THE OHIO STATE UNIVERSITY

Bioretention Cell Performance, Construction, and Maintenance

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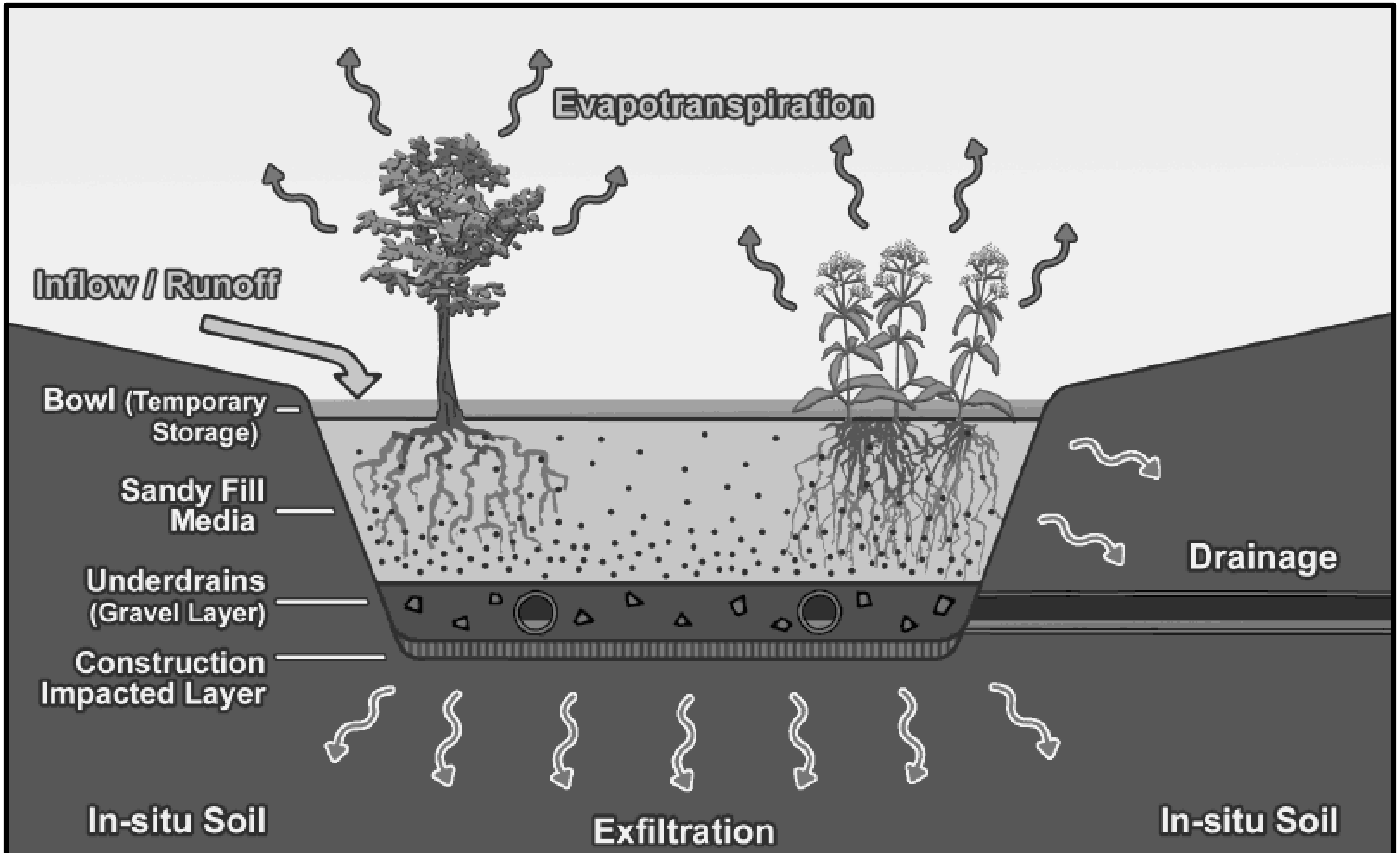
South Africa Workshop Series

Bioretention Typical Cross-Section

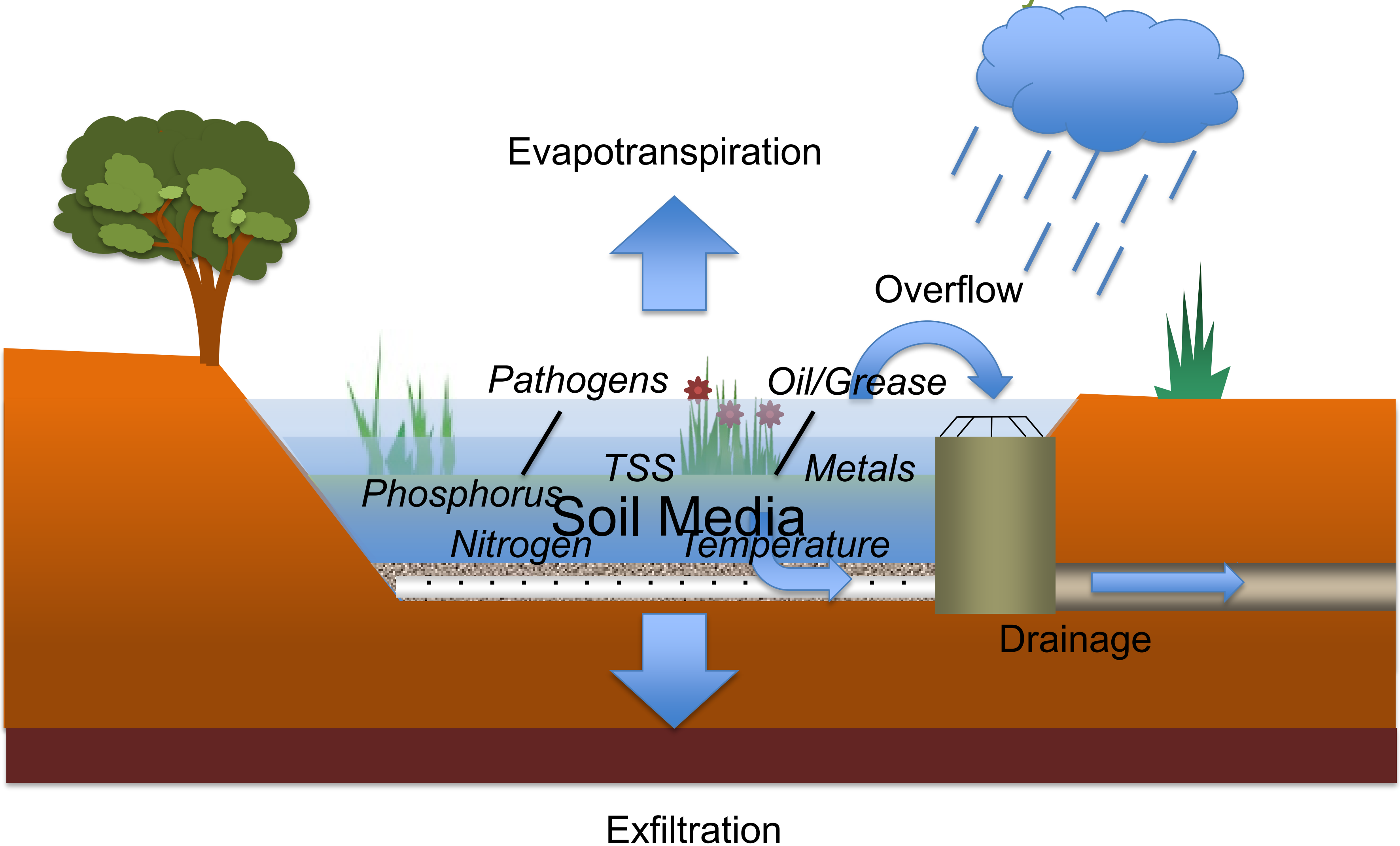


Bioretention Provides…

- Runoff volume reduction through exfiltration (groundwater recharge) and evapotranspiration
- Slow release of treated water through the underdrain
- Water quality improvement through filtration, sedimentation, adsorption, and plant and microbial processes
- Green space and ecological benefits

