Nutrient Science Advisory Board – NCDEQ – May 7, 2021

Stormwater Research Supported by the NC Policy Collaboratory (& Friends)

Bill Hunt, Ph.D., PE
Department of Biological & Agricultural Engineering
NC State University

NC Policy Collaboratory

Funded Projects

- Bioretention
- Sand Filters
  - Supported with funds from NCL&WF
- Stormwater-Treating Street Trees (e.g. Silva Cells)
  - Supported with funds from NCL&WF
- Submerged Gravel Wetlands
  - 100% funded by NCL&WF & City of Greensboro
- Floating Wetland Islands
  - Supported with 319(h) & NCL&WF funds

Who (really) did the work…

- Bioretention – Jeffrey Johnson
- Sand Filters – Jackson Tate & Dan Line
- Stormwater Treating Street Trees – Sarah Waickowski & Amethyst Kelly
- Submerged Gravel Wetlands – Caleb Mitchell & Sarah Waickowski
- Floating Wetland Islands – Molly Landon & Jeffrey Johnson

SCMs vis-à-vis the Model Effort

- Nutrient Load Change provided by SCM calculated using one of 2 simple formulas:

$$L_{out} = Lin \times \%Red$$

Or

$$L_{out} = Volin \times \%VolRed \times Conc_{Effl}$$

- *KEY POINT: IT IS ASSUMED THAT SCM'S WORK THE SAME OVER A 30-YEAR LIFE*

During Ph.D.
18 years ago.

Background

- This research revisits a BRC previously monitored from June 2002 – April 2003
  - Hunt, W.F., Jarrett, A.R.R., Smith, J.T., Sharkey, L.J., 2006. Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina. J. Irrig. Drain. Eng. 132, 600–608. doi:10.1061/(ASCE)0733-9437(2006)132:6(600)

- Second monitoring period:

  February 2017 – March 2018


Willow Dr
Conner Dr
U.S. Hwy 15/501
Walnut St
K&W Cafeterias, Inc.
Silverspot Cinema
University Place
Willow Dr
Southern Season
Hickory Dr
Shepherd Ln
S Estes Dr
Ridgefield Rd

Site Characteristics

Characteristic	Chapel Hill BRC
Year constructed	2001
Underlying soil	Clay, clay loam, and silty clay
2002-2003 Drainage area (m^2)	600 (0.15 ac)
2017-2018 Drainage area (m^2)	1,120 (0.28 ac)
Imperviousness	100%
BRC surface area (m^2)	90 (970 sq. ft)
Bowl storage (mm)	95 (4 in.)
Media depth (m)	1.2 (4 ft)
K_{sat} (mm/s)	0.009 – 0.021 (1.3 – 3.0 in/hr)
Original media P-index	4-12 (3.7 – 11.1 mg/kg)
Vegetative cover	Perennial grasses, trees, shrubs

