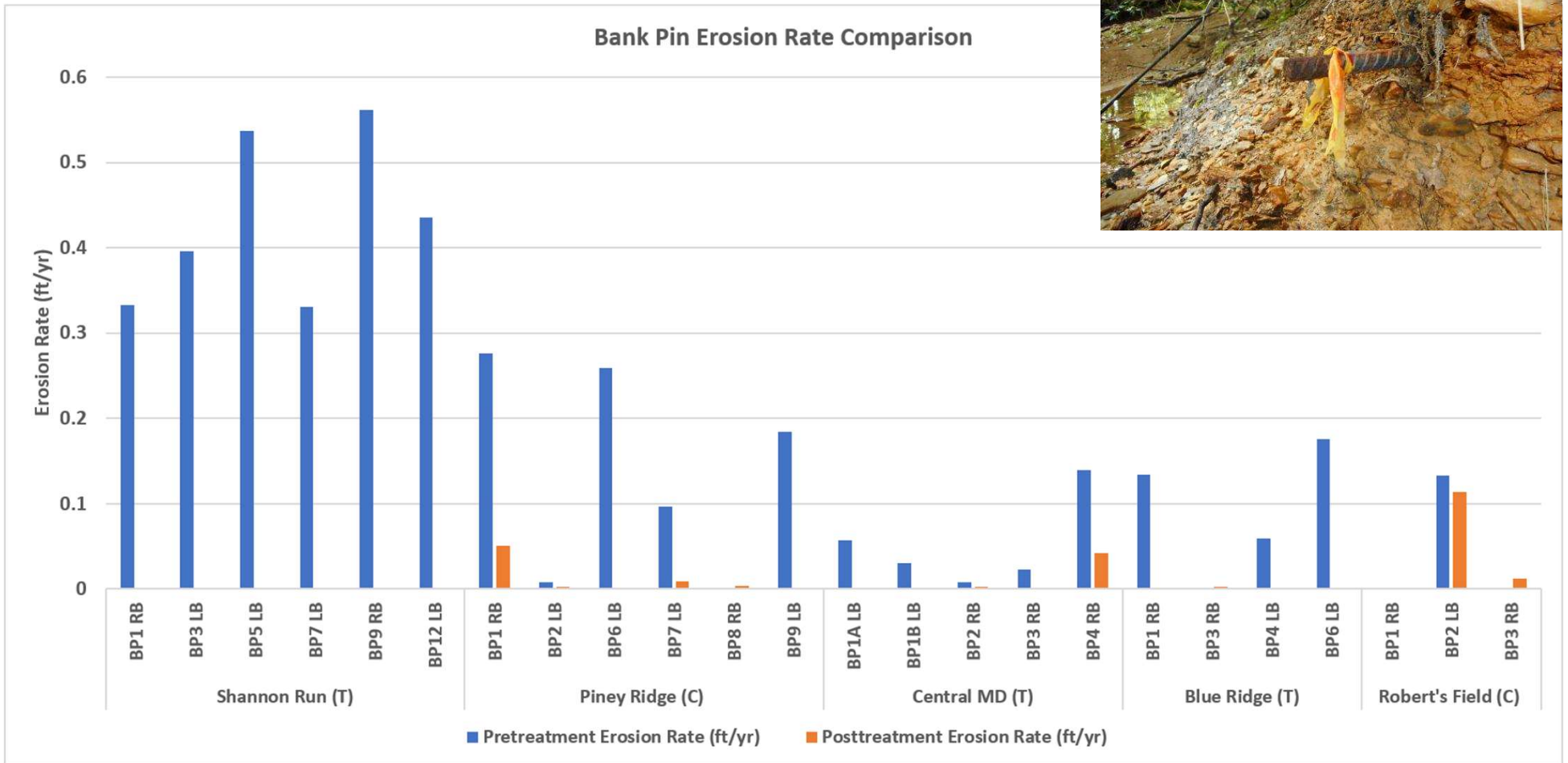
Each bar represents one cross-section; T = treatment, C = control

Analysis Period Pre-Treatment Post-Treatment



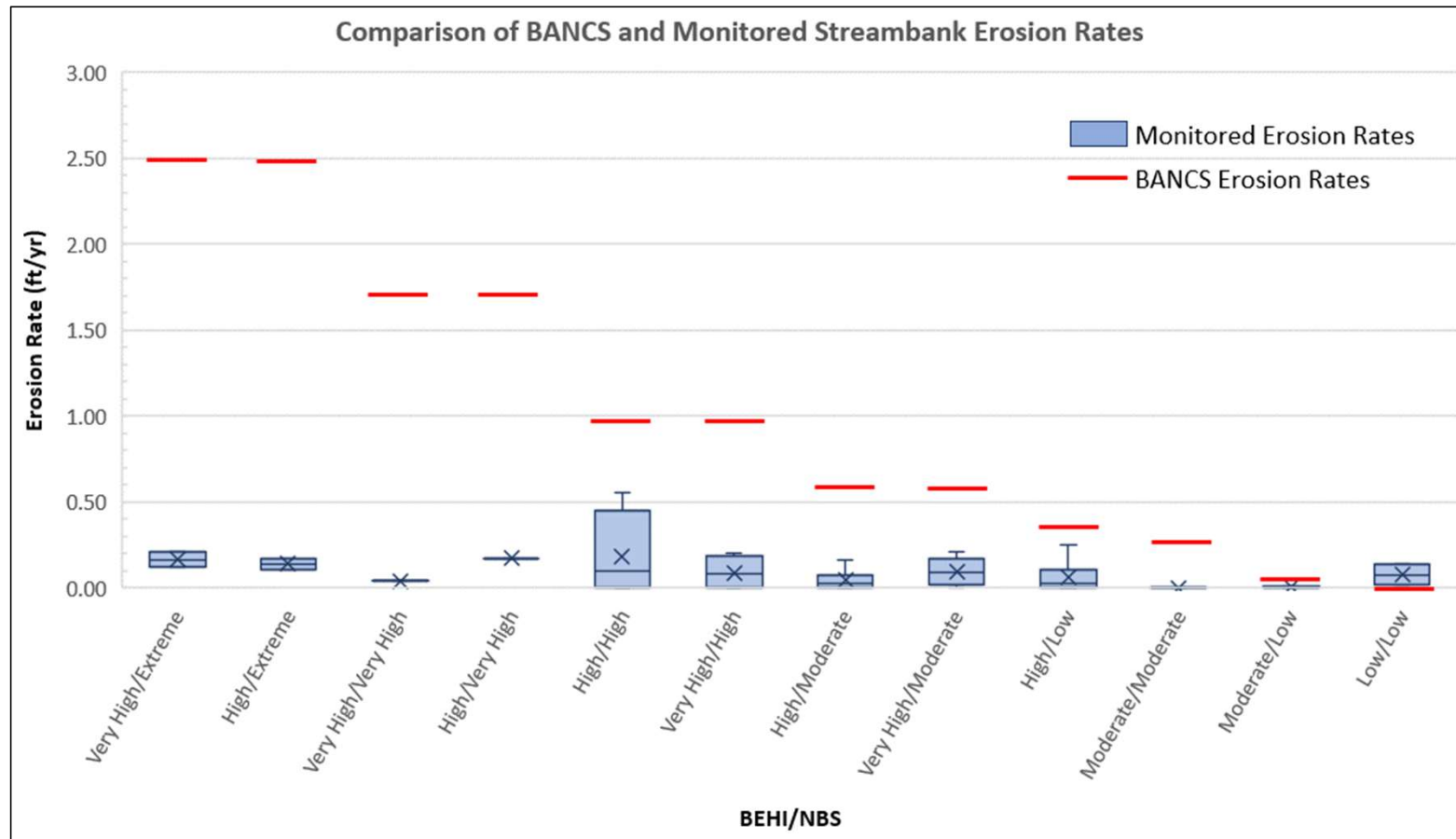
H2: Geomorphology

Bank Erosion Rates – Bank Pins



H3: Load Estimation

BANCS Overestimates Erosion Rates



H3: Load Estimation

	BANCS		Monitoring Data		
Study Site	Pretreatment Total TSS Load ¹ (tons/yr)	Post- Treatment Total TSS Load ¹ (tons/yr)	Pretreatment TSS Load (tons/yr)	Post- Treatment TSS Load (tons/yr)	% of Total Bank Length with Representative Monitoring Location ²
Central MD SVC (T)	42.11	45.04	3.42	8.92	89.8%
Piney Ridge (C)	59.25	75.9	0.72	0.40	31.3%
Shannon Run (T)	54.49	56.54	11.06	7.35	52.5%
Robert's Field (C)	24.26	27.21	1.01	1.83	91.5%
¹ The loads represent the total load at edge-of-stream without a sediment delivery factor or stream restoration efficiency applied as per the CBP stream restoration crediting protocols.					
² Total bank length obtained from the top of bank survey from the longitudinal profile and includes both the left and right bank lines.					

Additional Analyses to be Completed

- Comparison of longitudinal profiles pre/post treatment
- Complete channel change analysis (in addition to the bank erosion/deposition results presented today)
- Particle size distribution analysis
- Measured curve number comparison to the theoretical predevelopment, post development, and retrofit design curve numbers
- Channel Stability - frequency of bankfull flow exceedance before and after treatment
- Revise stage-discharge curves and storm event definitions for remaining sections and add all observed data to our hydrology analyses.
- Complete an analysis of the curve number for additional storm events.
- In Phase 1, we abandoned the Blue Ridge treatment site due to ongoing construction but now we have a (delayed) post-treatment data for this site.

Thoughts and Lessons Learned

- Geomorphic changes take a while to see. We didn't see some changes in Phase 1 that are now present.
- Methods for estimating streambank sediment load can significantly affect results.
- Importance of pond retrofit maintenance. Malfunctions can undo the treatment results as we saw with Shannon Run.
- Make sure you have a "backup" pressure transducer to avoid gaps in measurement.
- Initial assessments suggest that the practices continue to mitigate storm flows, and we will understand this in more detail as we look at more data.

Funding & Acknowledgments

This research was funded through the Pooled Monitoring Initiative (PMI), Restoration Research Program.

Award #20593 | Center for Watershed Protection | 2022 - 2026

The Pooled Monitoring Initiative funds applied science to advance restoration research for cumulative impacts, comparative effectiveness of stormwater practices, pollutants of emerging concern, and trade-offs with new research questions added annually.

<https://cbtrust.org/grants/restoration-research/>



Thanks to the Many Funders and Partners!



Thank You

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Translation Slides

What are the take home points?
What does this mean for me?

Translation Slides by Deborah J. Cappuccitti,
Maryland Department of the Environment

What are the take home points?

- All ponds provided 2 and 10-year peak control prior to retrofit
 - Peak control known to increase the duration and magnitude of erosive flows
- Observations after cp_v retrofit show evidence of stream recovery
- Recovery is difficult to quantify:
 - Time: Recovery is slow - need time to observe improvements
 - Not consistent: Other watershed factors influence conditions (examples where the control at Piney is showing better results than the retrofit at Central)
 - Limits of existing tools: BEHI/NBS data are not useful for predicting recovery
 - Erosion rates are significantly over-estimated when compared to actual field conditions
 - Need better regional curves data to support use of the “one” Hickey Run curve
 - Recovery is observed with bank pin data but it takes years to get this data

What does this mean for me?

What do I take from this if I am a practitioner:

- Need for better regional curve data – to provide more accurate estimates of erosion rates to help predict channel recovery
- Better regional curve data can help improve accuracy for stream restoration crediting

What do I take from this if I am a regulator:

- Results show promise for future MS4 crediting. Need additional data to better understand applicability.
- In the meantime: Field data showing pollutant load reductions may justify a site-specific credit (i.e. Shannon Run)

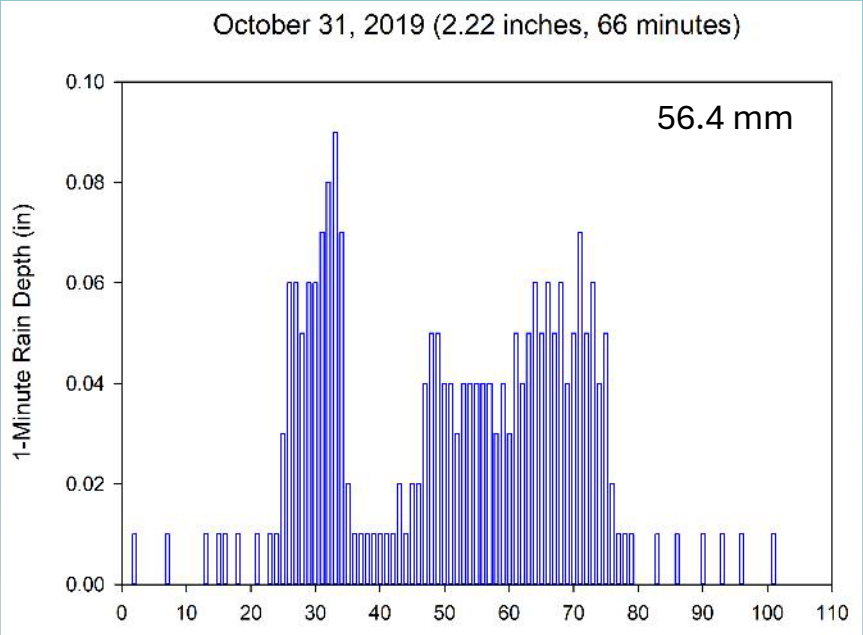
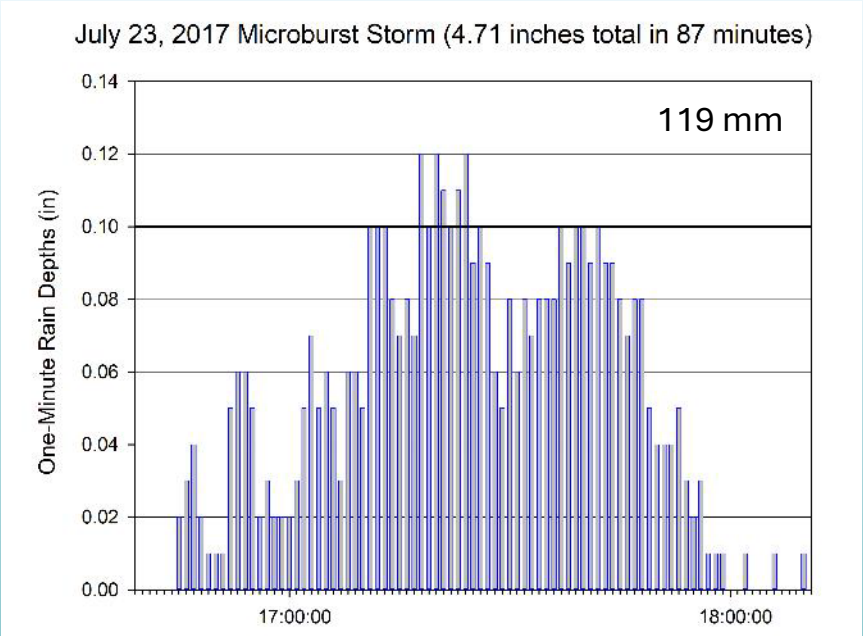
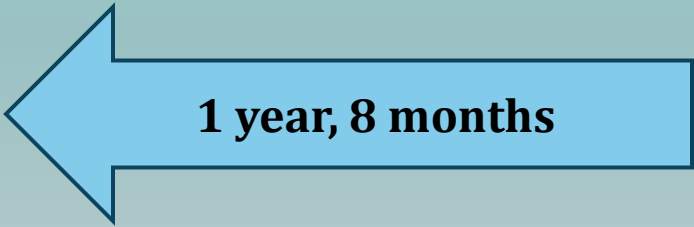
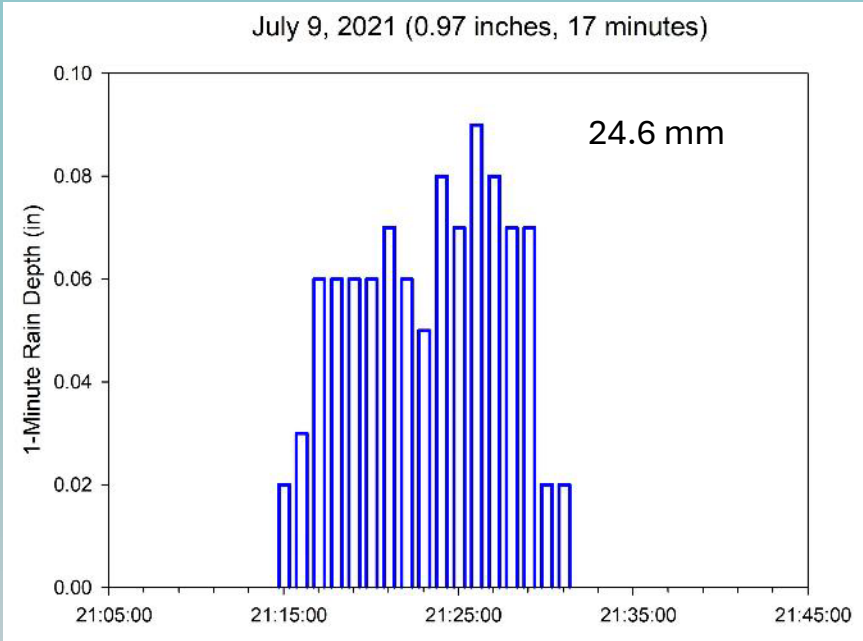
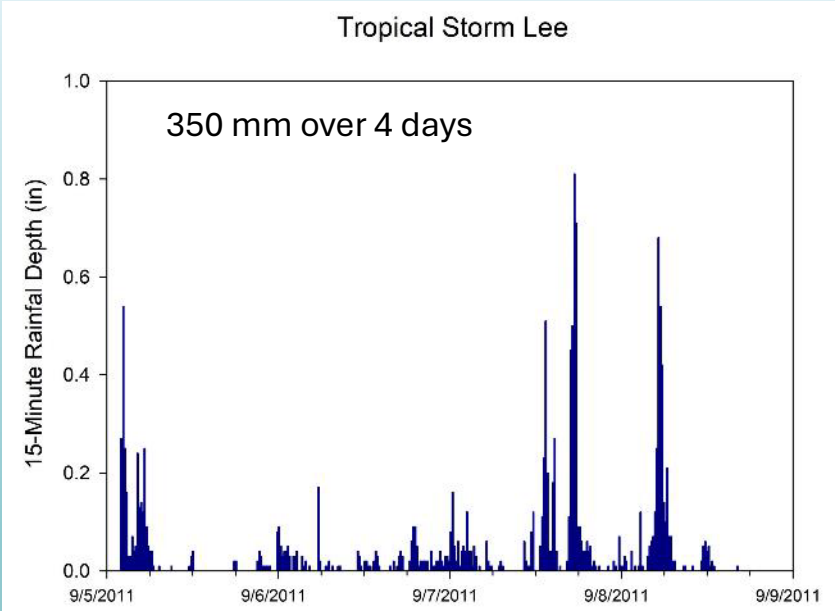
Impacts of Urban Soil Compaction on Stormwater Runoff Volumes and BMP Sizing

Shirley E. Clark, PhD, PE, BC WRE, ENV SP, F ASCE
Distinguished Professor of Environmental Engineering

Bishwodeep Adhikari, PhD
Assistant Professor of Environmental Engineering

Ghasem Razavi
PhD Student

More Frequent Short-Duration, High-Intensity Storms





Flooding throughout
Watershed during
Microburst Storm of
4.71 inches in 85
minutes

(Photos by Borough residents
and personnel)



Construction Procedure:

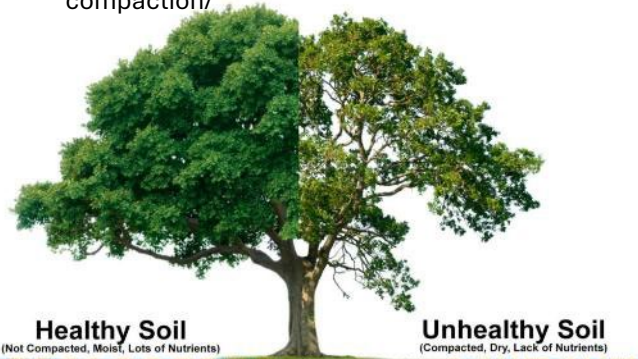
1. Clear Land and Grade
2. Compact Soils on Building Footprint and Staging/Working Areas
3. Add topsoil and Compact
4. Rototill to Unknown Depth
5. Plant Grass or Lay Sod



9 inches of soil
water storage



<https://rtectreecare.com/soil-compaction/>



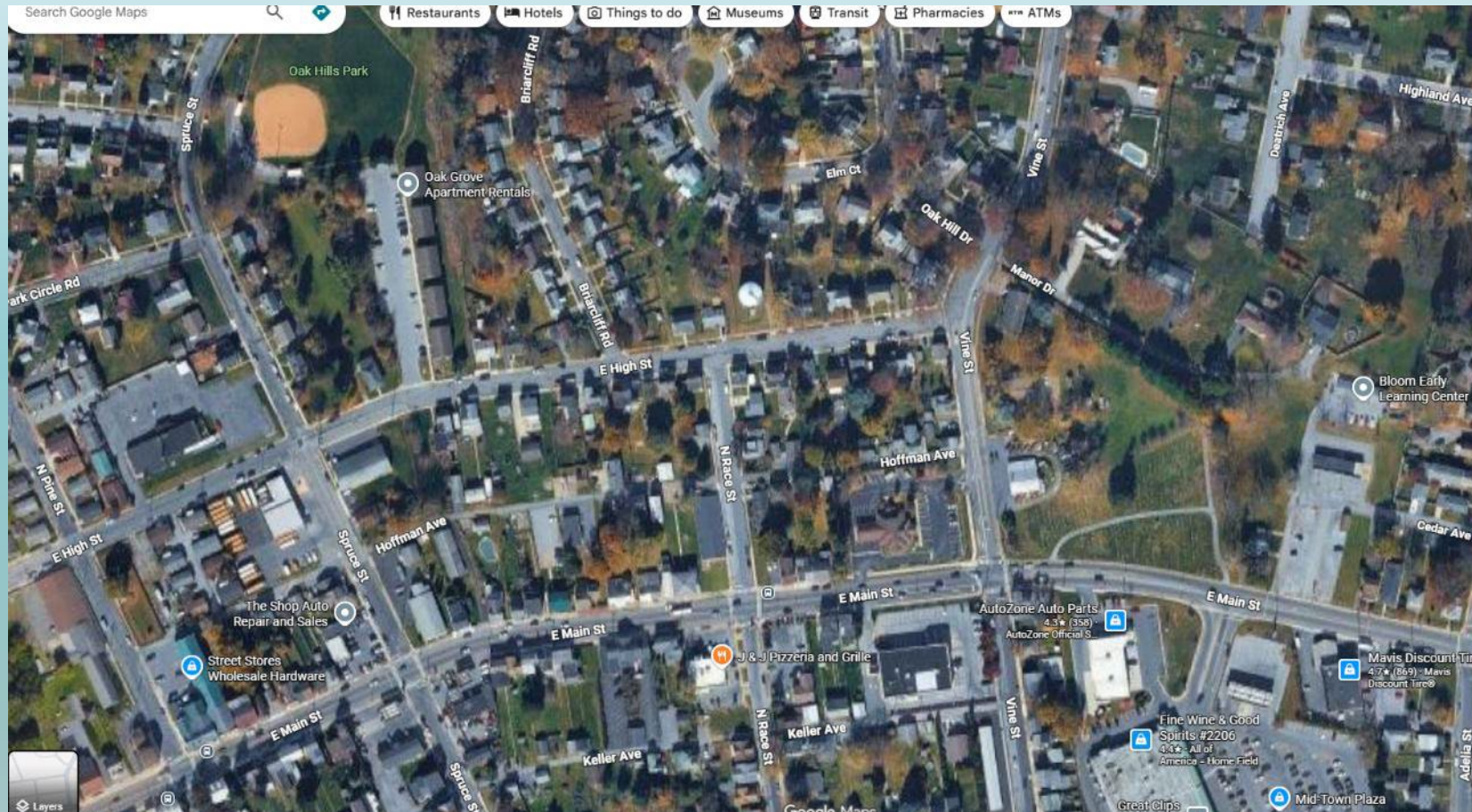
2 – 2.5 inches of soil
water storage



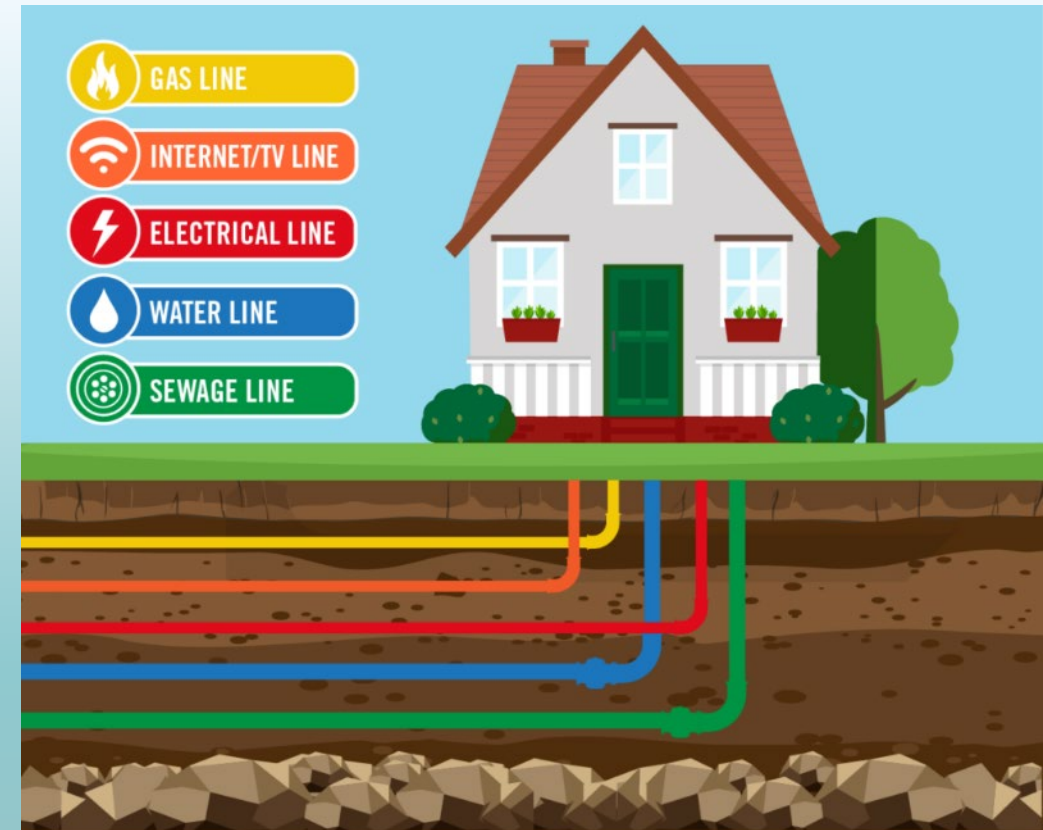
m/soil-compaction-problems-solutions.html



Challenge of Older Cities: Space for GSI



- New York City and Washington, DC: Median residential lot size of 2,700 sq ft with >50% impervious.
- Many newer homes, even on these small lot sizes, have gotten larger.
 - Washington, DC: Between 2010 and 2020, larger homes on median lot size of just 1,700 sq ft (94% lot usage).
- Philadelphia: Median residential lot size of approx. 1,100 sq ft.
- Baltimore:
 - Current: Rowhouse Districts permits lots down to 1,100 sq. ft. for rowhouses, while at least 2,500 sq. ft. for semi-detached developments.
 - Current: Detached/Semi-Detached require minimum lot sizes ranging from 3,000 sq. ft. to 5,000 sq. ft.
 - Historically, could be less than 1,000 sq ft to 2,500 sq ft in much of older sections of city

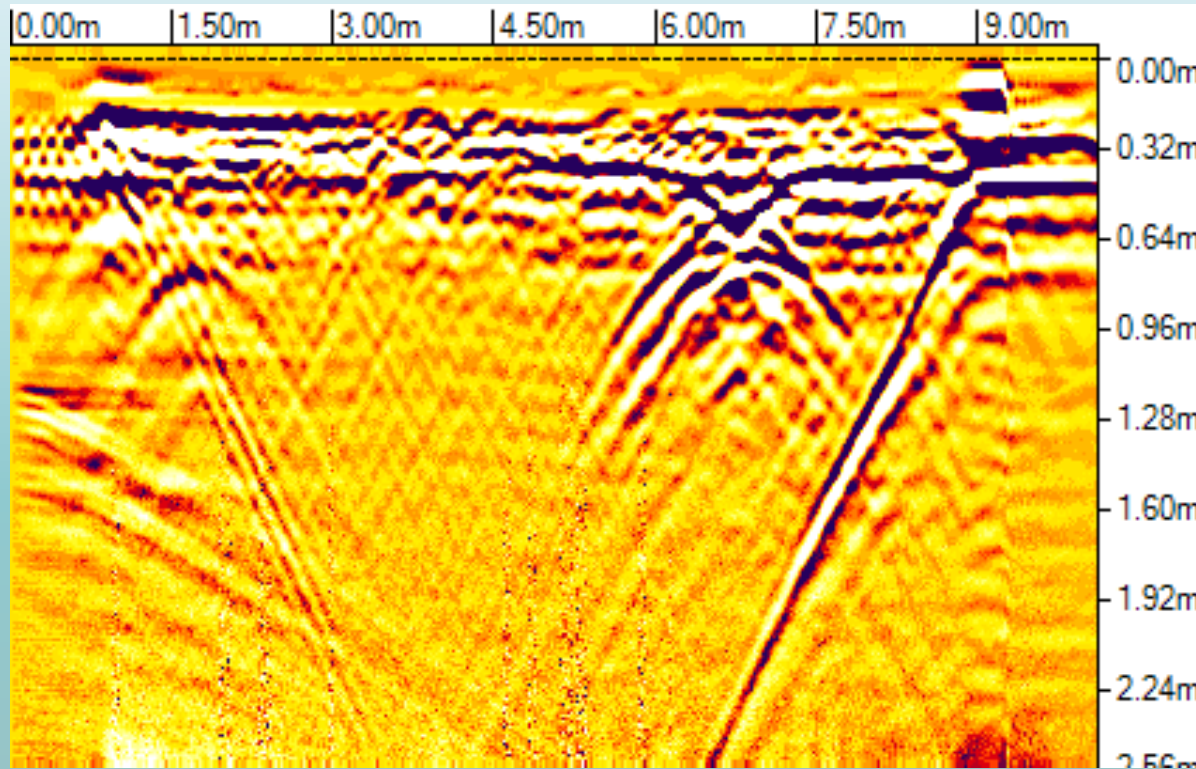


<https://dpcoftexas.org/home-owners-and-811/>

URBAN KARST BEHAVIOR

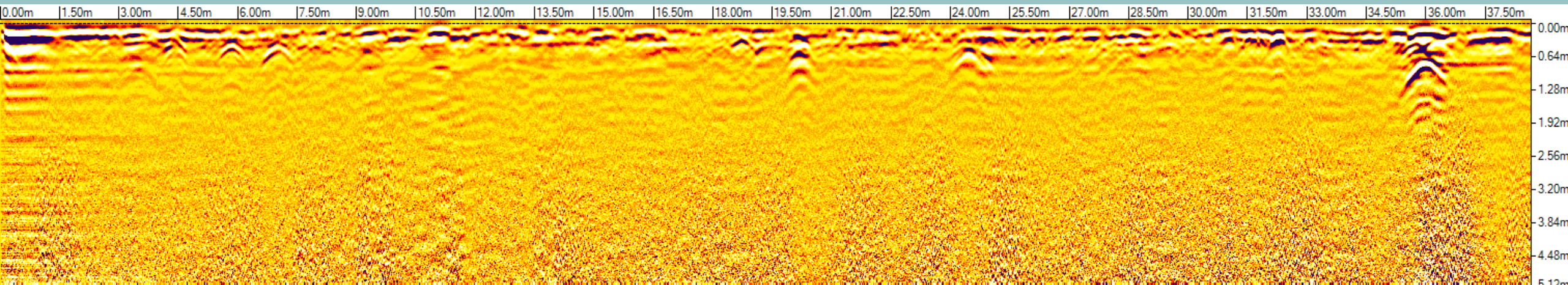
<https://pipespy.com/blog/underground-utility-replacement/>

Urban Soils Are Heterogeneous and Penetrated by Utilities



← Under Pavement

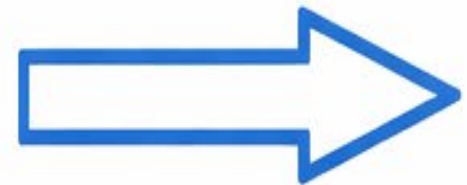
Grass Area Behind Building



Where Does the Water Go?



Surface Soil Layer: Flow Restricted by Grass Mats, but Wets Easily
Above Compaction Layer



Compaction Depth

Depth to 2070 kPa (300 psi)
resistance



Comparison of SWMM Infiltration Choices

Infiltration Editor

Infiltration Method: HORTON

Property	Value
Max. Infil. Rate	26
Min. Infil. Rate	8.67
Decay Constant	24.24
Drying Time	7
Max. Volume	4.5

Maximum rate on the Horton infiltration curve (in/hr or mm/hr)

OK Cancel Help

Infiltration Editor

Infiltration Method: MODIFIED_HORTON

Property	Value
Max. Infil. Rate	26
Min. Infil. Rate	8.67
Decay Constant	24.24
Drying Time	7
Max. Volume	4.5

Maximum rate on the Horton infiltration curve (in/hr or mm/hr)

OK Cancel Help

Infiltration Editor

Infiltration Method: GREEN_AMPT

Property	Value
Suction Head	3.5
Conductivity	0.5
Initial Deficit	0.25

Soil capillary suction head (inches or mm)

OK Cancel Help

Infiltration Editor

Infiltration Method: CURVE_NUMBER

Property	Value
Curve Number	80
Conductivity	0.5
Drying Time	7

SCS runoff curve number

OK Cancel Help

Horton is the only option that allows for a restrictive layer.

Compaction, Infiltration, Soil Moisture at Many Sites



Procedure In the Field: Depth to Compaction Layer

Step 1. Insert cone penetrometer to depth where resistance is 300 psi.



Step 2. Measure the depth of penetration.



Step 3. Repeat in multiple locations at the site. Highlights variability (so can determine an average depth) and patterns (such as a leaky water line which increases compaction depth).

Map of Behind Ferry House

Probe #	Moist (%)	Temp (°F)	Conduct (mS)	Comp. (in ³)	mini-Comp (kg/cm ²)
1	16.6	84	0.05	2.75	2.0
2	23.7	90	0.10	3.5	2.25
3	18.6	91	0.05	6	3.0
4	23.3	86	0.07	4.75	3.5
5	25.4	87	0.08	4.75	2.75
6	25.1	86	0.12	3.75	2.75
7	23.2	85	0.07	3.25	1.75
8	26.6	82	0.06	3.25	2.25
9	25.9	81	0.10	4.75	1.75
10	19.0	86	0.07	4.25	1.75
11	15.8	84	0.06	5	2.25
12	17.3	83	0.04	4.5	3.0

Step 4. Dig small hole and collect soil sample.



Step 5. Add sand to graduated cylinder and fill hole (level to ground surface) with sand. Record volume.