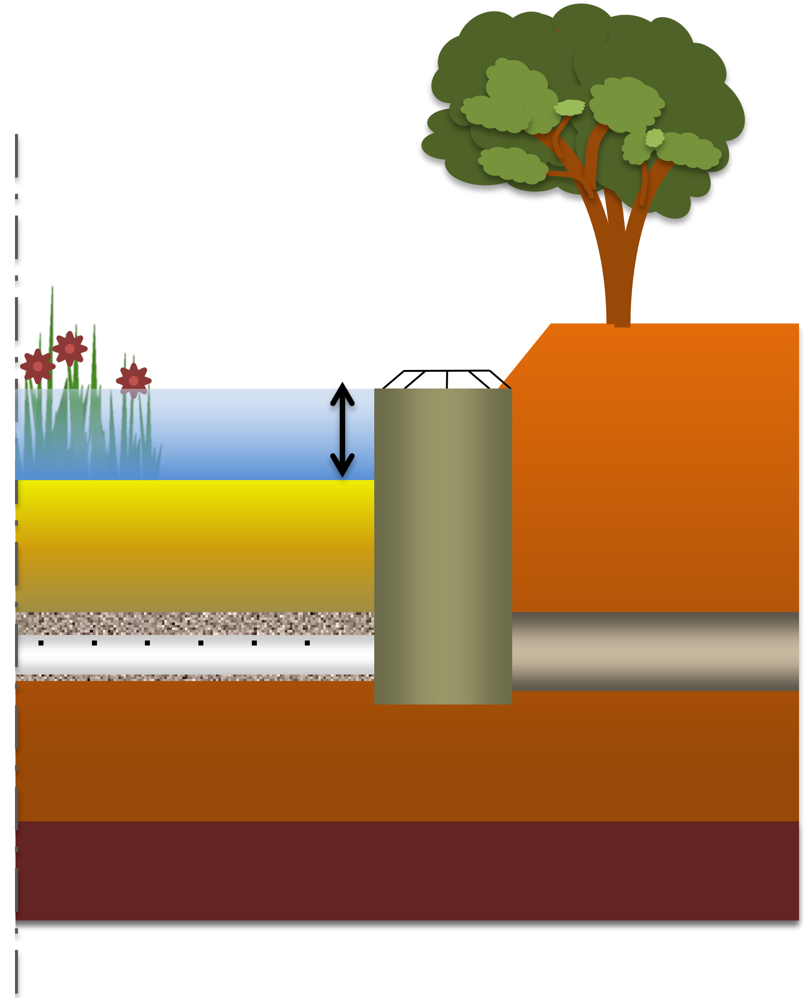
How Bioretention *Should* Work

*If built & maintained correctly

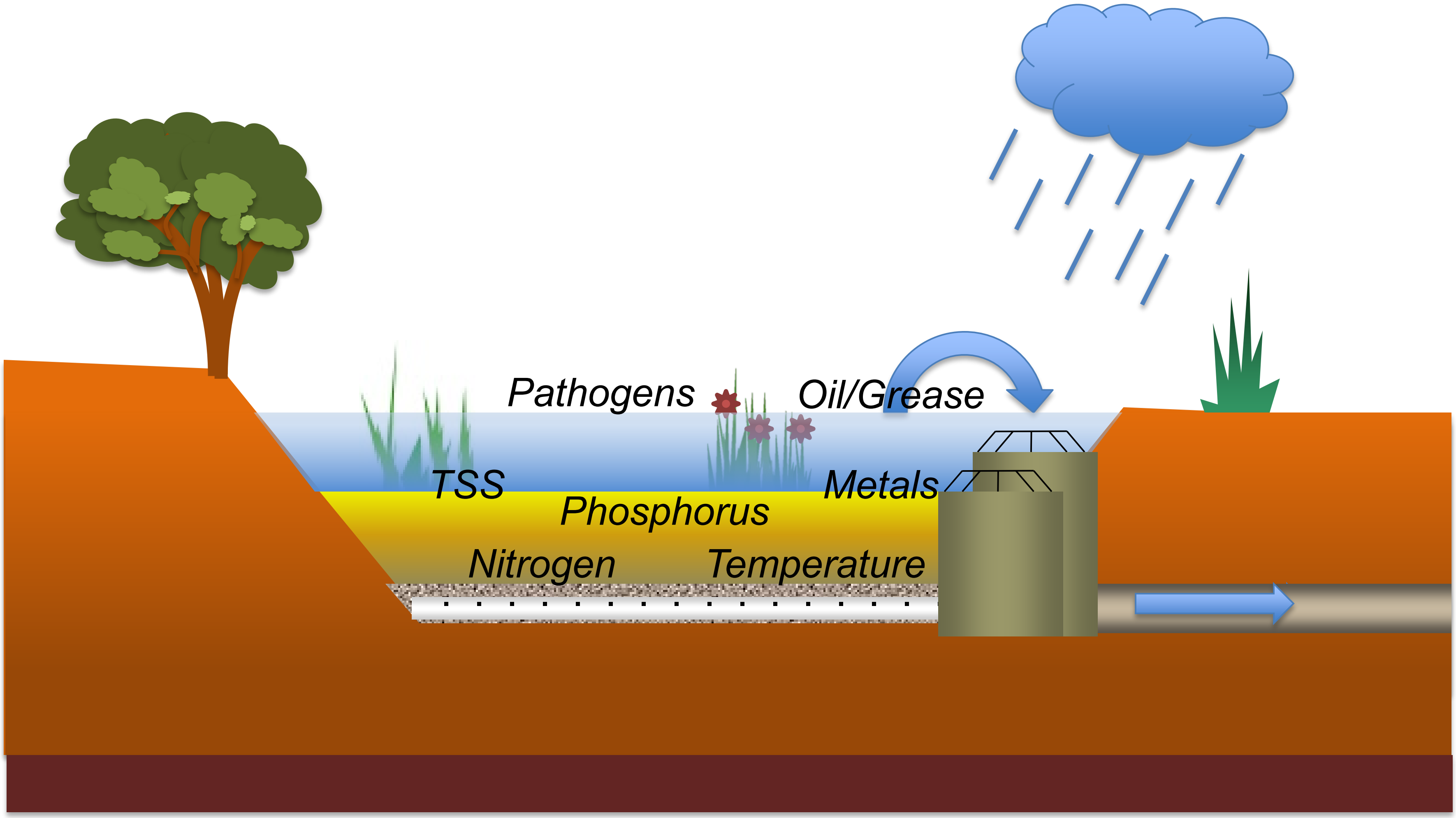


Ohio Bioretention Design Standard

- Water quality volume = runoff from first 19 mm of rain
  - Storage provided in bowl above mulch surface
  - Assumes no infiltration during event (static design)
- 30 cm max. ponding



What *Could* Happen…



Ponding?

Correct Overflow Height

+ 4 Hours

+14 Hours

- No water in bowl within 24 hours of end of rainfall
- Completely drain within 48 hours

How Does Bioretention Work: Pollutant Removal Mechanisms

- Sedimentation (temporary)
  - Trash, TSS, phosphorus
- Microbial processes (denitrification)
  - Nitrogen
- Chemical processes & media filtration
  - Metals, phosphorus
- Exposure to sunlight & dryness
  - Pathogens, oil & grease
- Infiltration

Where can you find Bioretention?

Car Parks


Prince George's
County, Maryland
Constructed 1989

Residential

Roadway / Transportation

Portland, OR

Stockholm, Sweden


BUMP

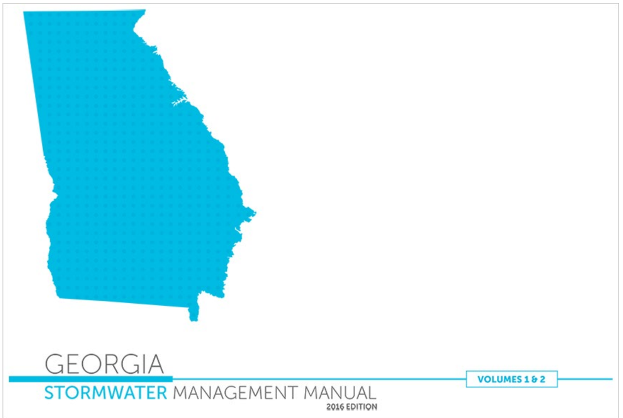
Ultra-Urban Applications

Take Home Point

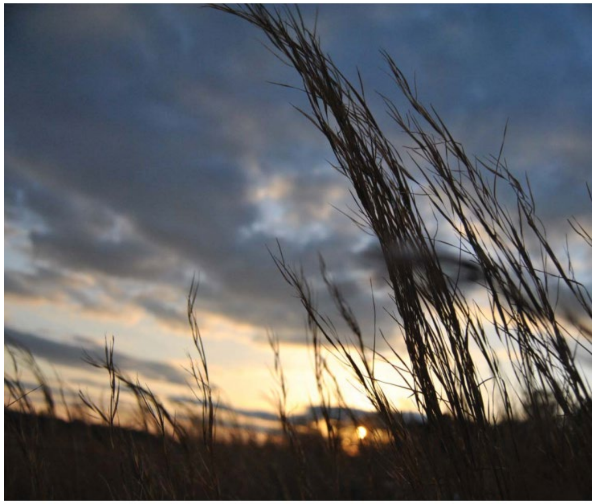
- Bioretention systems have a wide variety of applications
  - Residential areas
  - Commercial
  - “Ultra urban”
- Most applications treat either roof or vehicular (impermeable) surfaces

Design Guidance

- Refer to your local jurisdiction's guidelines
  - Generally accepted design guidance will be presented here
  - Supported by research results



Low Impact Development Handbook
for the State of Alabama



Alabama Department of Environmental Management
Alabama Cooperative Extension System
Auburn University

