Stormwater Thermal Reduction Through Bioretention Media Layers

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

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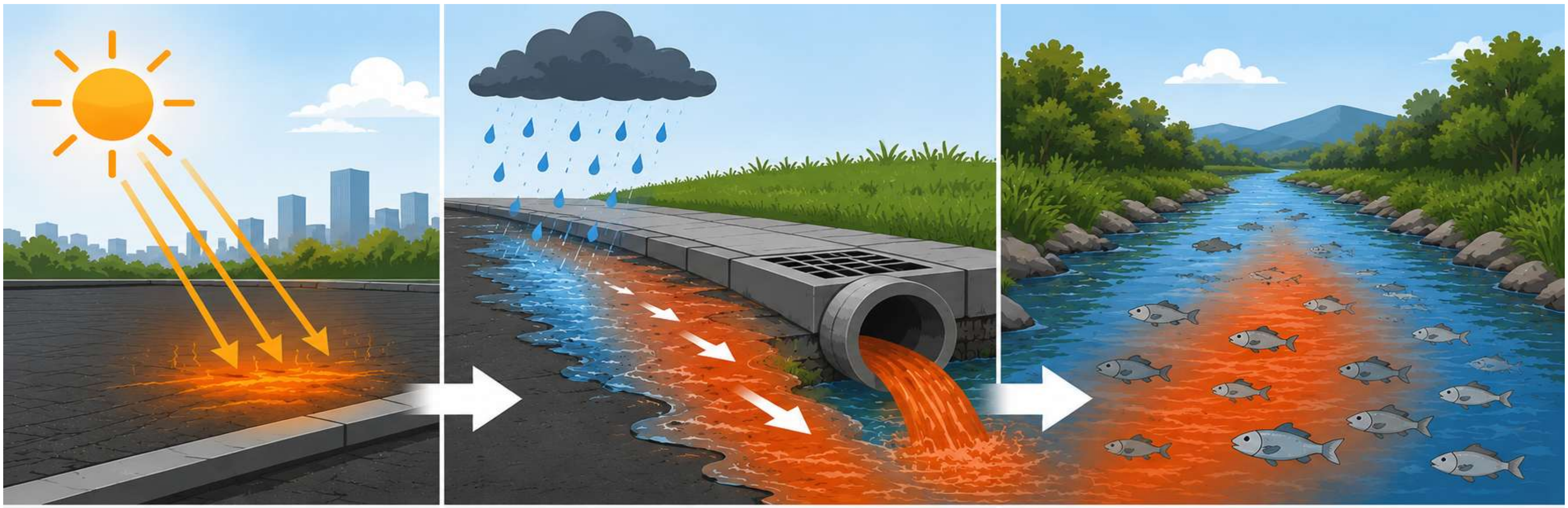
Stormwater Thermal Pollution — Why It Matters

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.

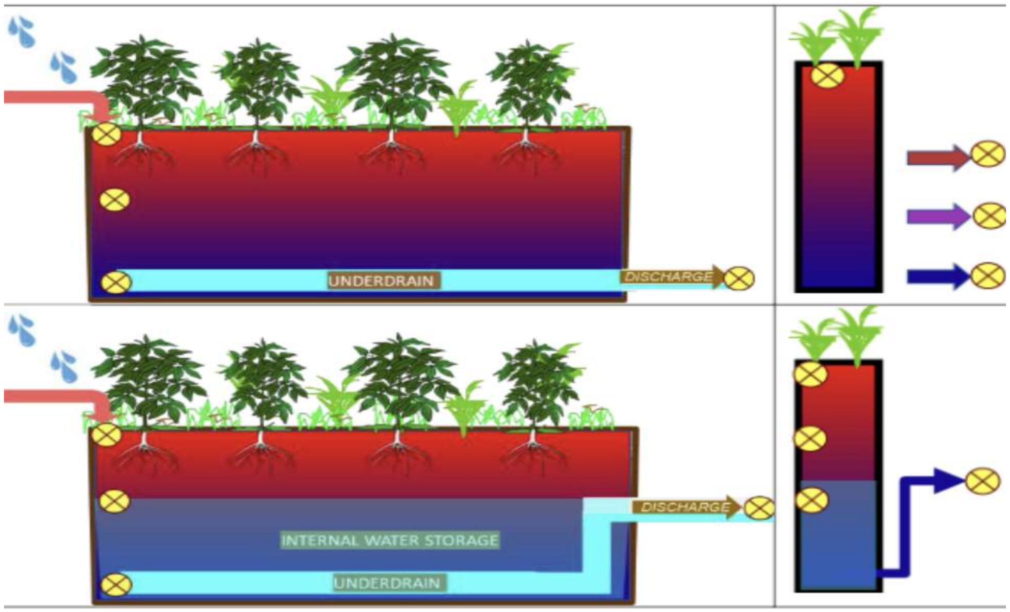
Research Questions and Hypotheses

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

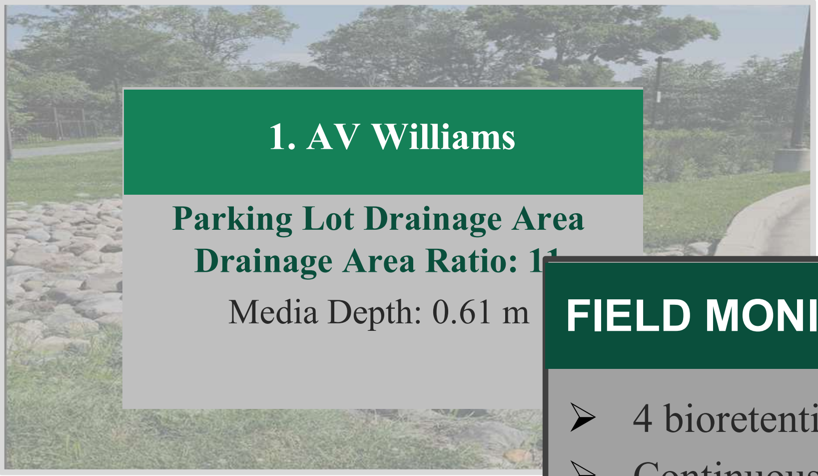
Deeper media and smaller **drainage area ratio** (DAR) = Greater cooling capacity.

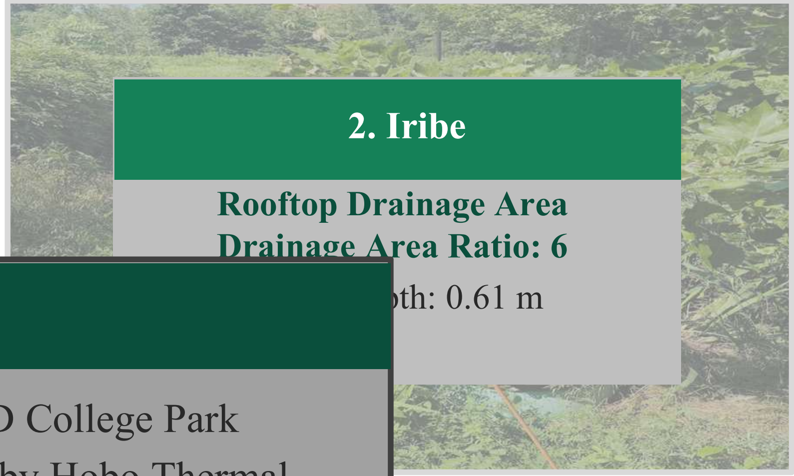
Temperature reduction changes with hydraulic retention time and is controlled by media particle size distribution.