DATA COLLECTED:

1. Compaction depth
2. Volume of sand required to fill hole

Soil sample collected and brought back to lab to weigh before and after drying at 103 – 105 C.

In the Field: Soil Characterization and Moisture Sensor Installation

Step 1. Dig hole and note any changes in soil profile.



Step 2. Note other observations (rock content, depth of roots, etc.).



Step 3. Insert soil moisture sensor per manufacturer's instructions.



Step 4. Measure depth of sensor installation.



DATA COLLECTED:

1. Sensor installation depth
2. Depth of roots and incongruities
3. Presence of rocks, etc.

First Step Calculations: Bulk Density, Porosity

Step 1. Calculate the bulk density of the soil sample.

Bulk Density, ρ_b :

$$\rho_b = \frac{\text{Mass of oven dried soil}}{\text{Volume of sand that replaced soil}}$$

Step 2. Calculate the total porosity.

Porosity, n :

$$n = 1 - \frac{\rho_b}{2.6 \text{ g/cm}^3}$$

2.6 g/cm³ is the approximate particle density for soil particles (range typically is 2.5 – 2.7 g/cm³).

Step 3. Determine whether an assumption that effective porosity (n_e) = total porosity (n).

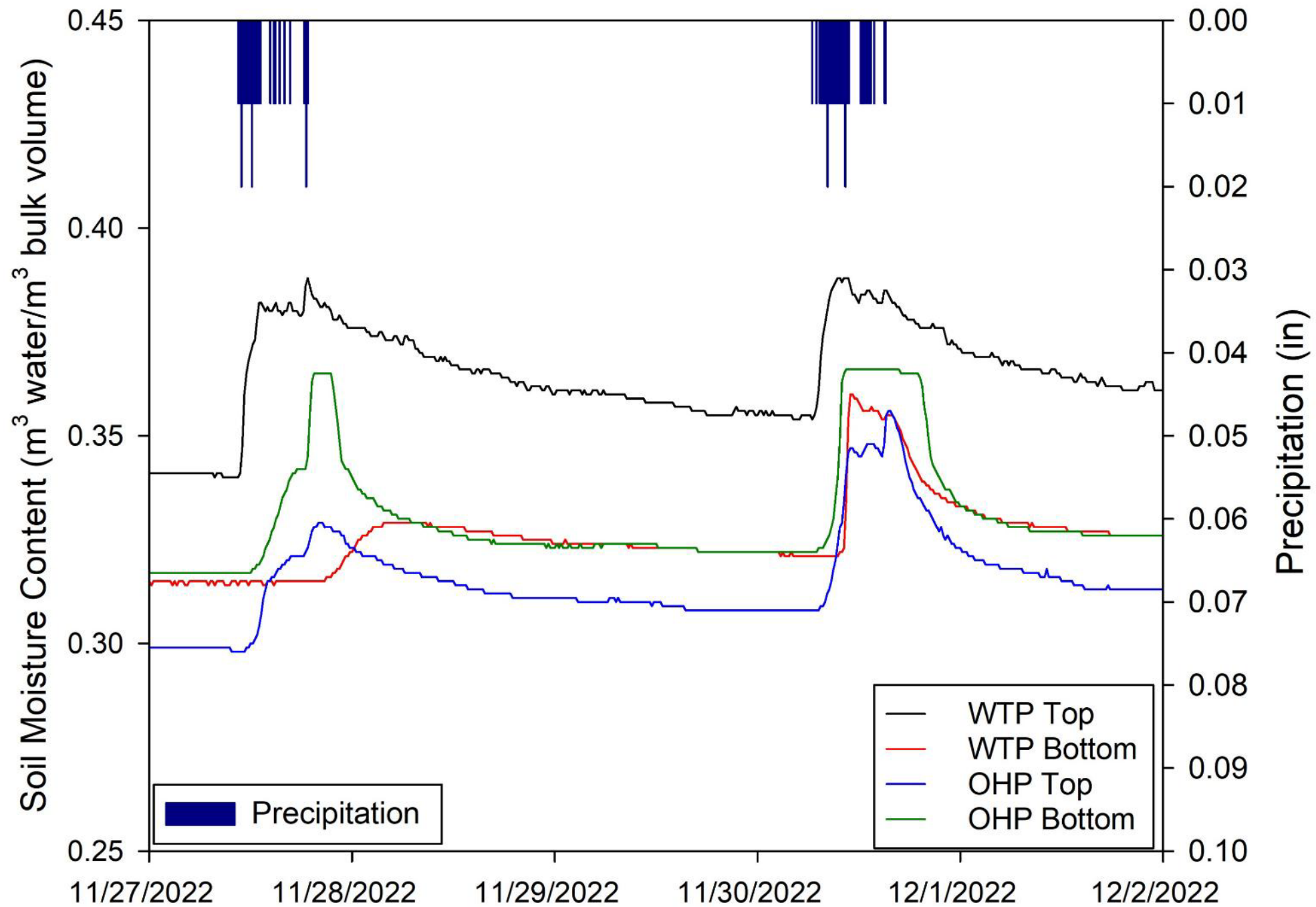
- If soil where sensor is installed was added on top of compaction layer to grow vegetation, this assumption should be reasonable.
- If sensor installed in compacted layer, use effective porosity from table for sand or silt (recommend 50-75% of max).

Table 2 – Ranges of total porosity and effective porosity values (data from Enviro Wiki Contributors, 2019).

Total and Effective Porosity		
	Total Porosity	Effective Porosity
Unconsolidated Sediments		
Gravel	0.25 – 0.44	0.13 – 0.44
Coarse Sand	0.31 – 0.46	0.18 – 0.43
Medium Sand		0.16 – 0.46
Fine Sand	0.25 – 0.53	0.01 – 0.46
Silt, loess	0.35 – 0.50	0.01 – 0.39
Clay	0.40 – 0.70	0.01 – 0.18

LICENSE

[Hydrogeologic Properties of Earth Materials and Principles of Groundwater Flow](#) Copyright © 2020 by The Authors. All Rights Reserved.



Impact of Shallow Compaction Layer

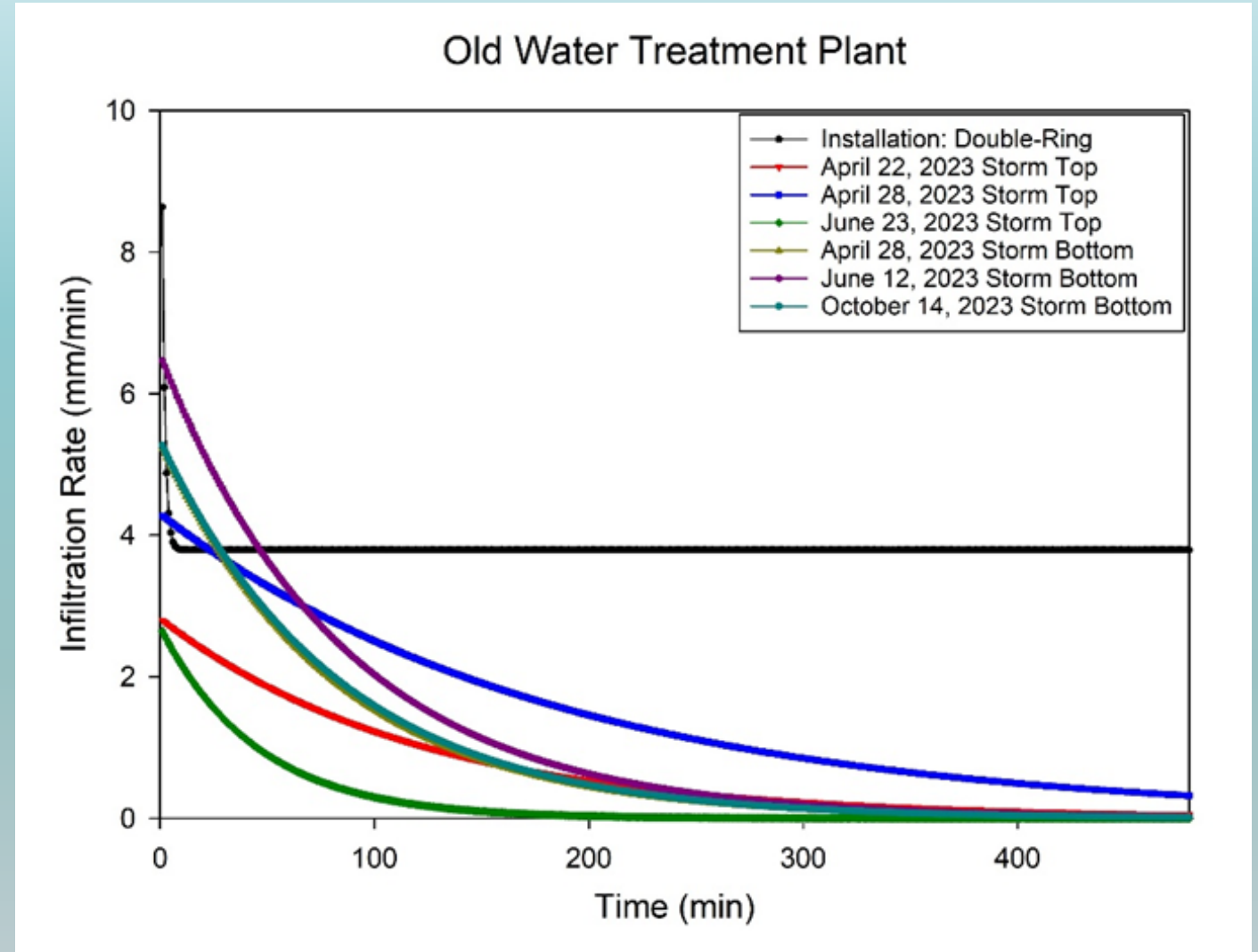
- Challenge: 3 to 6 inch soil depth layer difficult to install 2 soil moisture sensors with enough separation to get accurate depth measurements as a function of time.
- Solution: Compaction layer tell us the depth of bowl. Then:

$$F_{\text{(total water infiltration)}} = [D_{\text{(Depth to compaction layer)}}] [\eta_e_{\text{(effective porosity)}}]$$

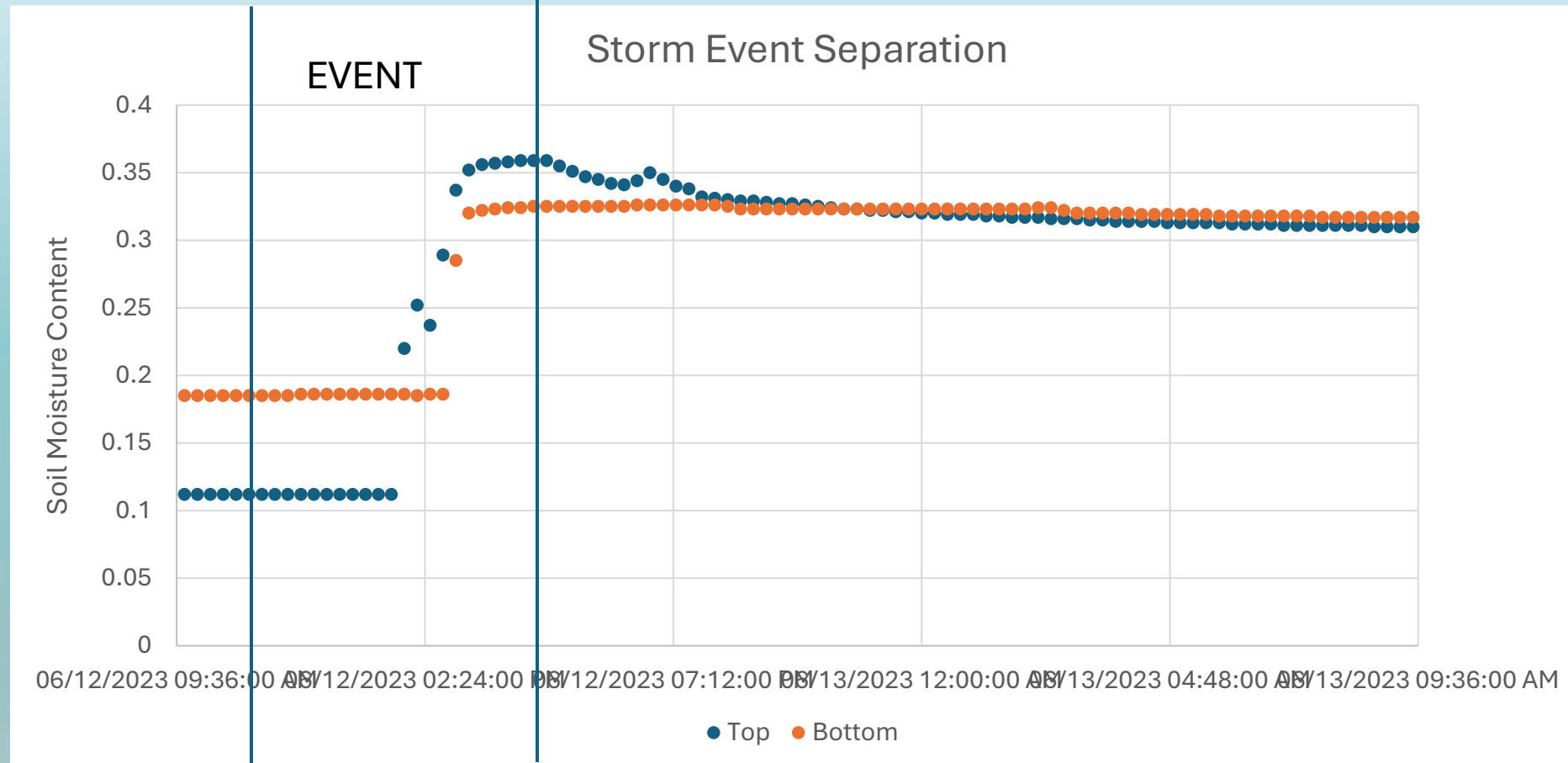
The modified Horton Equation becomes:

$$\frac{(\text{fraction remaining to saturation})F}{\Delta t} = f_c + (f_0 - f_c)e^{-kt}$$

Site with Compaction Layer and “Interesting” Topsoil: Surface Double Ring Infiltrrometer Not Reflective of Subsurface



Second Step Calculation: Separating Soil Moisture Readings into Storm Events



Infiltration equations show that rate of infiltration decays over time. Soil moisture increases as water infiltrates with increases in soil moisture slowing over time.

Therefore, events to analyze are exponential growth sections of the curve.

Third Step: Modified Horton Equation Using Soil Moisture

Horton's Equation was selected because, in SWMM, Horton and Modified Horton are the only two infiltration equations where the maximum water storage volume can be entered as of this time.

Horton's Infiltration Equation:

$$f_p = f_{\infty} + (f_0 - f_{\infty})e^{-k_d t}$$

where:

- f_p = infiltration capacity into soil (ft/sec)
- f_{∞} = minimum or equilibrium value of f_p (at $t = \infty$) (ft/sec)
- f_0 = maximum or initial value of f_p (at $t = 0$) (ft/sec)
- t = time from beginning of storm (sec)
- k_d = decay coefficient (sec^{-1}).

Third Step: Modified Horton Equation Using Soil Moisture

Horton's Infiltration Equation Modified Using Soil Moisture:

$$\frac{\left(\frac{\theta_s - \theta}{\theta_s - \theta_0}\right) D(n_e)}{\Delta t} = f_c + (f_0 - f_c)e^{-kt}$$

Where: θ_s = saturated soil moisture (maximum soil moisture for an event)

θ_0 = initial soil moisture (minimum soil moisture for an event)

θ = soil moisture at any time t

D = depth to sensor or depth to compaction layer

n_e = effective porosity

f_c = final infiltration rate (should be asymptotically approaching K_{sat})

f_0 = initial infiltration rate

k = decay constant

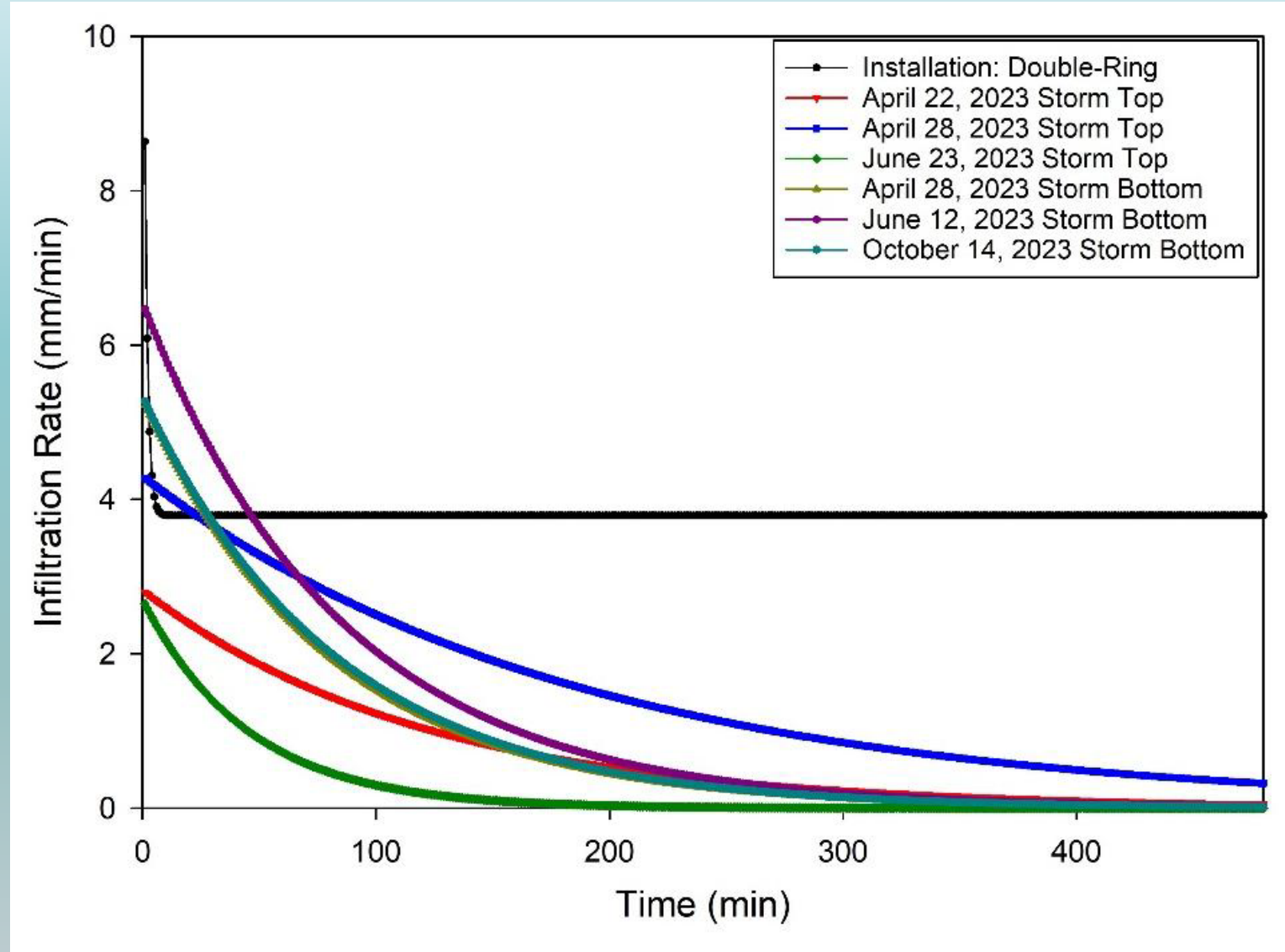
t = time

Left side of equation comes from sensors and field measurements.

Use nonlinear regression to calculate f_0 , f_c , and k for use in SWMM.

RESULTS: Comparison to Double-Ring Infiltrometer

- Site: Upper and lower layer separated by compaction layer. Both layers are rocky with coal fragments.
- Double-ring infiltrrometer on surface produces distinctly different results for f_c (the limiting infiltration rate). This is likely due to the heterogeneous nature of the soil layer.
- Analysis with soil moisture allows for replicate analysis and the sensors are installed in areas with less rocks and fractures in the soil. Rocks and fractures create preferential flow paths.



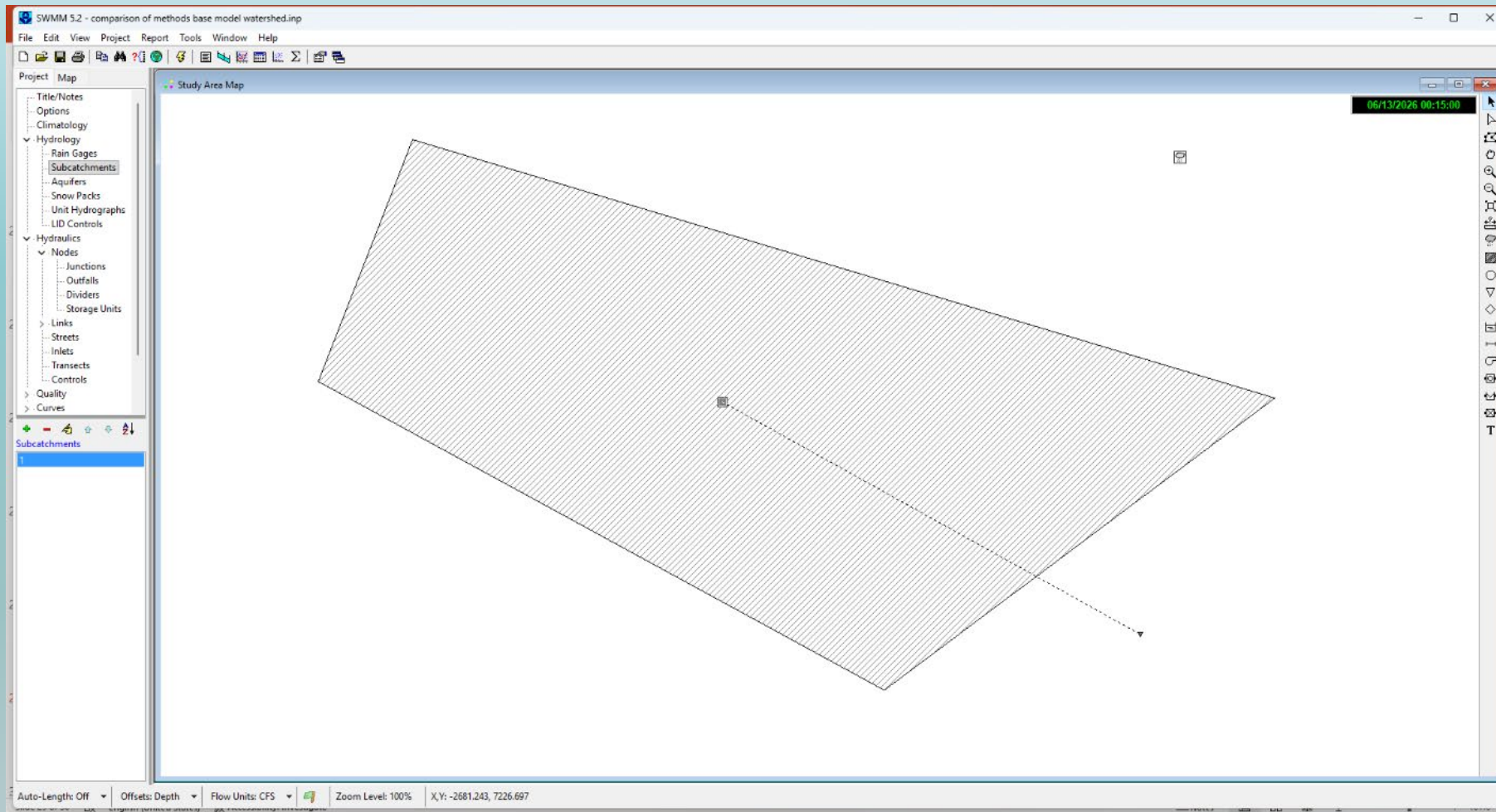
Translation to Curve Number Procedure

Horton Parameters for
Stilson Loamy Sand

$$\begin{aligned}f_0 &= 8.11 \text{ in/hr} \\f_c &= 1.55 \text{ in/hr} \\k &= 6.55 \text{ hr}^{-1}\end{aligned}$$

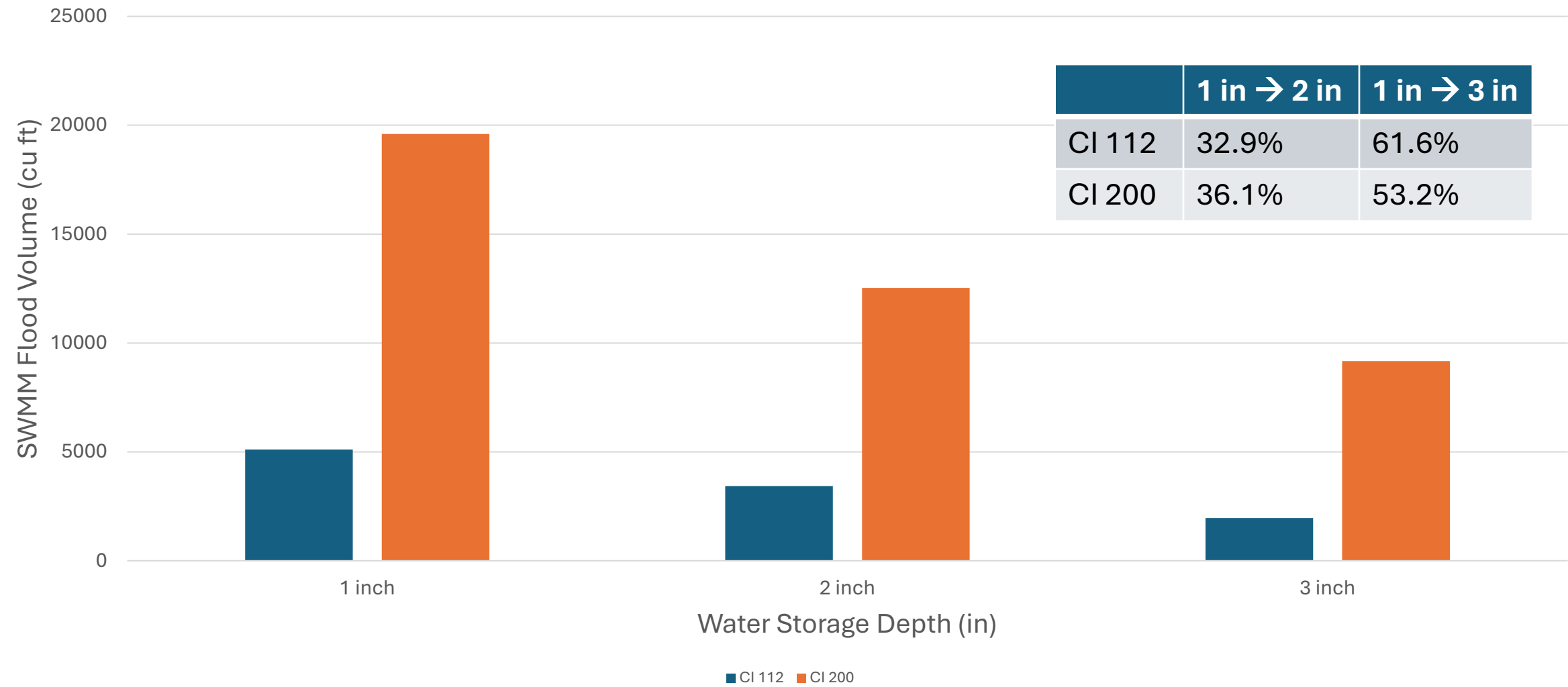
Horton Parameters for
Sandy Clay (bare)

$$\begin{aligned}f_0 &= 8.6 \text{ in/hr} \\f_c &= 0.90 \text{ in/hr} \\k &= 120 \text{ hr}^{-1}\end{aligned}$$