Monitoring

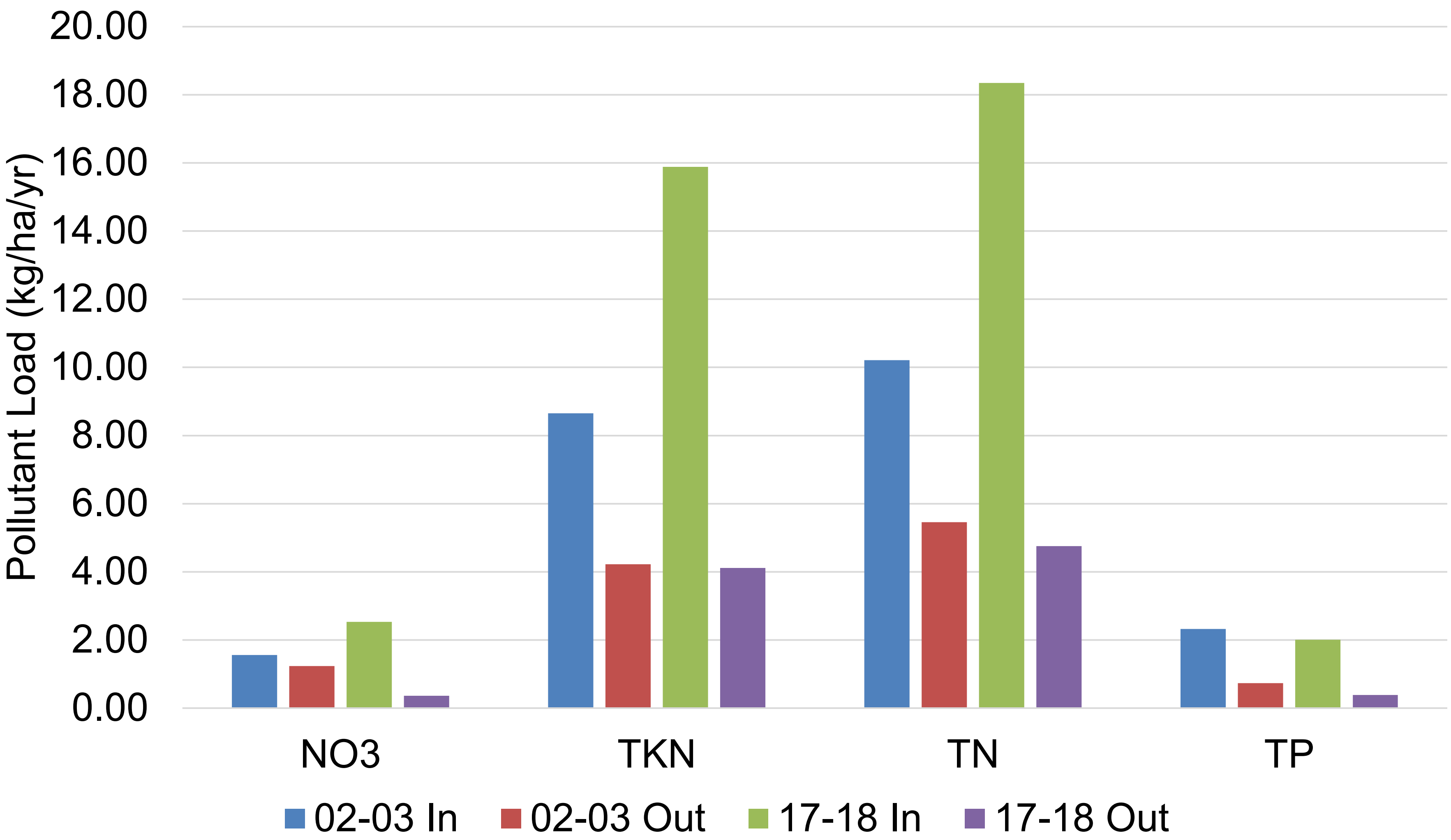
- Inflow and outflow measured using ISCO 730 bubbler modules and sharp crested v-notch weirs
- Flow weighted composite samples at inlet and underdrain collected with ISCO 6712 portable samplers
- Samples analyzed for TKN, NH_3-N, NO_3-N, TP, Ortho-P, and TSS