North Carolina
Stormwater Control Measure
Credit Document

VOLUME 1
REGULATIONS
STORMWATER MANAGEMENT MANUAL

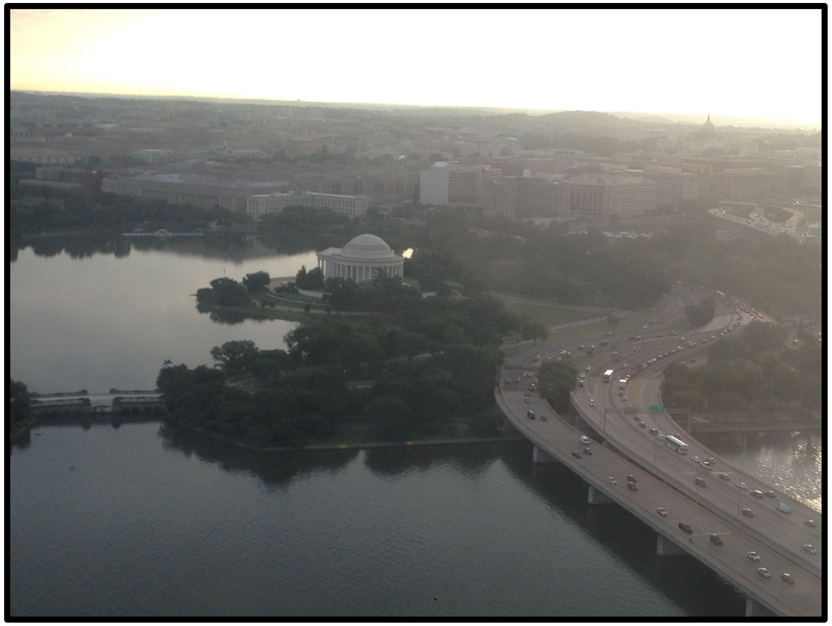
METRO WATER SERVICES

Rainwater and
Land Development

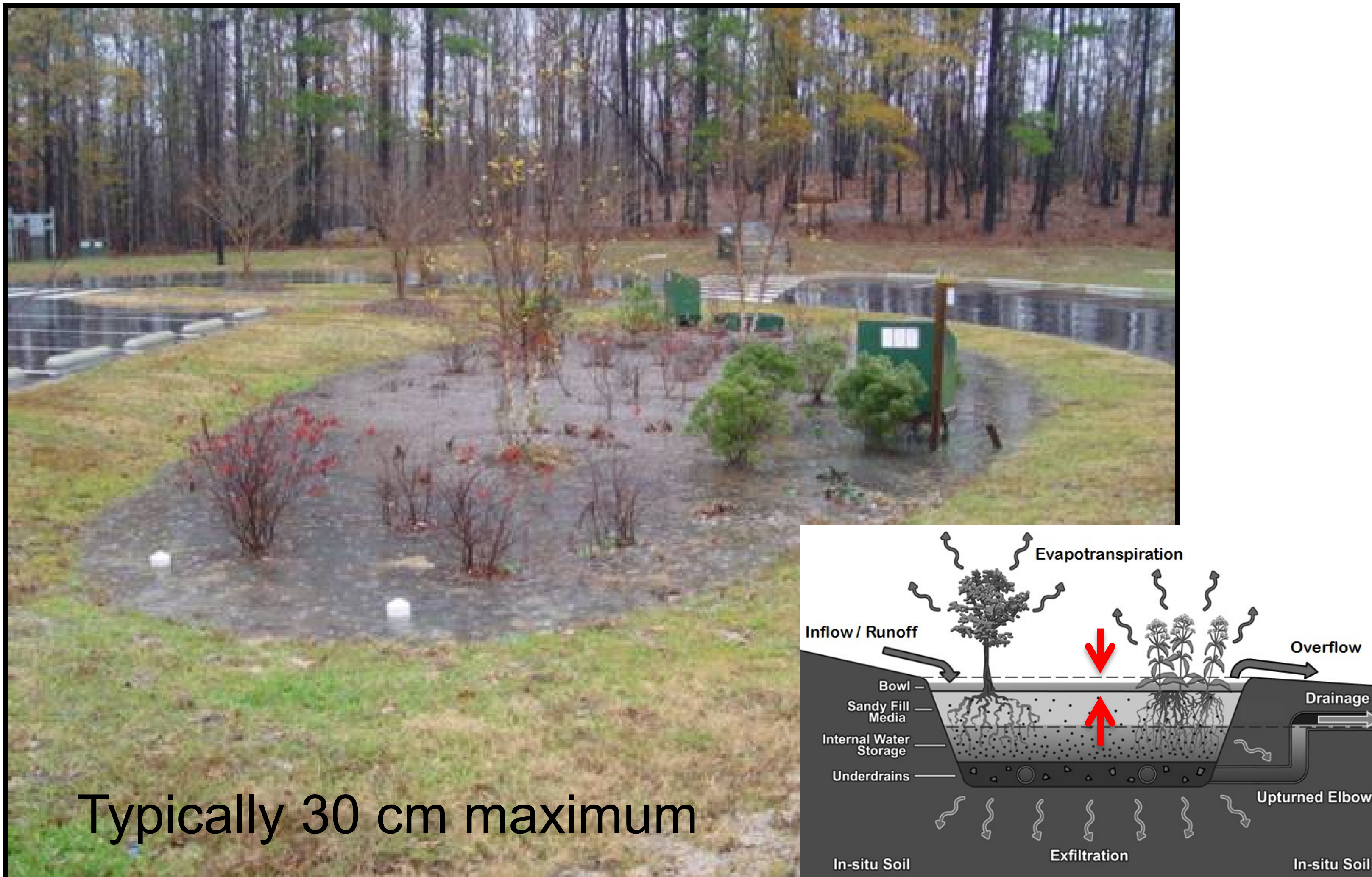
Ohio's Standards for Stormwater Management
Land Development and Urban Stream Protection

Size the Bioretention Cell

- Determine runoff volume from the watershed
  - Curve number
  - Simple method
  - Small storm hydrology method
- Typically based on water quality volume (19-38 mm storm)



Ponding Depth Determines Surface Area of BRC



Bioretention Surface Area Calculation

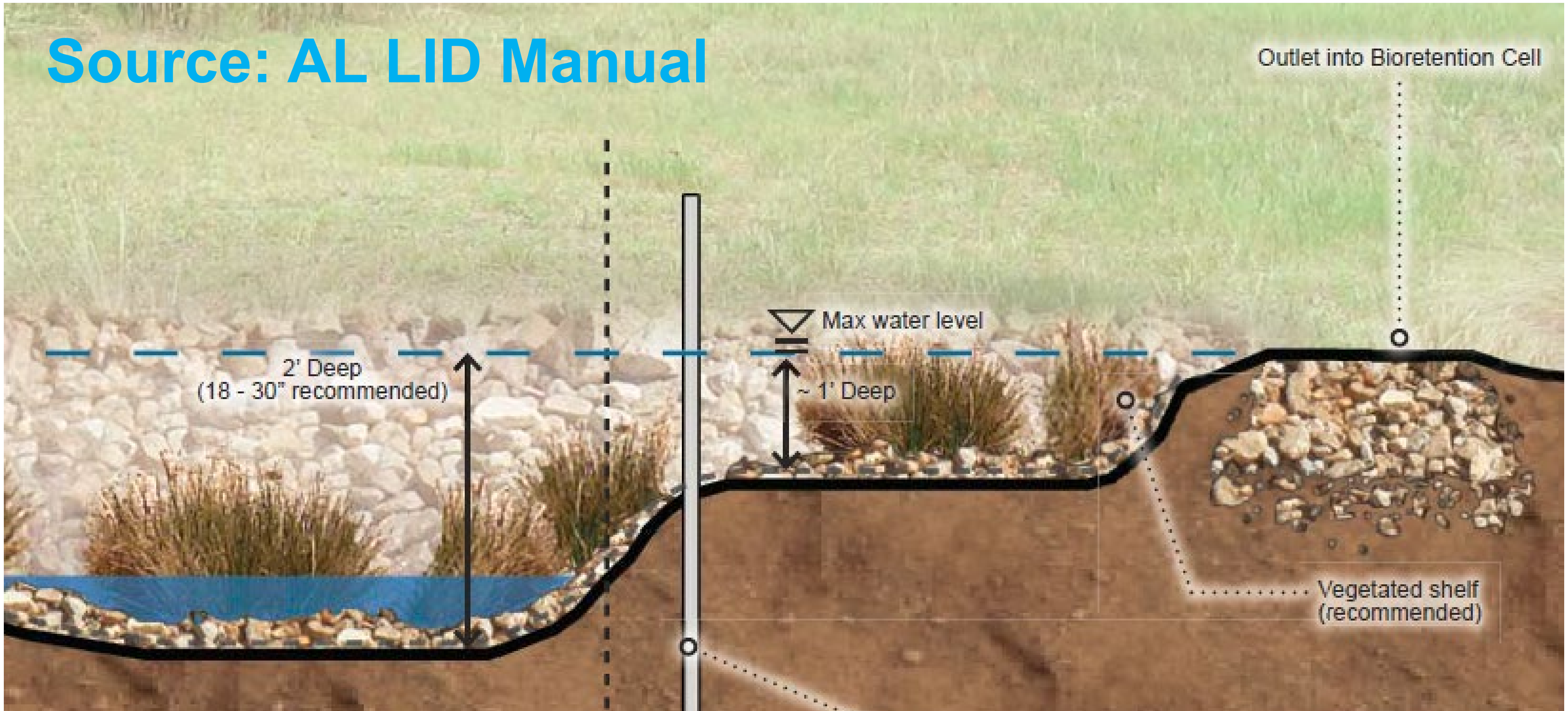
- Surface area calculated for design storage volume from pre/post calculations

$$SA_{BR} = Volume_{Design} / depth_{BRC}$$

- Where SA is surface area (m^2), Volume (m^3), and depth is BRC ponding depth (m)
- This does not include the forebay or pretreatment area

What About Peak Flows?

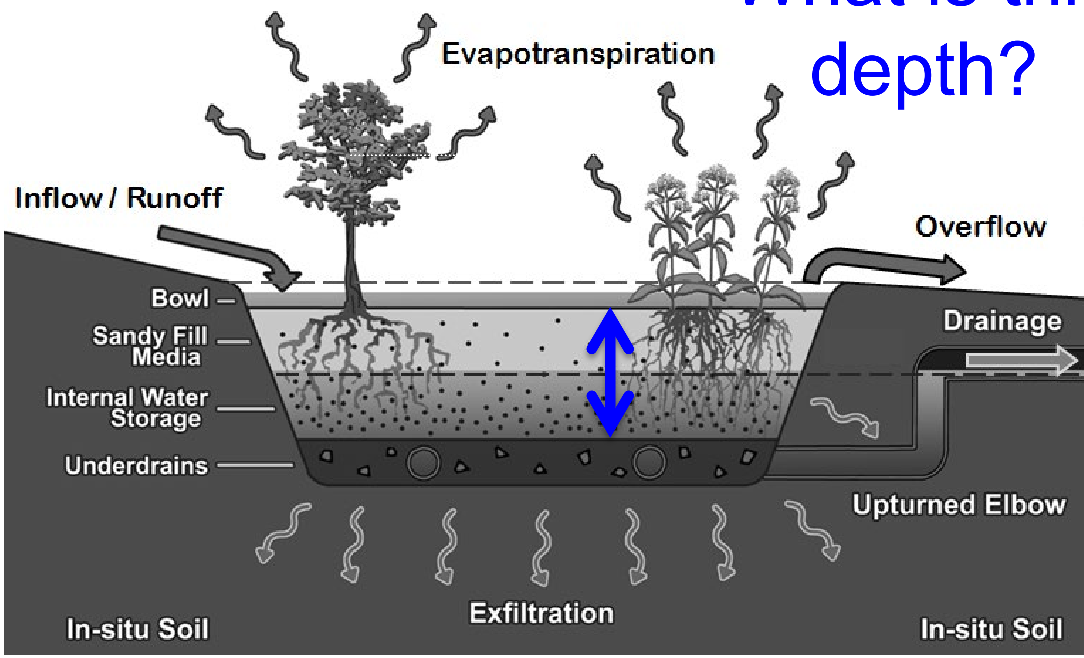
- Store water quality volume in 30 cm bowl
- Mitigate peak flow in an additional 15-30 cm of bowl storage



Media Depth

- Major Cost Consideration

What is this depth?



Fill Media Depth Depends on 3 Factors

- Vegetation Health
- Hydrologic Goals
- Water Quality Needs
- Perhaps the most restrictive goal dictates design

Bioretention Soil Depth: Vegetation Health

Vegetation	Depth (cm)	Comments
Grass	60	Minimum
Shrubs/Trees	90	Minimum
Shrubs/Trees	100-120	Optimum

Some thoughts…

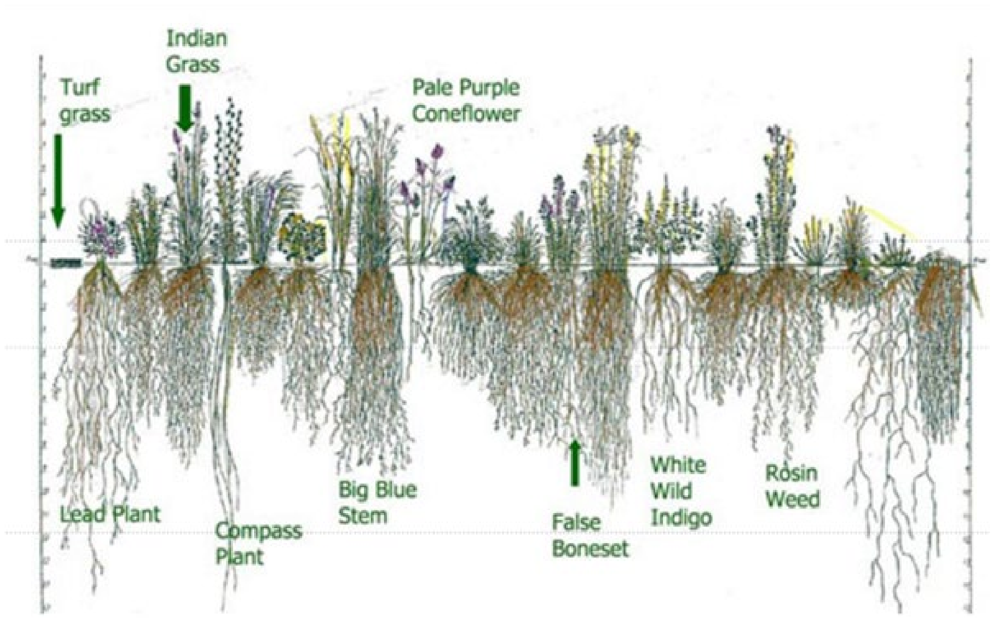
1. **Deeper media depths provide moisture reserves for extended dry periods. IWS may also help.**
2. **Deeper cells provide runoff volume reduction, regardless of in-situ soil type, recharging the groundwater**