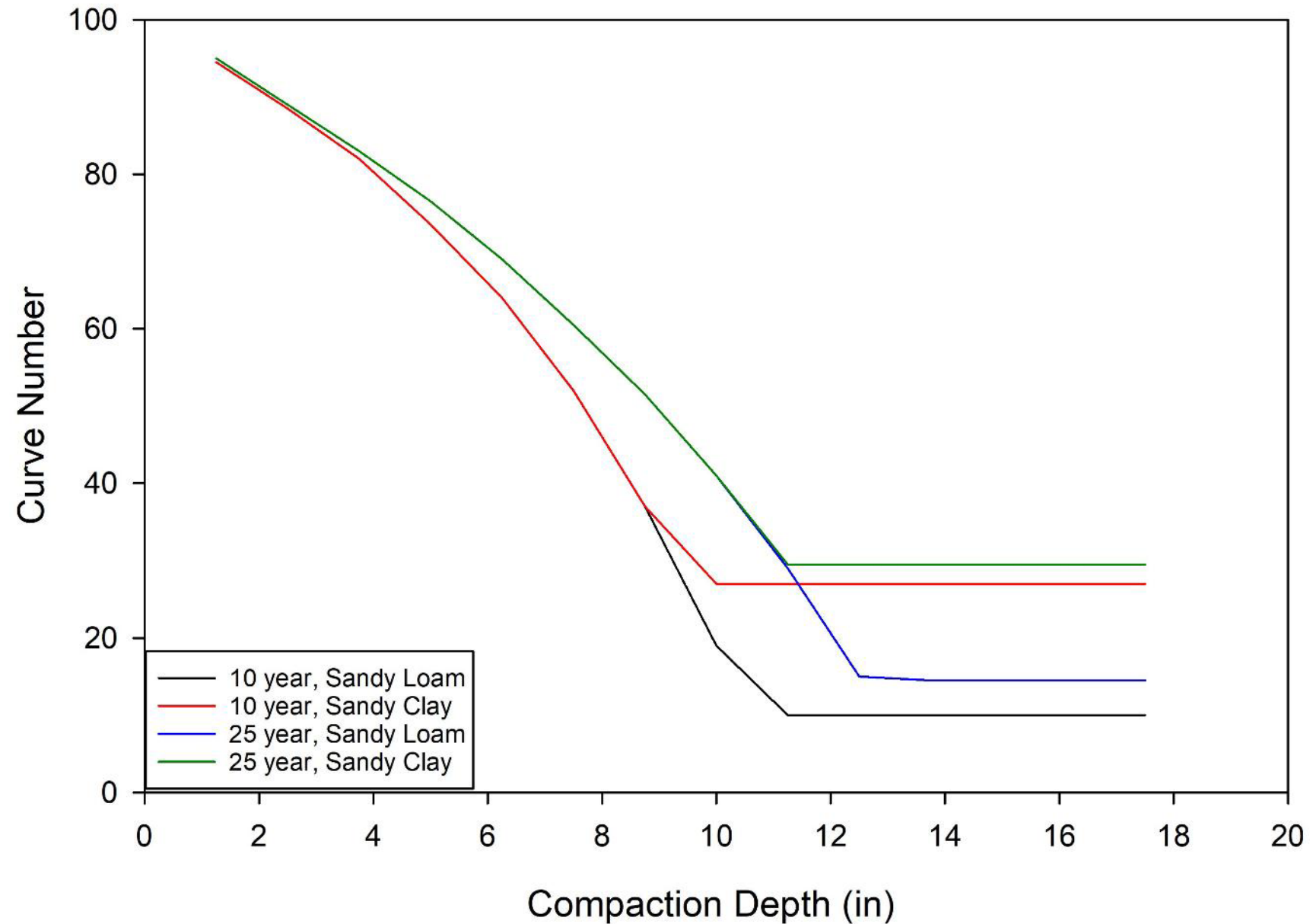


Impact of Shallow Restoration: Node Flood Volume

Flood Volume at 2 Critical Nodes



Curve Number as a Function of Compaction Depth

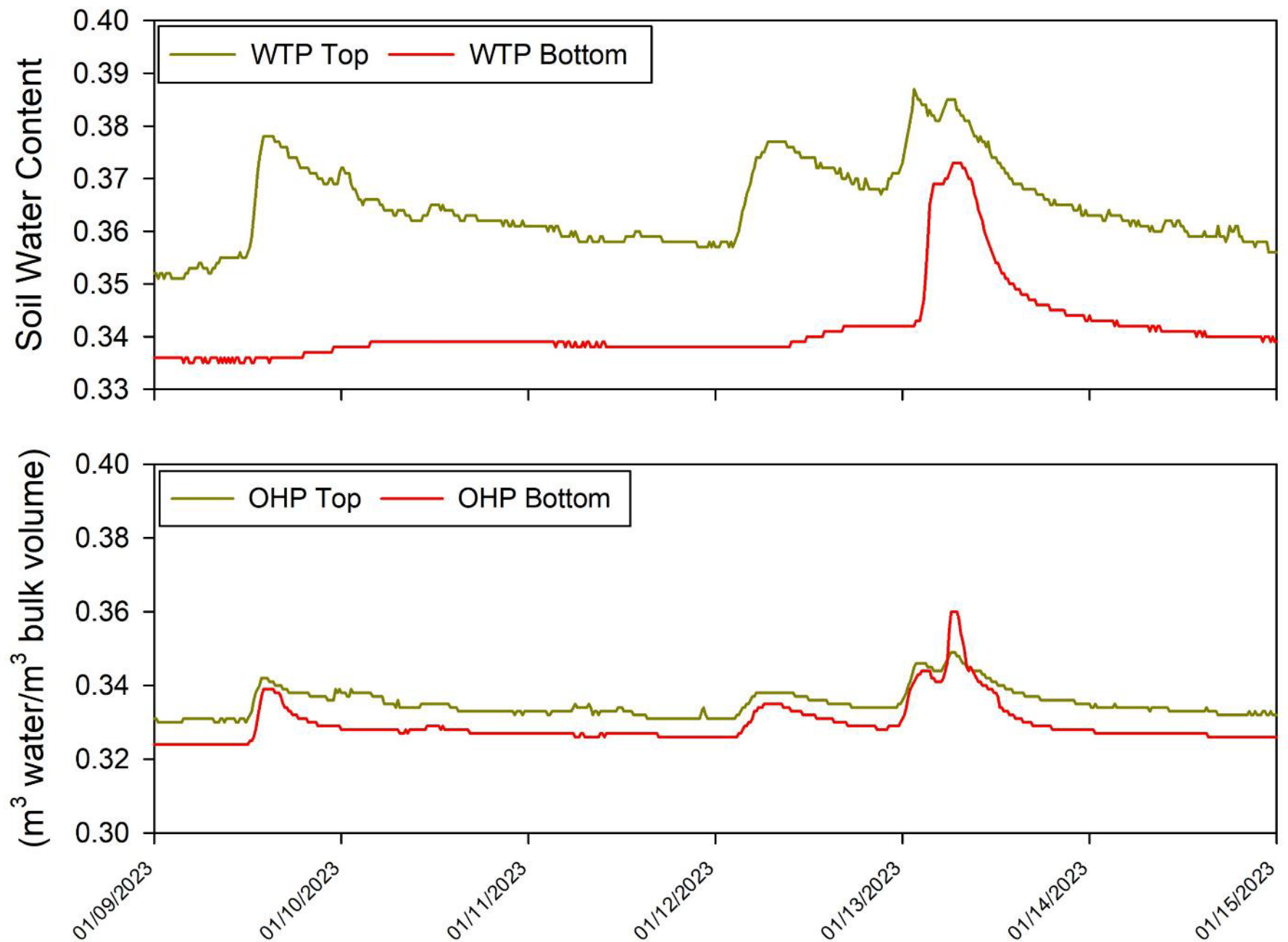


Next Challenge: Compaction Layer Appears to be Semi-Permeable



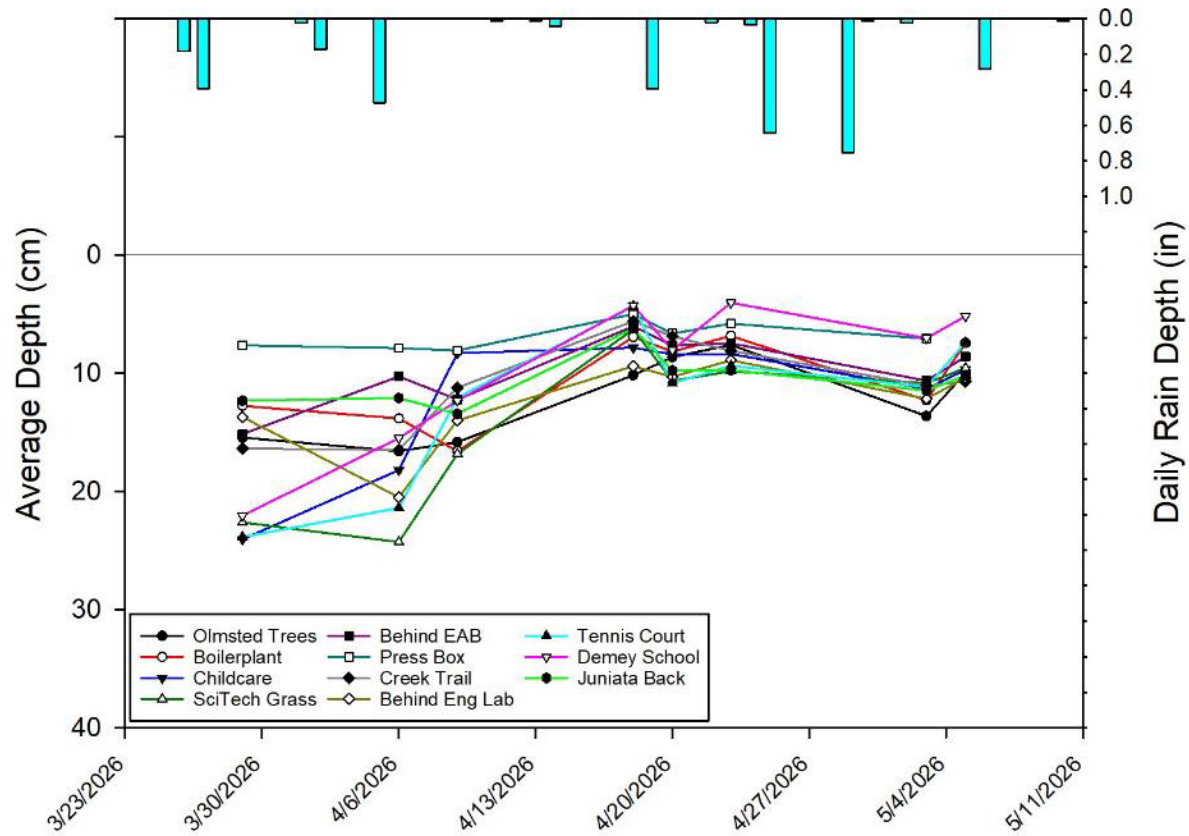


January 2023 Soil Moisture

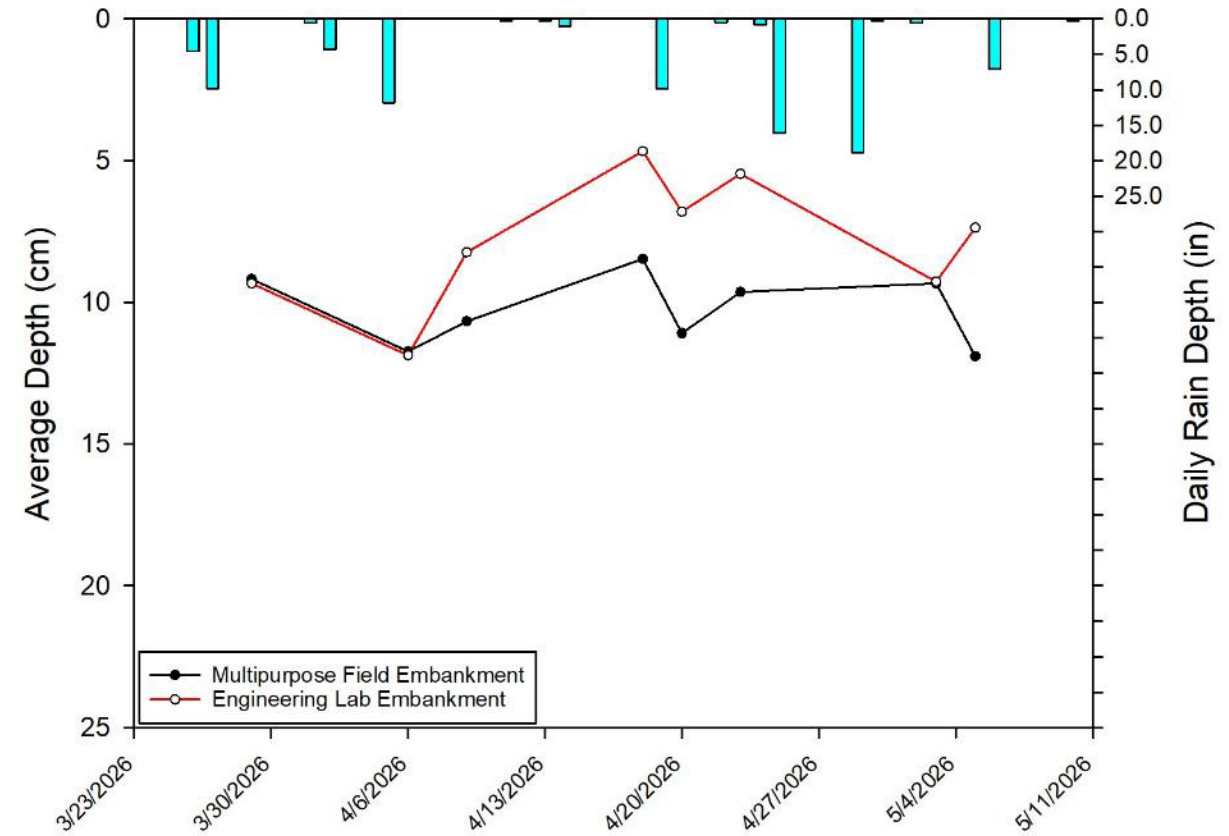


Change in Compaction Depth as a Function of Antecedent Rainfall

Compaction to 300 psi: Grassy Open Areas



Compaction to 300 psi: Embankments



Conclusions to Date

- Simplified field procedure for collecting data for following parameters:
 - Compaction depth
 - Double-ring infiltrometer (not required but will give information on rapidity of infiltration through surface mat)
 - Installation of sensor and collection of data
 - 15-minute data acceptable
 - Bulk density field measurement by replacing sample with sand
- Depth of soil water storage above compaction layer vital (3 inch: $CN = 51/Runoff = 1.37$ in vs 1 inch: $CN = 88/Runoff = 3.14$ in)
- Challenges are that the compaction layer likely is semi-permeable (barely permeable) – but SWMM is not

Impacts of Urban Soil Compaction on Stormwater Runoff Volumes and BMP Sizing

Translation Slides by
Kimberly Grove, Chief
Office of Research and Environmental Protection
Baltimore City DPW

Proposed SWM Regs WQ_v

Treat the specific runoff depth that corresponds to 90% of the average annal runoff.

Current

$$WQ_v = \frac{(1.0)(R_v)(A)}{12} \text{ Eastern Rainfall Zone} \quad P = 1.0 \text{ inches of rainfall}$$

where:

- WQ_v = water quality volume (in acre-feet)
- R_v = 0.05 + 0.009(I) where I is percent impervious cover
- A = area in acres*

Proposed:

$$WQ_v = \frac{Q_i \times A_i}{12 \text{ in/ft}} + \frac{Q_p \times A_p}{12 \text{ in/ft}} \quad (\text{Equation 2.8})$$

where:

Q_i = the direct runoff depth from the impervious area calculated based on a CN of 98 and a P of 1.0 inch or 1.5 inches, depending on the rainfall zone. Referring to Table 2.3, Q_i equals 0.79 inches for the Western Rainfall Zone and 1.28 inches for the Central/Eastern Rainfall Zone.

Q_p = the direct runoff depth from the pervious area calculated based on the weighted pervious CN and a P of 1.0 inch (Western Rainfall Zone) or 1.5 inches (Central/Eastern Rainfall Zone) as provided in Table 2.3 or calculated using Equations 2.1 and 2.2.

A_i = impervious area within the drainage area to the BMP

A_p = pervious area within the drainage area to the BMP

➤ Direct runoff depth (Q) is determined using the equations below:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (\text{Equation 2.1})$$

and

$$S = \left(\frac{1000}{CN} \right) - 10 \quad (\text{Equation 2.2})$$

Based on $I_a = 0.2S$ and where:

I_a = initial abstraction (inches)

S = the potential maximum retention (inches) related to the CN through soil and cover conditions

Q = depth of runoff (inches)

P = depth of rainfall (inches) provided in Table 2.2 for the county where the project is located and the applicable design storm

HSG	CN
A	39
B	61
C	74
D	80
Imp. Area	98

Proposed SWM Method Only, $P = 1''$

WQ_v for LOD = 1 ac, $P = 1''$
Prop HSG A (% Current)
Prop HSG D (% Current)

Red

Ex. $A_i = 50\%$
Pr. $A_i = 40\%$
 $\Delta A_i < 0$

431 CF
612 CF

Red

Ex. $A_i = 40\%$
Pr. $A_i = 40\%$
 $\Delta A_i = 0$

574 CF
756 CF

New

Ex. $A_i = 39\%$
Pr. $A_i = 39\%$
 $\Delta A_i = 0$

1,120 CF
1,304 CF

New

Ex. $A_i = 39\%$
Pr. $A_i = 40\%$
 $\Delta A_i > 0$

1,148 CF
1,330 CF

New

Ex. $A_i = 39\%$
Pr. $A_i = 100\%$
 $\Delta A_i > 0$

2,871 CF
2,871 CF

Does de-paving actually help?

USDA Soil Survey:

Urban Complex – HSG D

Grading Specifications:

Cut vs. Fill (compaction)

Geotechnical / Infiltration

Test Requirements

Alternative BMP: Soil Restoration

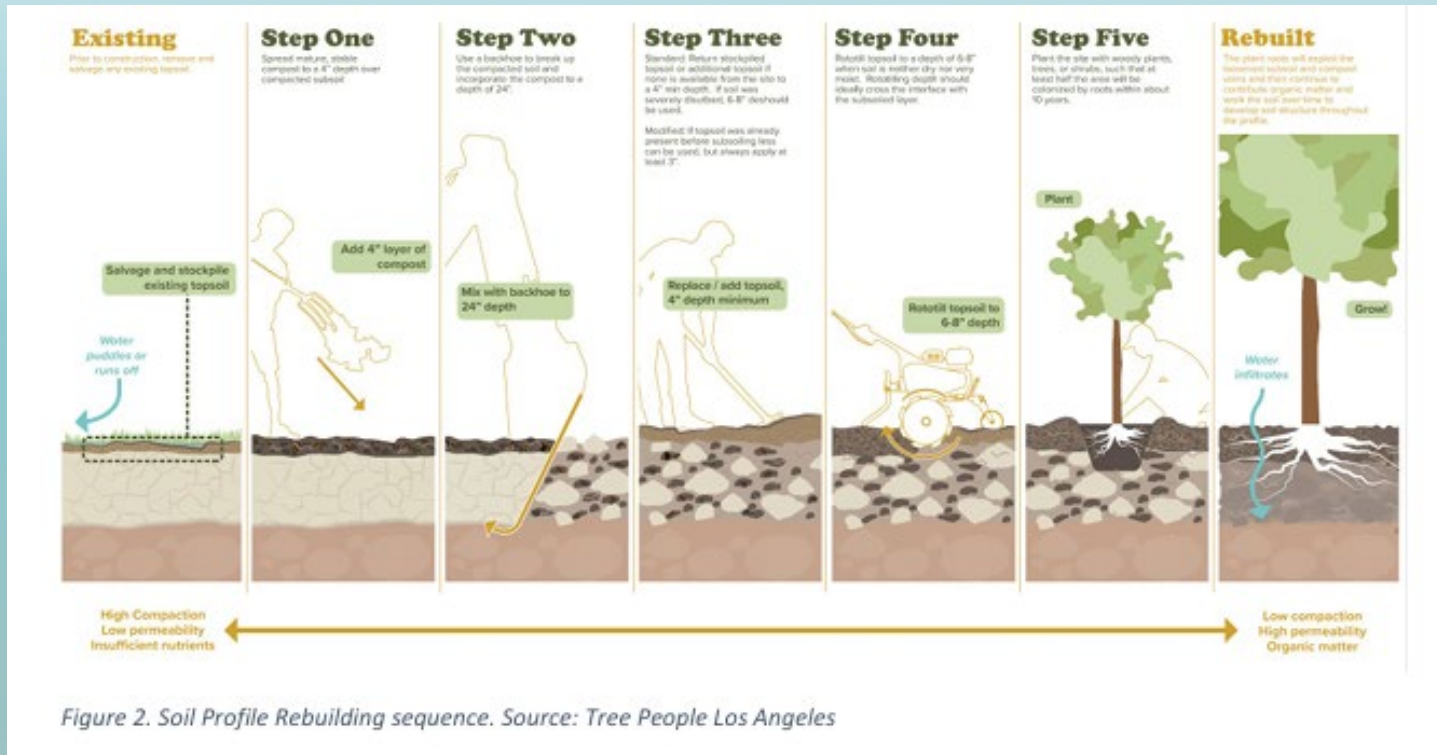


Table 14. Load Reductions and EIA_r for Urban Soil Restoration

Level	Depth (inches)	Load Reduced (lbs/acre/yr)			EIA _r per Acre of Soil Treatment
		TN	TP	TSS	
Compacted Pervious					
1	15	4.4	0.72	278	0.40
2	20	8.9	1.44	557	0.80
Impervious					
1	15	13.7	0.70	1,696	0.91
2	20	15.0	0.77	1,864	1.00

Soils where the depth to a water impermeable layer is less than 20 inches and/or the depth to the high water table is less than 24 inches are considered as hydrologic soil group (HSG) D when determining runoff characteristics. These soil characteristics are not available for the urban soil restoration credit. Appendix G provides the design criteria that must be met for each level of restoration.

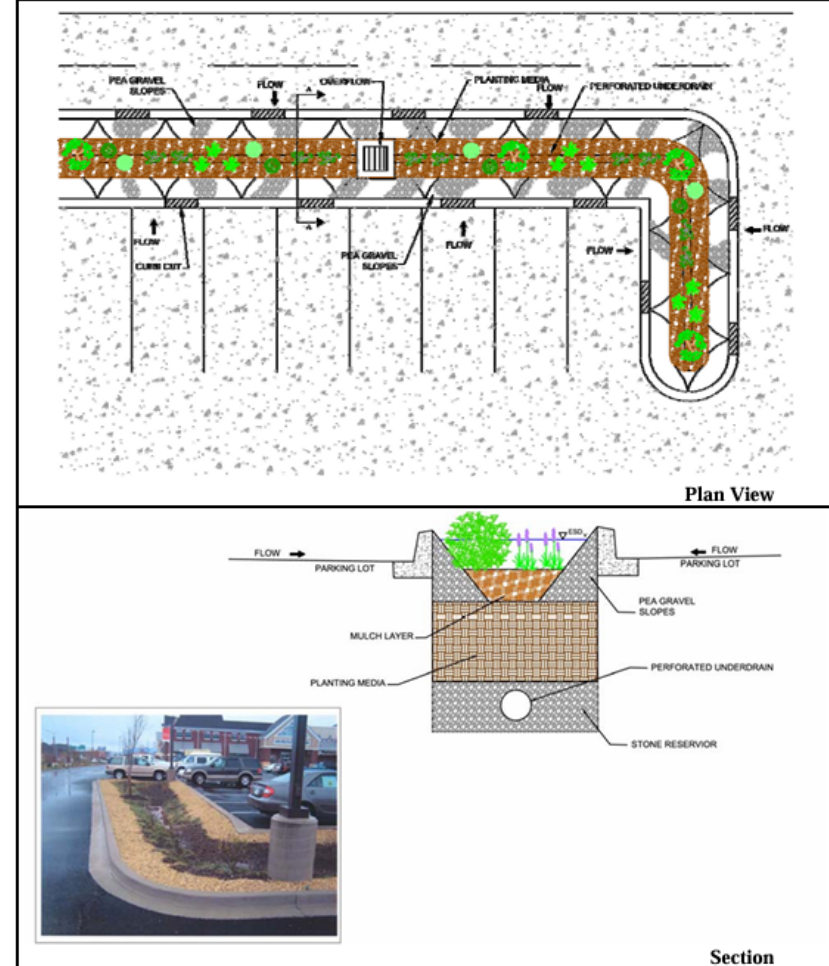
Source: MDE, MS4 Accounting Guidance, 2021

Research findings: Shallow restoration of 3 to 5 inches can reduce runoff volumes 30%.

What does this mean for me?

- SWM BMP Regulatory Review
 - Field tests
 - Grading specifications
 - Underdrains
- MS4 Compliance Strategy:
 - Land Cover Conversion
 - Complete Streets
- City-wide Stormwater H & H Model
 - USDA Soil Survey Update
 - Flood Mgt: Soil vs. Structural Controls

Figure 5.14 Micro-Bioretention (Variation 1 - Parking Lot)





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CIVIL & ENVIRONMENTAL
ENGINEERING



Stormwater Thermal Reduction Through Bioretention Media Layers

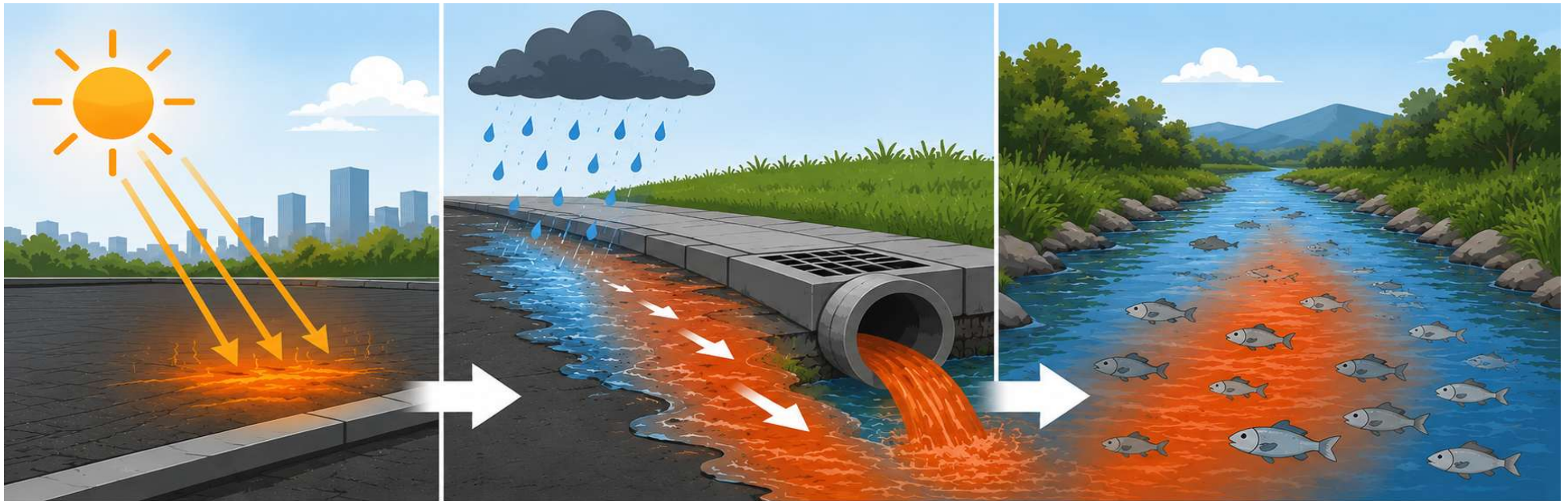
*Effectiveness of restoration practices at the project scale,
Pollutants of Emerging Concern, Thermal.*

Allen P. Davis, PhD, PE, Iffat Afreen & Theodore Zabel
Department of Civil & Environmental Engineering



Stormwater Thermal Pollution — Why It Matters

Heated runoff increases stream temperature and affects aquatic life.



HEAT

Sun heats impervious surfaces.



HOT RUNOFF INTO DRAIN

Rainfall creates heated runoff that flows into drains.



WARMS STREAM

Heated runoff warms the stream and impacts aquatic life.

Research Questions and Hypotheses

Focus: How does media depth, DAR and inlet temperature govern thermal reduction ?



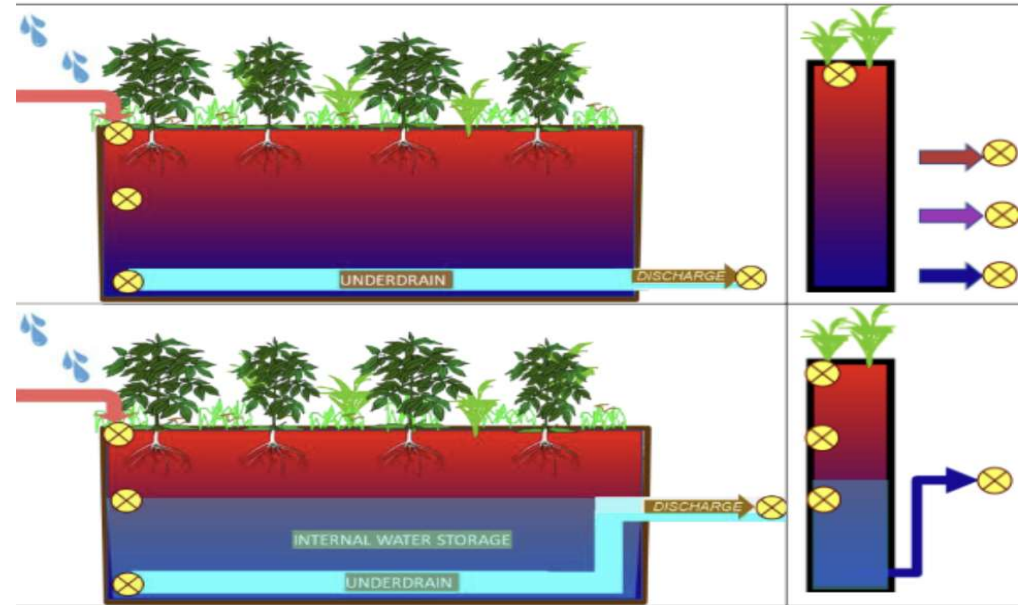
Deeper media and smaller **drainage area ratio** (DAR) = Greater cooling capacity.



Temperature reduction changes with hydraulic retention time and is controlled by media particle size distribution.



Internal water storage with cooler water boosts thermal reduction.



2025 Field Monitoring

1. AV Williams

Parking Lot Drainage Area
Drainage Area Ratio: 11

Media Depth: 0.61 m

2. Iribe

Rooftop Drainage Area
Drainage Area Ratio: 6

Media Depth: 0.61 m

FIELD MONITORING

- 4 bioretention cells - UMD College Park
- Continuous temp logging by Hobo Thermal Probes at 5 mins interval- inlet & outlet
- **Total 143 monitored storm events**

3. 11B

Parking Lot Drainage Area
Drainage Area Ratio: 45
Internal Water Storage

Media Depth: 1.2 m

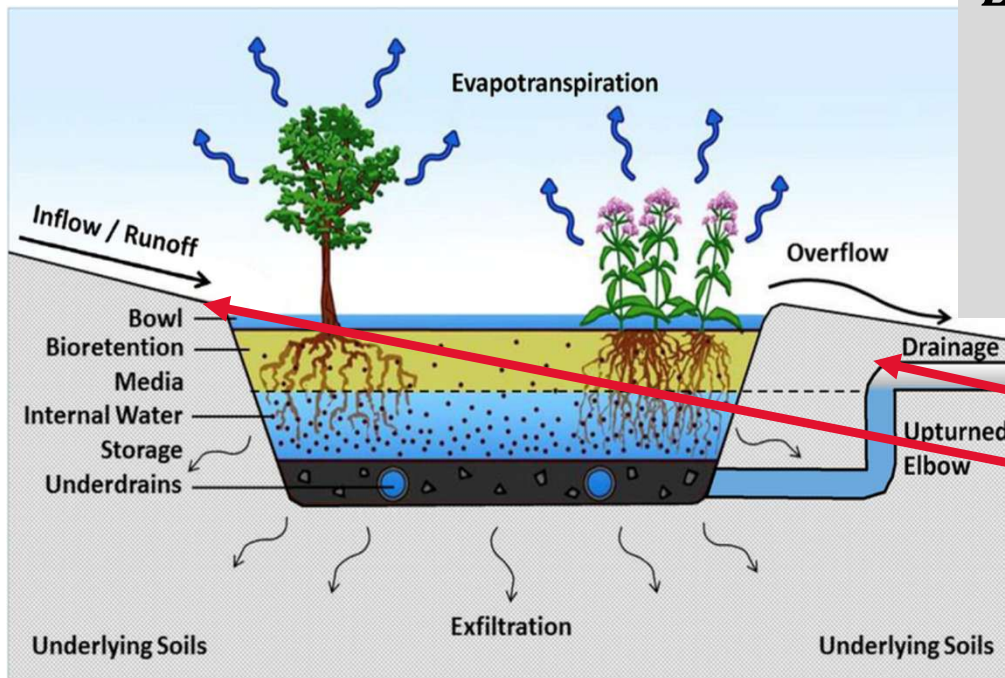
4. LG

Parking Lot Drainage Area
Drainage Area Ratio: 268

Media Depth: 0.61 m

Performance Metric

EMT captures the overall thermal load delivered during a storm event



$$\text{Event Mean Temperature} = \frac{\sum T_i \cdot Q_i \cdot \Delta t}{\sum Q_i \cdot \Delta t}$$

Here,

T_i = Temperature at time i ($^{\circ}\text{C}$)

Q_i = Flow rate at time i

Δt = Time step

$$\Delta \text{EMT} = \text{Inlet EMT} - \text{Outlet EMT}$$

↑ Higher ΔEMT = Better cooling.

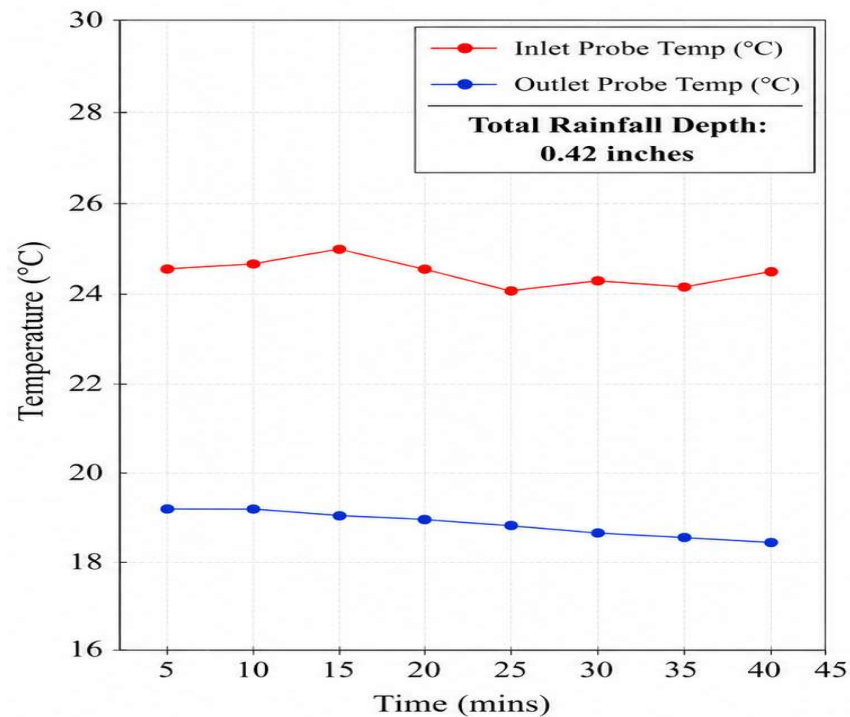
Cross section of bioretention cell (image by Shawn Kennedy, NC State University)

Field Storm Events — Inlet and Outlet Temperature vs. Time

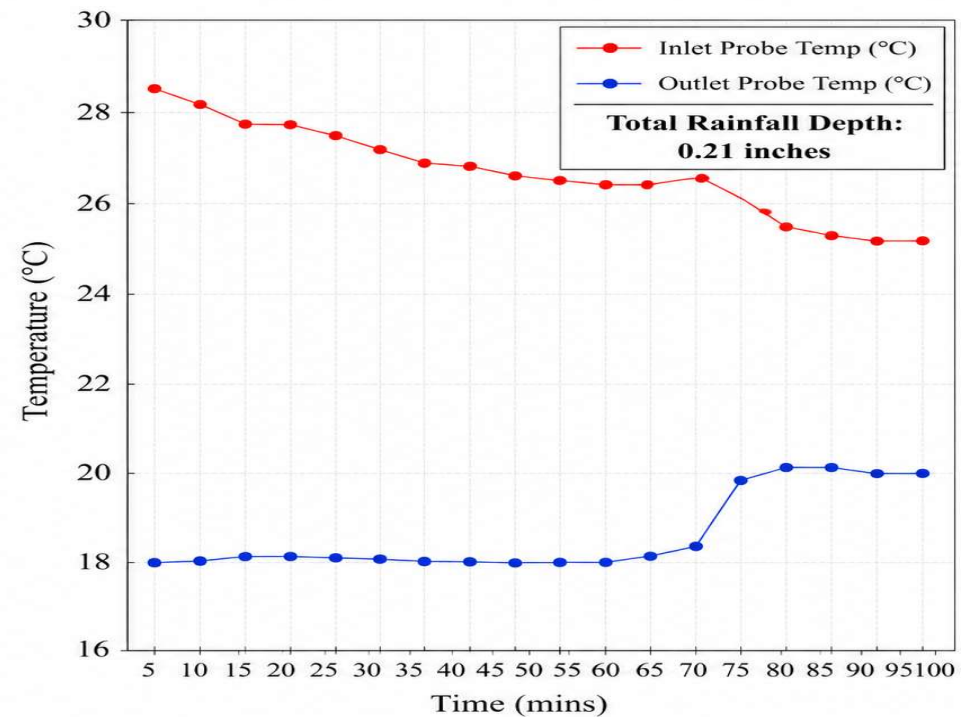
Outlet temperatures remained lower than inlet temperatures during both storm events.

Media Depth: 24 inches.