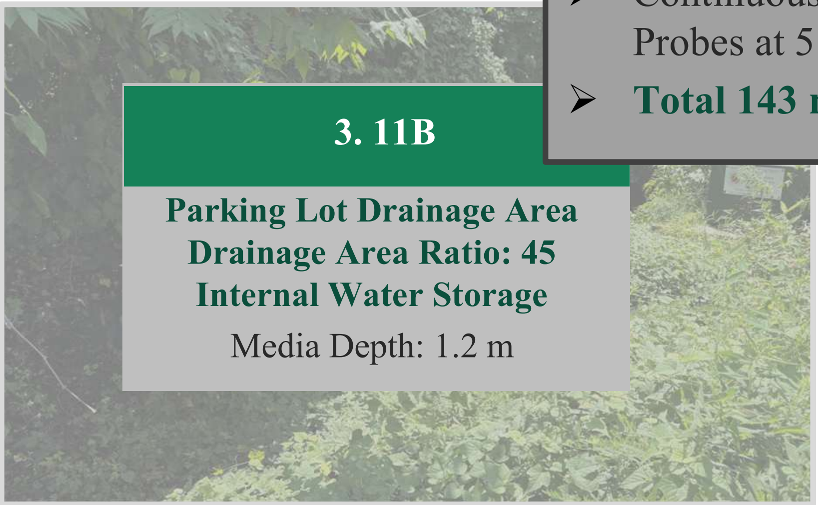
Internal water storage with cooler water boosts thermal reduction.

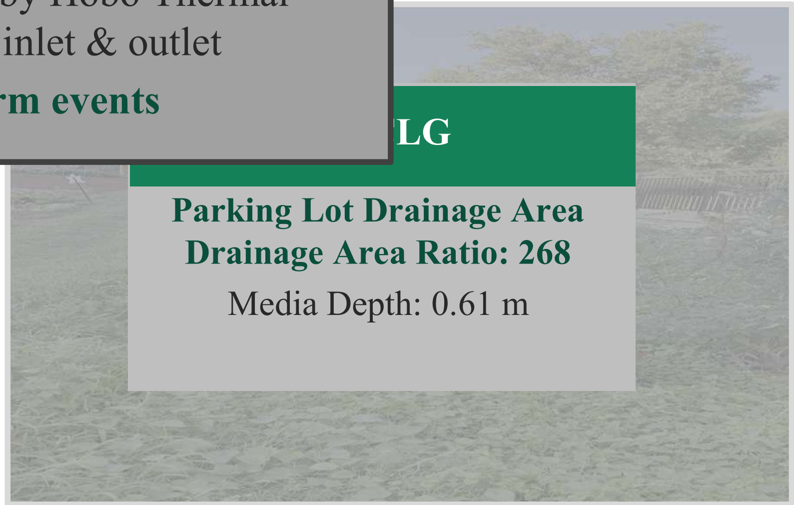


2025 Field Monitoring









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**

Performance Metric

EMT captures the overall thermal load delivered during a storm event

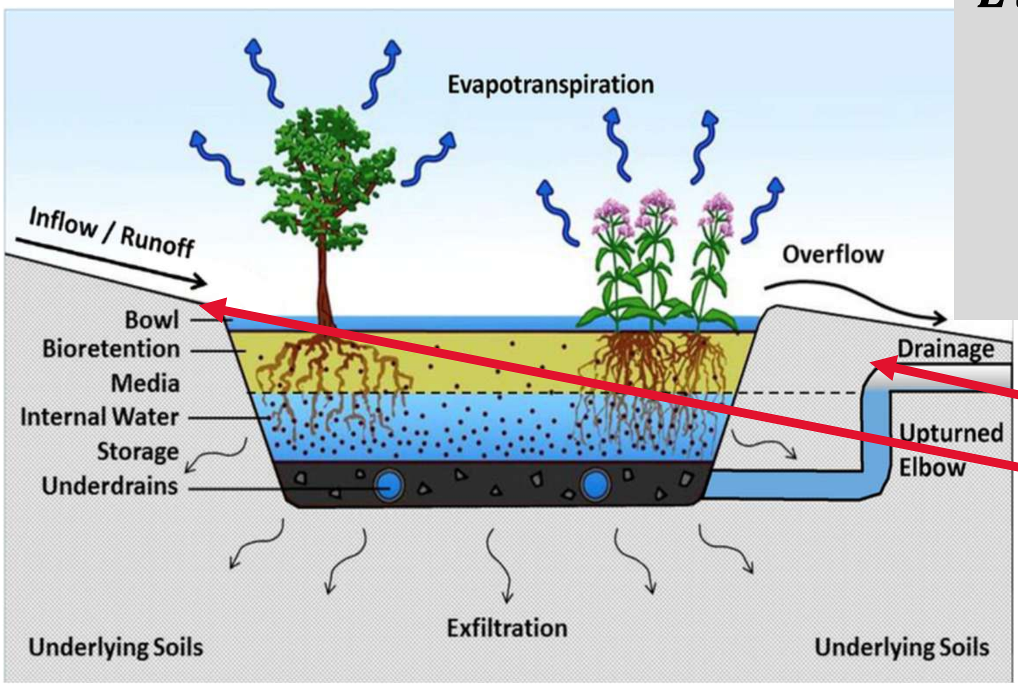
$$\textit{Event}\ \textbf{Mean Temperature} = \frac{\sum Ti \cdot Qi \cdot \Delta t}{\sum Qi \cdot \Delta t}$$

Here,

Ti = Temperature at time i (°C)

Qi = Flow rate at time i

Δt = Time step



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

ΔEMT = Inlet EMT − Outlet EMT

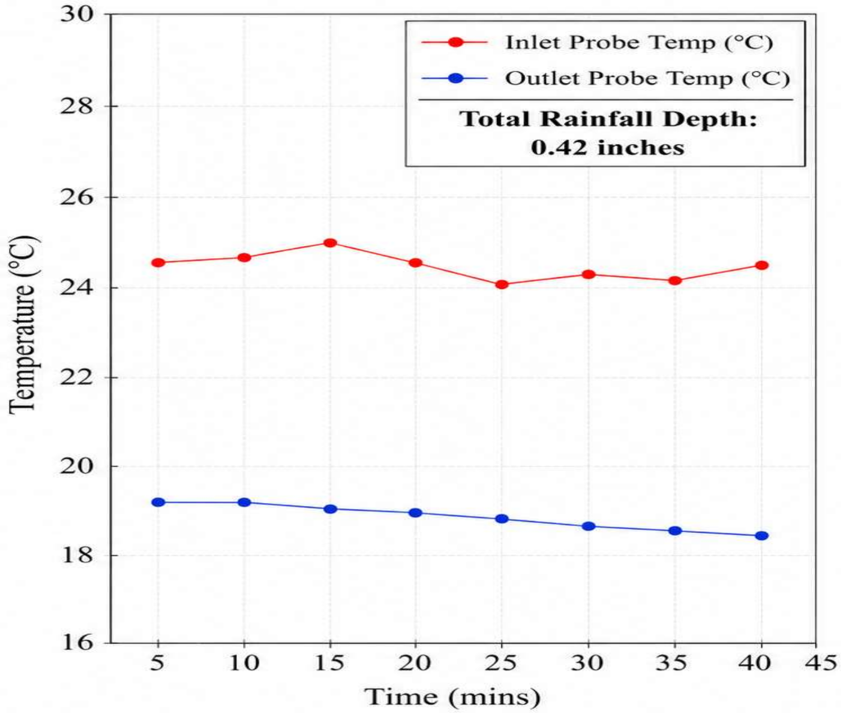
↑ Higher ΔEMT = Better cooling.