Grassed Bioretention

Graham, NC High School

Deep Rooted, Native Veg

- Deep rooted vegetation creates macropores for infiltration / offsets clogging
- Bacteria around roots break down pollutants
- Droughty soils
  - Naturally adapted
  - Long dry periods



Literature/Research Justification for Minimum Media Depths: WQ

Pollutant	Depth (cm)	Studies
TSS	30	Diblasi et al. 2009, Li et al. 2008
Metals	30	Li and Davis 2008, Hatt et al. 2009
Oil & Grease	30	Diblasi et al. 2009,
Phosphorus	60 (min); 90 (conservative)	Hatt et al. 2009, Hsieh and Davis 2007, Passeport et al. 2009
Nitrogen	90	Passeport et al. 2009
Temperature	90 (min); 120 (optim)	Jones and Hunt 2009

DON'T FORGET HYDROLOGY… deeper media = greater potential for volume control

Media Selection

CRITICAL FOR NUTRIENTS

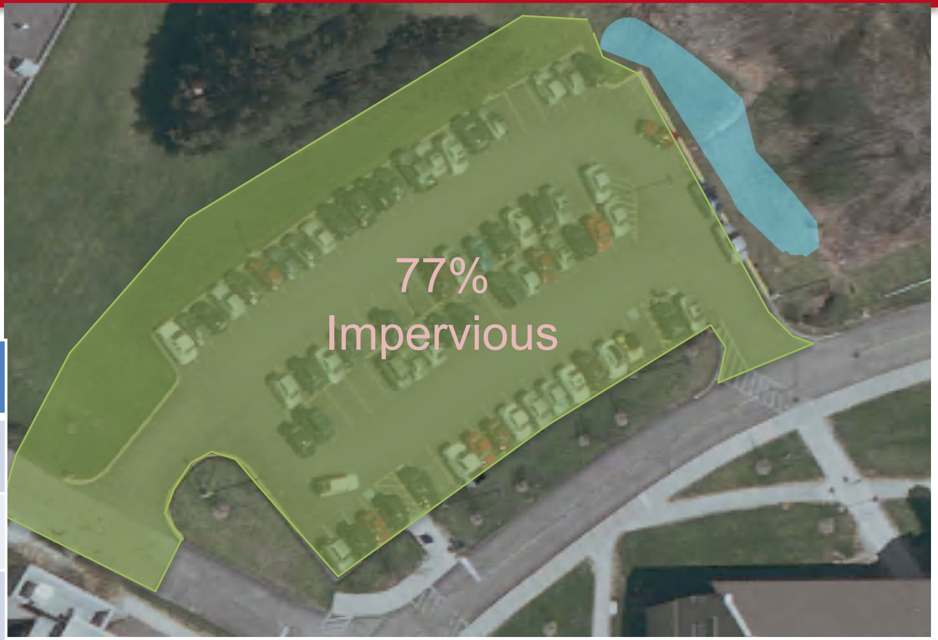
- If designed or specified incorrectly, bioretention can be a source of pollution

NC/AL Bioretention Media Mix

Media Component	Standard Specification
Sand	>85-88%
Fines	8 - 12%
Organic Matter	3 - 5% by volume or ~1% by mass
P Content	12-36 mg/kg (no compost)
Permeability	Drain the bowl in 12 hours

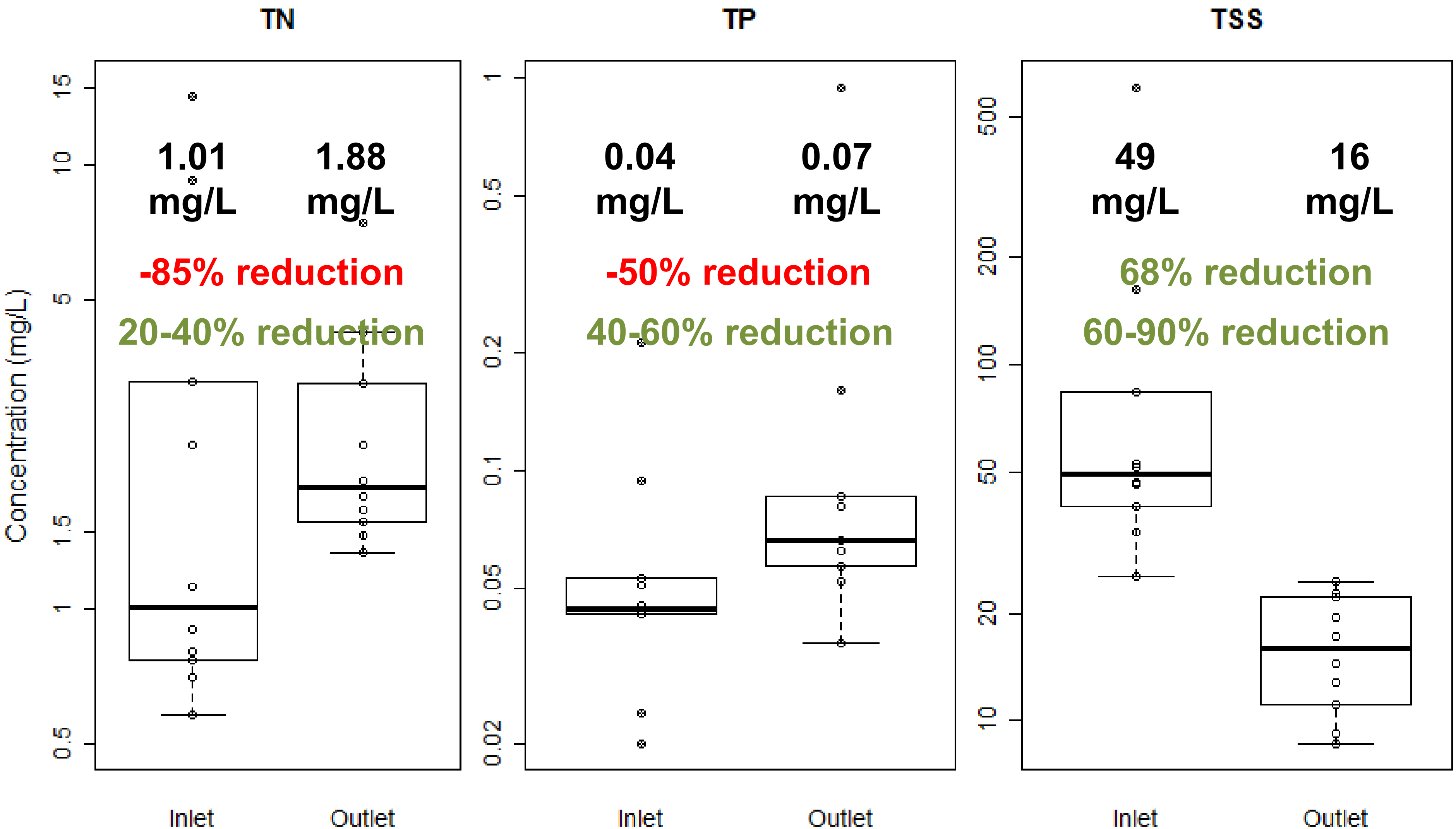
Ursuline College Bioretention Cell

Characteristics	UC
Catchment area	0.36 ha
Imperviousness	77%
Bioretention surface area	182 m^2
Media characteristics	87% sand, 4% silt, 9% clay, 5% by mass OM
Vegetation	Forbs & perennial grasses



Ursuline College BRC

(n=10 samples)



What is the Culprit?

- Soil media mix controls performance
  - Organic Matter:
    - 3-5% by mass (compost) – OH
    - 1% by mass (pine bark) - NC
    - 3% by mass (compost) - MN
  - Mehlich III P content:
    - 15-60 mg/kg - OH
    - 12-36 mg/kg - NC
    - 10-30 mg/kg - MN


Tea.co.uk

Do BRCs Work for Runoff Reduction?