7th June 2025 Storm Event

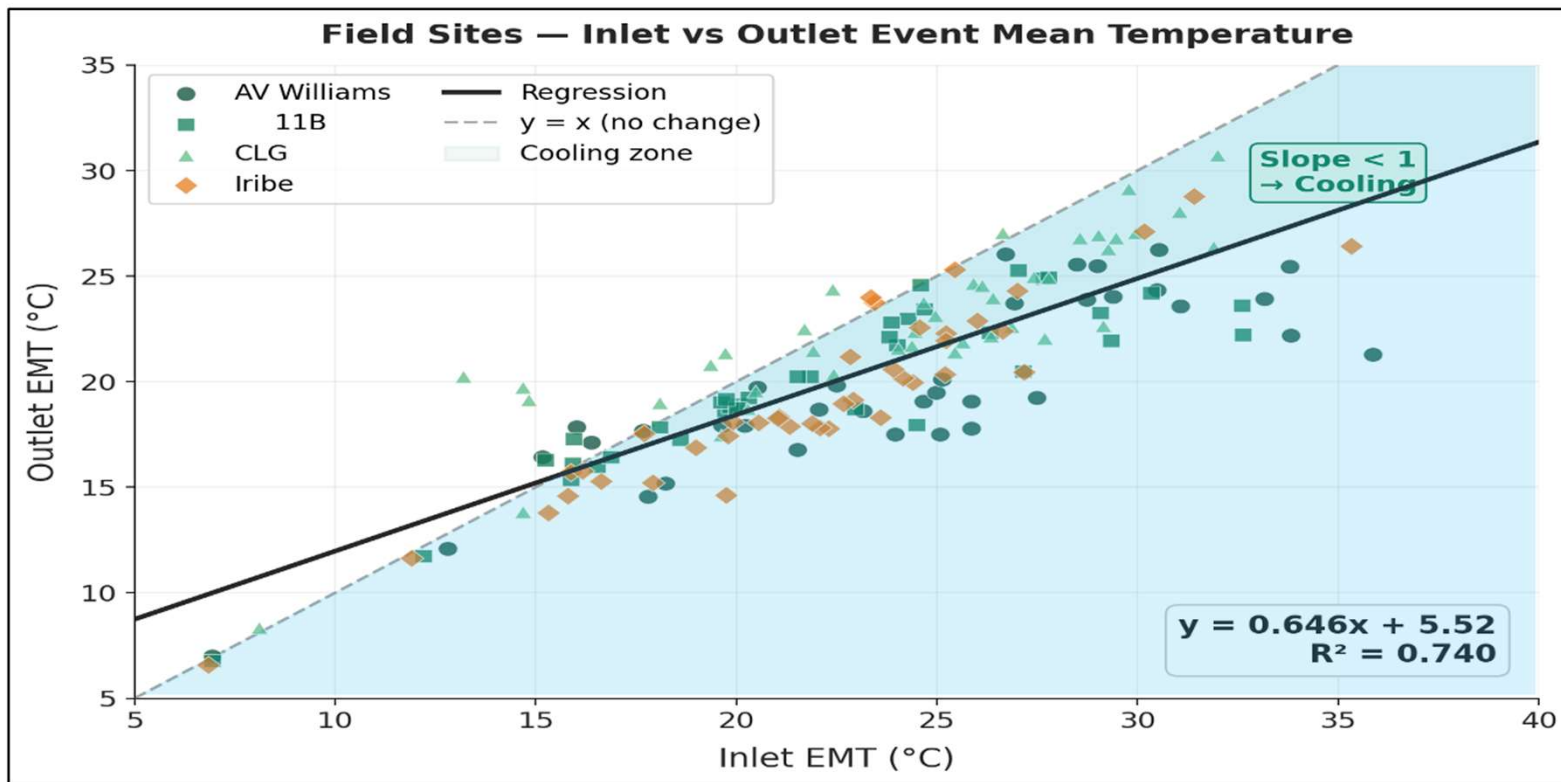


13th June 2025 Storm Event



Field Performance — Inlet vs. Outlet EMT

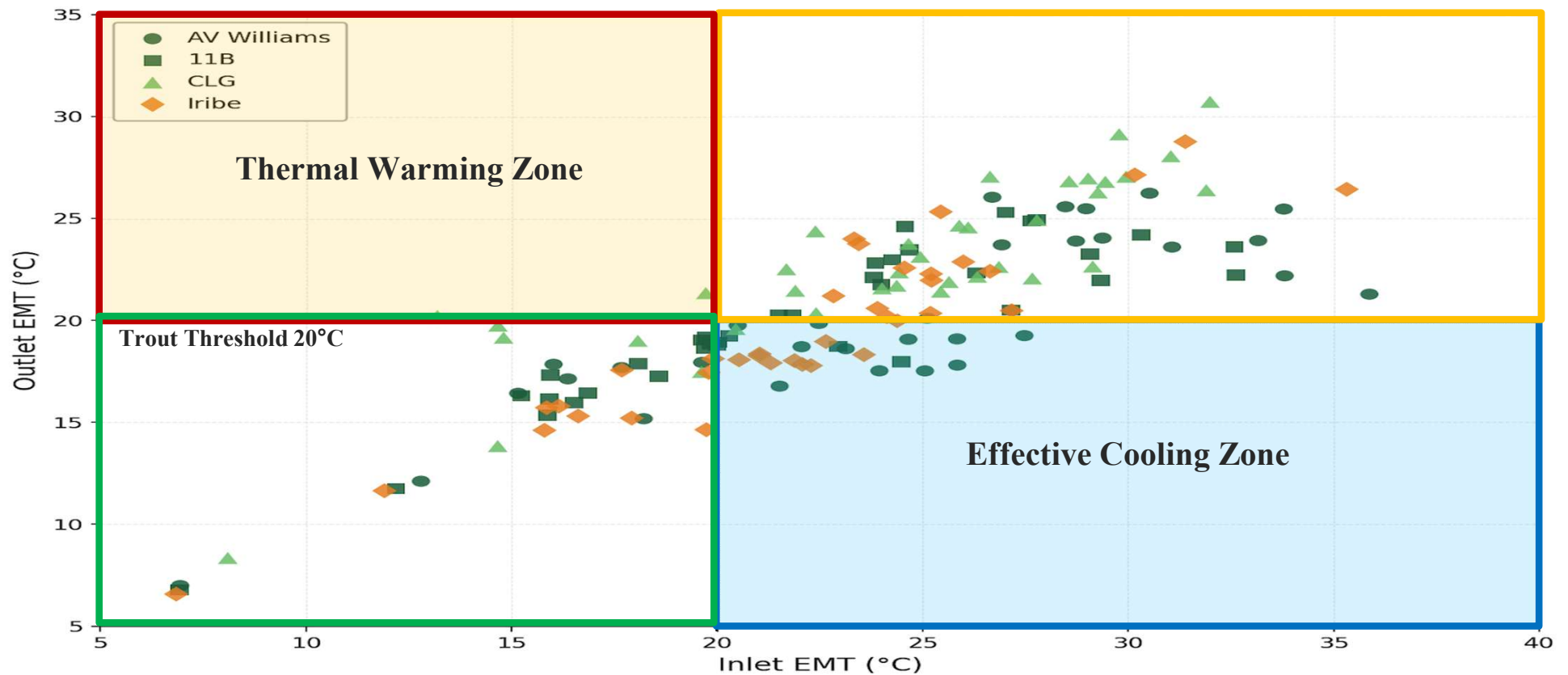
All sites show cooling across nearly all events



➤ Slope < 1.0 →
Bioretention
reduces EMT

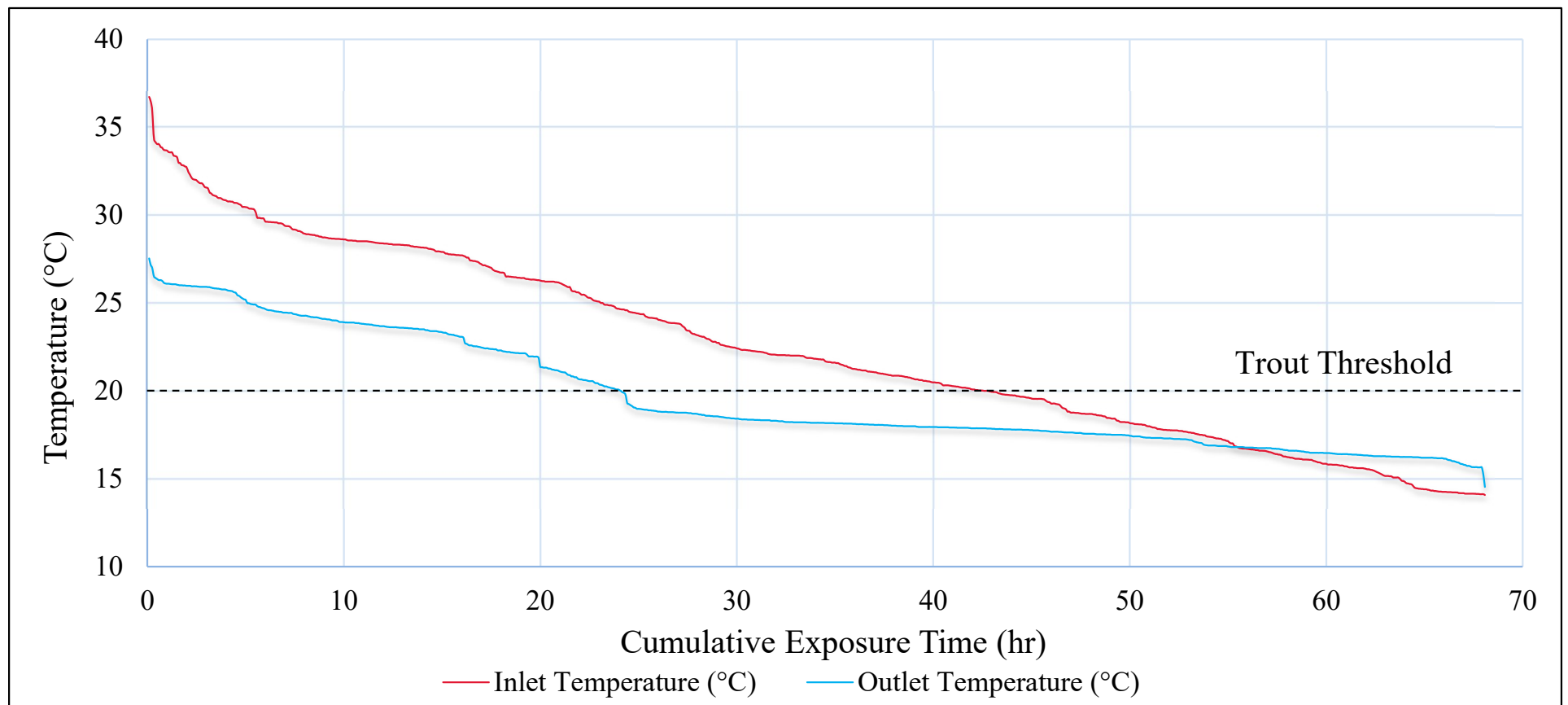
Thermal Performance Relative to the 20°C Trout Threshold

Bioretention system reduces thermal stress (cooling zone) on cold-water species.



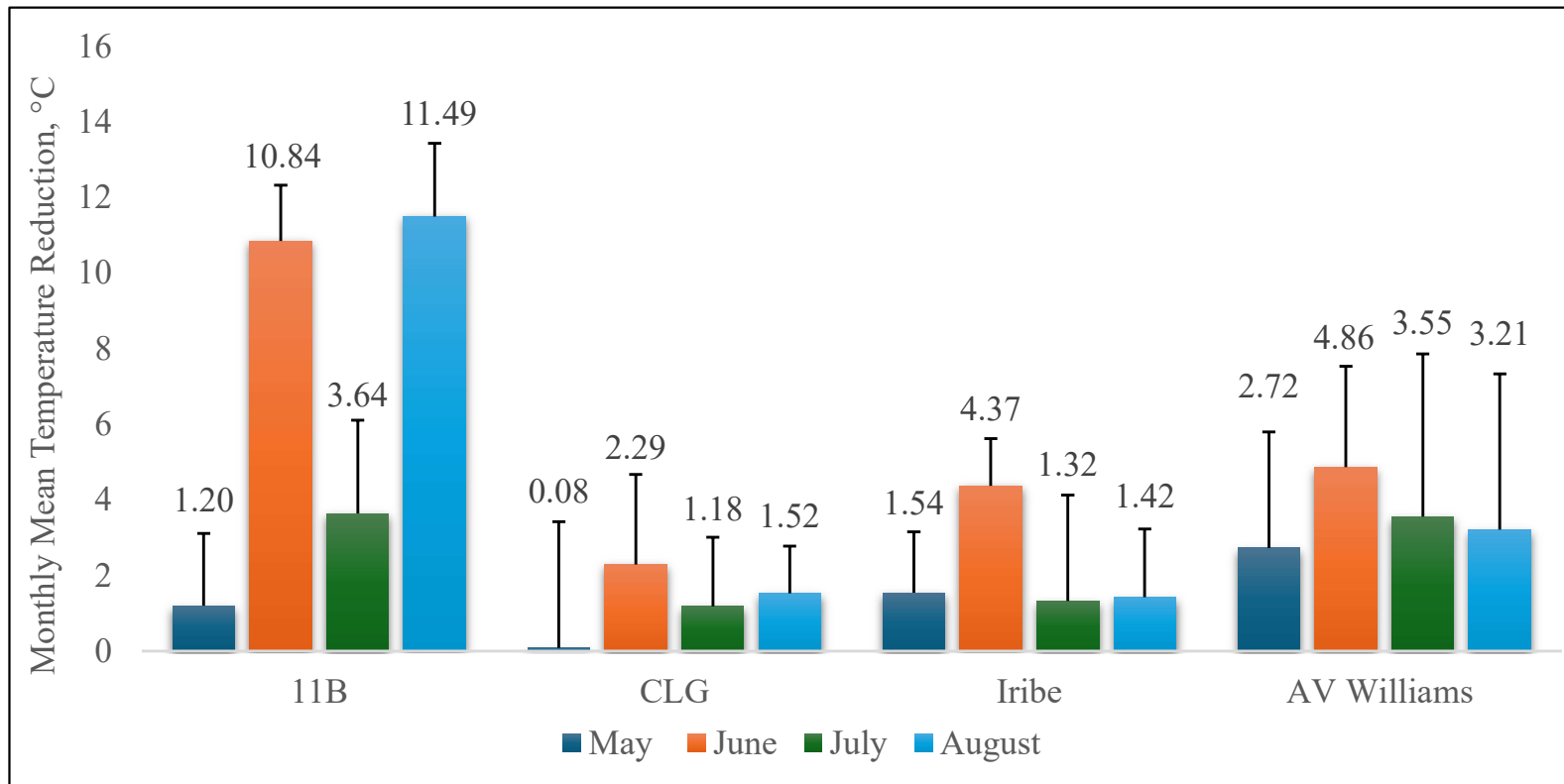
Field Performance — Temperature Duration Curve (AV Williams)

Bioretention reduced $>20^{\circ}\text{C}$ thermal exposure by ~18 hours



Field Performance — Seasonal Influence on Thermal Reduction

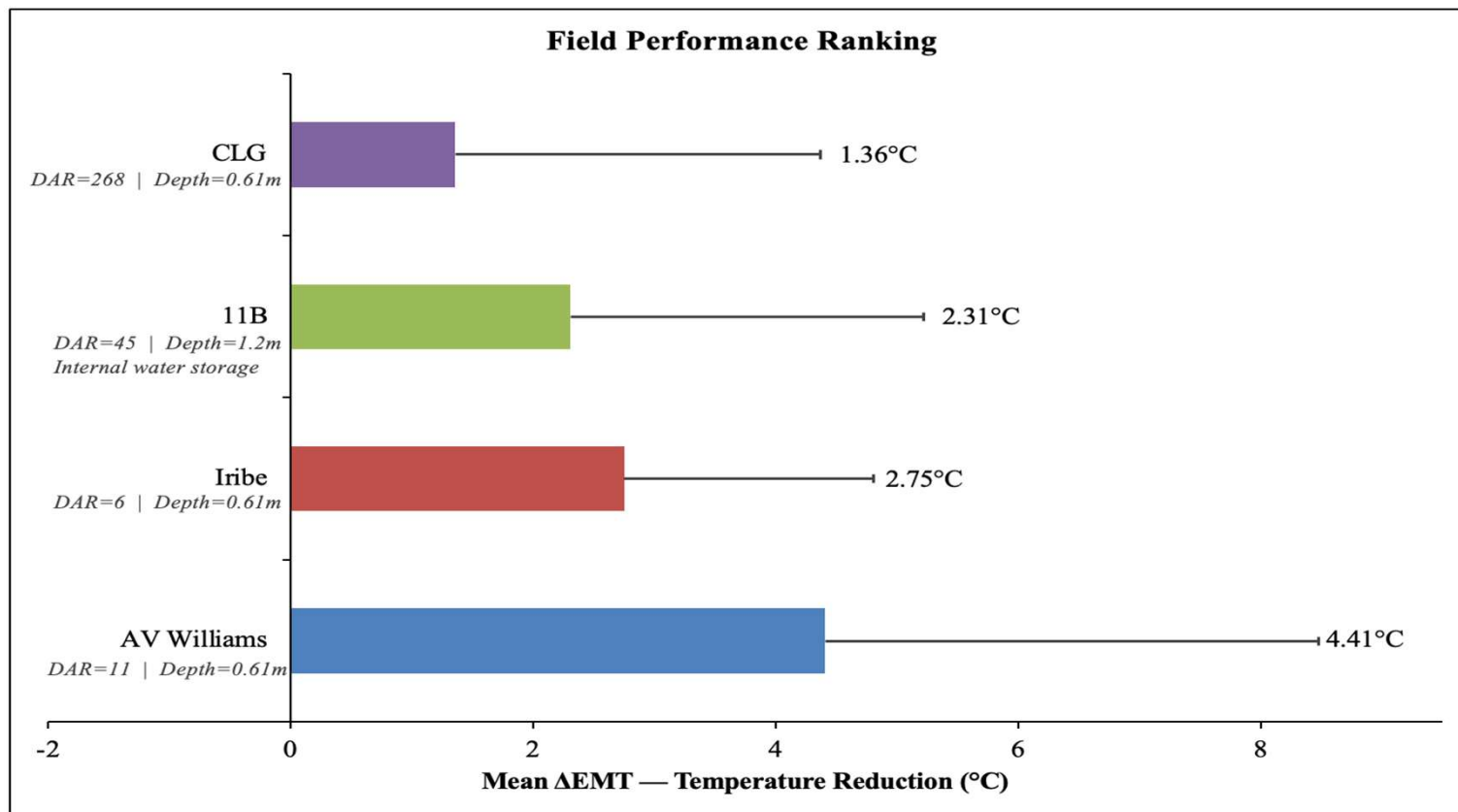
June - July = Highest Monthly Mean Temperature Reduction



- **Highest reduction (summer peak)**
- **Lower thermal input → lower reduction**
- **Inlet EMT is dominant**

Field Performance — Site Comparison by Mean Δ EMT

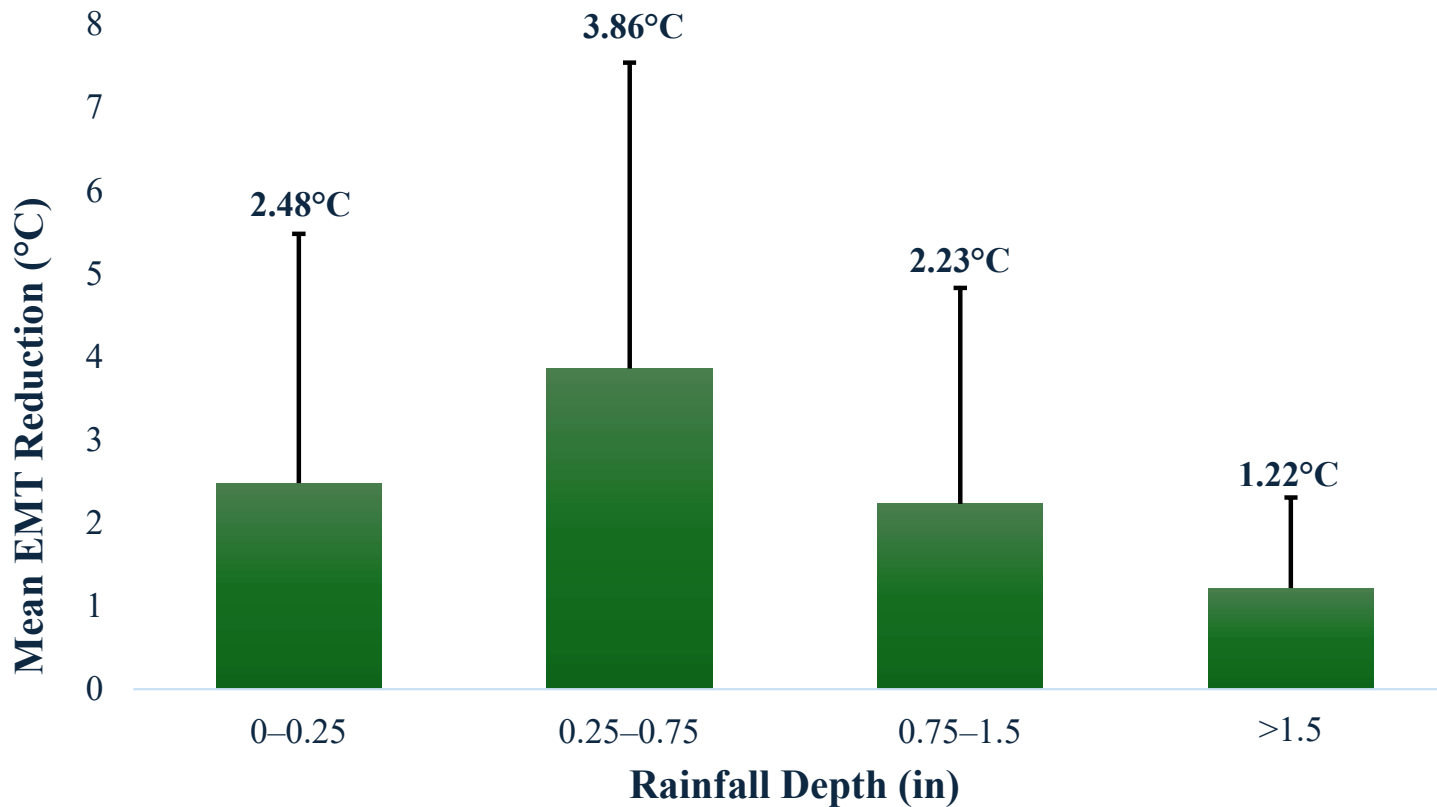
AV Williams (DAR = 10.6) shows highest cooling — CLG (DAR = 268) shows lowest cooling.



- **Parking lot drainage**
→ CLG, 11B & AV Williams
- **Rooftop drainage** → Iribe

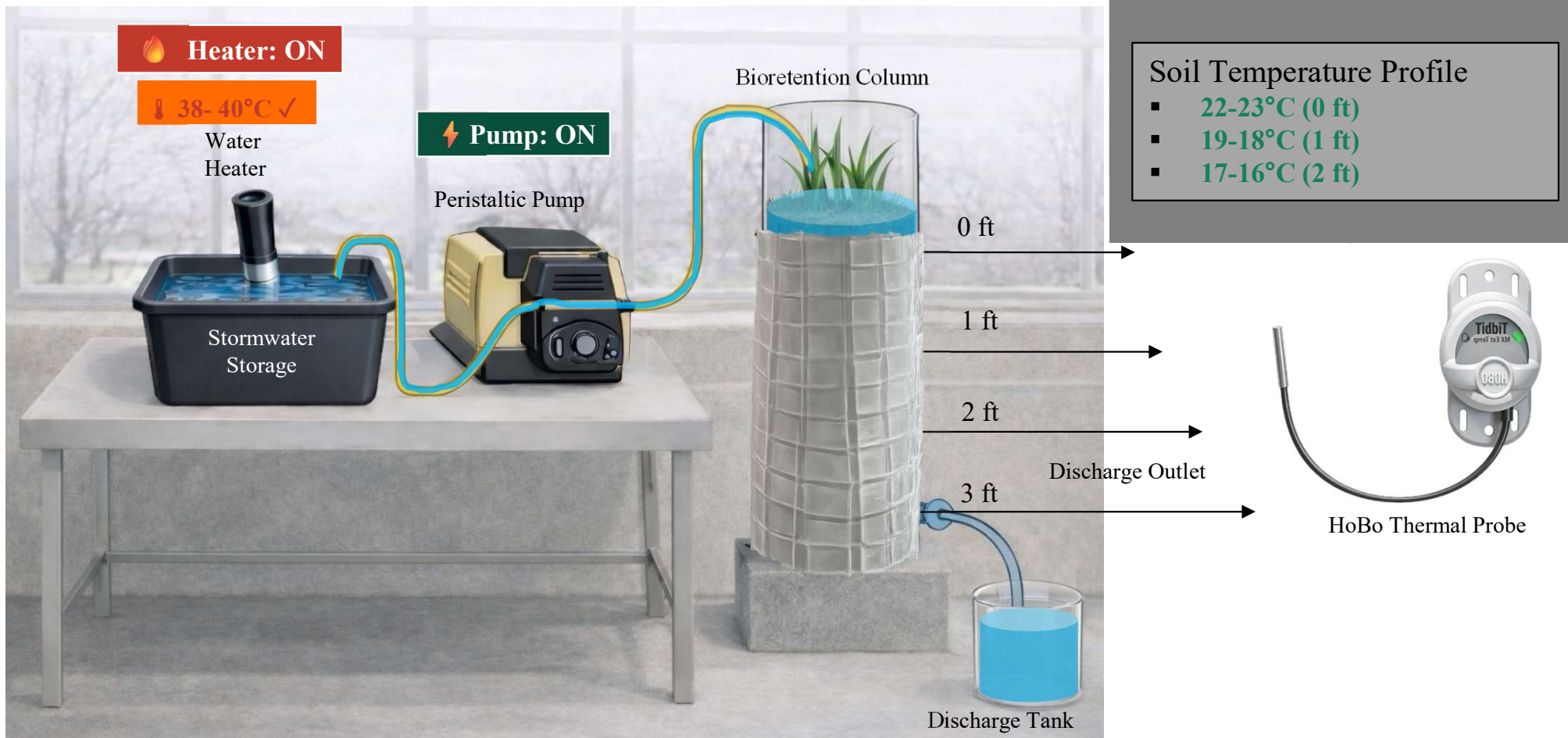
Field Results — EMT Reduction vs. Rainfall Depth

Moderate storms maximize cooling efficiency.



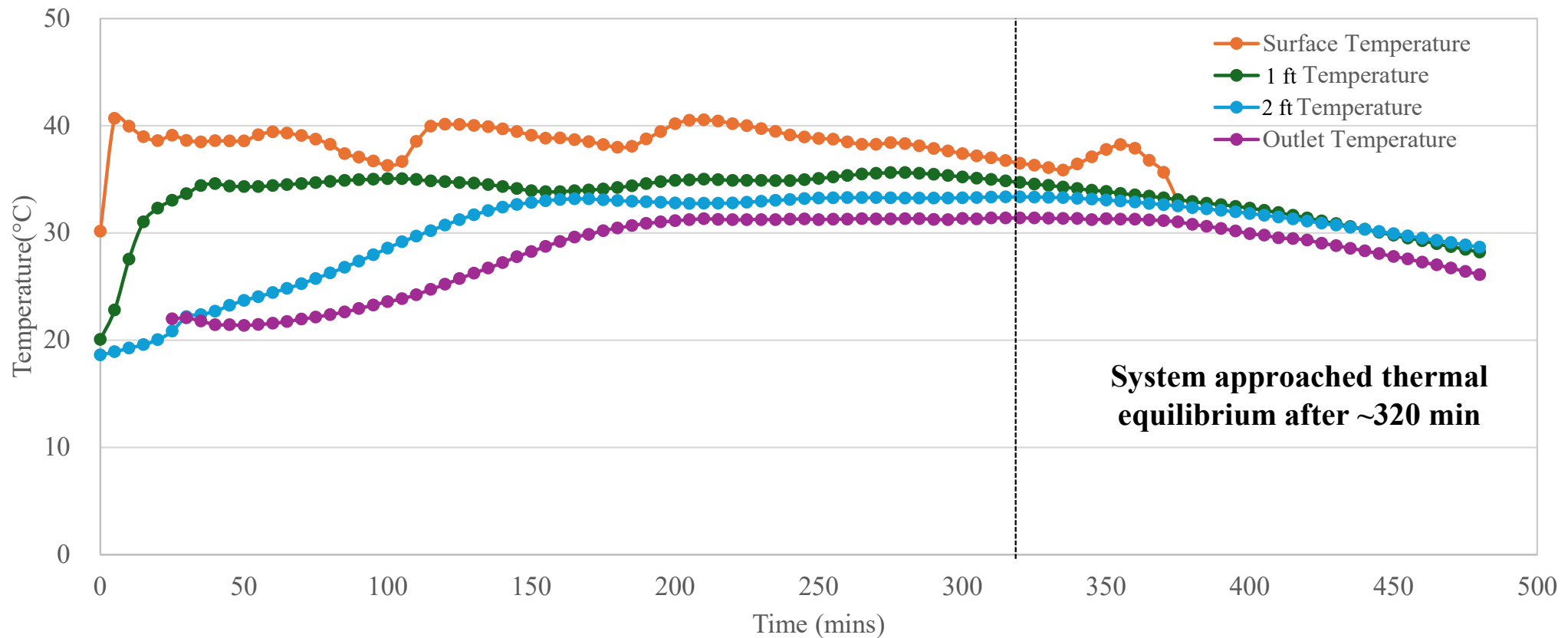
- 0.25–0.75 in storms → highest reduction (~3.86°C)
- Small & large storms → lower performance

Bioretention Column — Experimental Setup



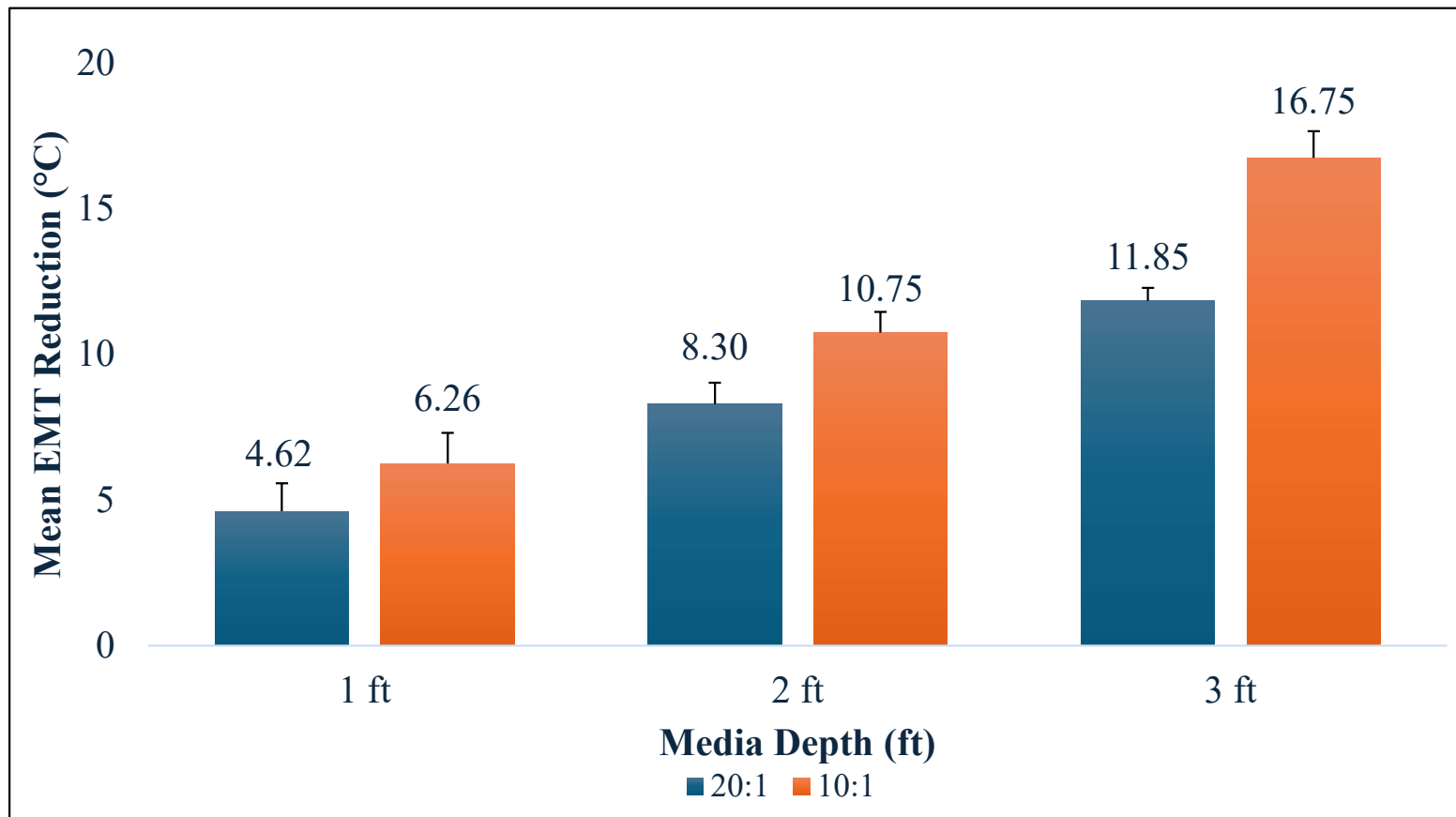
Column Test Results — Temperature vs. Time

Deeper layers stayed cooler for longer during the storm event (under the conditions employed)



Column Test Results — EMT Reduction vs. Media Depth & DAR

Going from 1 ft to 3 ft triples cooling capacity . Lower DAR corresponds to greater cooling.



Based on 6 column tests:

► 3 ft media depth achieved the greatest cooling
20:1 DAR: 11.9°C
10:1 DAR: 16.8°C

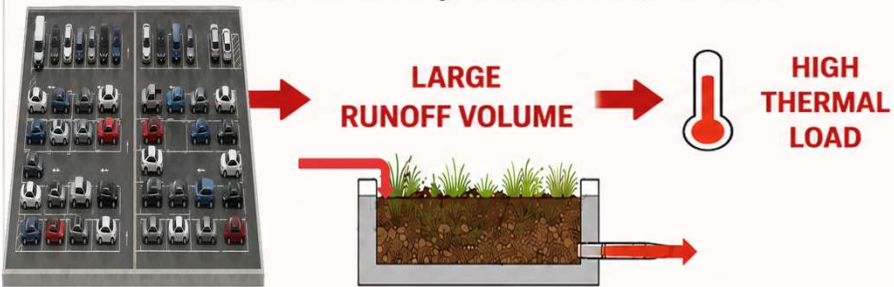
► Reducing DAR improved cooling by
+1.6°C at 1 ft
+2.5°C at 2 ft
+4.9°C at 3 ft

Scientific Basis of Thermal Reduction

More media volume per runoff volume = More cooling

HIGH STORMWATER : MEDIA VOLUME RATIO

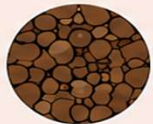
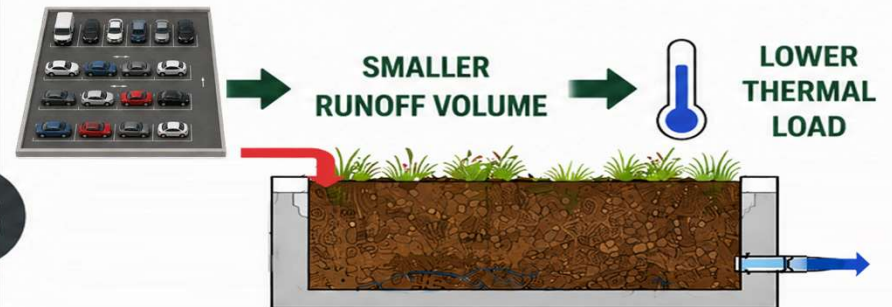
More stormwater per unit media volume



VS

LOW STORMWATER : MEDIA VOLUME RATIO

Less stormwater per unit media volume



LESS MEDIA VOLUME

Less contact with media
Less heat exchange

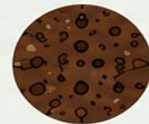


LESS
HEAT
EXCHANGE



SPECIFIC HEAT CAPACITY (c_p)

Lower overall heat
storage by media



MORE MEDIA VOLUME

More contact with media
More heat exchange



MORE
HEAT
EXCHANGE



SPECIFIC HEAT CAPACITY (c_p)

Higher heat storage
by media

→ LESS COOLING ❄️

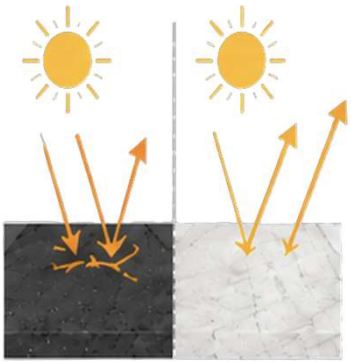
→ MORE COOLING ❄️ ❄️ ❄️

Design Recommendations For Thermal Reduction

1

Albedo

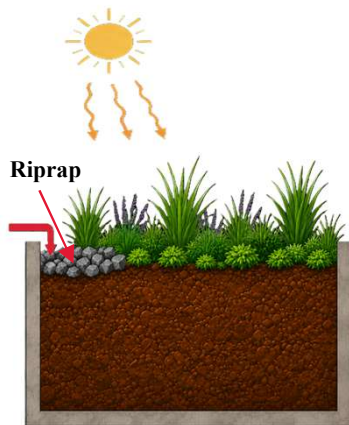
Low Albedo High Albedo



Applying high-albedo coatings reduces solar contact.

2

Vegetation & Shading



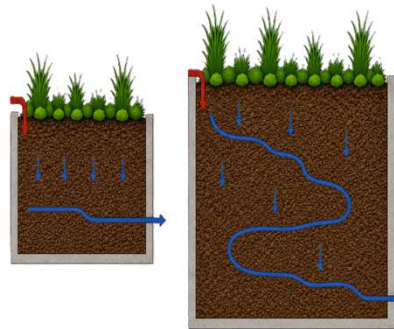
More vegetation and less riprap reduce solar contact and heat retention.

3

Stormwater: Media Ratio & Travel Path

Low Media Volume
Short Path

High Media Volume
Long Path



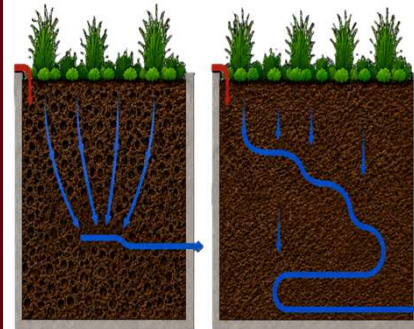
Larger volumes increase water-media contact time

4

Porosity & Infiltration

High Porosity
Fast Infiltration

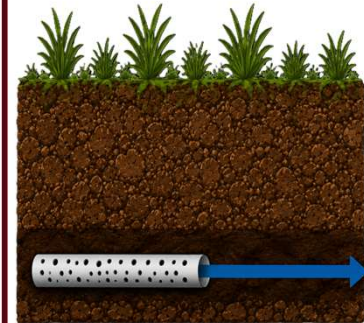
Low Porosity
Slow Infiltration



Design basin with low porosity to increase water/media contact time.

5

Subsurface Conveyance



Use underdrains to move water slowly below the surface.