Field Storm Events — Inlet and Outlet Temperature vs. Time

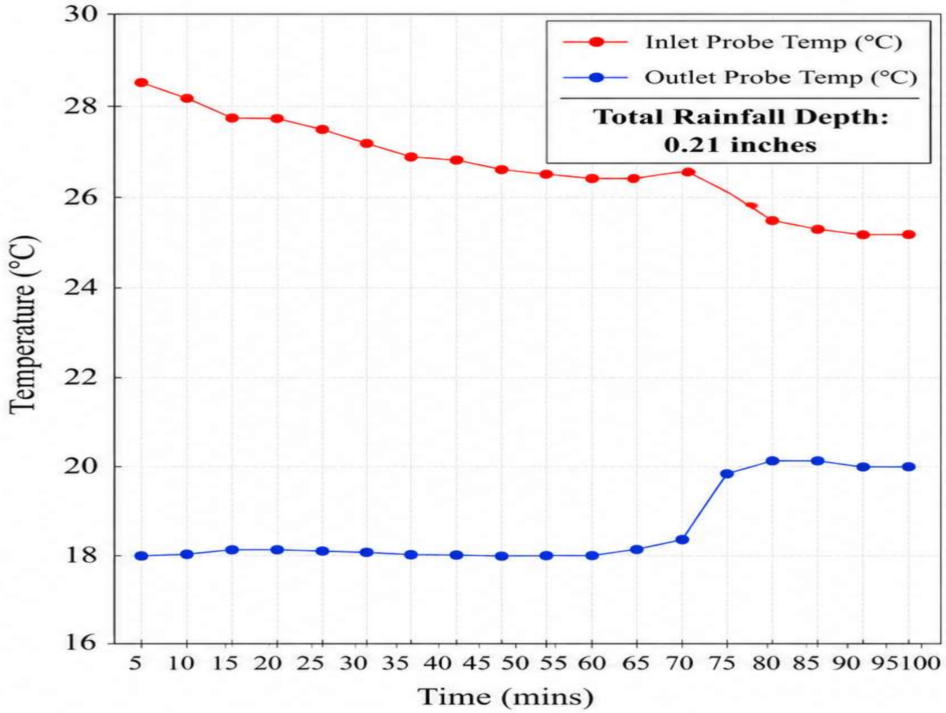
Outlet temperatures remained lower than inlet temperatures during both storm events.

Media Depth: 24 inches.