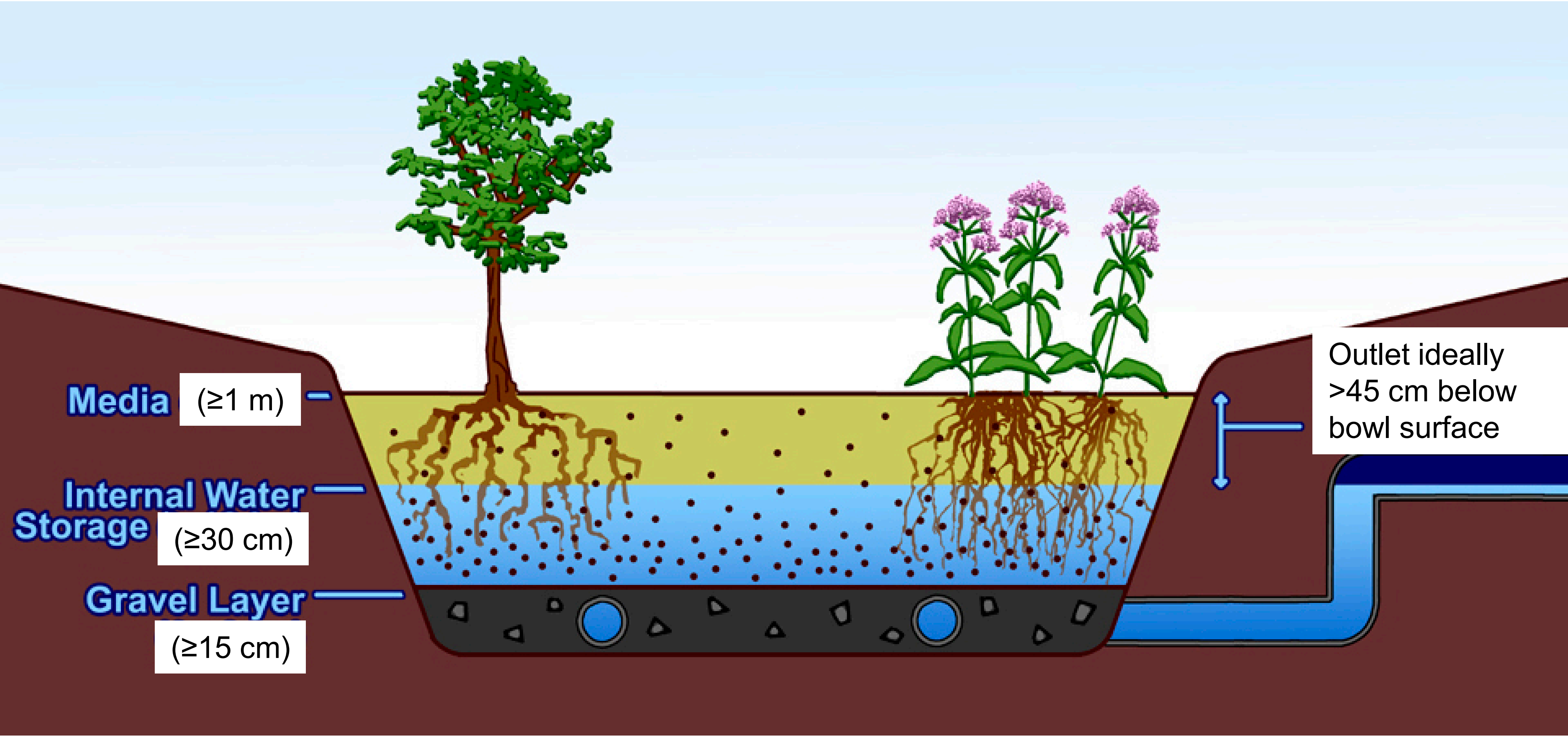
Cell	Drawdown Rate (in/hr)	Drainage (%)	Overflow (%)	Exfiltration + ET (%)
UC	0.43	33	8	59
HA South	0.20	51	7	42
HA North	0.17	57	7	36
Rocky Mount Sand	152.4	0	0	100
Rocky Mount SCL	5.3	18	7	75

* Source: Brown 2011

Results of long-term monitoring

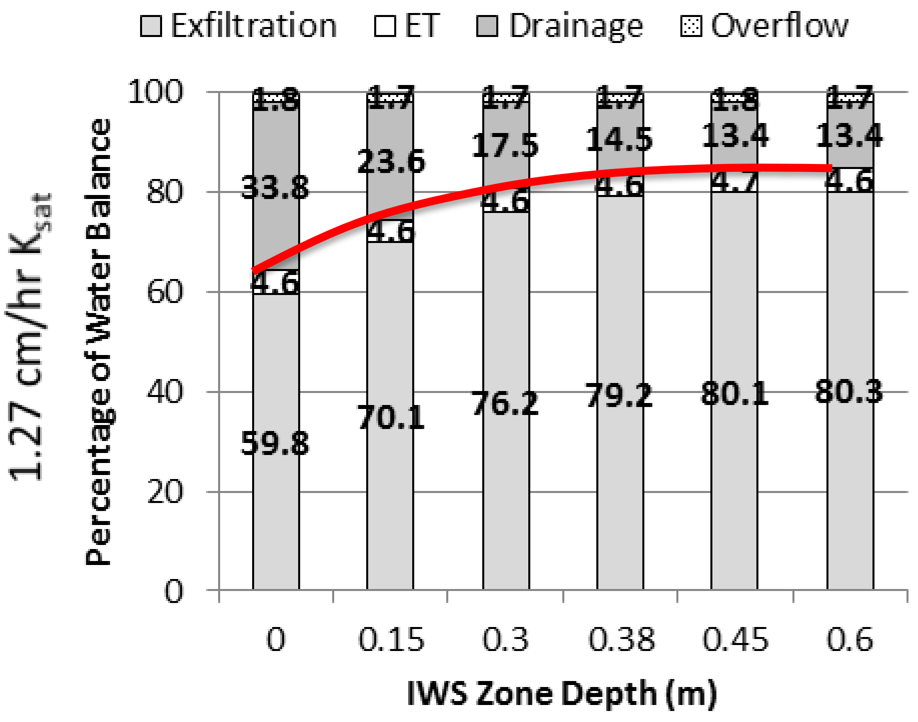
Stormwater Modeling

Internal Water Storage Design



Leave 45 cm of media above IWS zone

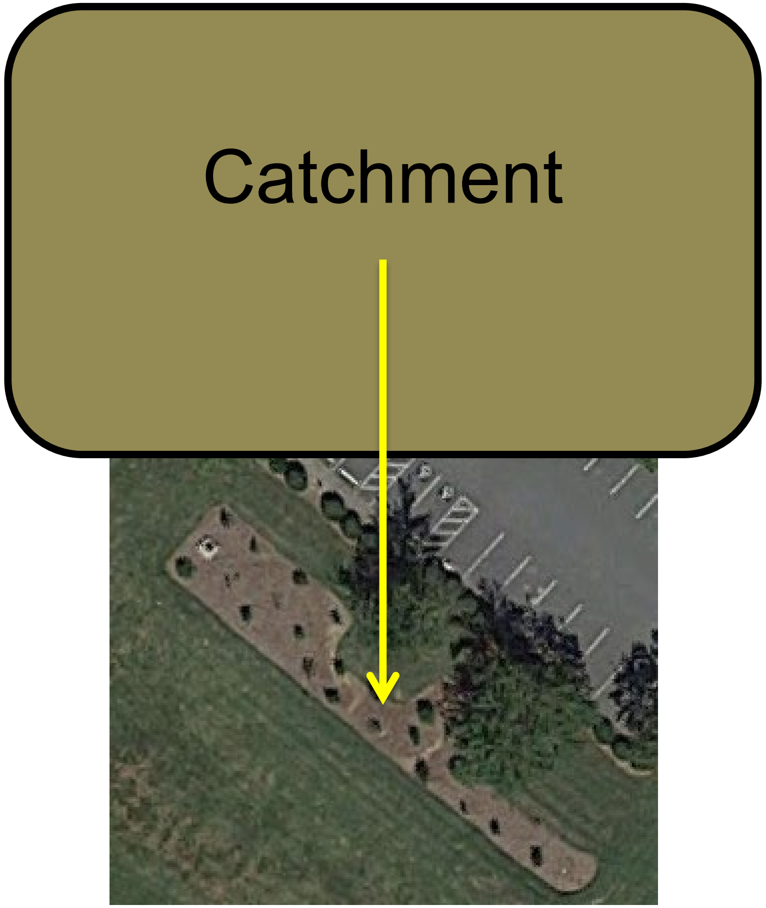
Need aerobic media to support plants

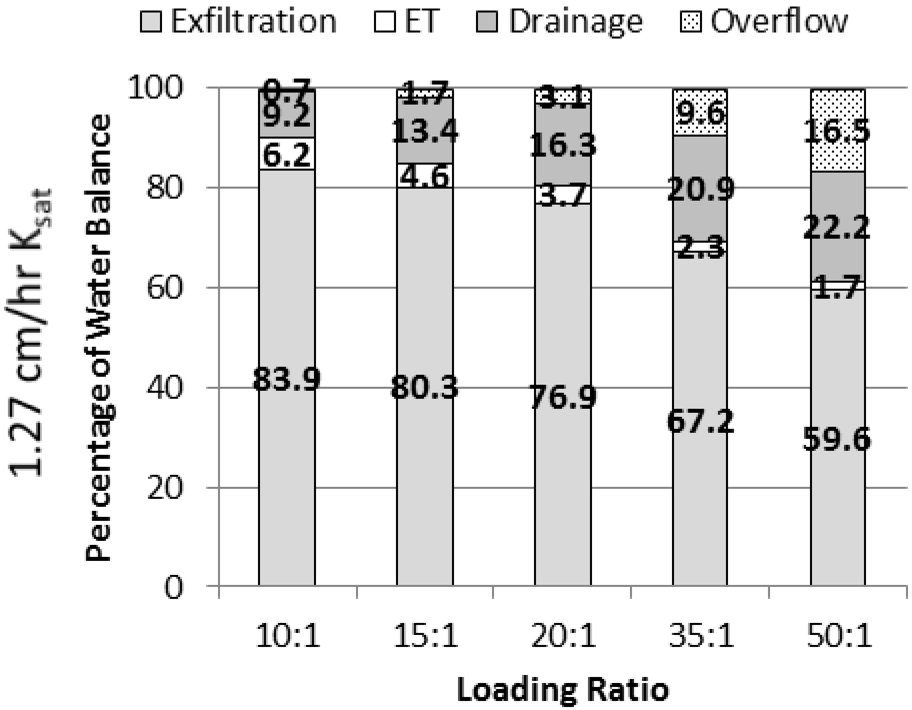


Exfiltration
ET
Drainage
Overflow
1.27 cm/hr K_{sat}
Percentage of Water Balance
100
80
60
40
20
0
1.8
33.8
4.6
59.8
1.7
23.6
4.6
70.1
1.7
17.5
4.6
76.2
1.7
14.5
4.6
79.2
1.8
13.4
4.7
80.1
1.7
13.4
4.6
80.3
0
0.15
0.3
0.38
0.45
0.6
IWS Zone Depth (m)

Over/Under-Sized Bioretention

- Ohio design event = 22 mm
- Catchment Area : Bioretention Area Ratio
  - **10:1**
  - **15:1**
  - **20:1 (base model)**
  - **35:1**
  - **50:1**





Exfiltration
ET
Drainage
Overflow
1.27 cm/hr K sat
Percentage of Water Balance
100
80
60
40
20
0
0.7
9.2
6.2
83.9
1.7
13.4
4.6
80.3
3.1
16.3
3.7
76.9
9.6
20.9
2.3
67.2
16.5
22.2
1.7
59.6
10:1
15:1
20:1
35:1
50:1
Loading Ratio

Bioretention Cell Construction Case Study

- Contributing drainage area:
  - 0.4 ha
  - (split between two BRCs)
- Centipede grass sod
- 1 meter media depth

Large Cell SA: 186 m^2
Captured 25 mm event

Small Cell SA: 93 m^2
Captured 7.5 mm event

On-Site Meetings: Critical

Excavation to ~170 cm

Outlet Structure Installed

Continuing Construction – Checking Grades

Compaction?

How Does Compaction Affect Infiltration?