Ongoing Work

-  Additional Column & Field Monitoring (Summer 2026)
-  Media Characterization
-  Field Infiltration Testing
-  Thermal Empirical Model Development
-  Design Guidance Development
-  Final Project Report (December 2026)

Funding & Acknowledgments

This research was funded through the Pooled Monitoring Initiative (PMI), Restoration Research Program.

Funding Partners: Maryland Department of Natural Resources, Anne Arundel County, Baltimore City, Montgomery County, Charles County, Harford County, Frederick County, and the Chesapeake Bay Trust

Award #23853 | University of Maryland | 2024-2026



The Pooled Monitoring Initiative funds applied science to advance restoration research for cumulative impacts, comparative effectiveness of stormwater practices, pollutants of emerging concern, and trade-offs with new research questions added annually.

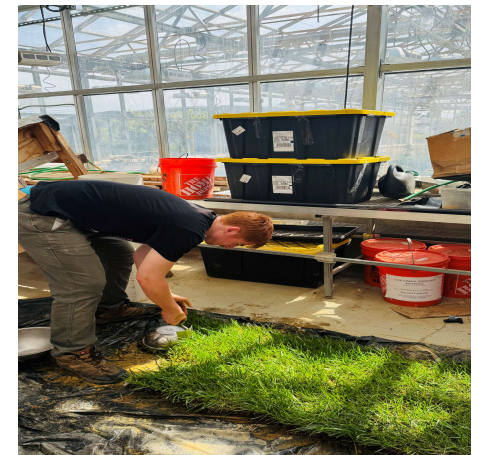
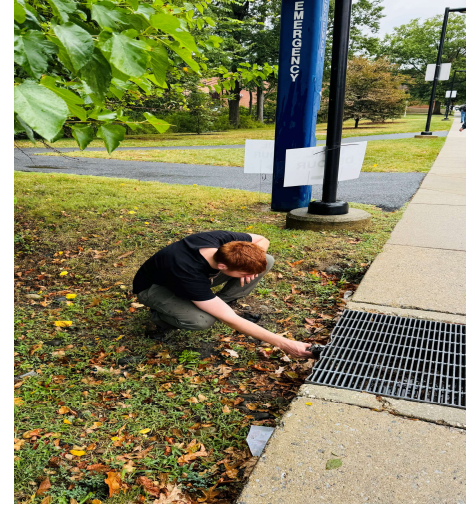
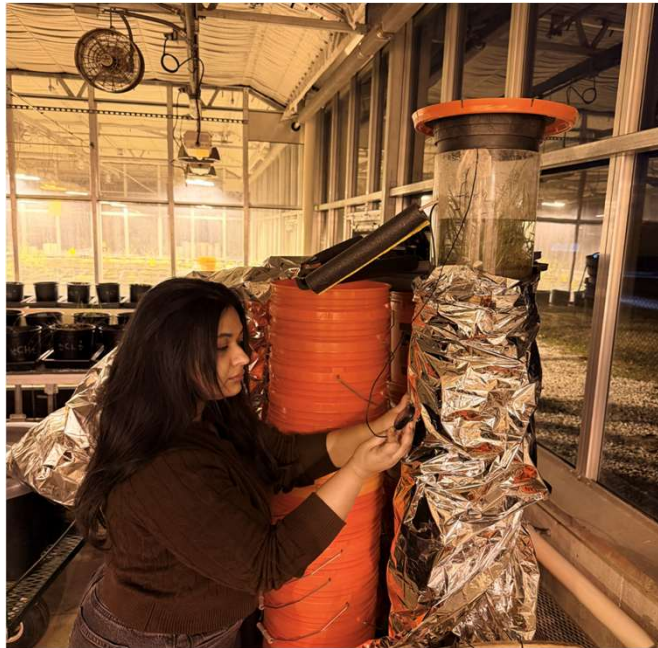


- We consider the vegetation on top of our bioretentions and look for ways to reduce solar exposure by using less rip-rap, but there's more to the bioretention story.
- Finding a balance between properly draining a bioretention and adjusting the media layers, using lower porosity in relation to overall depth, is equally important.
- When possible, a media depth of 3 feet with an underdrain or an increased flow path is ideal.
- Although there are positive data showing cooling effects in their discharges, bioretentions are still not the most effective option in cold-water tributaries.
- The most effective temperature reductions typically occur during rainfall events between 0.25 and 0.75 inches.
- As a retrofit, size and depth will be a challenge, as we are typically already constrained by surface and underground utilities and other existing assets.

Take-Home Message

Bioretentions can help reduce thermal impacts, but their effectiveness depends on thoughtful design—balancing vegetation, media depth, porosity, and drainage. While they provide some cooling benefits, especially during smaller storms, they are not the strongest standalone solution for protecting cold-water tributaries.

Photos



Photos



Development of a simplified approach of PCB loading estimation using a combination of passive sampling and sediment trapping



UMBC

B.5.c.iii. Effectiveness of restoration practices at the project scale; Pollutants of Emerging Concern; Toxics (PCBs).

- ▶ *Can a combination of passive sampling and sediment traps be used as more effective and low-cost alternative to traditional stormwater sampling to monitor PCB concentration during stormflow and baseflow?*
- ▶ *Can the simplified approach proposed be used to estimate PCB loading from stormflow and baseflow to determine PCB mass loading and identify ongoing sources?*

Nathalie Lombard, Upal Ghosh - University of Maryland Baltimore County

Partners:

Barbara Krupiarz, Elisabeth Green, Ben Daniels – MDE

Christopher Clark - PG County, Stormwater Management Division

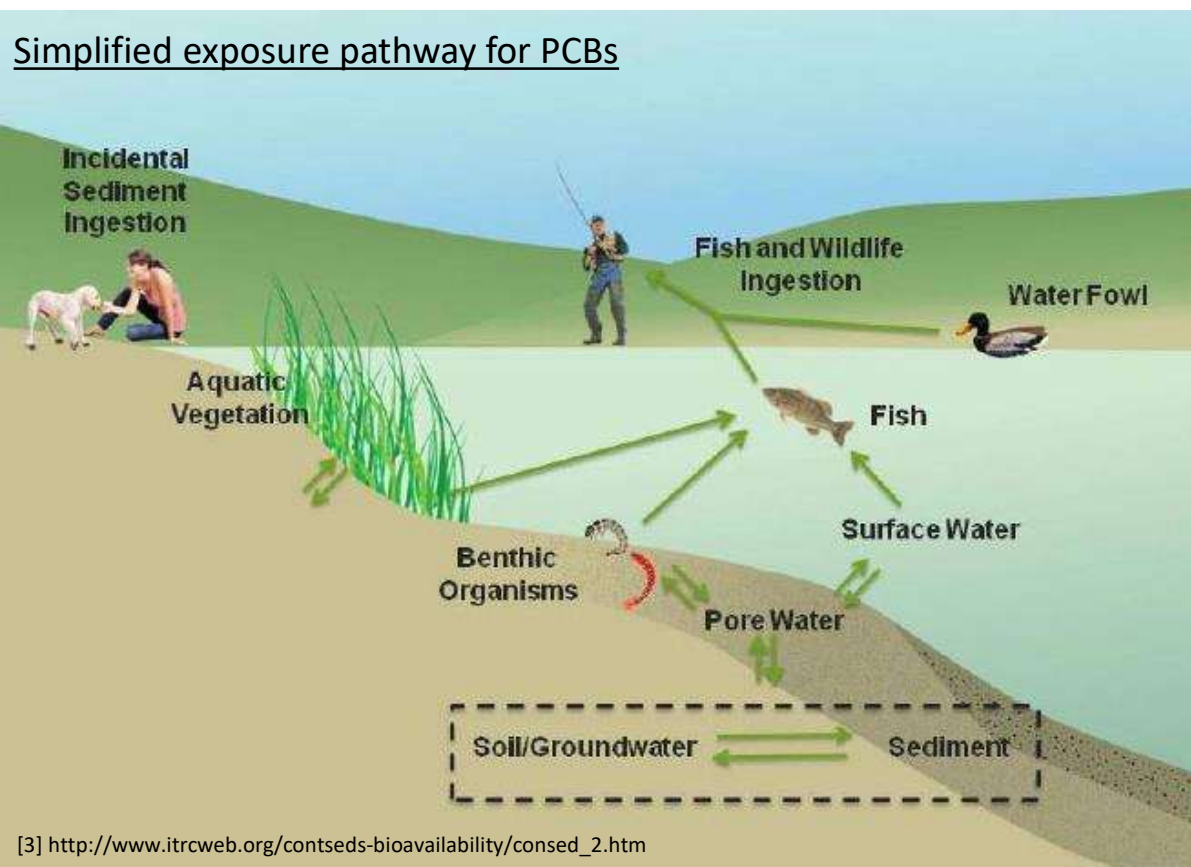
Research Question and Hypotheses



1. Freely dissolved PCB concentrations during stormflow can be measured using specially deployed short-term passive samplers.
2. Suspended sediments collected in strategically placed low-cost sediment traps can provide PCB concentrations in suspended sediments that are comparable to those determined using ISCO sampling devices.
3. Accurate PCB loading estimates are possible using a combination of passive sampling and sediment trapping that also delineates dissolved vs. suspended solids loads and baseflow vs. stormflow contributions.
4. Accurate delineation of the PCB loadings along a stream is able to identify ongoing land sources of pollution.
5. Incorporating state of the art passive sampling into loading estimates enables an accurate and chemical activity-based assessment of PCB transport that links monitoring to the ultimate endpoint of bioaccumulation in fish.

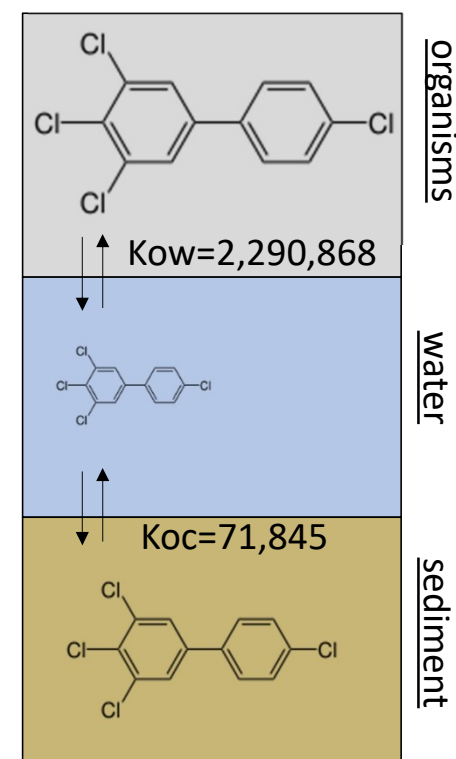
PCB dissolved concentration are critical to monitor

PCBs are hydrophobics: High concentration in sediment and organisms, Low concentration in water (sparingly soluble)
But PCB concentration in water is the main driver for uptake in organisms



PCB partitioning between phases

Example of PCB#81



Need for low-cost and integrative measurement of PCB in stormwater



Collection of dissolved and particulate fractions



<https://www.usgs.gov/media/images/grab-sampling>

- ☹ Inexpensive
- ☹ Do not require highly qualified personnel

- ☹ Unsafe during storm events
- ☹ Snapshot measurement of the storm event



<https://www.teledyneisco.com/>

- ☹ No personnel on site during storm collection
- ☹ Programmed to sample varying size of samples
- ☹ Integrative measurement possible

- ☹ Expensive, limited number of sites monitored
- ☹ Require qualified personnel for setup and maintenance
- ☹ Require batteries, electricity

Dissolved PCBs in water



Feasibility of Short-Term and Flow-Weighted Long-Term Measurements Using Equilibrium Passive Sampling

Oindrila Ghosh, Louis Cheung, Nathalie Lombard, and Upal Ghosh*

Cite This: <https://doi.org/10.1021/acsestwater.5c00686>

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ABSTRACT: Short-term surface water measurements are often critical in assessing pollutant inputs from episodic events, while long-term flow-weighted measurements are needed for loading calculations. For either application involving hydrophobic pollutants, equilibrium passive sampling is currently less explored. In this paper, we first evaluate the feasibility of short-term sampling of polychlorinated biphenyls in polyethylene and polydimethylsiloxane samplers using a combination of mathematical modeling, laboratory-scale experiments, and field demonstration. Laboratory-scale experiments under a range of flow conditions revealed that short-term measurements of dissolved polychlorinated biphenyls using an 18 μm thick polyethylene sheet are possible with 24 h of exposure in high-flow conditions. The optimized samplers deployed at Anacostia River, Washington, DC, were able to measure the water concentration during a storm event and showed that the concentrations were not diluted by the high flow and that the loading during the storm event was substantial. Laboratory experiments revealed that with increasing flow velocity, the diffusive boundary layer thickness decreased and the resulting mass transfer rate increased for the sampler. The positive correlation between flow and exchange rate enables a passive approach for flow-weighted water quality sampling across changing flow conditions in a river.

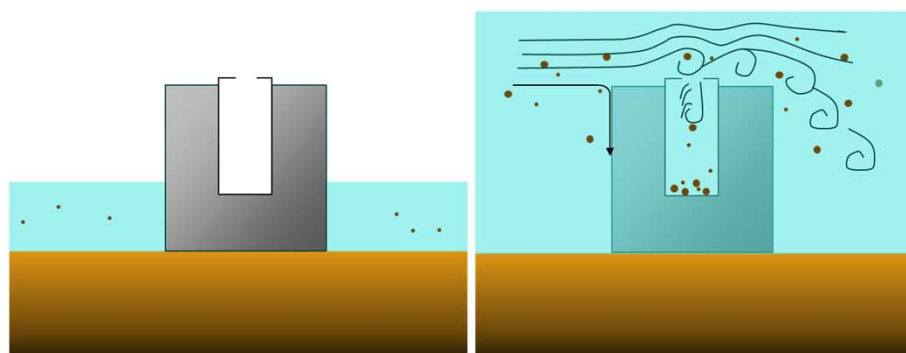
KEYWORDS: passive sampling, freely dissolved concentrations, polyethylene (PE), short-term sampling, flow-weighted sampling

PCBs in suspended sediments



Baseflow

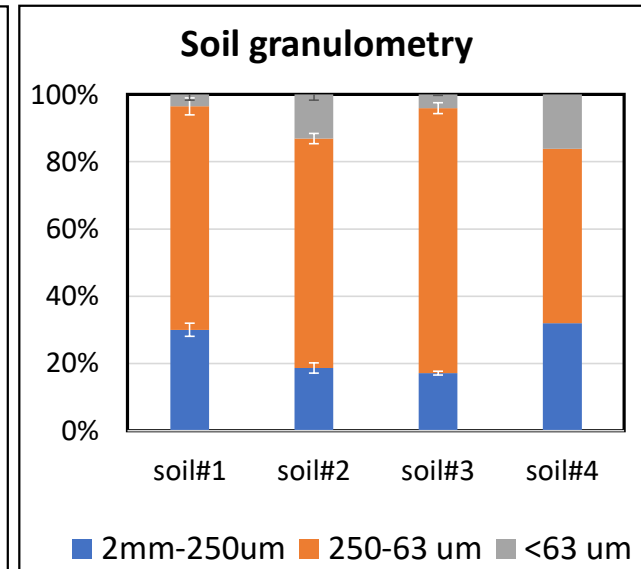
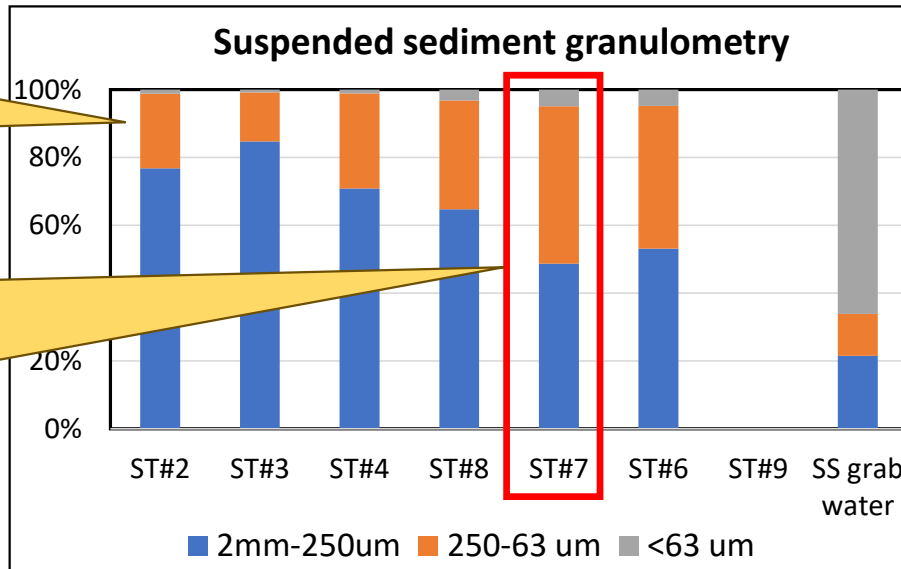
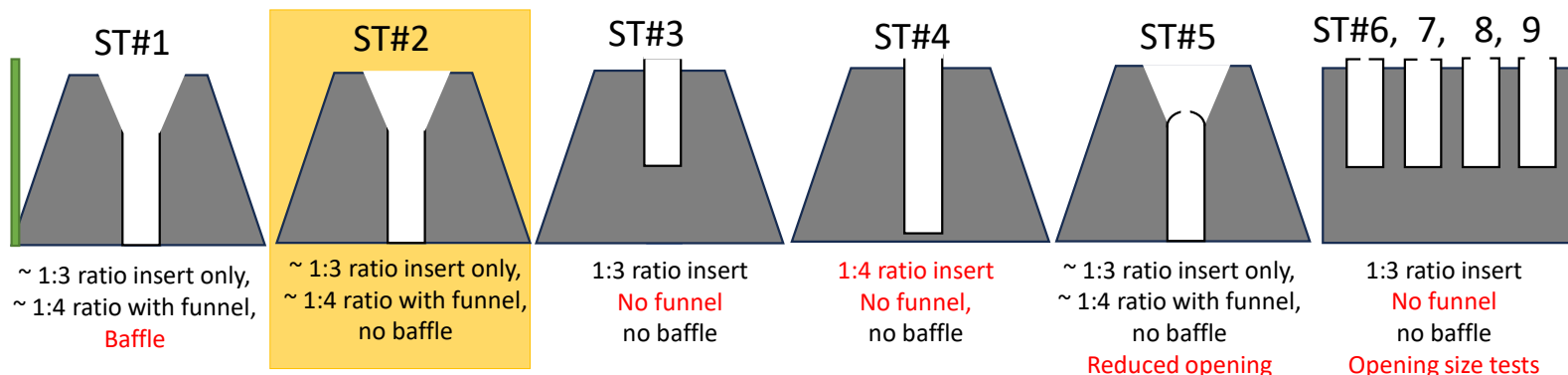
Stormflow



Sediment trap optimisation



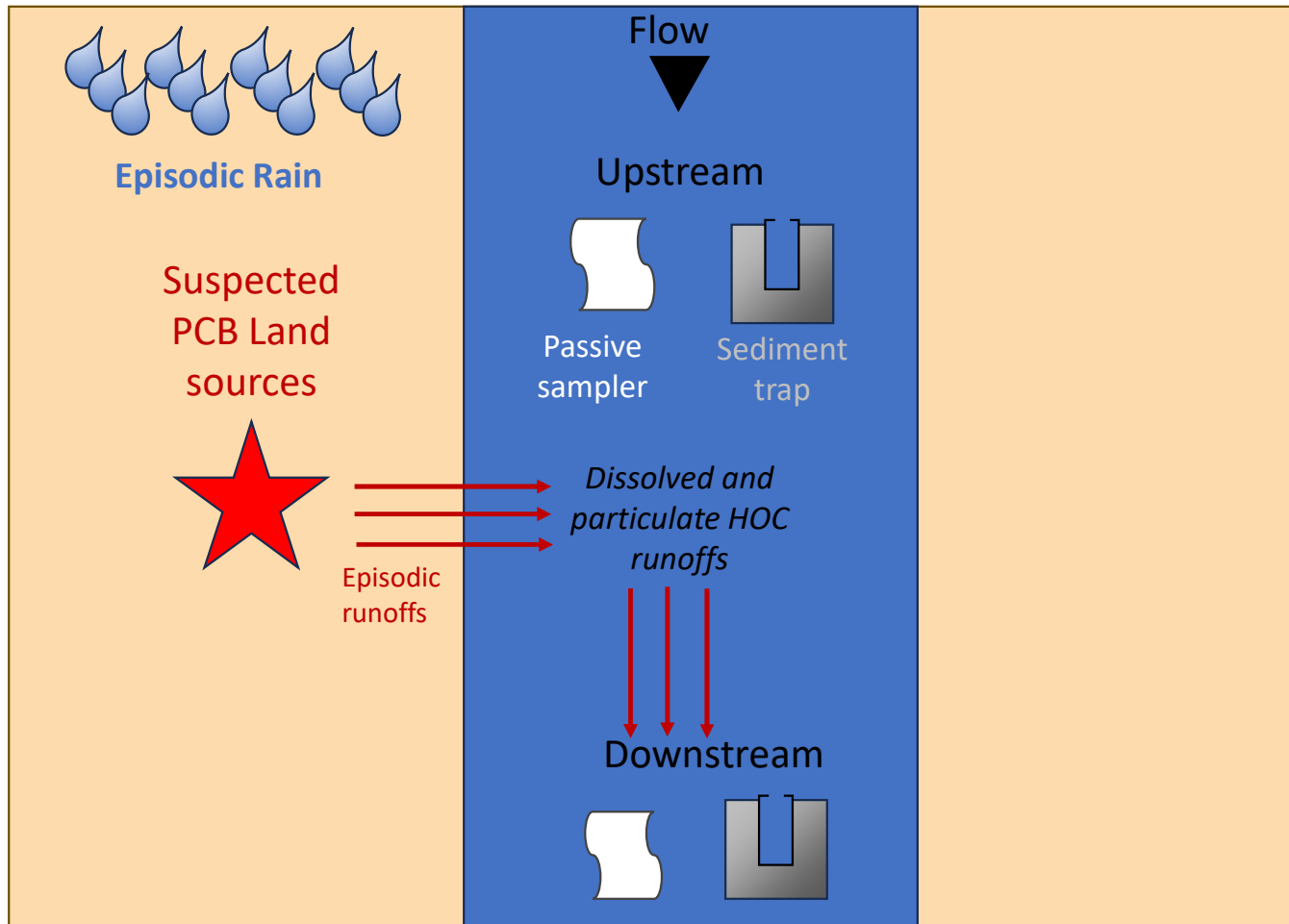
Several sediment trap iterations tested over 4 storms events at LBC1



Configuration tends to overfill with SS

Best compromise for finer SS and sufficient amount collected for PCB and TOC analysis

The approach



Comparison upstream vs downstream:

Increase of PCB concentration downstream vs upstream confirms presence of a PCB source

Comparison baseflow vs stormflow:

PCB concentration dilution during storms indicates a baseflow source

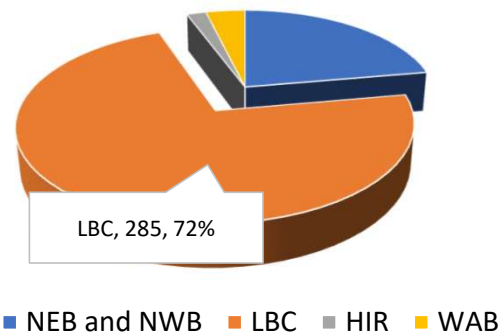
PCB loads calculation:

Delineate baseflow vs stormflow contribution to the impairment

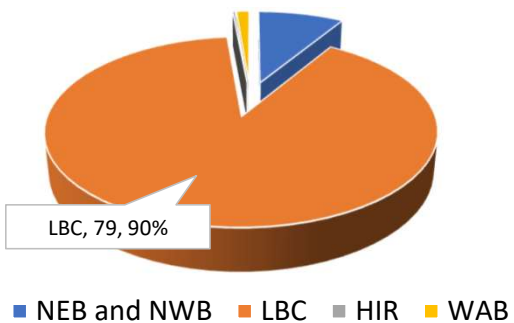
Study site



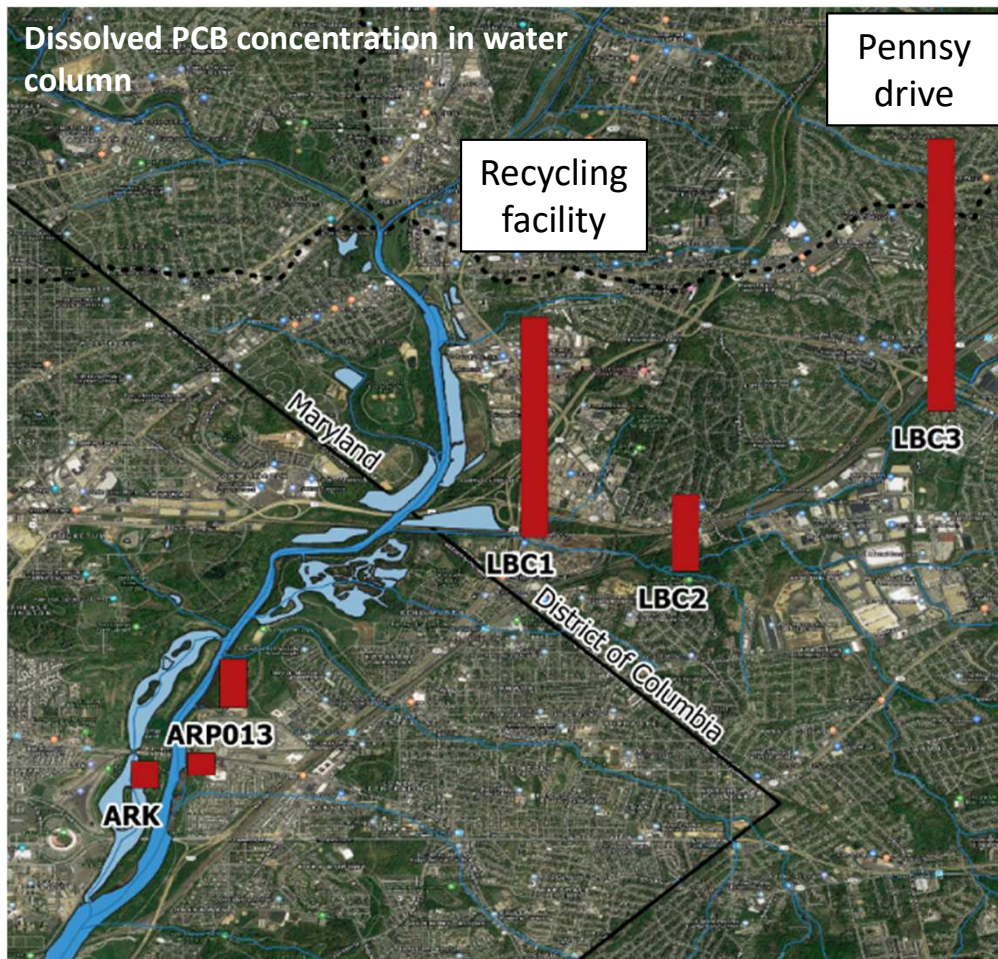
Total PCB loads from Tributaries (g/year)



Dissolved PCB loads from Tributaries (g/year)



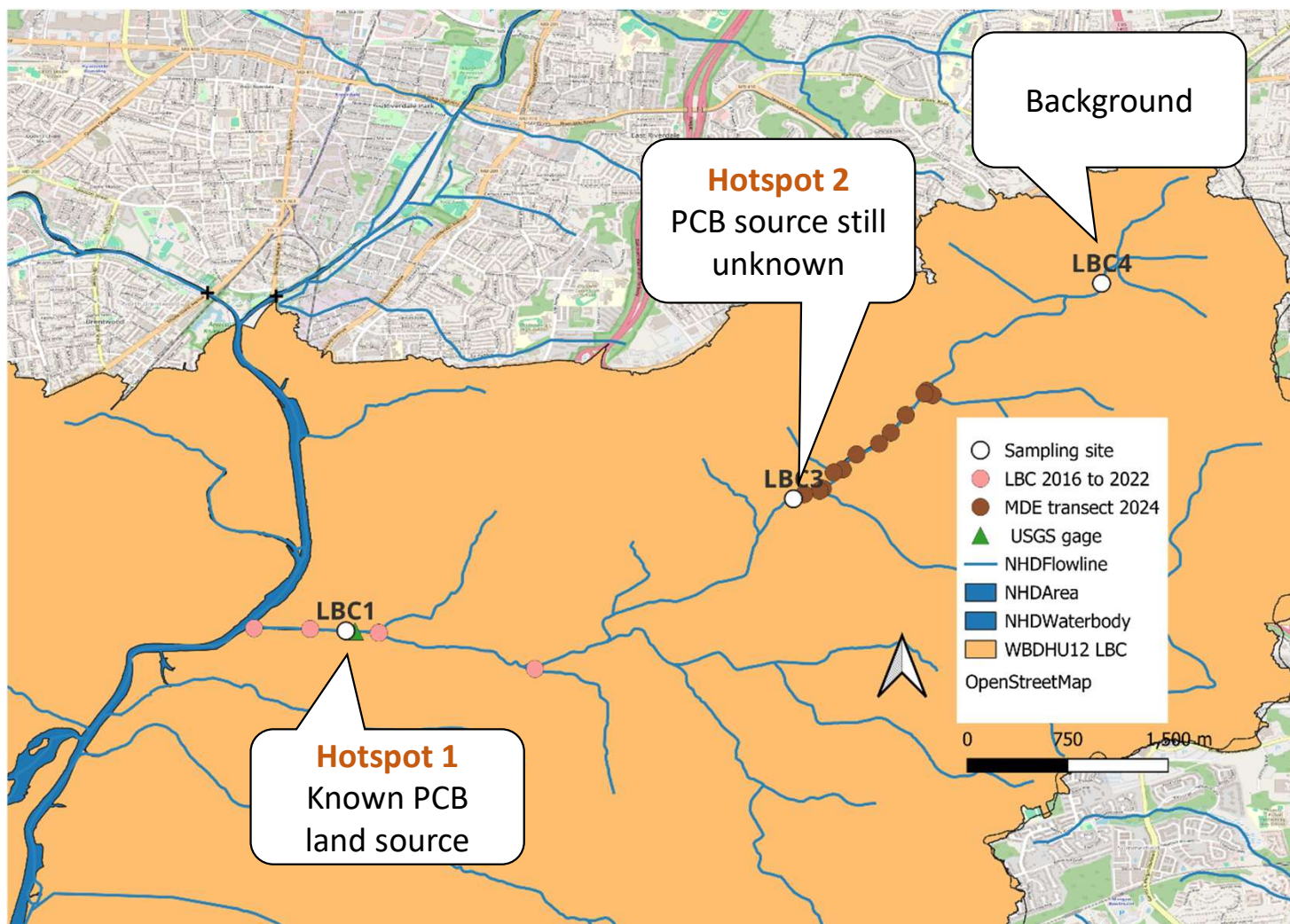
Dissolved PCB concentration in water column



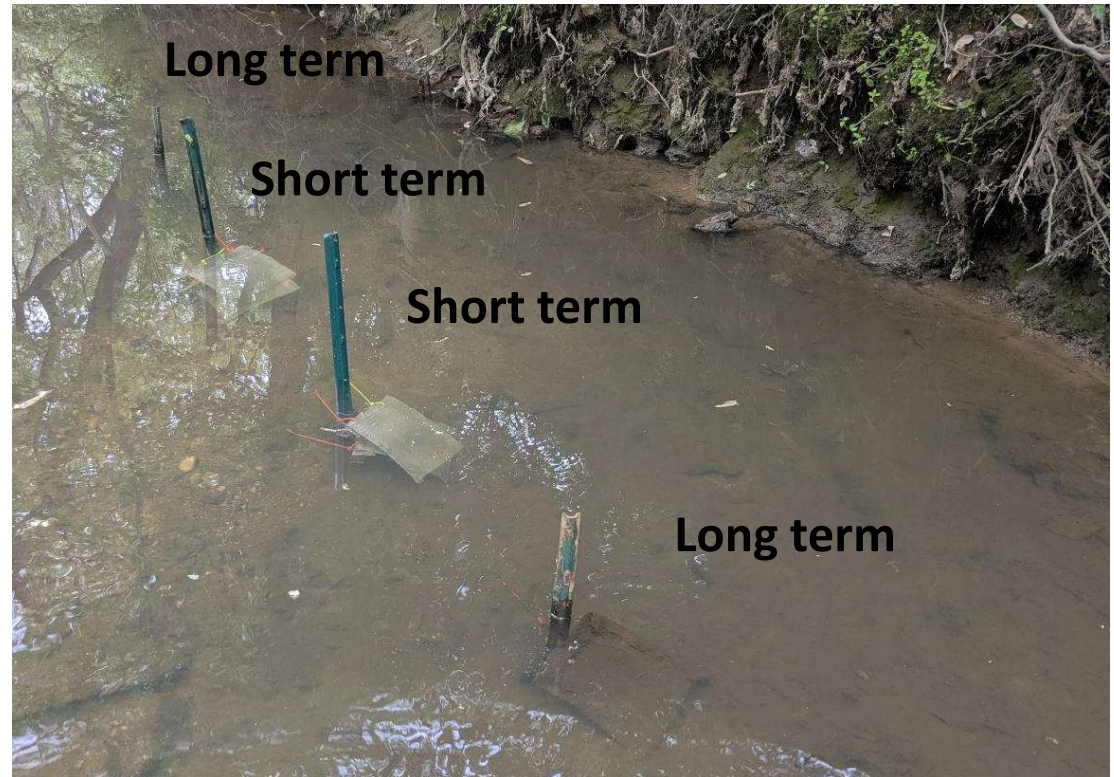
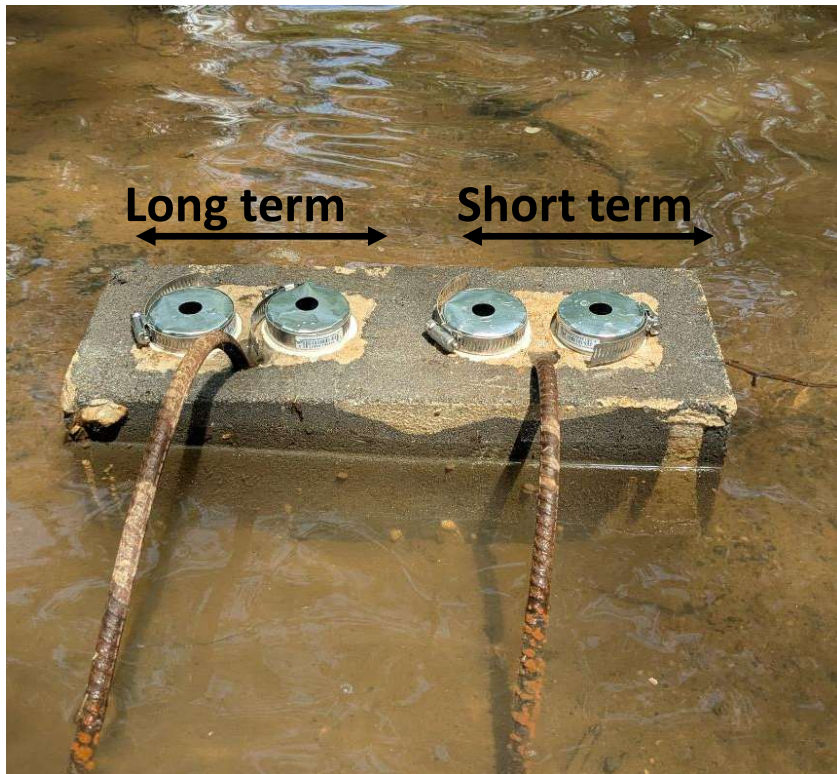
- ☐ PCB in water and SS data collected in 2017
- ☐ LBC is a major source of PCB to the Anacostia River
- ☐ Two hot spots of PCB contamination confirmed by multiple studies
- ☐ Source identification ongoing at LBC3/Pennsy drive