7th June 2025 Storm Event

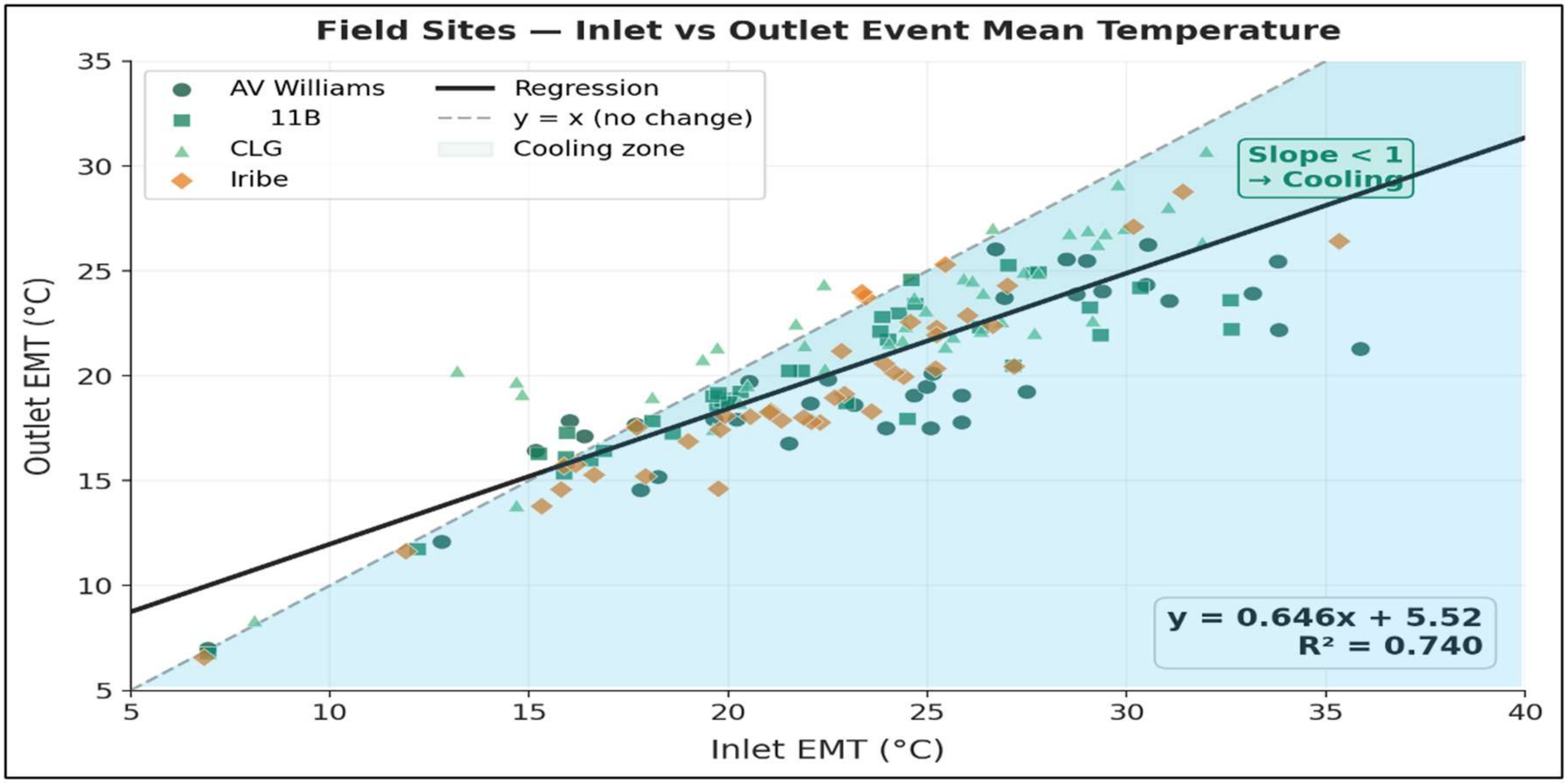


13th June 2025 Storm Event



Field Performance — Inlet vs. Outlet EMT

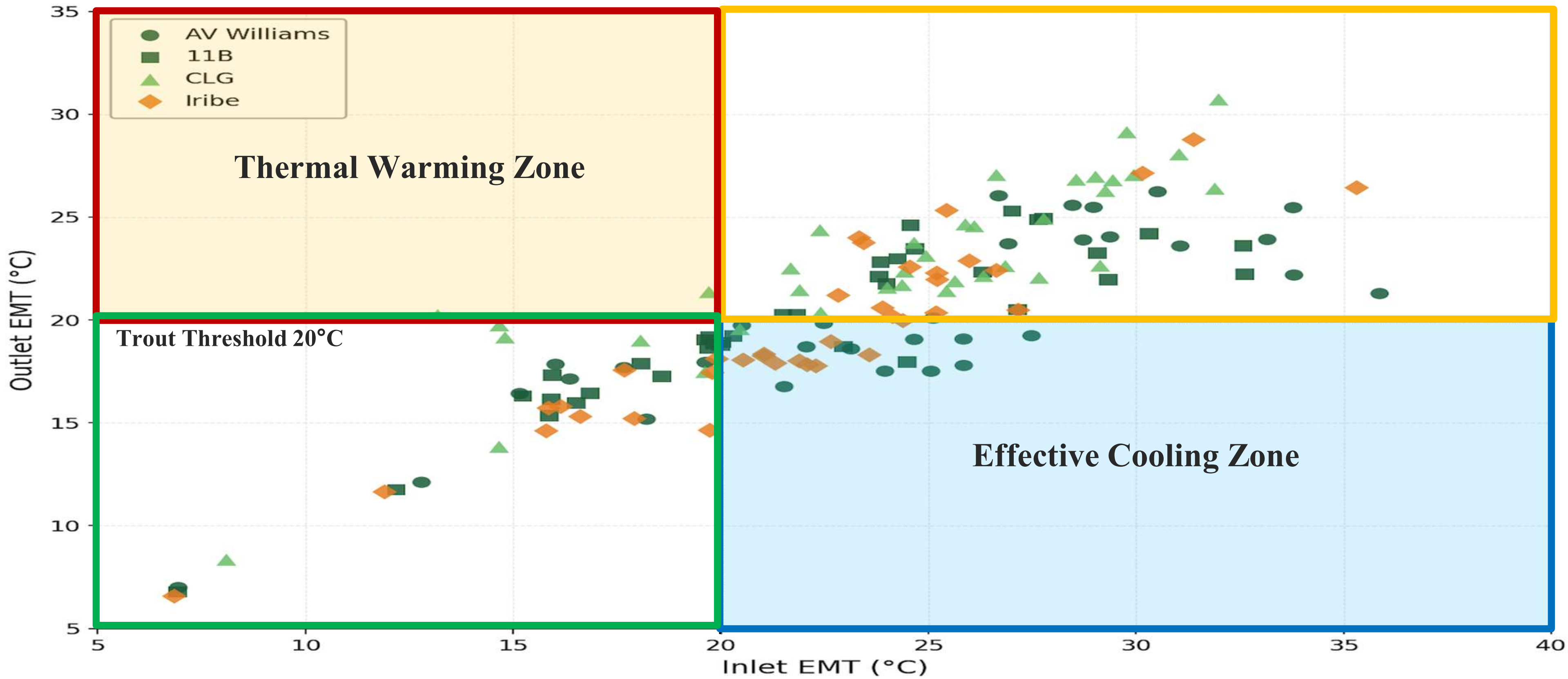
All sites show cooling across nearly all events



- **Slope < 1.0 → Bioretention reduces EMT**

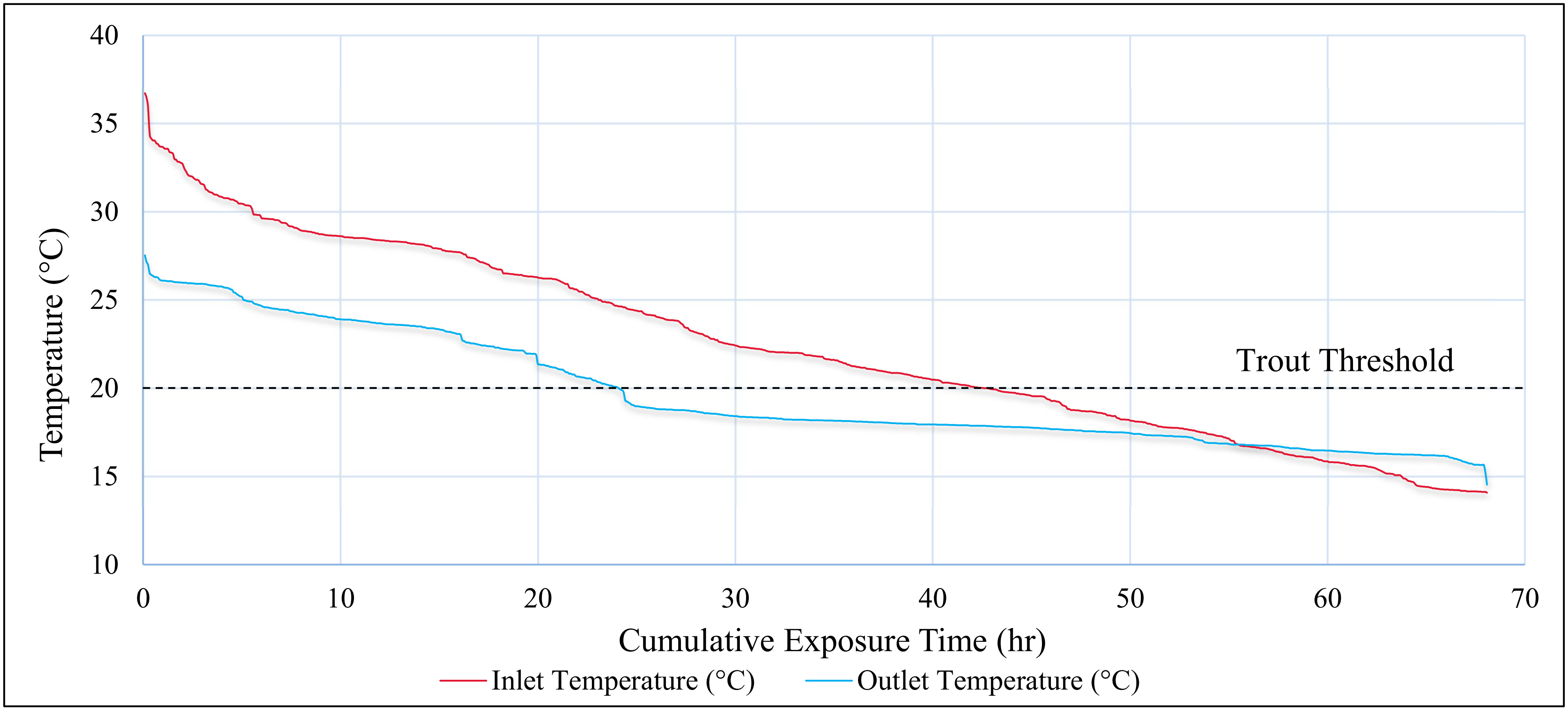
Thermal Performance Relative to the 20°C Trout Threshold