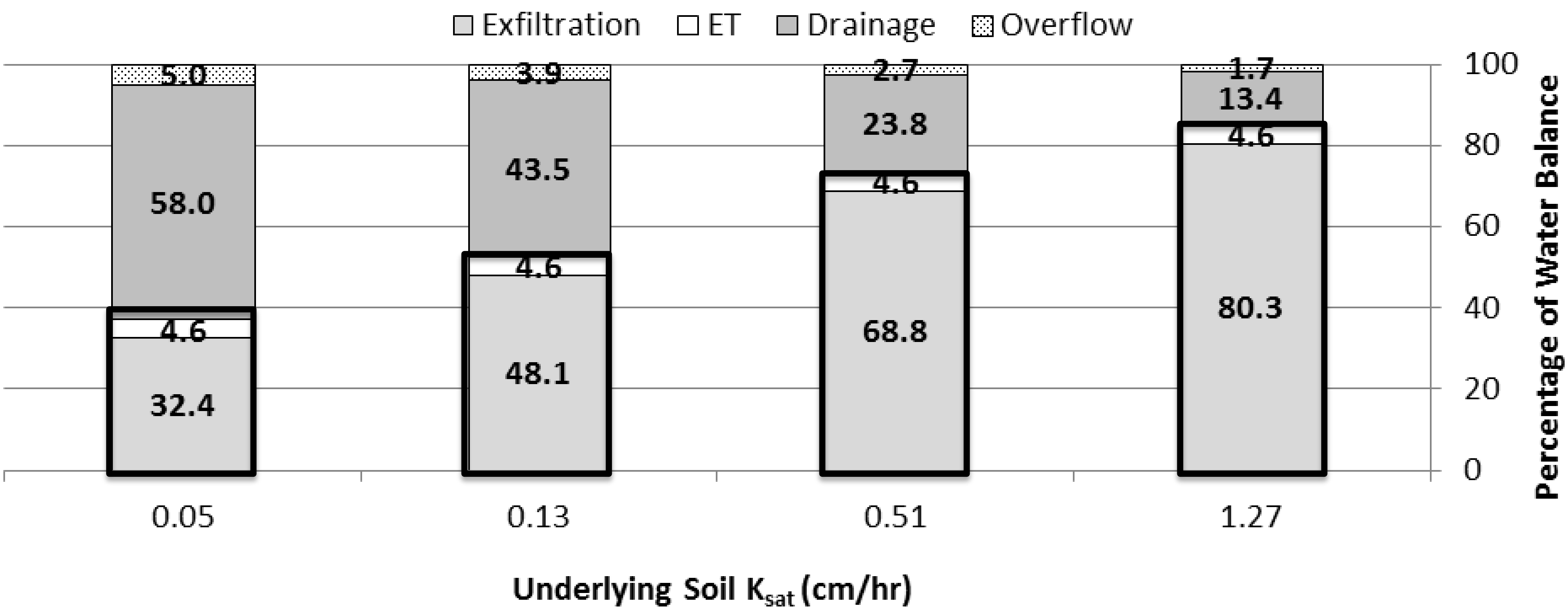
- Pitt et al., 2009:
  - **In sandy soils**, compaction can decrease infiltration rate by one order of magnitude
  - **In clay soils**, compaction can decrease infiltration rate by factor of 50
- Must minimize subgrade compaction to promote exfiltration

Does Excavation Technique Matter?

- Brown & Hunt, 2010:
  - Tested infiltration and hydraulic conductivity of "scooped" vs. "raked" subgrades
  - Raking decreased bulk density, significantly improved exfiltration
- Rake when dry for best performance, especially in silt/clay soils

Underlying Soil K_{sat}

Runoff Volume Reduction



- Minimize compaction of underlying soil to promote runoff volume reduction

Minimizing Compaction

- Excavate in dry conditions
- “Back out” equipment
- Use tracked vehicles
- Excavate final 22-30 cm with teeth of bucket (DO NOT SMEAR)

Underdrains

Upturned Elbow in Underdrain

Internal Water Storage

Clean #57 Drainage Rock

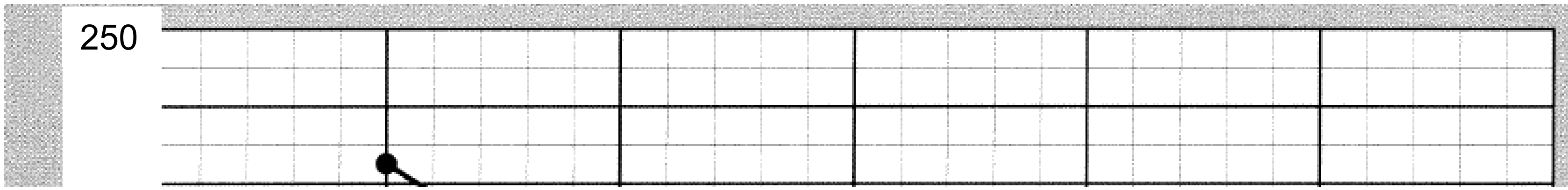
(2.4 – 37 mm diameter)

Forebay Grading

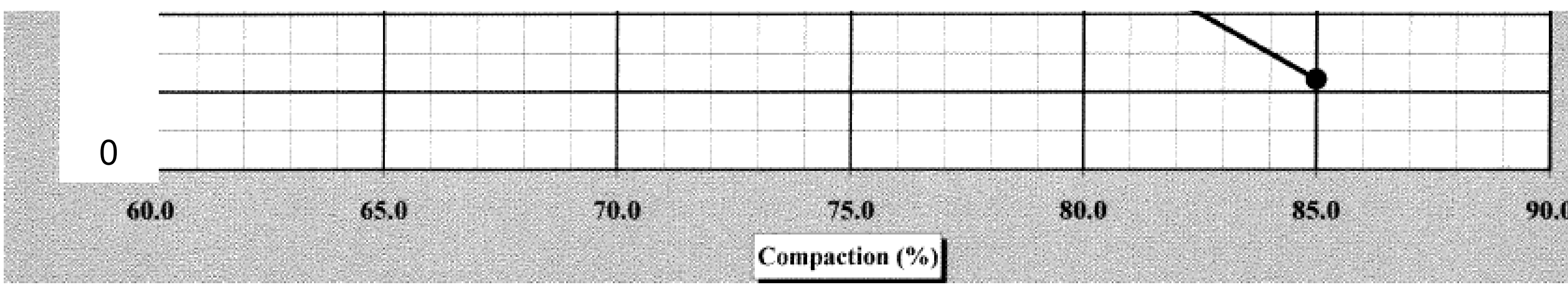
Completed Forebay

Media Installation

Compaction of Soil Media



- Compaction affects infiltration rate of soil media, which slows stormwater flow through soil and affects size of storm that can be treated
- Compacted soil also negatively affects plant growth