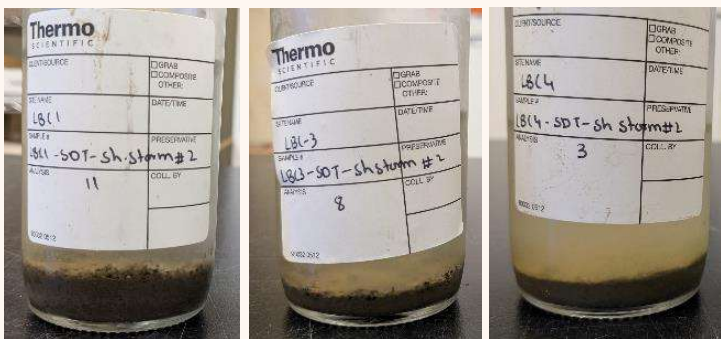
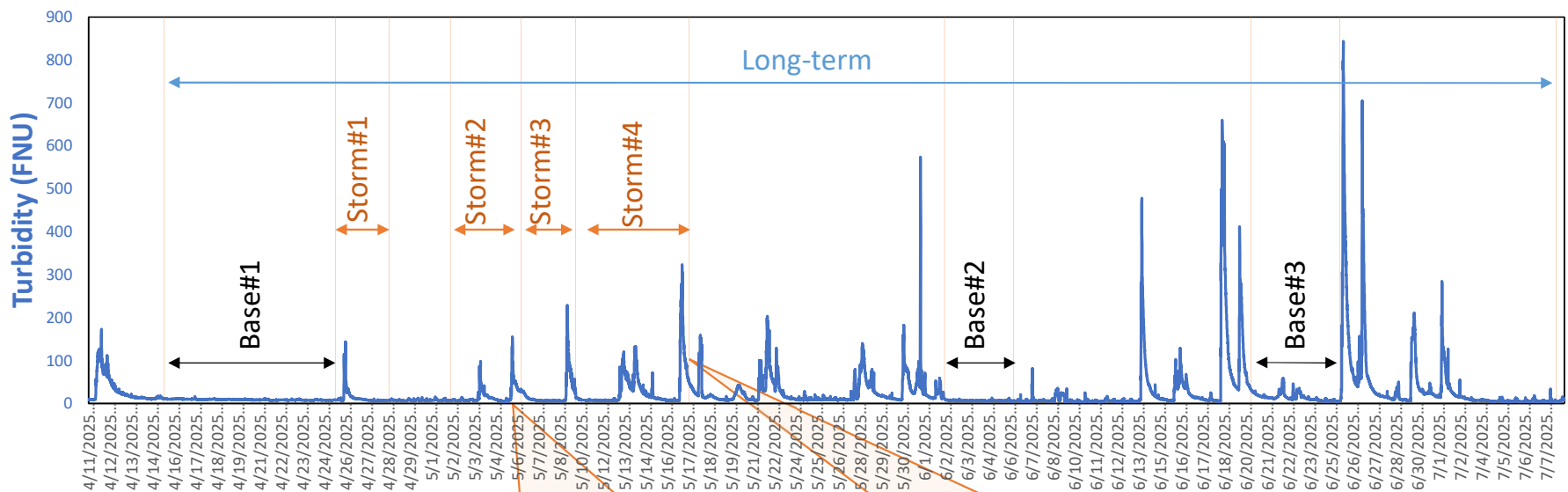
Sampling location



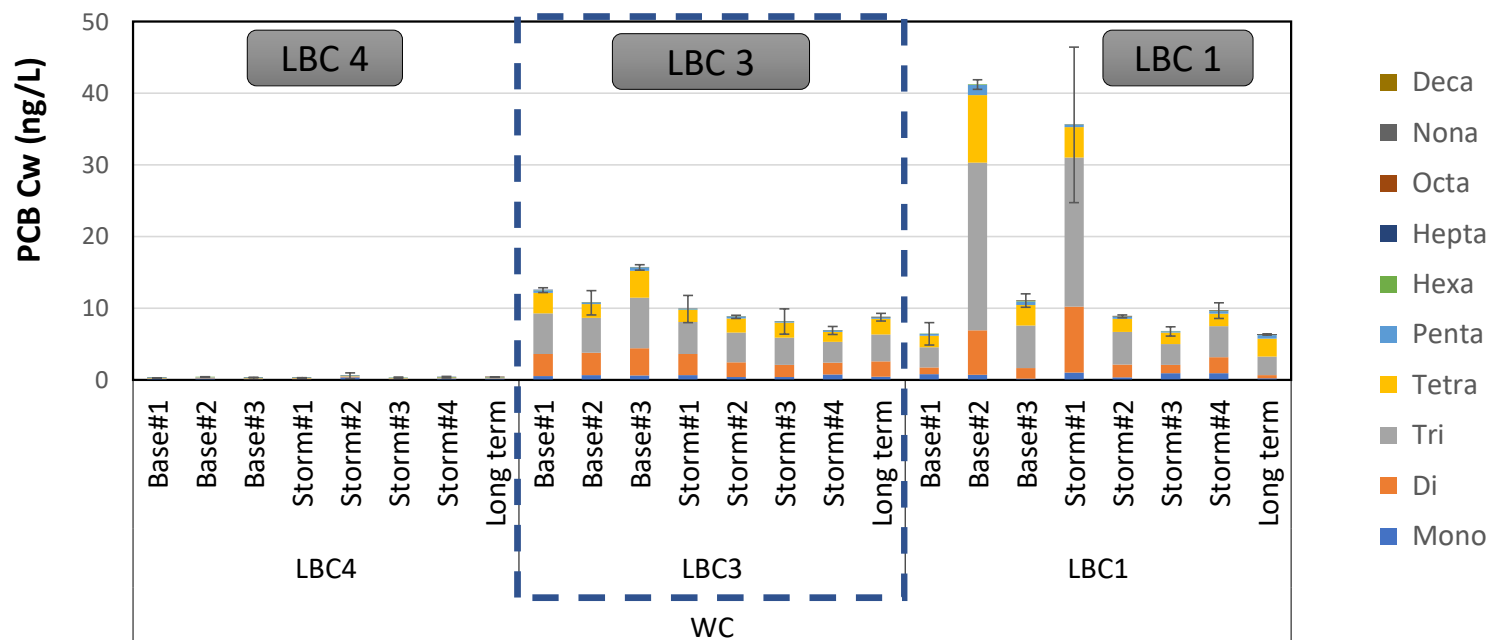
Sediment trap and passive sampler deployment



Sampling timeline

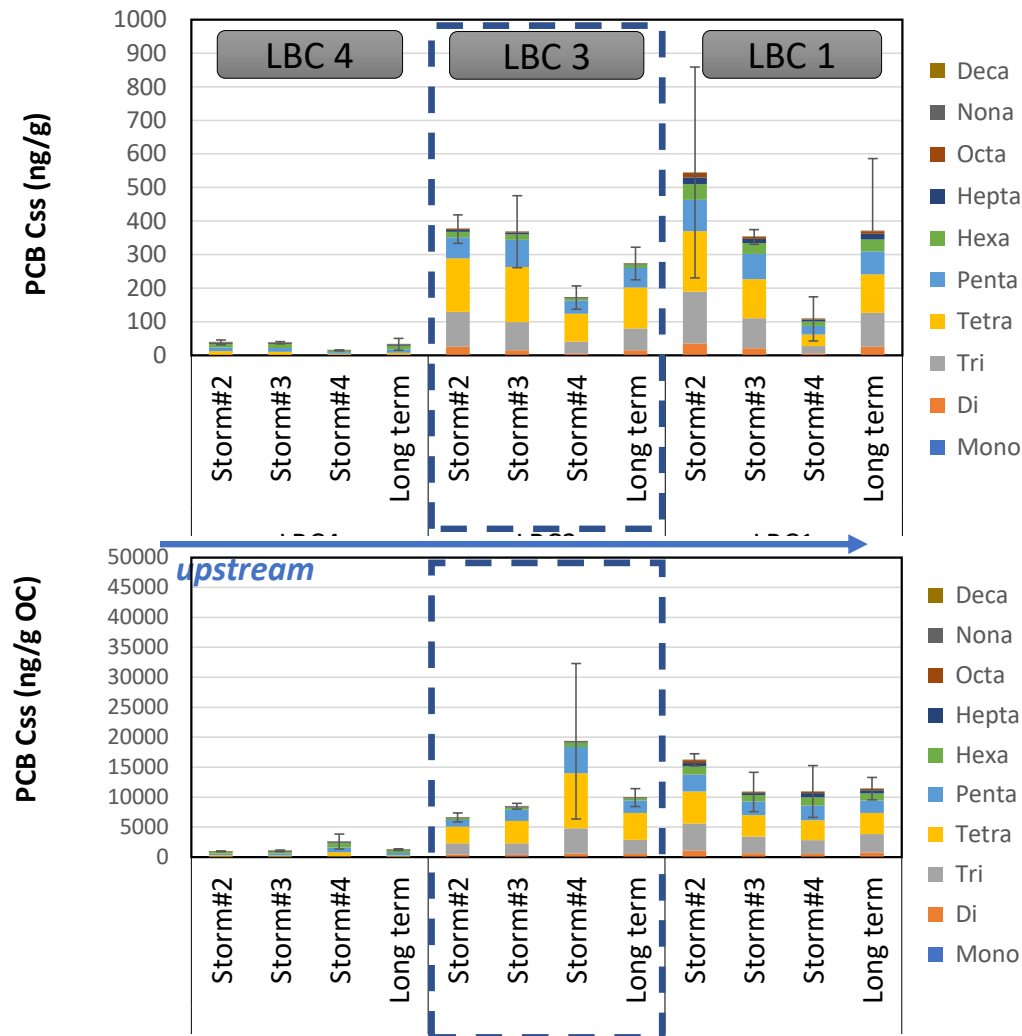


Dissolved PCB concentration can be measured during short-term



- ☐ Short-term measurements show higher PCBs concentration in water at LBC3 and LBC1
- ☐ Low intra variability between replicates (median RSD of 10%)
- ☐ Measurements comparable to that of 2017 and 2022
- ☐ Similar PCB levels between baseflow and stormflow (no dilution effect),
- ☐ Episodic high-concentration events at LBC1 (Base#2 and Storm#1)

Long term sediment trap provide representative PCB concentration in SS



- Higher PCB concentration in SS at LBC3 and LBC1 vs LBC4
- PCB concentration at LBC1 in 2025 is higher than that measured with ISCO sampler from 2017 (range of 5.4 - 140 ng/g)
- Variability of PCB concentration between storms
- Similar PCB concentration across storms per site after OC normalization
- Average PCBs from 3 storms similar to the long-term measurements per site
- Higher MW congeners at LBC1 versus LBC3 suggesting different sources

Our low-cost technology alternative can identify PCB land sources mobilized in particulate or dissolved form during rain event

- ☐ Low variability of PCB concentration in SS after OC normalization.
- ☐ Higher variability can be observed in dissolved forms across storms and baseflow depending on the site complexity.
- ☐ Transect monitoring recommended to track multiple potential sources such as outfalls or tributaries.
- ☐ Although tested in this project for PCBs, the methods have wide applications for other legacy and emerging pollutants

Next steps:

- ☐ PCB loading calculations to evaluate relative contribution of storm versus baseflow and identify the major inputs impacting downstream waterbody
- ☐ Test the approach in a second watershed

Funding & Acknowledgments

This research was funded through the Pooled Monitoring Initiative (PMI), Restoration Research Program.

Award #23847 | UMBC | 2025-2027

The Pooled Monitoring Initiative funds applied science to advance restoration research for cumulative impacts, comparative effectiveness of stormwater practices, pollutants of emerging concern, and trade-offs with new research questions added annually.



Maryland
Department of
the Environment



WEBSITE: <https://cbtrust.org/grants/restoration-research/>

Translation Slides



Chris Clark, Engineer IV, Water Quality Coordinator
Prince George's County Department of the Environment
Stormwater Management Division

What does
this mean
for me?

Low-cost monitoring tools can significantly expand PCB source investigations

Passive samplers and sediment traps provide a scalable alternative to traditional ISCO storm sampling.

Lower equipment and staffing requirements allow more locations to be monitored simultaneously.

Increased spatial coverage improves the ability to isolate active PCB source areas.

BE CAREFUL
WHERE YOU
PLACE YOUR
SAMPLERS!



What does
this mean
for me?

Dissolved-phase PCB monitoring provides critical insight

Dissolved PCB concentrations are directly linked to bioavailability and fish tissue uptake.

Traditional total-water sampling alone may overlook important transport mechanisms.

Separating dissolved and particulate loads improves understanding of remediation priorities.

What does
this mean
for me?

Stormflow and baseflow comparisons help identify source types

Elevated baseflow concentrations may indicate groundwater or legacy infrastructure sources.

Elevated stormflow concentrations may indicate surface runoff or sediment mobilization.

Comparative monitoring improves targeting of source-trackdown investigations.

What does
this mean
for me?

Sediment traps can support watershed screening efforts

Sediment traps provide time-integrated particulate sampling during storm events.

Trap optimization is important to ensure representative fine sediment capture.

The approach may be particularly useful in highly urbanized MS4 systems.

Key Takeaways for Regulators

Improved monitoring efficiency can support MS4 permit implementation

Simplified monitoring approaches may allow jurisdictions to evaluate more outfalls and tributaries within existing budgets.

Expanded monitoring coverage can accelerate PCB source identification efforts required under TMDL implementation programs.

Cost-effective approaches may improve long-term watershed trend monitoring.

Key Takeaways for Regulators

Monitoring methods support risk-based watershed management

Dissolved PCB measurements provide insight into bioavailable contaminant fractions.

Loading estimates help prioritize subwatersheds and potential source areas.

Data can improve targeting of enforcement, remediation, and restoration activities.

Key Takeaways for Regulators

Approach supports adaptive management frameworks

Results can inform iterative monitoring and source-trackdown strategies.

Monitoring can be refined over time as hotspot areas are confirmed or eliminated.

The methodology supports phased investigations rather than relying solely on large-scale intensive sampling campaigns.

There is the potential to use this methodology to also evaluate the effects on the status and mobilization of PFAS and other COC's, including pesticides, PAH's, etc.

Wrap Up

Prince George's County Perspective

Urban watersheds contain complex mixtures of legacy industrial contamination, stormwater transport pathways, and remobilized sediments.

Cost-effective screening tools are essential for identifying priority areas within large regulated MS4 systems.

Integrated monitoring approaches improve the County's ability to support PCB TMDL compliance and long-term restoration planning.

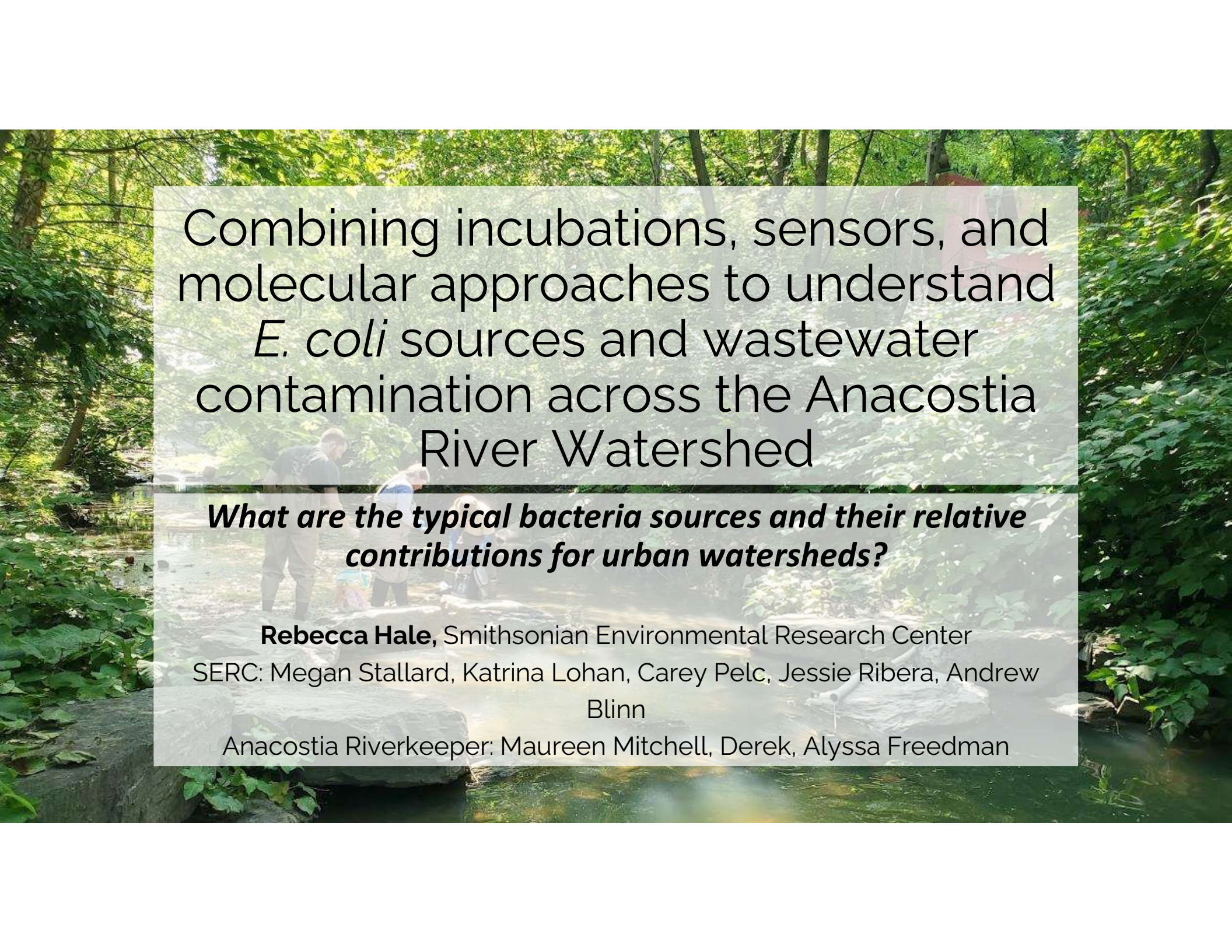
Expanded monitoring flexibility can help jurisdictions respond more effectively to emerging regulatory requirements and evolving contaminant investigations.



WE'VE COME A
LONG WAY.

THANK YOU!



The background image shows a lush green riverbank with dense foliage. In the middle ground, several people are gathered near the water's edge, some appearing to be sampling or testing the water. The scene is bright and sunny, with sunlight filtering through the trees.

Combining incubations, sensors, and molecular approaches to understand *E. coli* sources and wastewater contamination across the Anacostia River Watershed

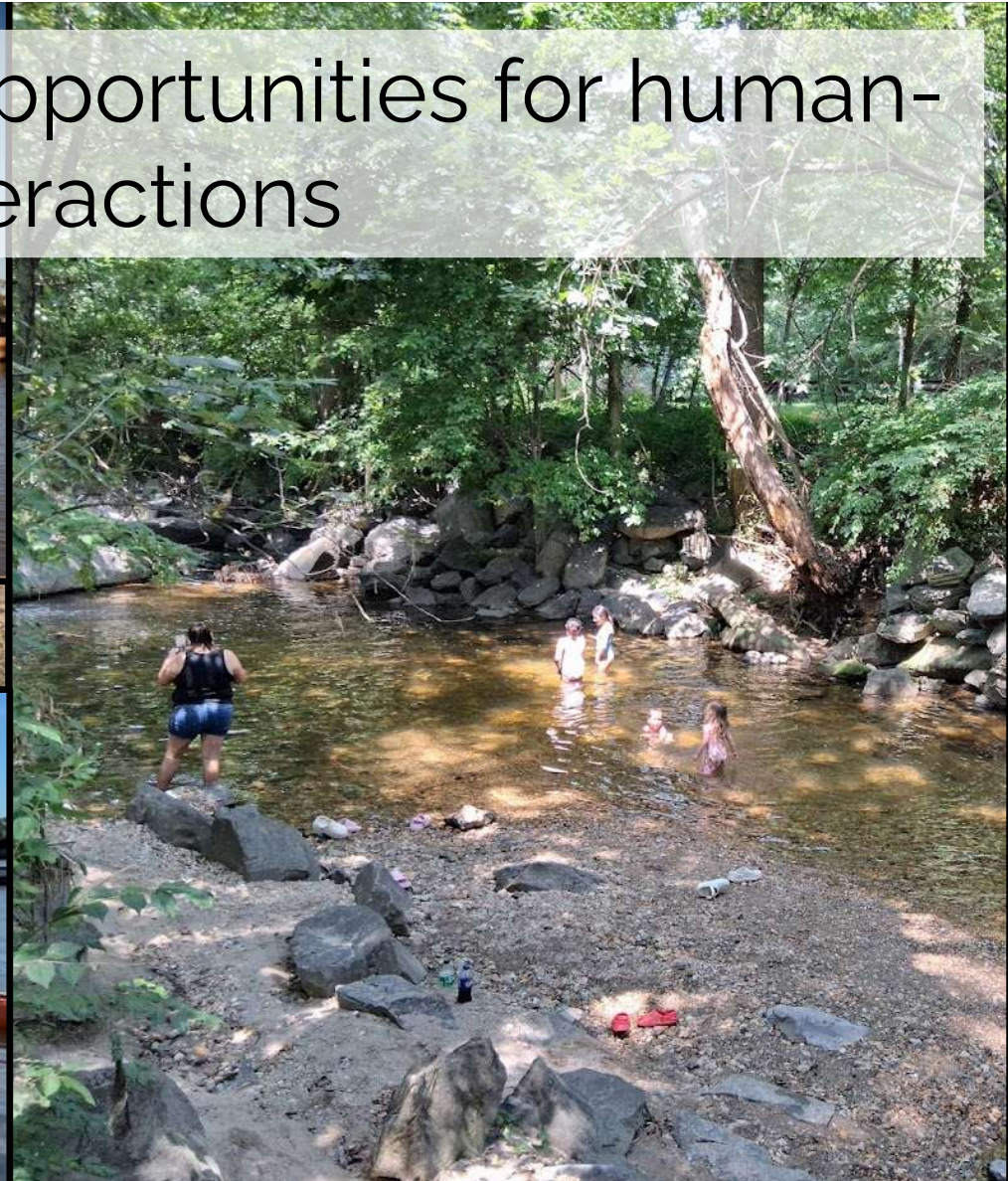
What are the typical bacteria sources and their relative contributions for urban watersheds?

Rebecca Hale, Smithsonian Environmental Research Center

SERC: Megan Stallard, Katrina Lohan, Carey Pelc, Jessie Ribera, Andrew Blinn

Anacostia Riverkeeper: Maureen Mitchell, Derek, Alyssa Freedman

Urban streams provide opportunities for human-nature interactions



But urban streams are often...gross



Fecal indicator bacteria are used to assess recreational risk

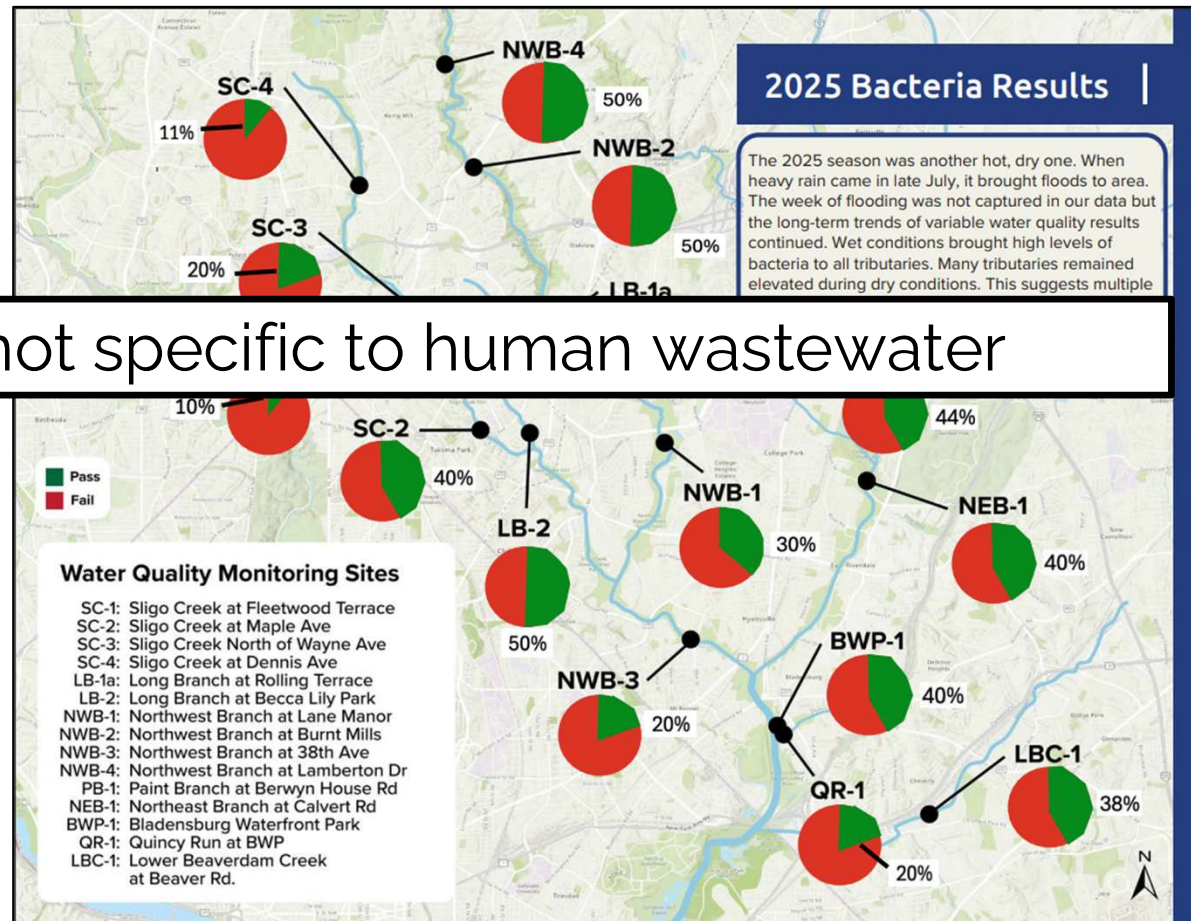
Across the Anacostia watershed, many streams are not safe



E. coli bacteria

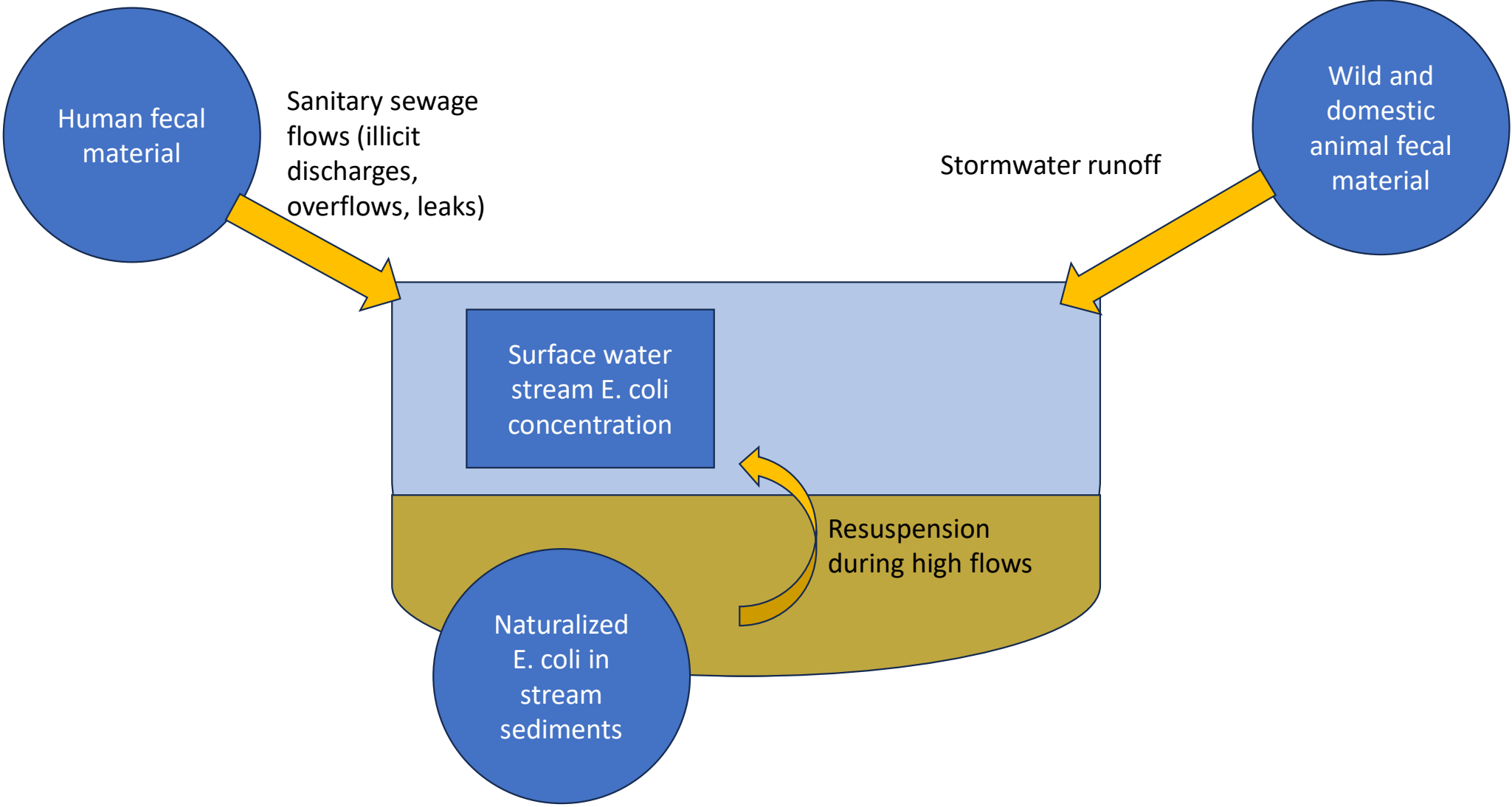
EPA standard: 410 mpn/100ml

Challenge: *E. coli* are not specific to human wastewater



Anacostia River Keeper 2025 Maryland Report

Q1: What are the dominant sources of E. coli across the Anacostia Watershed?



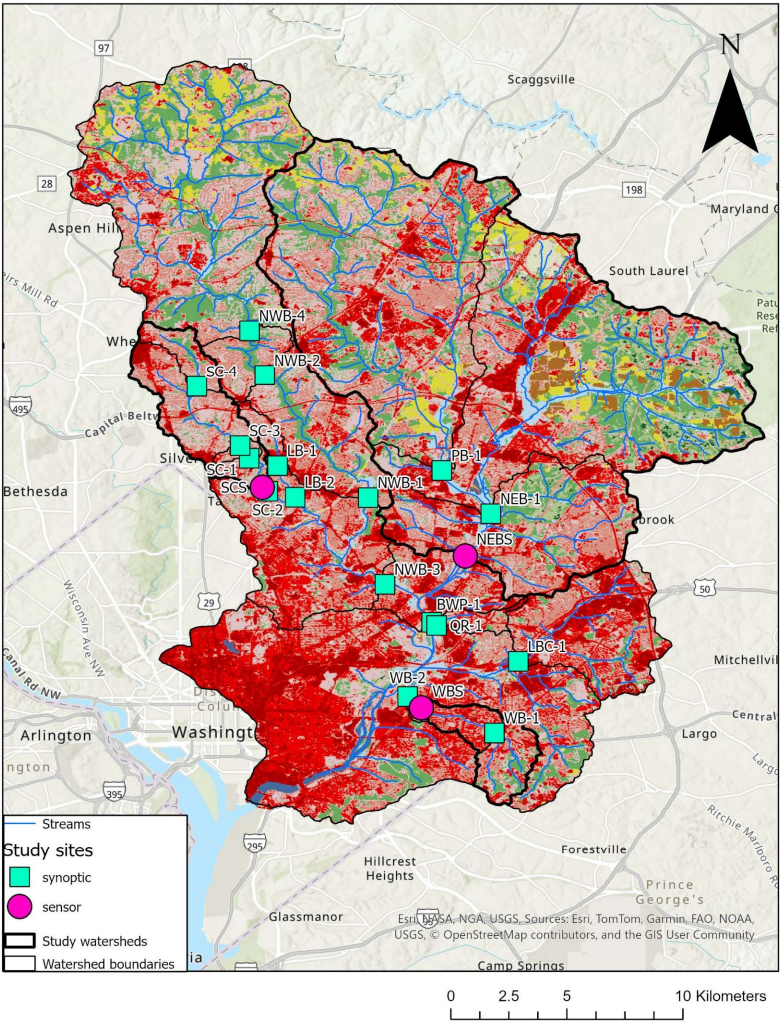
Q1: What are the dominant sources of E. coli across the Anacostia Watershed?

H1: Dominant sources of *E. coli* contamination will vary among streams depending on land cover and stormwater and wastewater infrastructure.