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



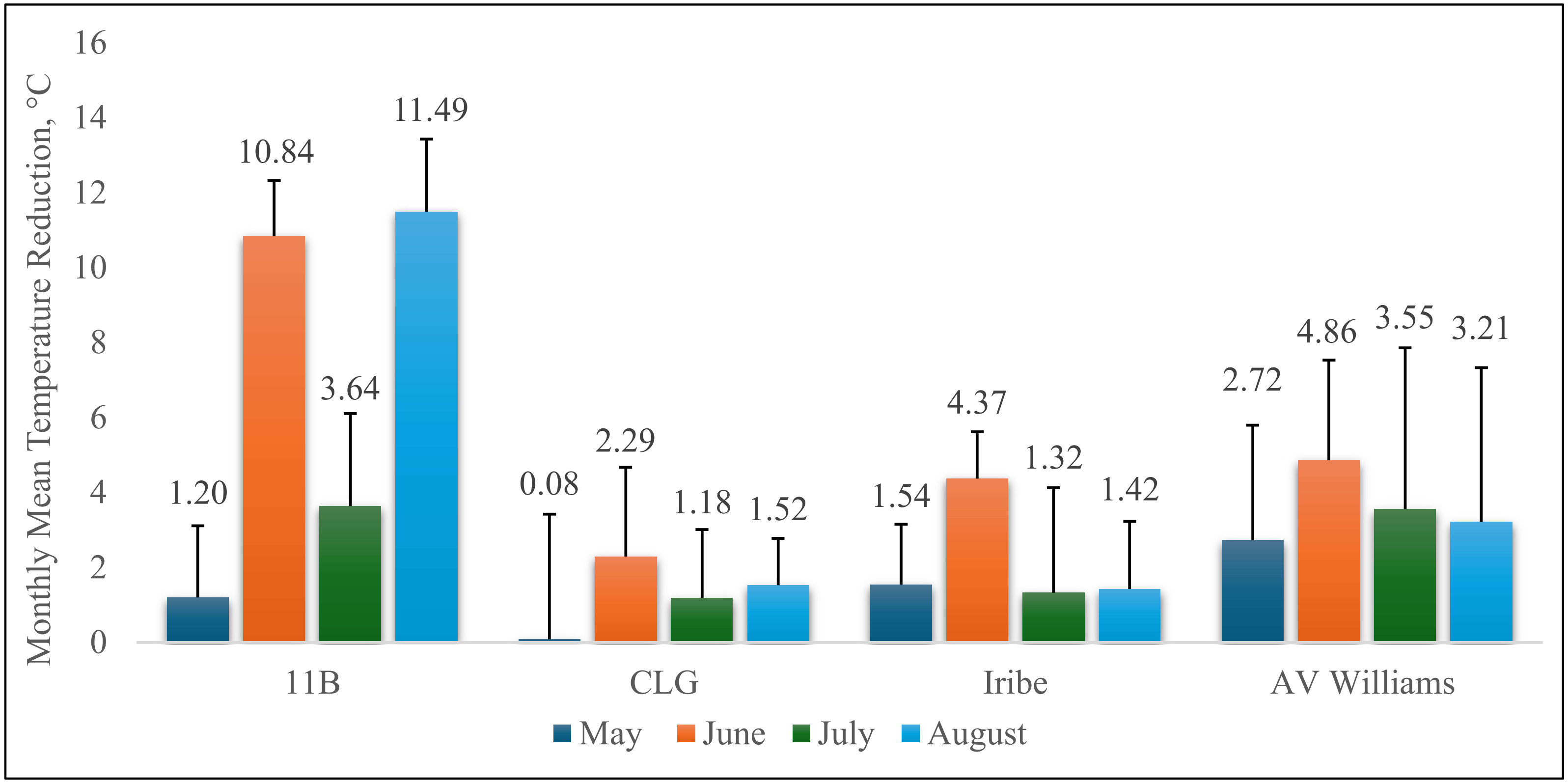
Field Performance — Temperature Duration Curve (AV Williams)

Bioretention reduced >20°C thermal exposure by ~18 hours



Field Performance — Seasonal Influence on Thermal Reduction

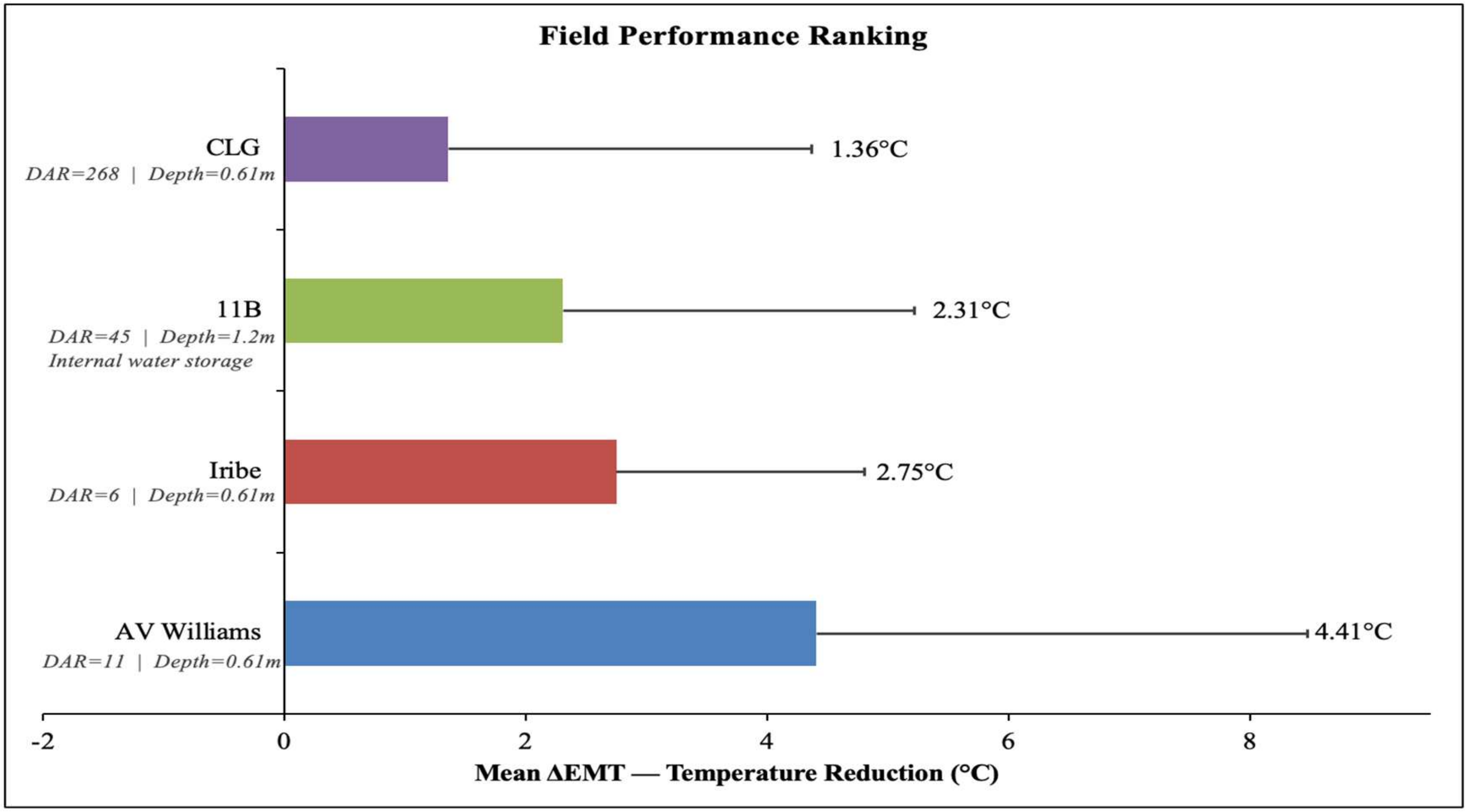
June - July = Highest Monthly Mean Temperature Reduction