Signage To Prevent Compaction

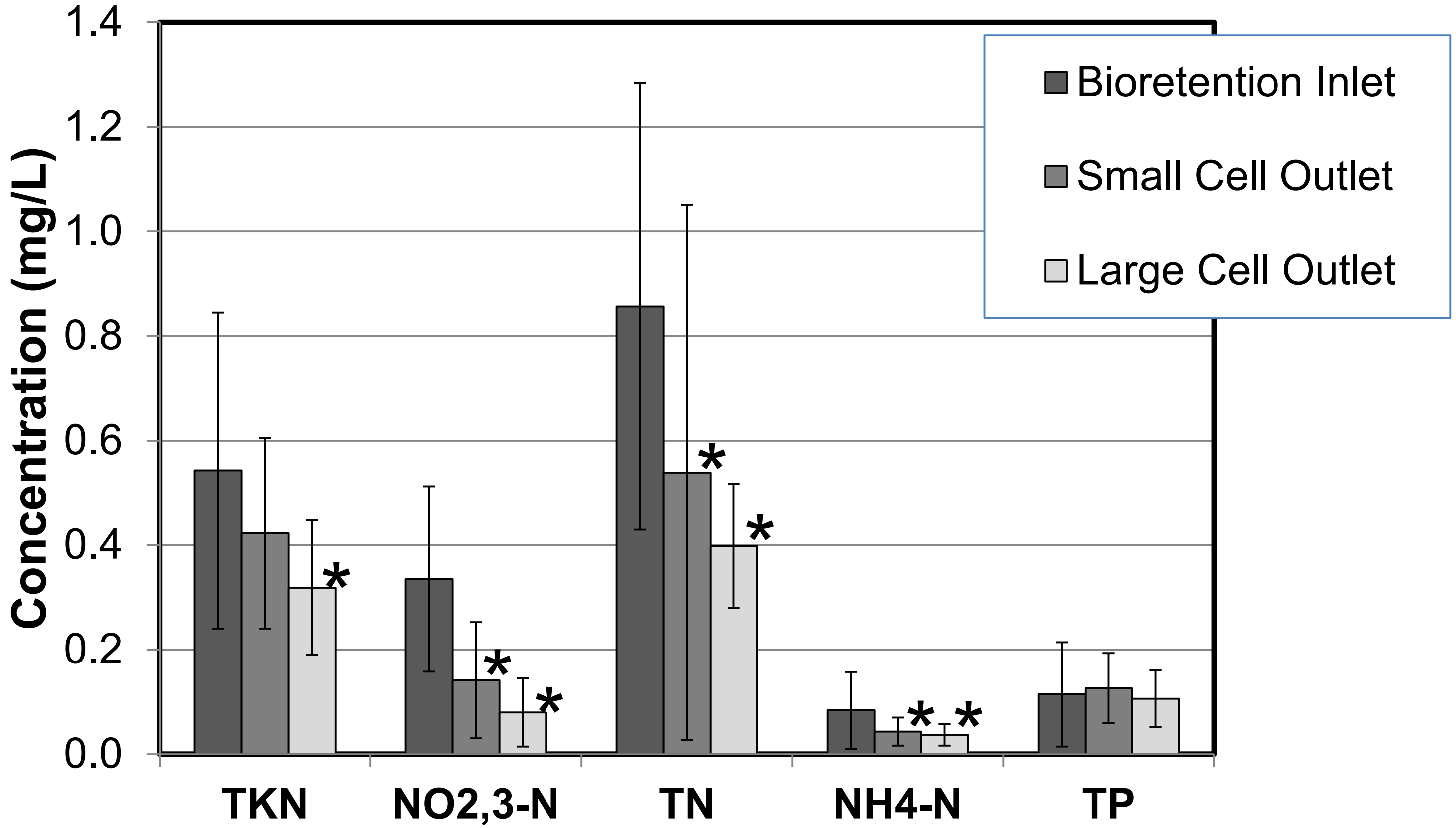
And Then it Rained…

Clogging Layer

Completed Bioretention Cell

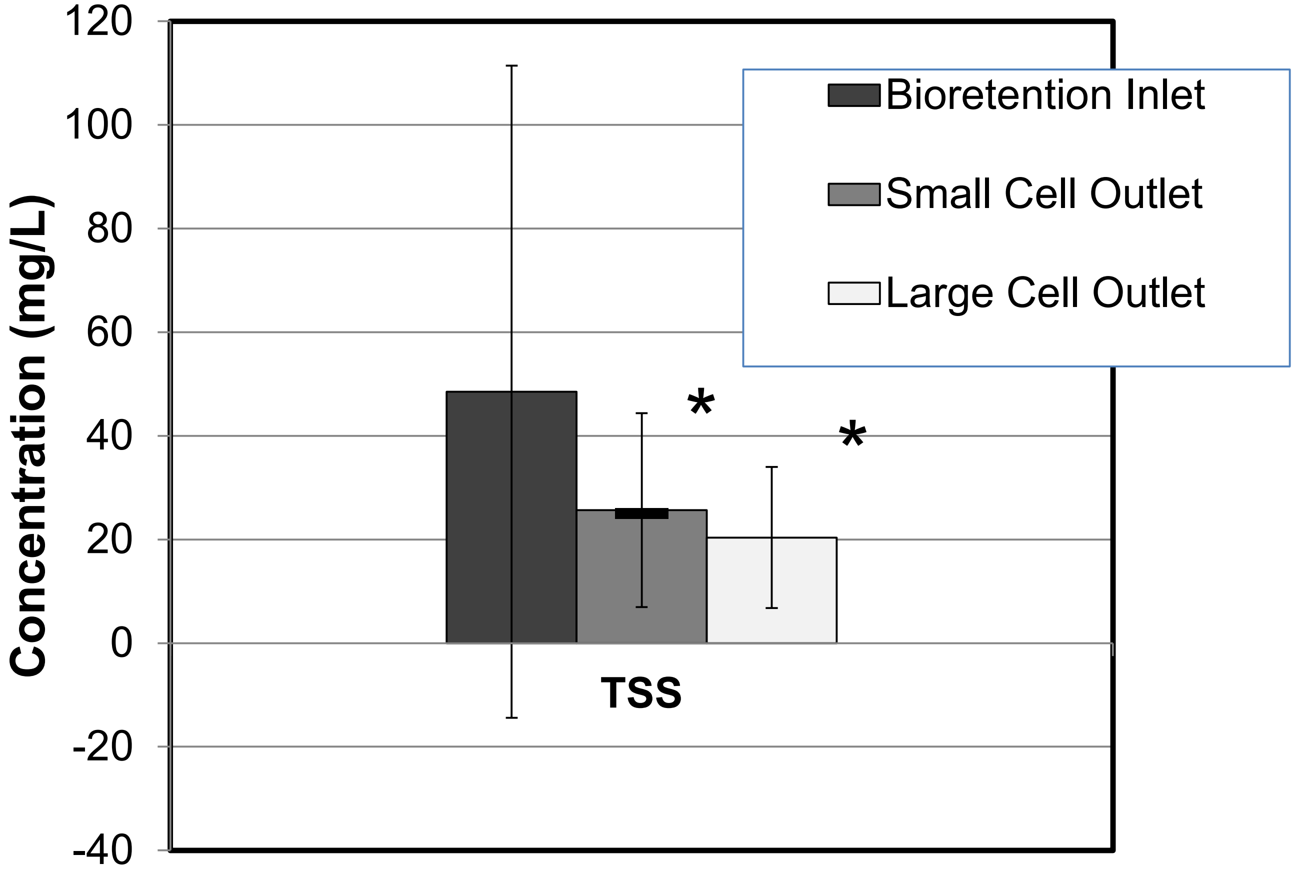
Bioretention Cell
EMC Reductions

Average influent and effluent nutrient concentrations



Bioretention Cell
EMC Reductions

Average influent and effluent TSS concentrations



Lessons Learned: Bioretention Construction

- Prevent compaction of media and underlying soil to improve infiltration/volume reduction
- Media selection critical to water quality performance (low organic matter, little or no compost)
- Construction sequencing critical
  - Build BRC as late in construction as possible
  - Vegetate side slopes as soon as possible

Key Maintenance Test

- Visit site within 24 hours of design rainfall event
- If water is still ponded bioretention cell has clogged & action is needed
- Do this once or twice per year

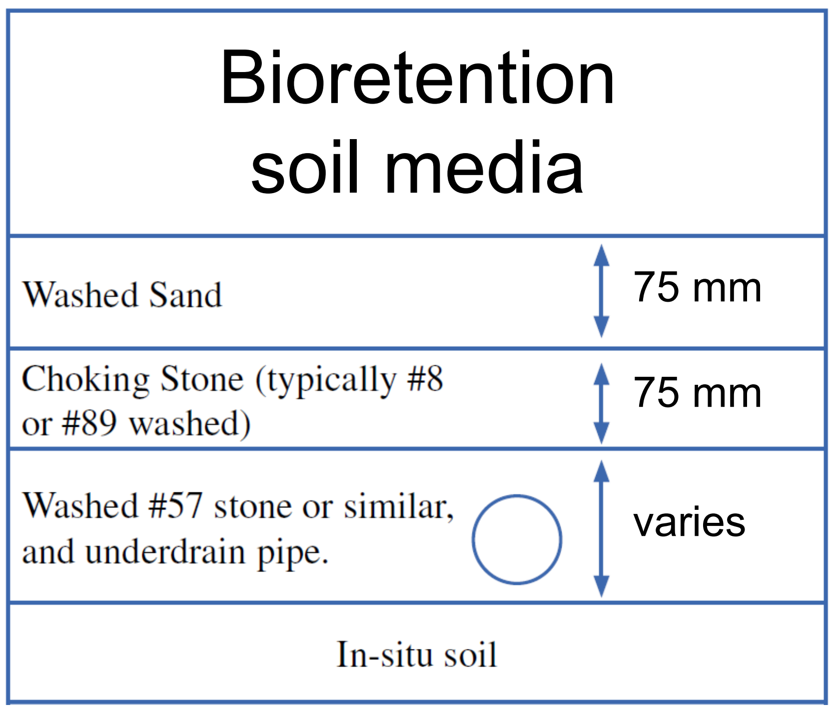
Why Would Bioretention Drain Too Slowly?

Slow Drainage: Filter Fabric

- Often clogs – older designs
- Typically between gravel layer and bioretention media
- How do you fix this? What can we do instead?

“New” Typical Design

- 75 mm concrete sand underlying media
- 75 mm pea gravel beneath sand
- #57 aggregate around underdrain



Adapted from Hunt and Lord (2006)

Clogging Layers

- Cause plant mortality, reducing bioretention performance (water quality and quantity) and create mosquito habitat
- Usually occurs during construction

Clogging Layer

Crusher Run Base

Bowl Drawdown

- Recommended bowl drawdown rate
  - 12 hours (25-100 mm/hr)
- Actual drawdown rate
  - 48+ hours (2.5 – 12 mm/hr)

Right after rainfall

What if it rains now?

~ 24 hours later

Fixing Bioretention

- Remove clogging layer & top 8 cm of media to increase surface ponding volume

Overflow Structure or High Flow Bypass

- Often the only outlet for large events (>19 mm)
- Critical to keep maintained
  - If clogged, can flood nearby buildings

What Can Happen…

- Clean off outlets after every large storm – can clog with mulch or trash

Improper Maintenance

Over-mulching

- 50-75 mm of mulch is desired…

Mulch Selection and Renewal

- Double or triple shredded hardwood bark is best
- Mulch should be renewed annually
  - Do not use rock for mulch layer
- Remove mulch if mulch depth >75 mm
- Too much mulch displaces water storage

Can Water Get Into the Cell?

Question: What Pretreatment is Needed?

- Bioretention needs pre-treatment
- Forebays
- Limit velocity of inflow to 30 cm/sec

Forebay

- Limits stormwater velocity as it enters bioretention cell
- Drops out sediment
- Prevents internal erosion in bioretention cell


Pretreatment: Swale

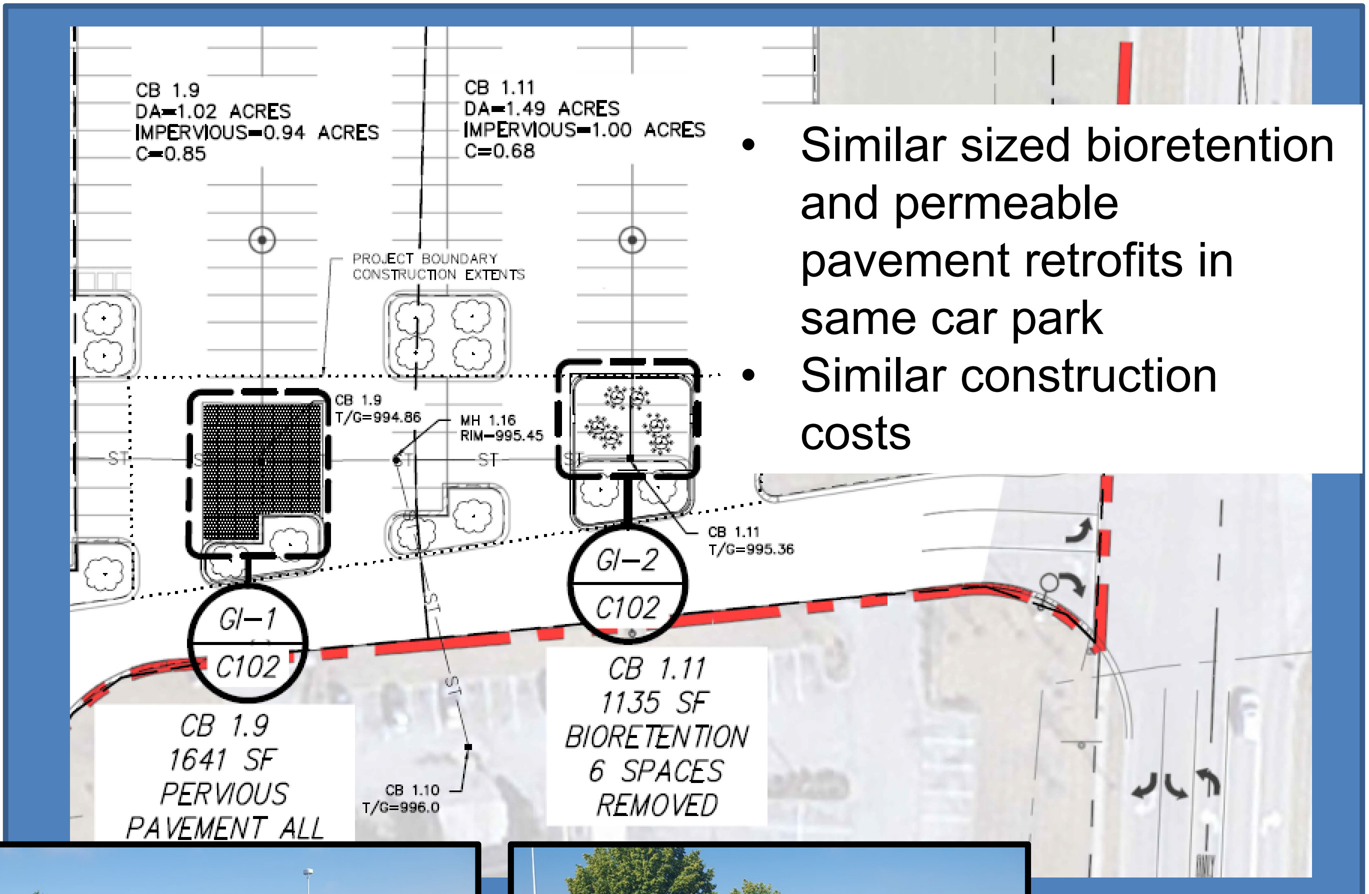
Gravel Verges and Grass Filter Strip in Series