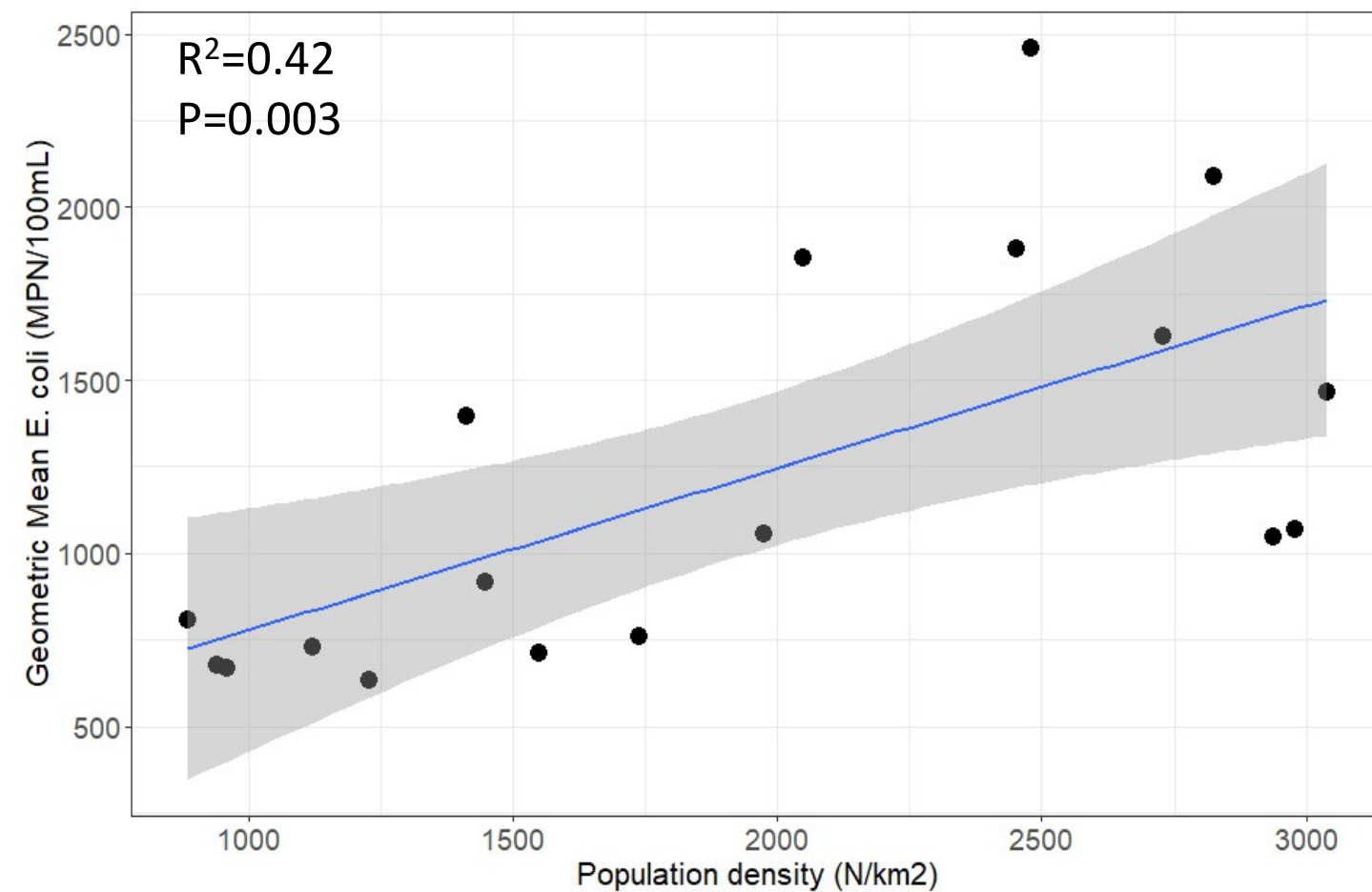
- more human and canine *E. coli* in watersheds with greater human population densities
- more wildlife-sourced *E. coli* in watersheds with greater forest cover

Approach:

1. Synoptic sampling: 20 locations 5 times
 1. Impervious cover: 19-49%
 2. Forest cover: 4-28%
 3. Population density: 890-4400 ppl/km²
2. Bacteria:
 1. Traditional incubation methods (IDEXX)
 2. Molecular source tracking (MST)



Mean *E. coli* concentrations associated with population density



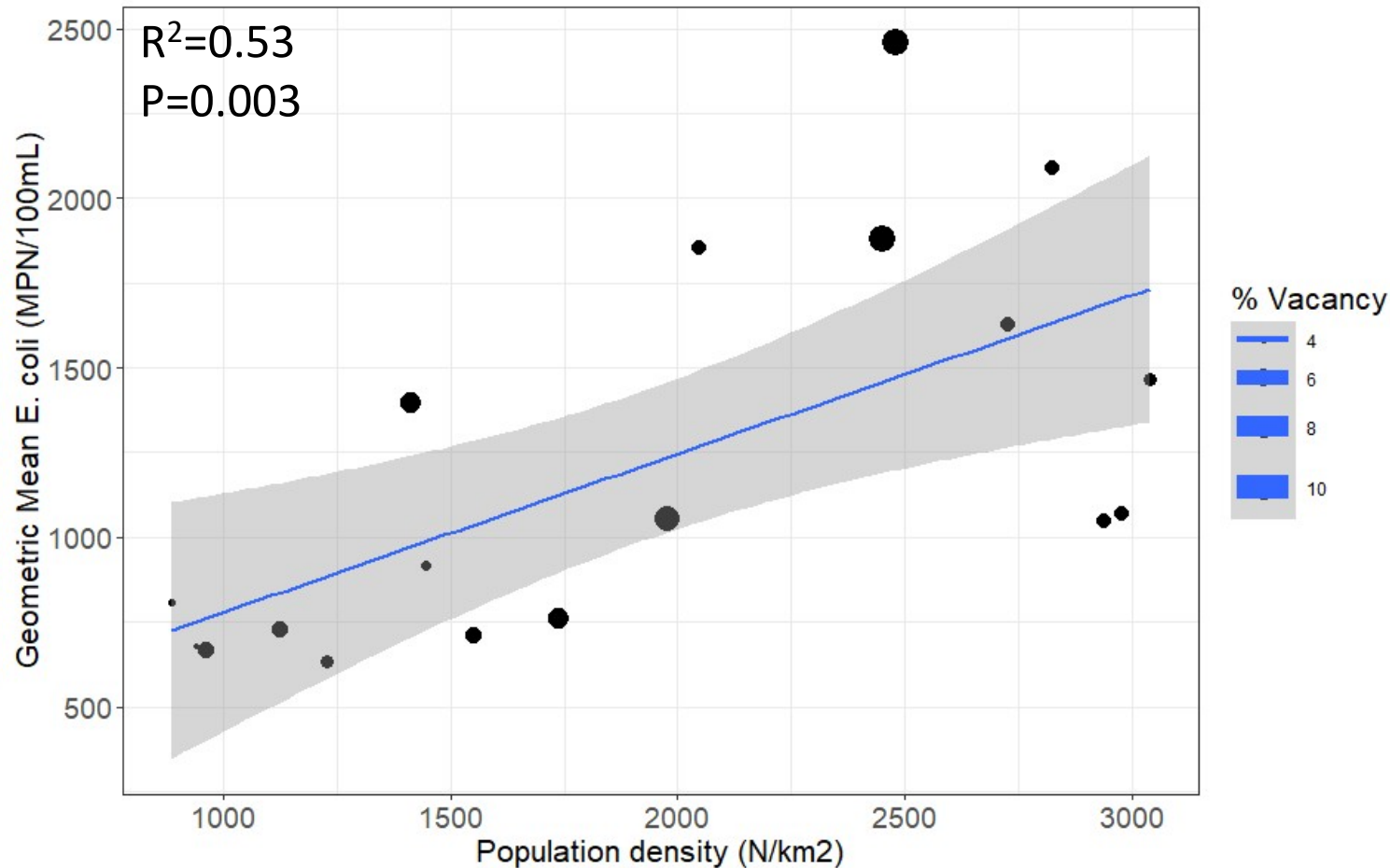
Equivalent predictors:

Housing density (+)

Tree cover over impervious (+)

Forest cover (-)

Mean *E. coli* concentrations associated with population density



Equivalent predictors:

Housing density (+)

Tree cover over impervious (+)

Forest cover (-)

Housing vacancy may be a proxy for infrastructure condition.

Microbial Source Tracking: what are sources of fecal bacteria?



DG3



HF183



GFD

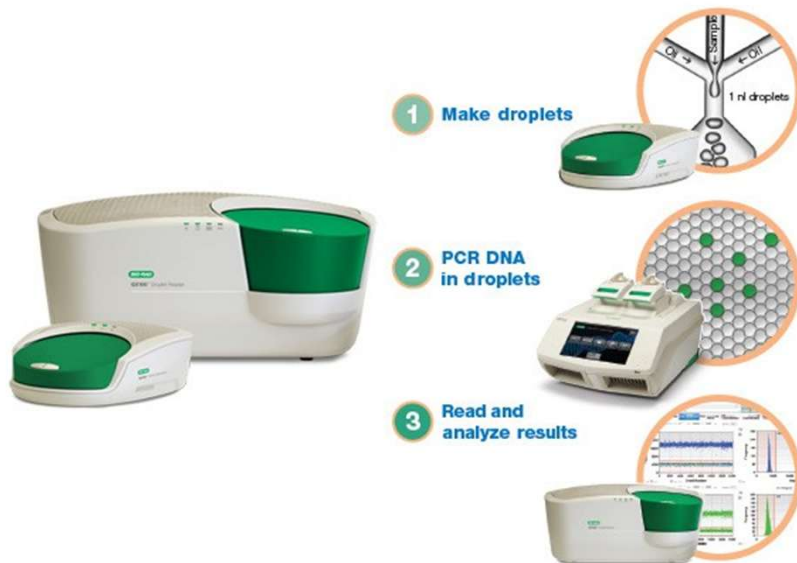


RumBac

Targets

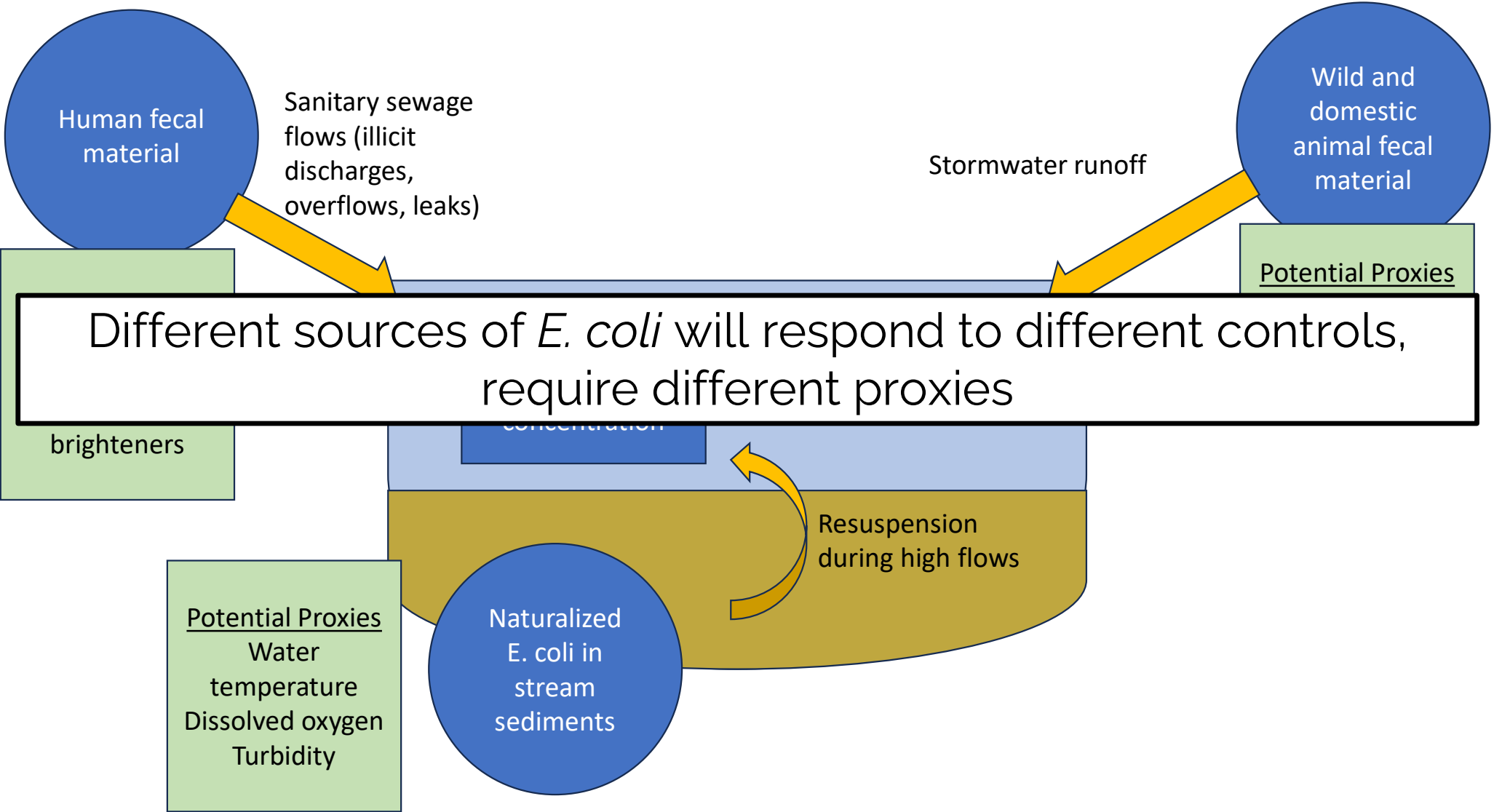


Digital droplet PCR technology

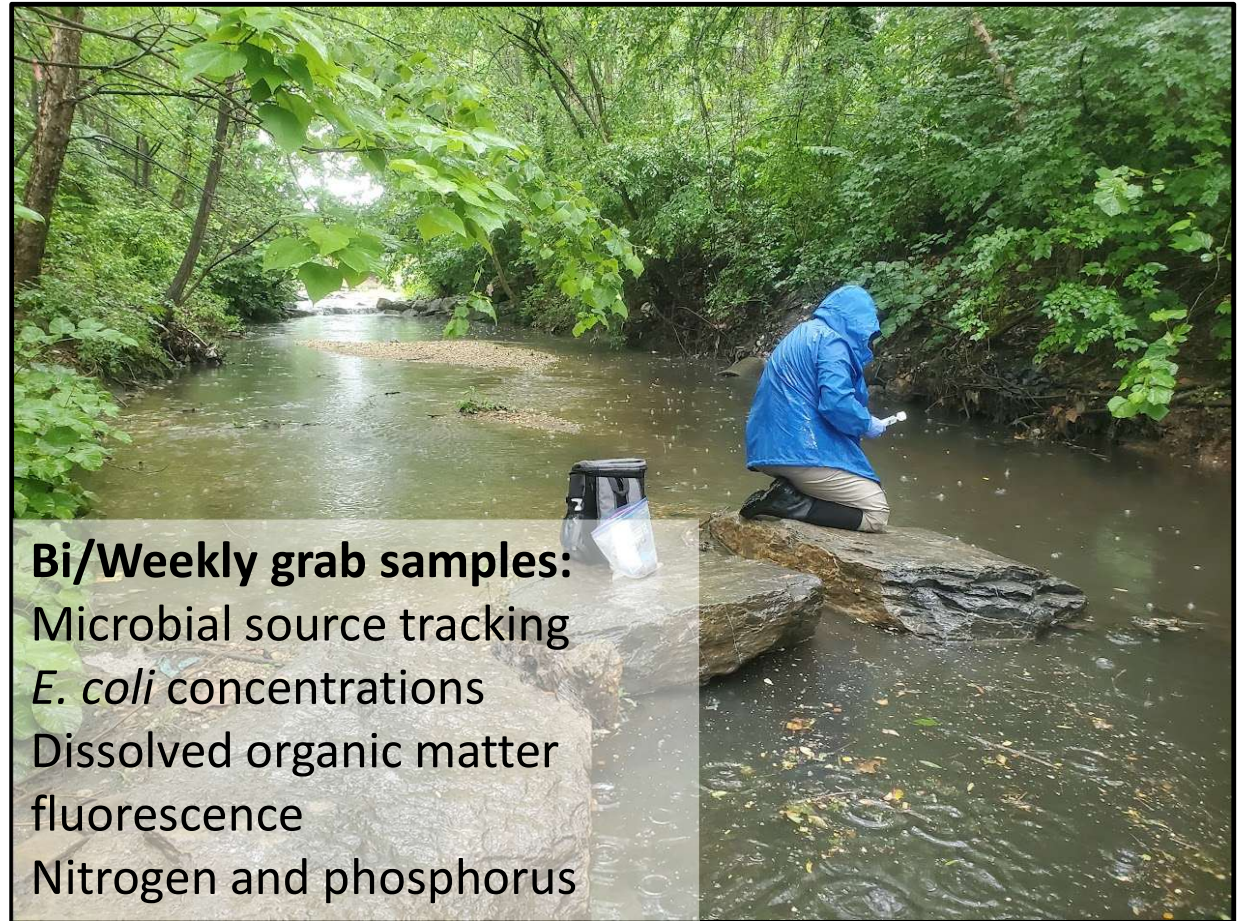


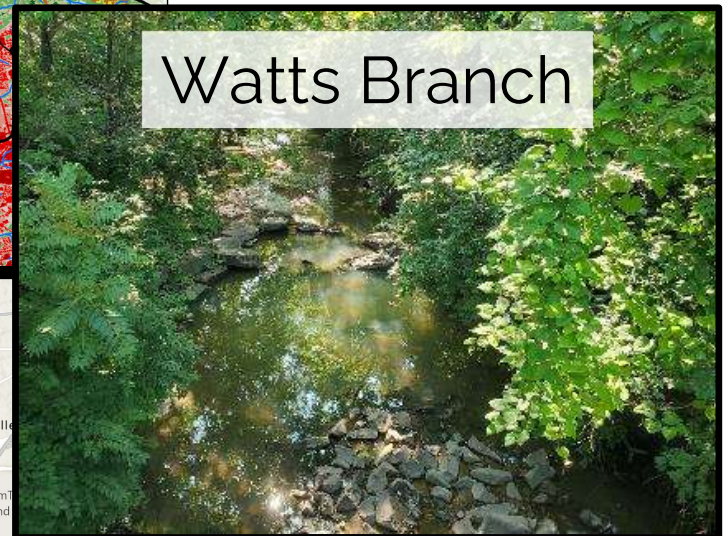
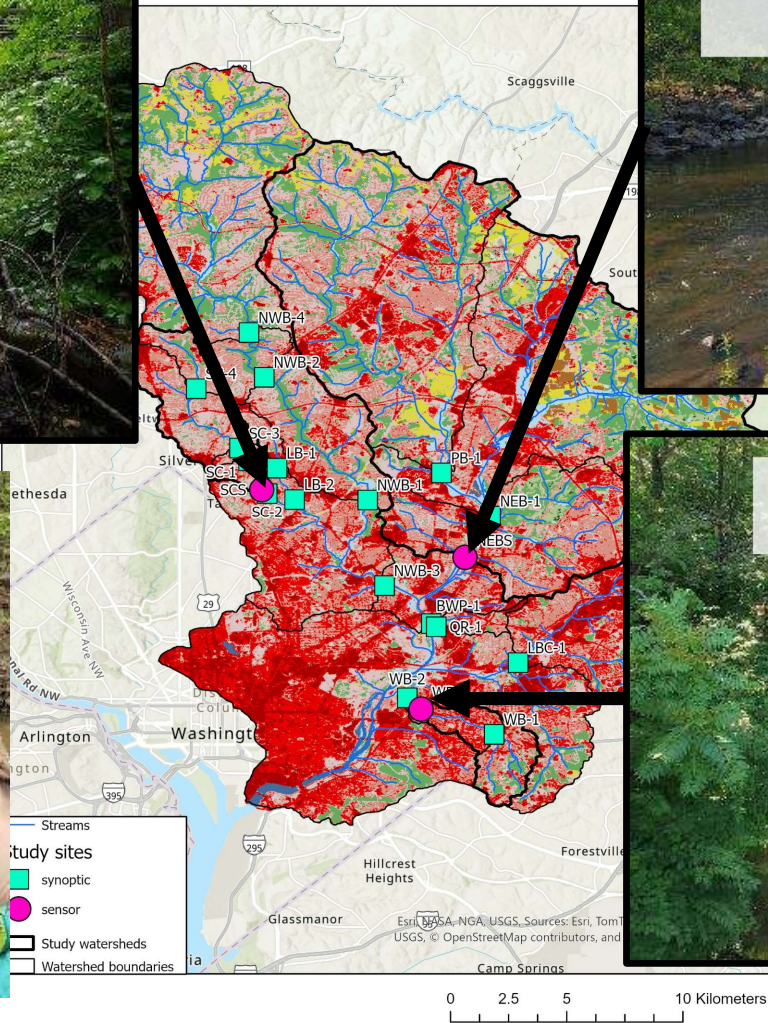
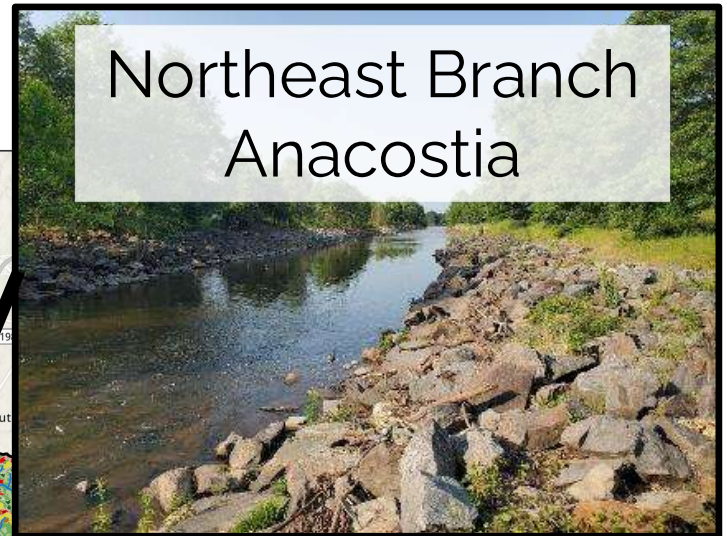
- Abundance of host-specific bacteria targets
- Expect to have completed end of summer

Q2: What sensor parameters are associated with *E. coli* concentrations?

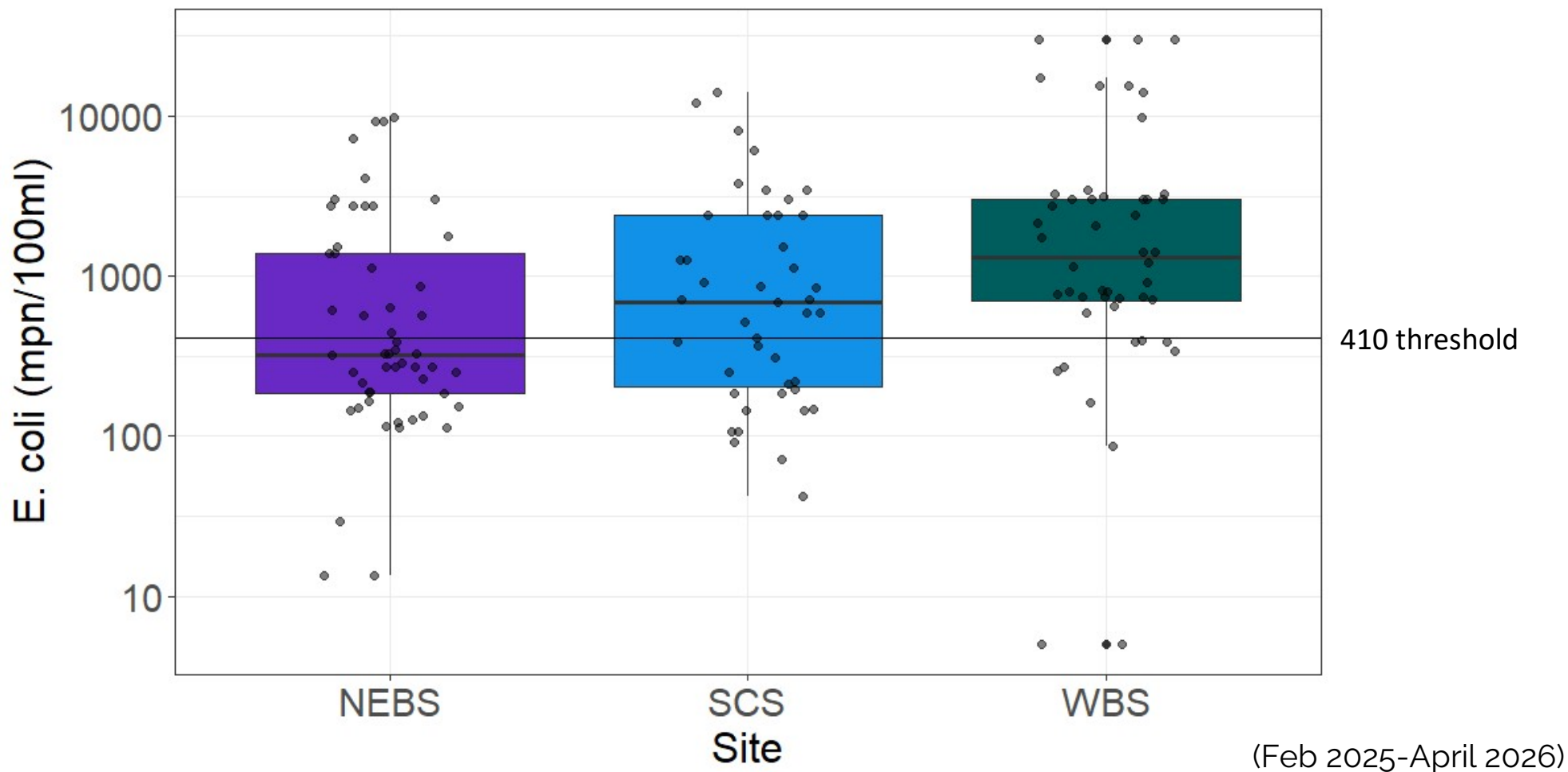


*Q2: What sensor parameters are associated with *E. coli* concentrations?*

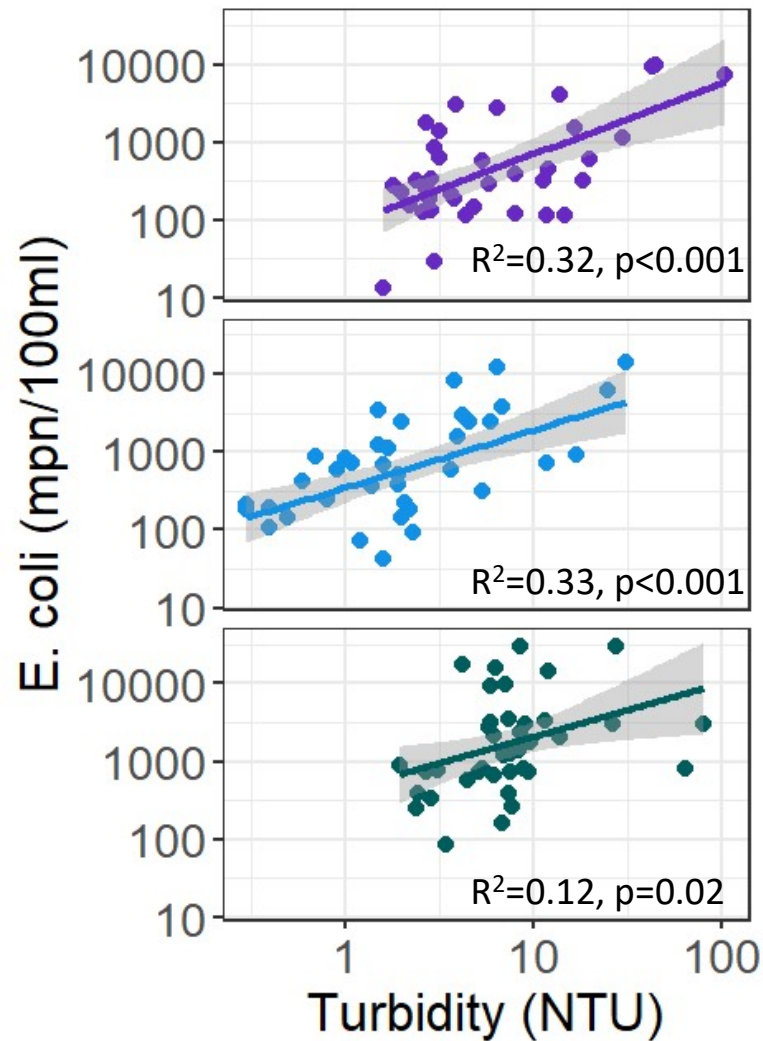




E. coli concentrations span 4 orders of magnitude within sites



E. coli concentrations are correlated with stormwater proxies

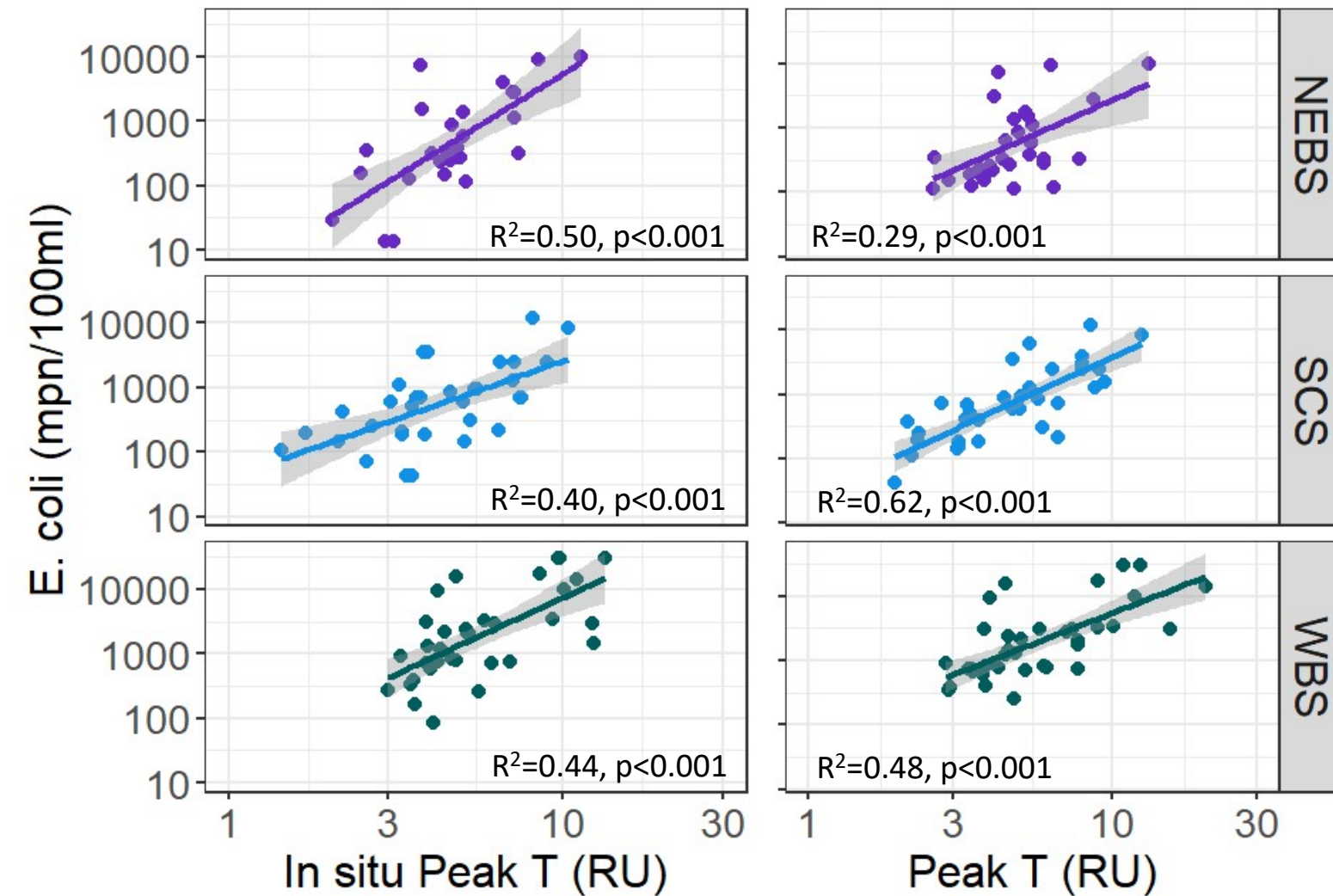


NEBS

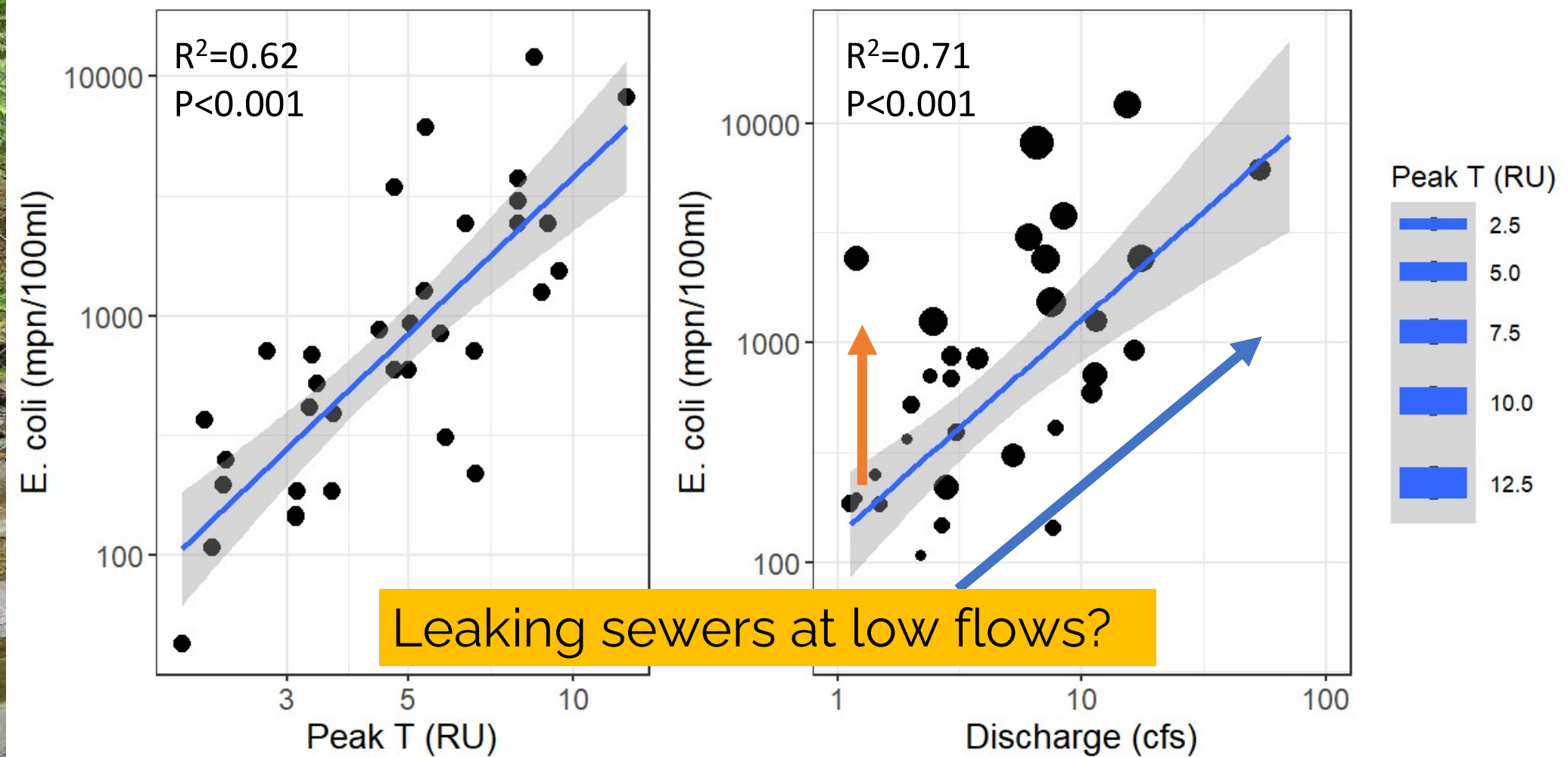
SCS

WBS

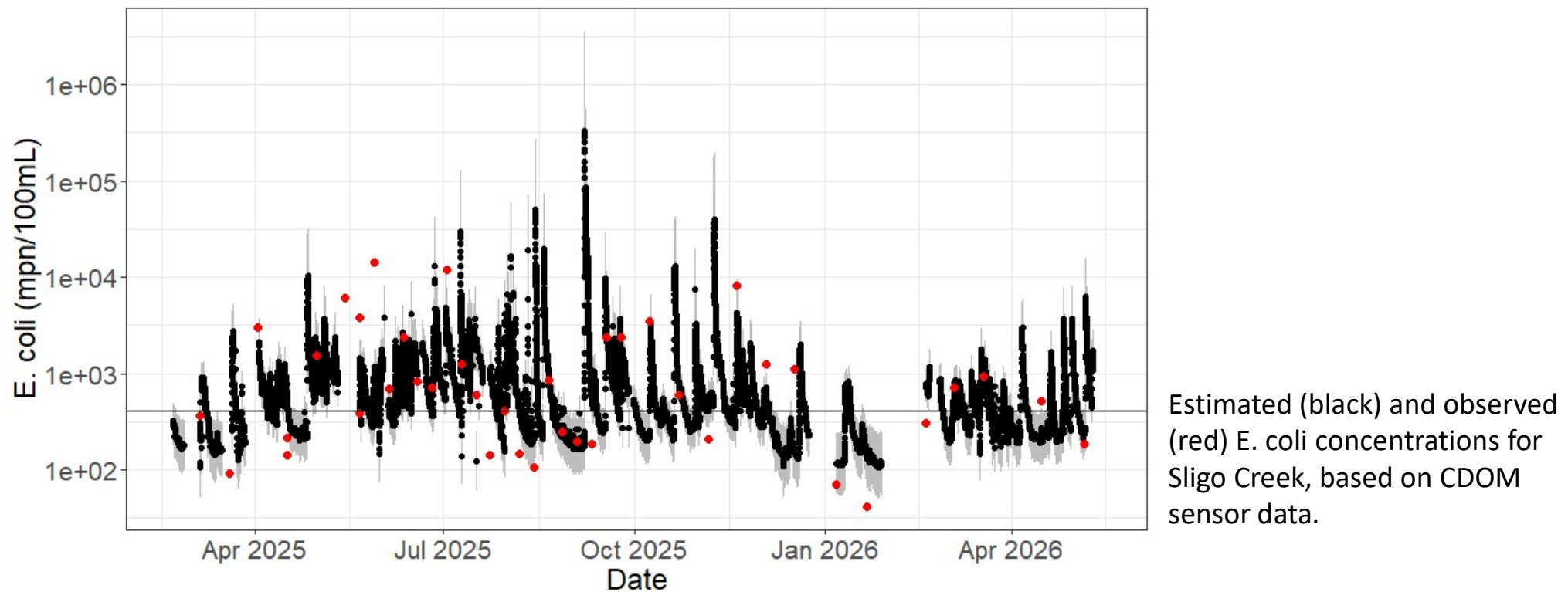
The best single predictor is tryptophan-like fluorescence