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

Field Performance — Site Comparison by Mean ΔEMT

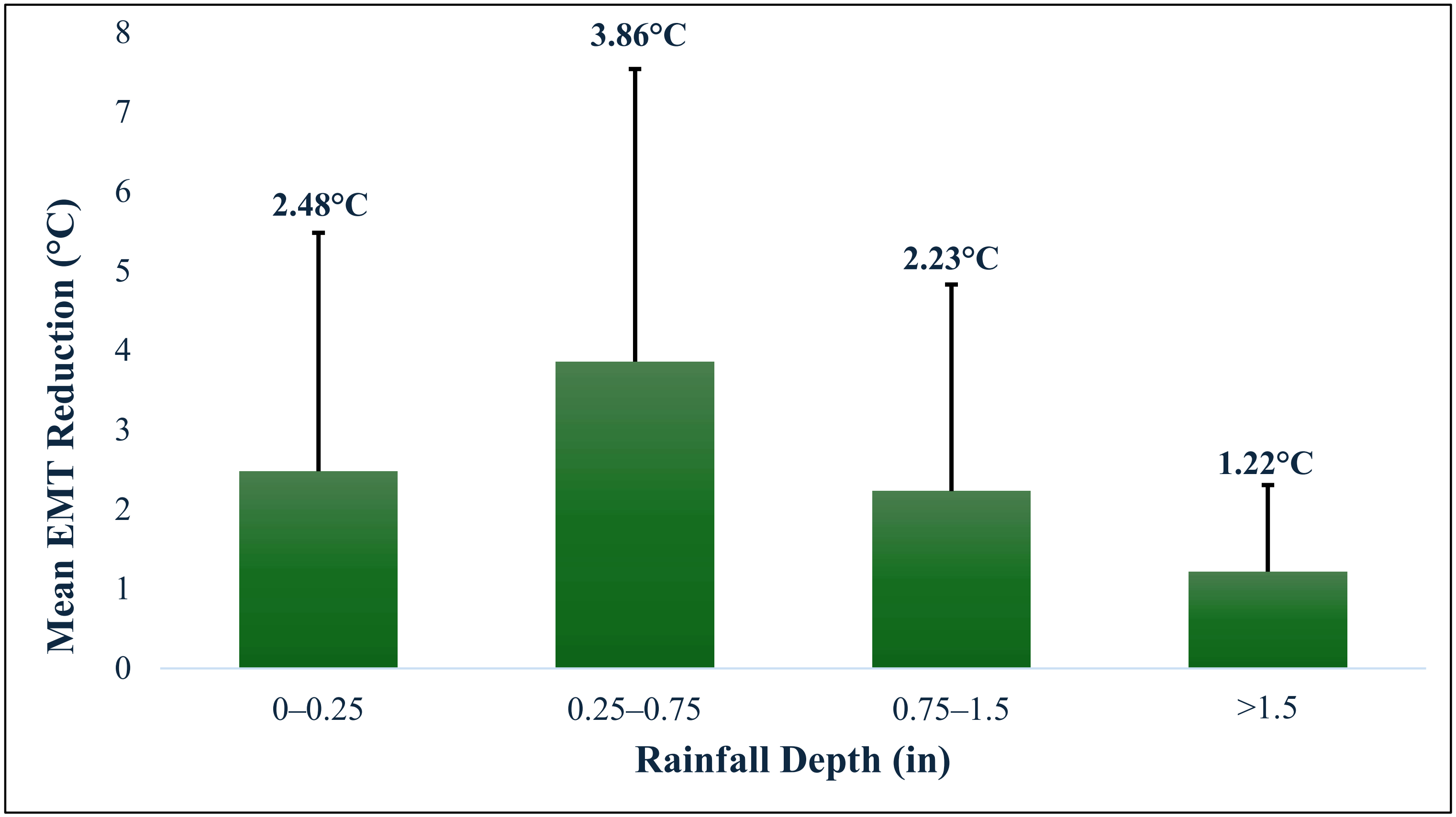
AV Williams (DAR = 10.6) shows highest cooling — CLG (DAR = 268) shows lowest cooling.



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

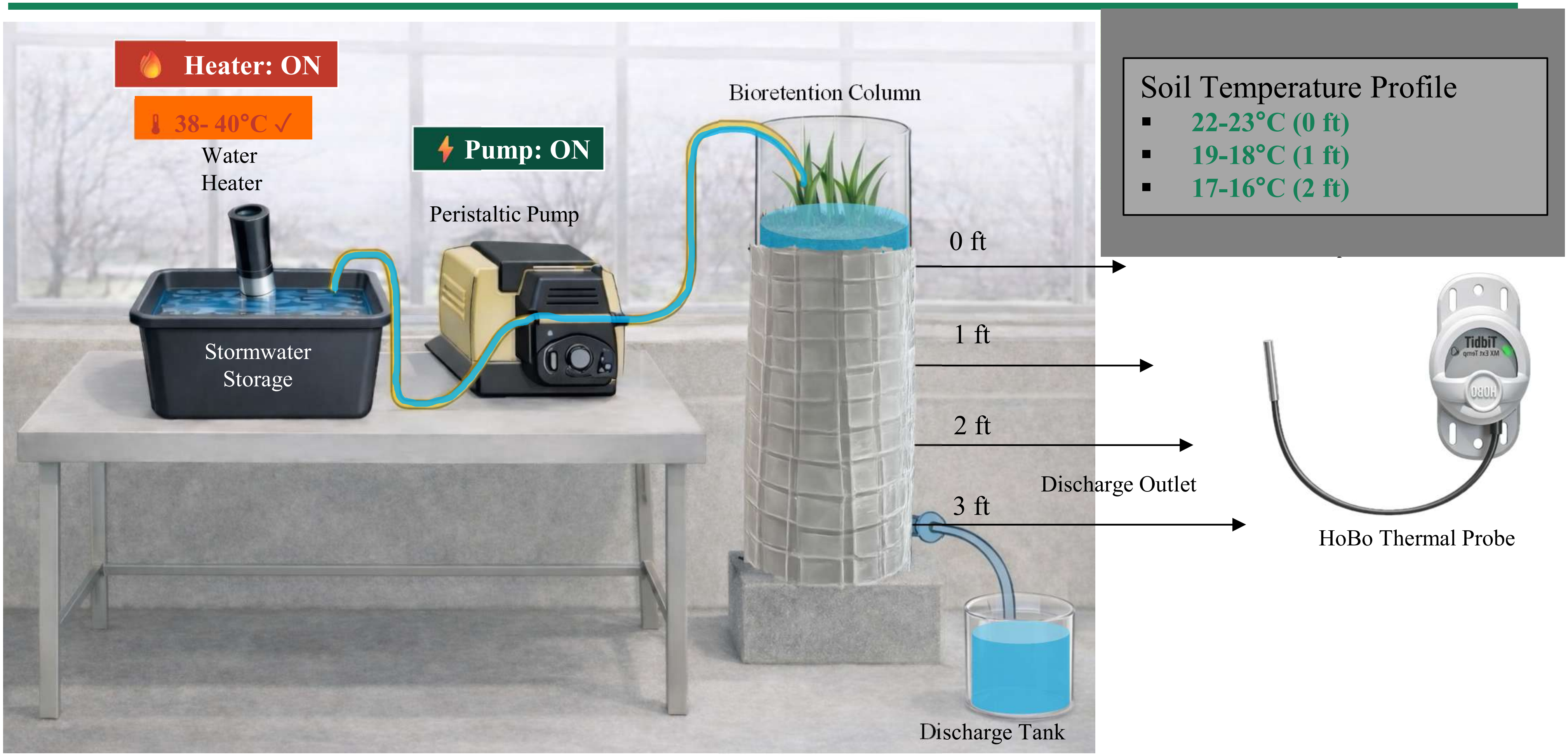
Field Results — EMT Reduction vs. Rainfall Depth

Moderate storms maximize cooling efficiency.