Same Gravel Verge 10 Yrs Later…

Underdrain Cleanouts

Needed in case underdrains become clogged

Comparing BRC and PP

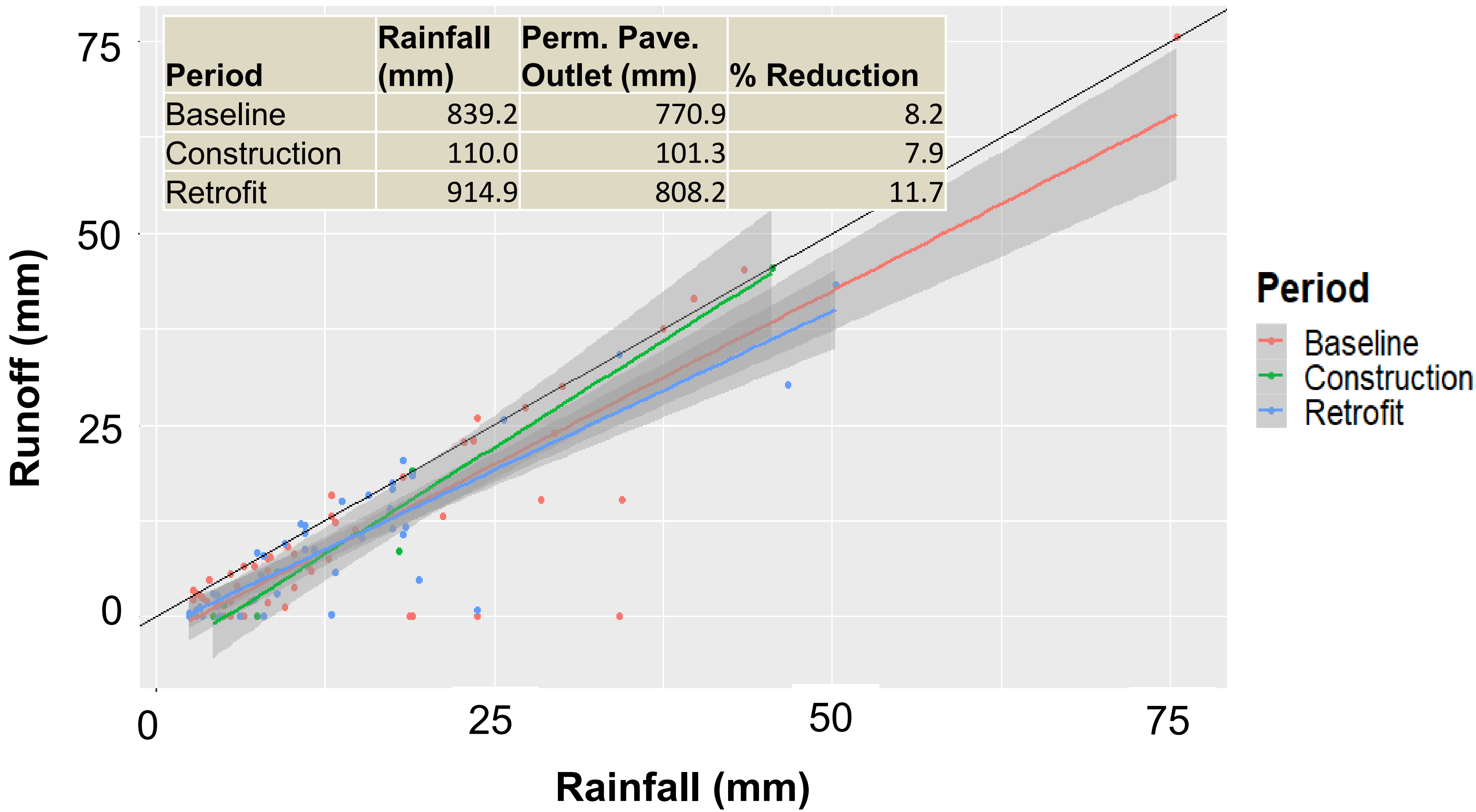


- Similar sized bioretention and permeable pavement retrofits in same car park
- Similar construction costs

Runoff Volume

Permeable Pavement

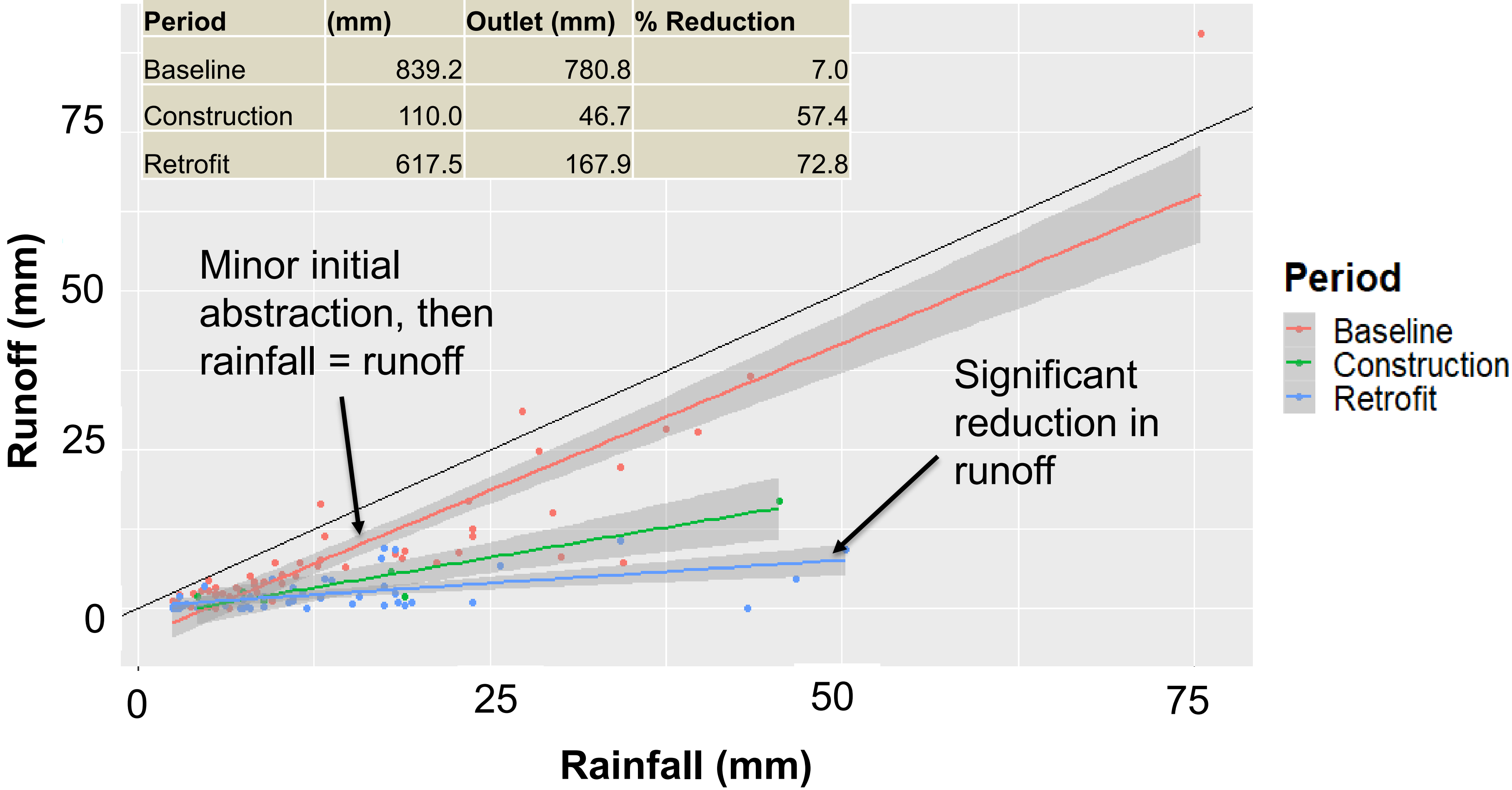
Period	Rainfall (mm)	Perm. Pave. Outlet (mm)	% Reduction
Baseline	839.2	770.9	8.2
Construction	110.0	101.3	7.9
Retrofit	914.9	808.2	11.7



Runoff Volume

Bioretention

Period	Rainfall (mm)	Bioretention Outlet (mm)	% Reduction
Baseline	839.2	780.8	7.0
Construction	110.0	46.7	57.4
Retrofit	617.5	167.9	72.8



Summary: Performance Comparison

Bioretention

- "Lose" 5-8% of watershed area to stormwater treatment
- Clogging may occur during construction
- Native / deep rooted plants help mitigate sediment load
- Pretreatment reduces sediment load
- Better nutrient, bacteria, & dissolved pollutant treatment

Permeable Pavement

- No lost real estate since you can park / drive on it
- Clogging occurs throughout life of device
- No plants present so clogging not offset
- Pretreatment is not feasible in most cases
- Primarily removes of sediment-bound pollutants

Summary: Maintenance Comparison

Bioretention

- Remove trash / debris
- Clean out the pretreatment device of accumulated sediment
- Prune trees and shrubs
- Replenish mulch
- Ensure overflow is free of clogs
- Little/no equipment needed

Permeable Pavement

- Clogging is the big challenge here
- Maintenance requires (sometimes heavy) equipment
- Typically street sweeper or pressure washer
- Maintenance predicated on run-on ratio

Construction Cost Comparison

Cost to treat 2 ha watershed

Characteristic	*Bioretention*	*Permeable Pavement*
Surface Area (m^2)	1000	10000
Construction Cost ($ per m^2)	86.1	21.5
Total Construction Cost ($)	86,111	215,278

Joburg Multi-Family

- 2 extra apartment blocks by using PICP throughout development
- Must undertake cost/benefit analysis

QUESTIONS?