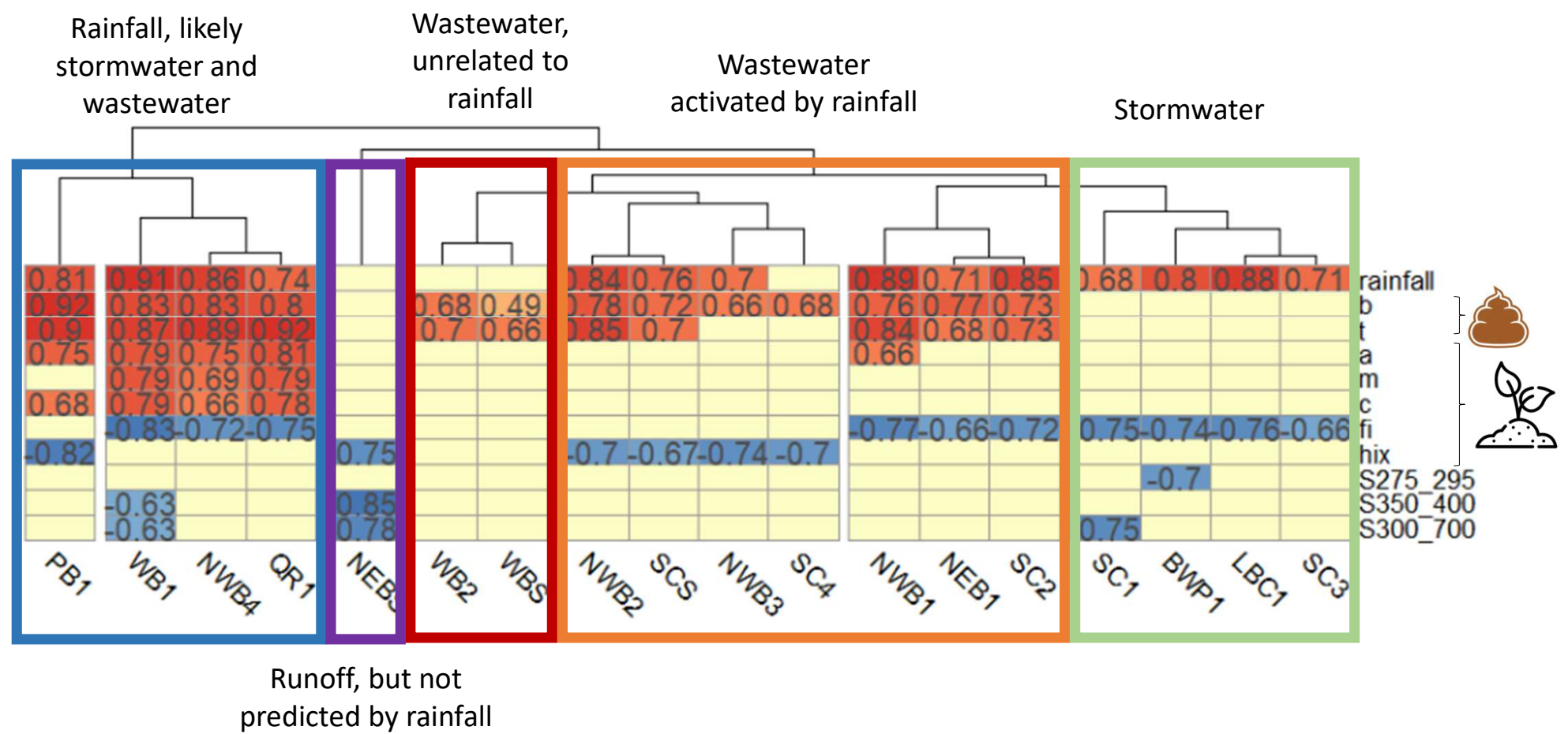
Wastewater proxies interact with flow at Sligo Creek



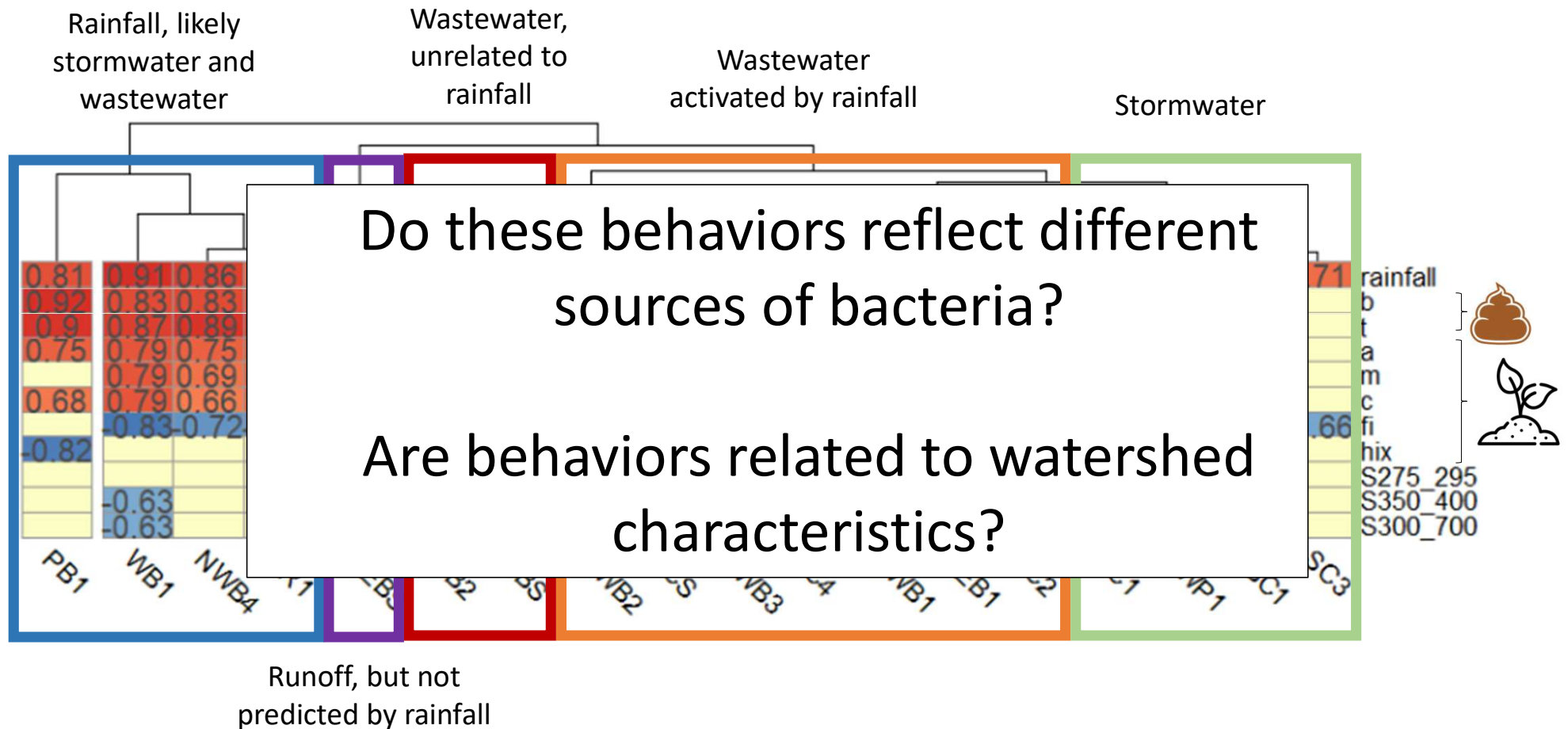
Goal: predictive models of *E. coli* for each site

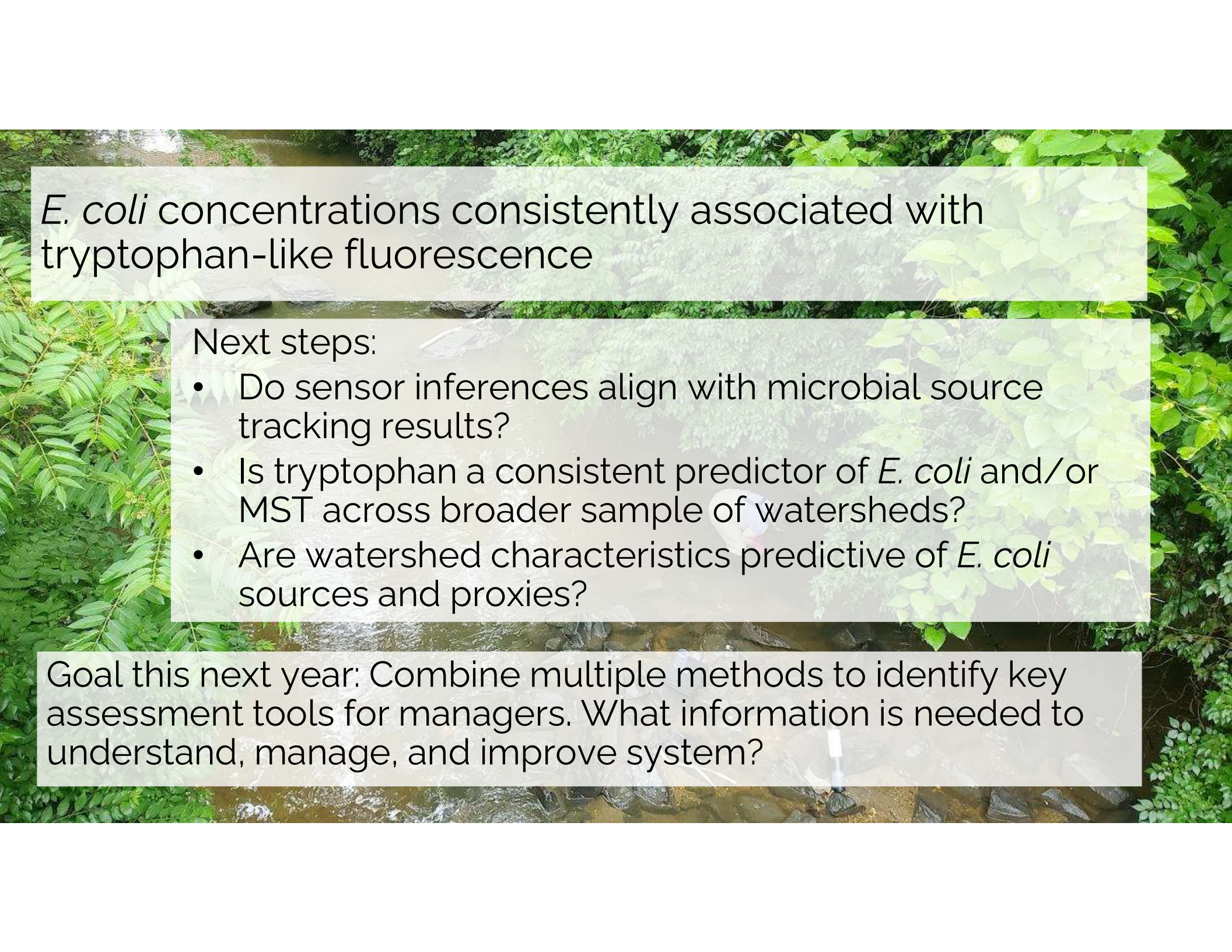


Controls on *E. coli* vary but there are general patterns



Controls on *E. coli* vary but there are general patterns





E. coli concentrations consistently associated with tryptophan-like fluorescence

Next steps:

- Do sensor inferences align with microbial source tracking results?
- Is tryptophan a consistent predictor of *E. coli* and/or MST across broader sample of watersheds?
- Are watershed characteristics predictive of *E. coli* sources and proxies?

Goal this next year: Combine multiple methods to identify key assessment tools for managers. What information is needed to understand, manage, and improve system?

Funding & Acknowledgments

This research was funded through the Pooled Monitoring Initiative (PMI), Restoration Research Program.

Award #23852 | Smithsonian Institution | 2025-2027

The Pooled Monitoring Initiative funds applied science to advance restoration research for cumulative impacts, comparative effectiveness of stormwater practices, pollutants of emerging concern, and trade-offs with new research questions added annually.



WEBSITE: <https://cbtrust.org/grants/restoration-research/>



Translation

What are the take home points?
What does this mean for me?

Translation Slides by Morgan Corey
Maryland DNR, Watershed and Climate Services

What does this mean for me?

- *E. coli* levels vary across Anacostia watersheds, making it hard for community members to anticipate safe conditions to fish, wade, and paddle
- Contamination comes from different sources with higher *E. coli* levels in populated areas pointing to human & pet waste as a major pollution source
- No one size fits all approach → Site-specific solutions based on the source of pollution
- Make it easy for residents to check WQ status & share risks
- Better anticipating wastewater pollution is needed to understand sources of pollutants and reduce bacteria levels in the Anacostia watershed
- Repairing old infrastructure is key to prevent urban wastewater pollution

What does this mean for me?

What do I take from this if I am a practitioner:

- Contamination of streams comes from different sources in the Anacostia
- Solutions must be site-specific
- This research informs how to monitor WQ & estimate costs to monitor (e.g. install sensors for WQ information, use trypto & CDOM as indicators)

What do I take from this if I am a regulator:

- Human wastewater is a major stressor in highly populated areas
- Target sites with high *E. coli* levels (Watts Branch) for the most impact
- Better anticipating typical wastewater pollution sources is needed to reduce bacterial contamination in highly impacted urban streams

A photograph of a rocky stream flowing through a dense forest. The water is dark and reflects the surrounding greenery. The streambed is covered with numerous grey and brown rocks of various sizes. The banks are lined with lush green trees and bushes, creating a dense canopy. The overall scene is serene and natural.

Thank you!

Questions?

Synthesizing Restoration Research to Inform Chesapeake Bay Decision-Making Pooled Monitoring Forum

Chesapeake Bay Trust Award #26574

Thursday, June 18, 2026



Presentation Overview

1. Project Context and Goals
2. Project Approach and What We Heard
3. Science Synthesis and Review Process
4. Product Suite Overview
5. Demo of Products
6. Next Steps

Our Team



Dr. Seth Theuerkauf
(Project Lead)

- Marine ecologist bridging science, policy & restoration (18+ yrs)
- Former NOAA and TNC scientist, Federal regulator
- *Leading science synthesis component of project*



Aaron Kornbluth

- 20+ yrs advancing marine policy & science communication
- Former Pew Oceans Senior Officer; co-created SOAR oyster restoration program
- *Leading communications product and policy connectivity*

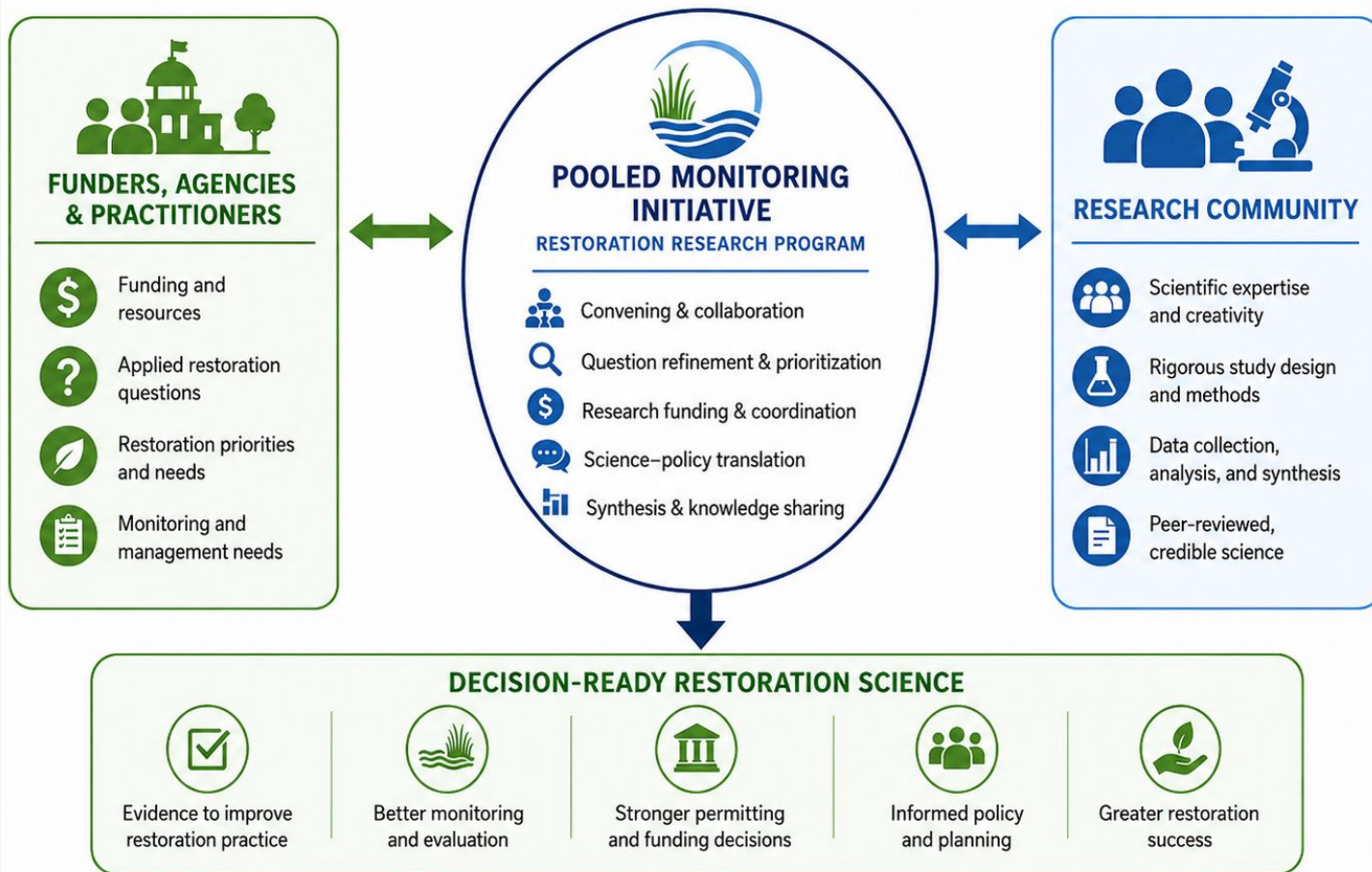


Andy Lacatell

- 35+ yrs leading Bay conservation & restoration initiatives
- Former TNC Chesapeake Bay Director; led world's largest oyster reef restoration
- *Supporting stakeholder engagement*

How the Pooled Monitoring Initiative Works

Turning restoration questions and resources into credible science for better decisions



Breadth of Science Supported

- **Stream Restoration** - 18 studies; 1,747 pages
- **Stormwater BMP Efficiency** - 13 studies; 850 pages
- **Pollutants of Emerging Concern (i.e., PCBs, salt, thermal, bacteria)** - 8 studies; 435 pages
- **Monitoring and Data Optimization** - 6 studies; 36 pages
- **Restoration Tradeoffs and Cross-Functional Benefits** - 15 studies; 320 pages

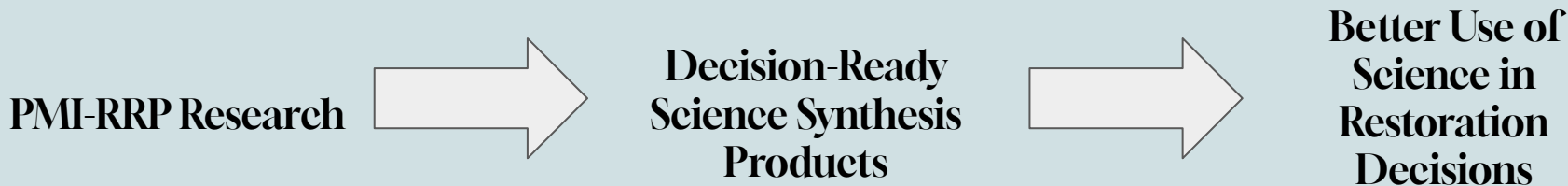
But breadth alone does not guarantee impact...

- Research findings are dispersed across many standalone studies
- Busy decision-makers need clear takeaways, not hundreds of pages of source material
- Results are not always organized around practical decision points
- *Without translation, valuable science can remain underused*

Project Objectives:

Turning Science into Usable Guidance

- **Synthesize** key findings, uncertainties, and practical implications across PMI–RRP studies
- **Translate** technical research into clear, decision-relevant guidance
- **Organize findings** around user needs and real-world restoration decisions
- **Develop accessible products** for practitioners, funders, regulators, and local governments
- **Increase the impact of PMI–RRP science** by supporting use in planning, funding, permitting, monitoring, and communication



Project Approach

1. Needs Assessment – Stakeholder Interviews + Survey

- a. 15 interviews and 28 survey responses to identify information needs, preferred formats, and decision contexts

2. Policy Landscape Analysis

- a. Reviewed the broader Bay restoration landscape to align products with real-world decisions and implementation needs

3. Science Synthesis

- a. Synthesized findings across five thematic areas using a reproducible AI-assisted workflow, expert review, and peer review

4. Product Development

- a. Developed five (5) synthesis briefing documents, three (3) interactive two-pagers, a social media toolkit, and a learning session package

What We Heard:

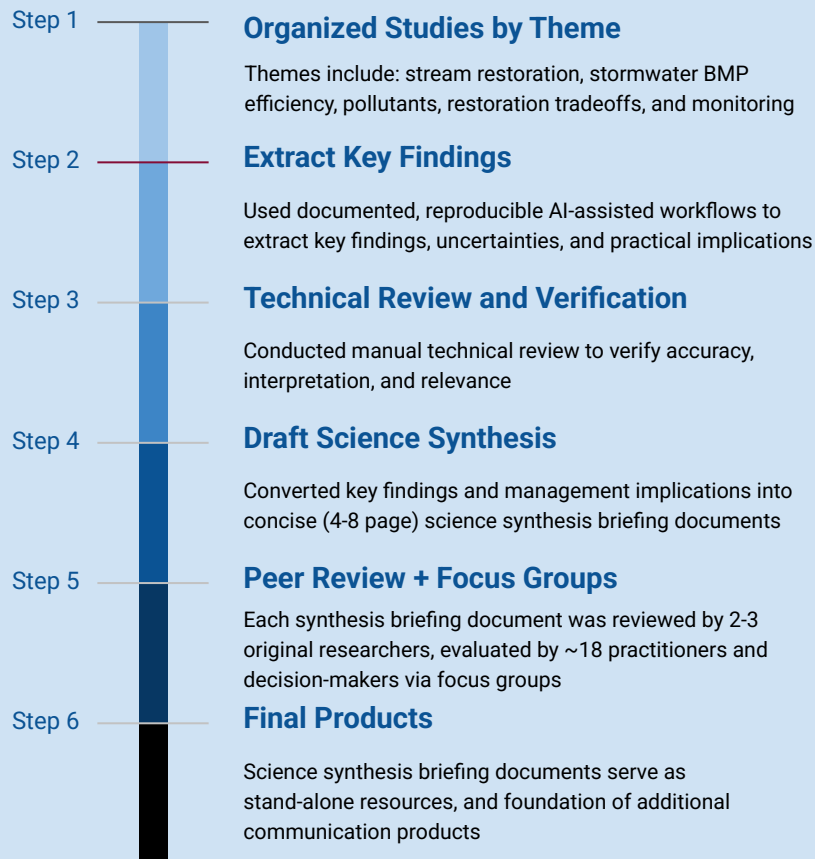
Users Need Concise, Actionable Products

Key Findings:

- a. **Information overload is a major barrier:** stakeholders need short, clear products, not long technical reports
- b. **Brevity matters:** 64% of survey respondents preferred 1–2 page fact sheets
- c. **Decision relevance is critical:** users want findings connected to restoration planning, funding, permitting, monitoring, and implementation
- d. **Success stories and practical examples are needed:** stakeholders want evidence of what works and why
- e. **Different audiences need different formats:** practitioners, regulators, funders, and policymakers require different levels of detail

Implication for this project: *Products needed to be concise, credible, audience-specific, and oriented around real-world decisions.*

Science Synthesis and Review Process



Product Suite Overview

Product Type	Primary Use
Science synthesis briefing documents (<i>PDF, 4-9 pages</i>) <i>Stream restoration; stormwater BMP efficiency; pollutants of emerging concern; restoration tradeoffs; monitoring and data optimization</i>	Technical grounding and decision support
Interactive two-pagers (<i>web-based</i>) <i>Stream restoration; stormwater BMP efficiency; salt management</i>	Accessible, web-based communication
Social media toolkit (<i>web-based</i>)	Outreach and awareness
Learning session package (<i>web-based</i>)	State-of-the-science knowledge transfer and facilitated discussion

Goal: *Make existing science easier to find, easier to understand, and easier to apply.*

Science Synthesis Briefing Documents

Stream Restoration Science: Actionable Lessons from a Decade of Pooled Monitoring Initiative Research in the Chesapeake Bay Watershed

Prepared by: Thriving Coasts Consulting

Lead Author: Dr. Seth Theuerkauf

Background

Stream restoration has become a core tool in watershed management across the Chesapeake Bay region and beyond to combat erosion, nutrient loading, and habitat degradation.

In practice, stream restoration encompasses a range of interventions, including channel reconfiguration, floodplain reconnection, legacy sediment removal, installation of in-stream structures, riparian vegetation management, and construction of regenerative stormwater

How to Use This Synthesis

This synthesis summarizes key findings from research supported through PMI-RRP. It is intended to help practitioners, regulators, funders, local governments, and restoration partners more easily apply regionally relevant science to planning, design, permitting, monitoring, and adaptive management decisions.

The findings presented here are not intended to serve as a comprehensive review of all published literature on this topic. Rather, this document distills the major findings, uncertainties, and management implications from this focused body of Chesapeake Bay watershed research developed to address practical restoration and stormwater management questions. Where relevant, individual studies referenced in this synthesis may draw upon or synthesize broader scientific literature, but the primary purpose of this document is to translate PMI-RRP-supported research into accessible, decision-relevant guidance.

1. Stream Restoration Effectiveness: What Works, Where, and Why

What PMI-RRP Science Shows

Stream restoration performance—across a range of restoration approaches—is highly context-dependent, producing variable nutrient and sediment reductions across watershed settings and restoration approaches. Multiple independent evaluations show that:

- **Nitrogen reductions are more consistently observed in headwater systems**, with the greatest reductions in annual total nitrogen (TN) loads and per-acre load reductions observed in smaller drainage areas with lower impervious cover, while larger lowland systems exhibit more variable and often weaker or less detectable load responses (Filoso 2020). However, restoring larger channels and longer reaches can increase **absolute** nitrate removal (Hester & Scott 2024), but monitoring studies indicate that smaller headwater streams are often more responsive and can achieve higher **relative** removal efficiency. These findings highlight tradeoffs among project scale, cost, feasibility, and biological disturbance, particularly as larger watersheds require greater restoration extent to achieve comparable treatment effectiveness.

Management Implications

For managers seeking nutrient reductions, available evidence indicates that restoration effectiveness is strongly influenced by watershed context, including stream order, impervious cover, and catchment size. Empirical and modeling studies show differing patterns of effectiveness across the channel network, with some studies indicating greater relative responsiveness in headwater systems, while others suggest larger downstream channels may yield greater cumulative benefits. These findings highlight that restoration outcomes are highly site-specific and dependent on watershed context (Filoso 2020; Hester & Scott 2024).

Interactive Communication Products



Science-Based Guidance for Salt Management

Lessons from the Pooled Monitoring Initiative's Restoration Research Program on Pollutants of Emerging Concern

📅 November 2025

📄 Export PDF

↔ Share

Pooled Monitoring Initiative
Science-Based Restoration

i About This Resource

🔗 How to Use This Page

- **Key Takeaways:** Quick actionable findings for resource managers working on salt management and pollutants of emerging concern
- **Implementation Guidance:** Detailed recommendations organized by topic area
- **Copy Button:** Click to copy any takeaway with full references
- **Share:** Use the share button above to distribute via email or social media
- **Export PDF:** Print or save as PDF for offline reference
- **Terms:** Hover over underlined terms for definitions

🔗 About the Pooled Monitoring Initiative

The Chesapeake Bay Trust's **Pooled Monitoring Initiative – Restoration Research Program (PMI-RRP)** was established to address scientific uncertainties around restoration effectiveness by funding targeted, policy-relevant research.



KEY TAKEAWAYS FOR RESOURCE MANAGERS



Reduce chloride loads at the source first

References: **2**  Copy

All common deicers mobilize contaminant "cocktails," but NaCl is the strongest driver of copper release and strongly mobilizes nutrient release—mobilizing an order of magnitude more Cu and significantly more dissolved nitrogen (TDN) than CaCl_2 (though comparable to MgCl_2) at equivalent doses. Sodium ions displace ammonium and chloride displaces phosphate on soil exchange sites, promoting organic colloid dispersion and releasing nutrients and metals together. Prioritize cutting NaCl and substituting $\text{CaCl}_2/\text{MgCl}_2$ where safety allows.



Expect late-winter/spring water-quality risk windows

References: **1**  Copy

Following winter salt (NaCl) applications, thaw events produce transient increases in effluent loads (e.g., +61% phosphorus and copper, +88% zinc, +66% total suspended solids), indicating short-term reductions in treatment efficiency rather than net export, with annual removals still exceeding ~85%.



Design and maintain for nutrient and salt resilience

References: **5** **6**  Copy

Internal water-storage (IWS) zones and healthy, diverse vegetation sustain denitrification and nutrient uptake despite elevated salinity. Sites without IWS or with salt-damaged vegetation exhibit higher nutrient export. Routine maintenance—spring sediment cleanouts and replacement of salt-injured plants—helps maintain nutrient removal efficiency.



AI Assistant

POLICY & IMPLEMENTATION GUIDANCE FOR WINTER SALTING

1. Set clear chloride-reduction strategies

Adopt "safety first, salt last"

References:   Copy

Prioritize mechanical removal of snow, pre-wetting, and brine application over dry granular salt. Brines deliver less chloride per unit area, reducing nutrient mobilization from over-salting.

Preferentially trim NaCl

References:   Copy

Na^+ exchanges with NH_4^+ , Ca^{2+} , and Mg^{2+} , releasing N and P along with metals. Where temperature allows, consider $\text{CaCl}_2/\text{MgCl}_2$ or blended products, while tracking their dosages and secondary chemistry.

4. Monitor during events — then adapt

Deploy high-frequency SC and NO_3^- sensors, monitor nutrients

References:     Copy

Monitoring NO_3^- alongside SC provides early warnings of road-salt influence and nutrient surges. TDN and PO_4^{3-} can be monitored via laboratory measurements of stream grab samples.

Use SC plateaus as operational checkpoints

References:   Copy

Use SC plateaus ($\sim 1,000\text{--}2,000 \mu\text{S cm}^{-1}$) as operational checkpoints for salt load reduction mid-season.

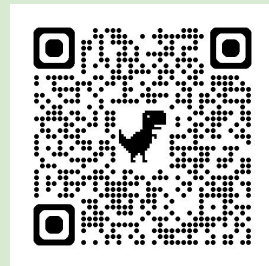
Checkpoint Range: $1,000\text{--}2,000 \mu\text{S/cm}$



AI Assistant

Next Steps

- **Syntheses and communication products available now on the PMI-RRP website!**
- Entering Phase II of this project, which centers on roll-out and supporting community uptake of the products.
- Future directions: (a) cross-walking syntheses with regulatory guidance, (b) expand scope of syntheses to include broader literature base, (c) develop additional communication products (e.g., shortform videos), and more!
- **Visit our table at the Forum - let's connect!**



seth@thrivingcoasts.com

Funding & Acknowledgements

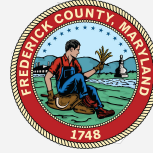
Thank you for your attention!

Visit our table at the Forum - let's connect!

This research was funded through the Pooled Monitoring Initiative (PMI), Restoration Research Program Award #26574 | Thriving Coasts Consulting, LLC | 2025-2026

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<https://cbtrust.org/grants/restoration-research/>



Maryland
Department of
the Environment



Bridging Science and Policy Translation Slides

What are the take home points?
What does this mean for me?

Translation Slides by Erik Michelsen, Anne Arundel County Department of
Public Works

What does this mean for me?

- The Trust has engaged experts in the field of science communication to provide digests of over a decade of information collected through the Pooled Monitoring Program to make it more accessible.
- Work products are focused on delivering brief, actionable findings, that can be incorporated into practice.

What does this mean for me?

What do I take from this as a practitioner?

- The syntheses on stream restoration, stormwater BMP efficiencies, and pollutants of emerging concern all offer insights into how to design and construct more effective restoration practices, and/or how to tailor them to achieve specific outcomes.

What do I take from this as a regulator?

- All work in regulated natural resources involves trade offs of one sort or another. These syntheses help bring to light both the potential benefits and drawbacks of restoration, depending on implementation characteristics such as location, approach, and practice.

What does this mean for me?

What do I take from this as a researcher?

- These syntheses provide a rich foundation of exploratory research ideas that could form the basis of future scientific work which more directly responds to some of the apparent trends or correlations identified in the initial work captured in these reports.