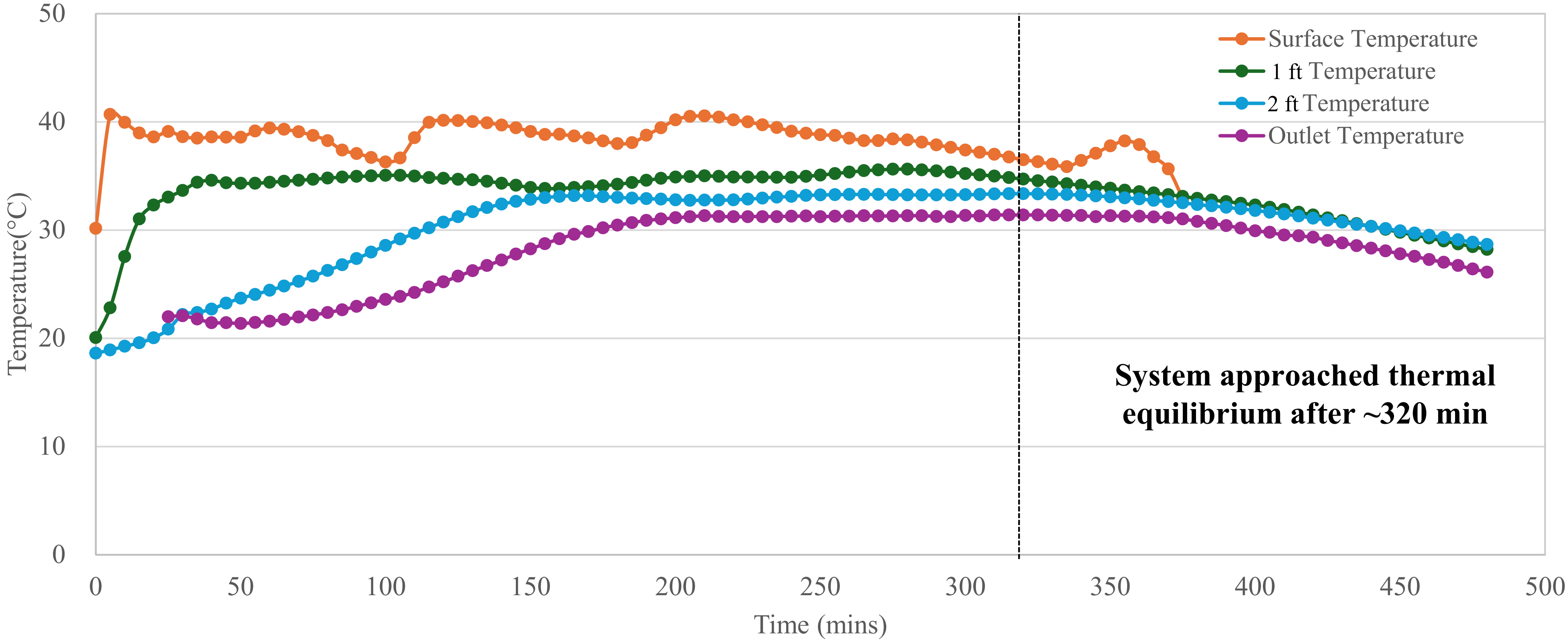
- **0.25–0.75 in storms → highest reduction (~3.86°C)**
- **Small & large storms → lower performance**

Bioretention Column — Experimental Setup



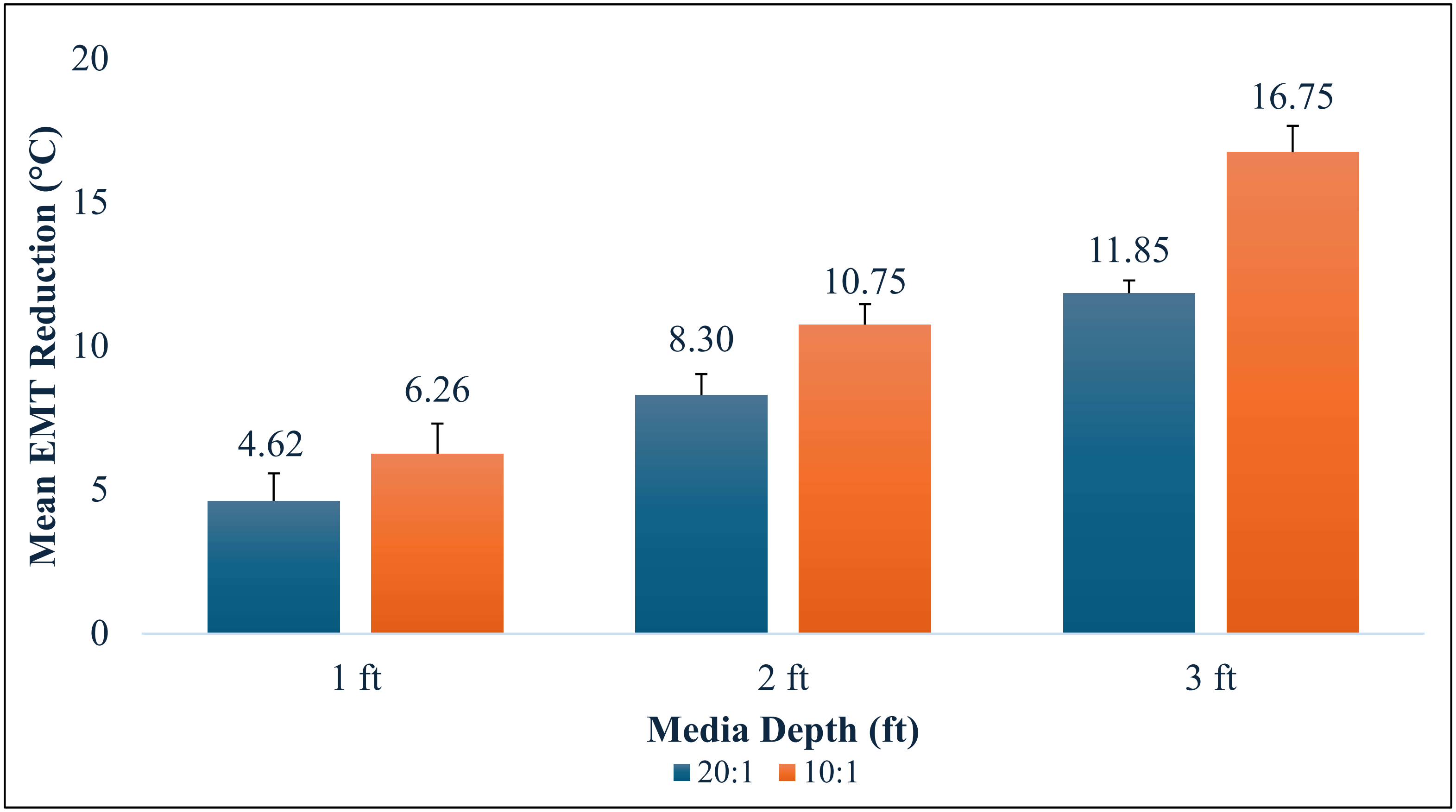
Column Test Results — Temperature vs. Time

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.



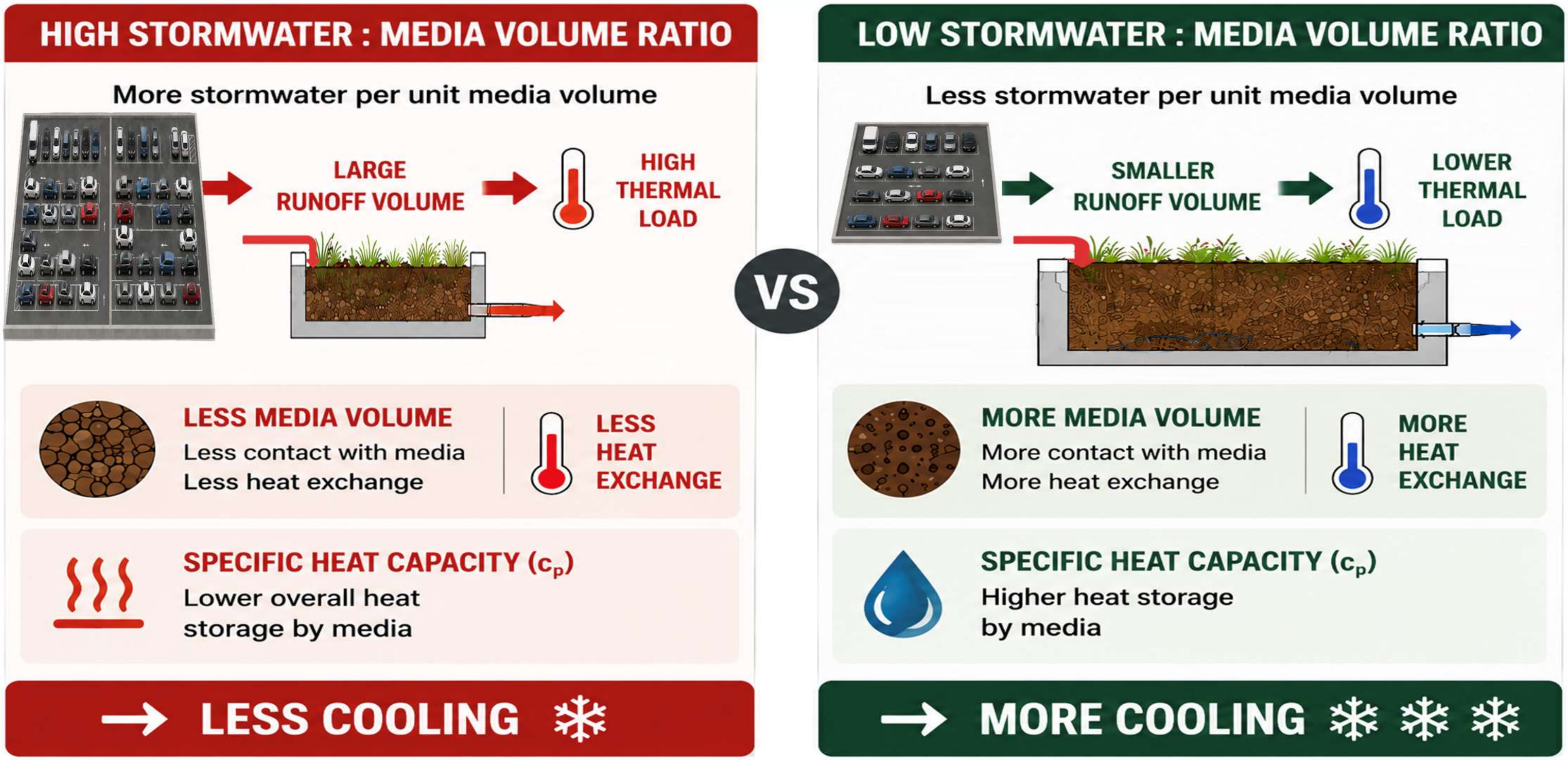
Based on 6 column tests:

➤ 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

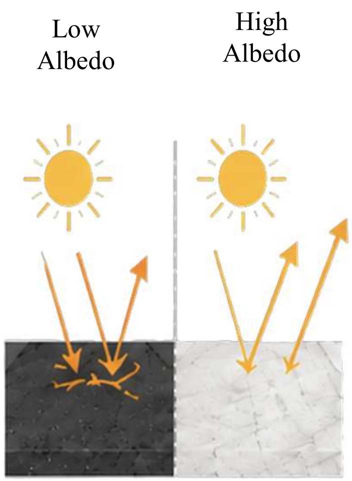
Scientific Basis of Thermal Reduction

More media volume per runoff volume = More cooling



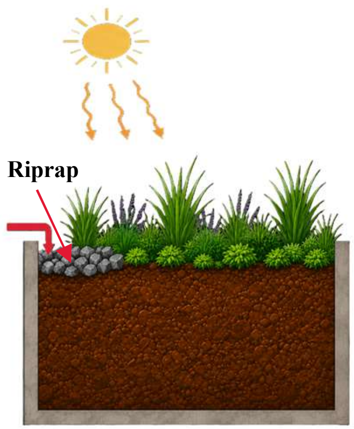
Design Recommendations For Thermal Reduction

1 Albedo



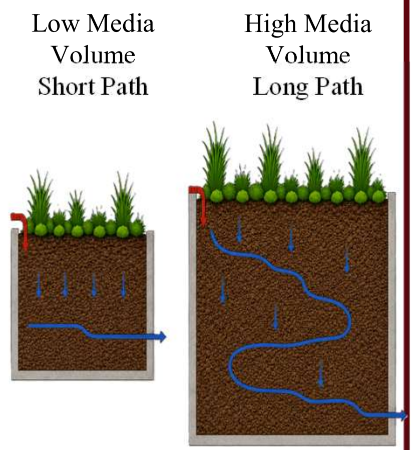
Applying high-albedo coatings reduces solar contact.

2 Vegetation & Shading



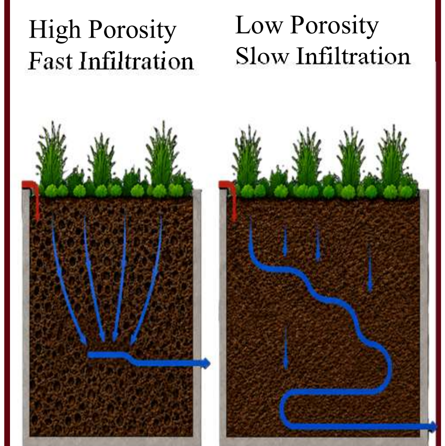
More vegetation and less riprap reduce solar contact and heat retention.

3 Stormwater: Media Ratio & Travel Path



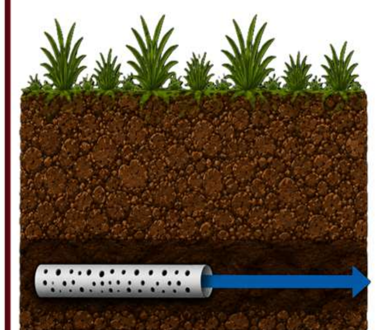
Larger volumes increase water-media contact time

4 Porosity & 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

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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.

Translation

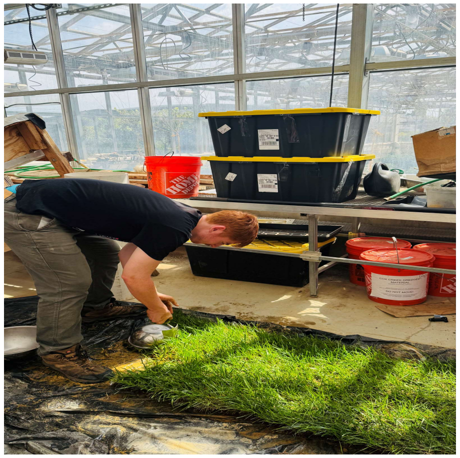
Don Dorsey, Frederick Co.

- 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