Results

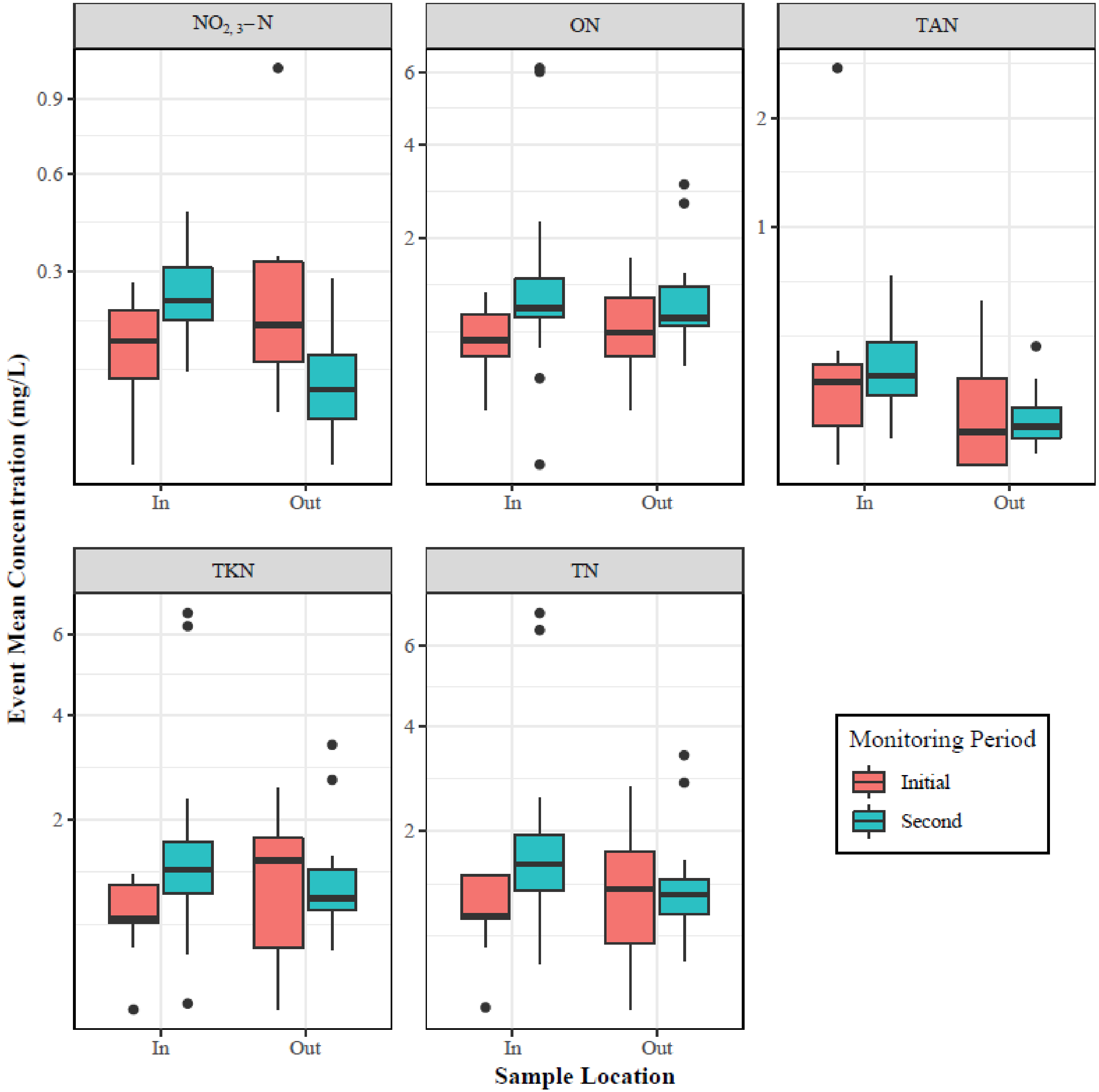
Pollutant	Initial Monitoring Period EMC In (mg/L)	Initial Monitoring Period EMC Out (mg/L)	Initial Monitoring Period Reduction (%)	Second Monitoring Period EMC In (mg/L)	Second Monitoring Period EMC Out (mg/L)	Second Monitoring Period Reduction (%)
TN	0.89	1.23	-37.6*	1.51	1.12	25.8*
TKN	0.74	1.41	-90.5*	1.29	0.95	26.4
TAN	0.17	0.05	70.6	0.19	0.06	68.4*
NO_3-N	0.15	0.18	-20.0*	0.23	0.08	67.4*
ON	0.56	0.70	-25.0*	0.95	0.84	12.1
TP	0.14	0.17	-21.4	0.14	0.09	39.3*
OP	0.07	0.05	28.6	0.02	0.03	-50.0
PBP	0.04	0.04	0.0	0.11	0.04	63.6

* denotes statistical significance ($p<0.05$).

Annual Load Comparisons



Results – Nitrogen



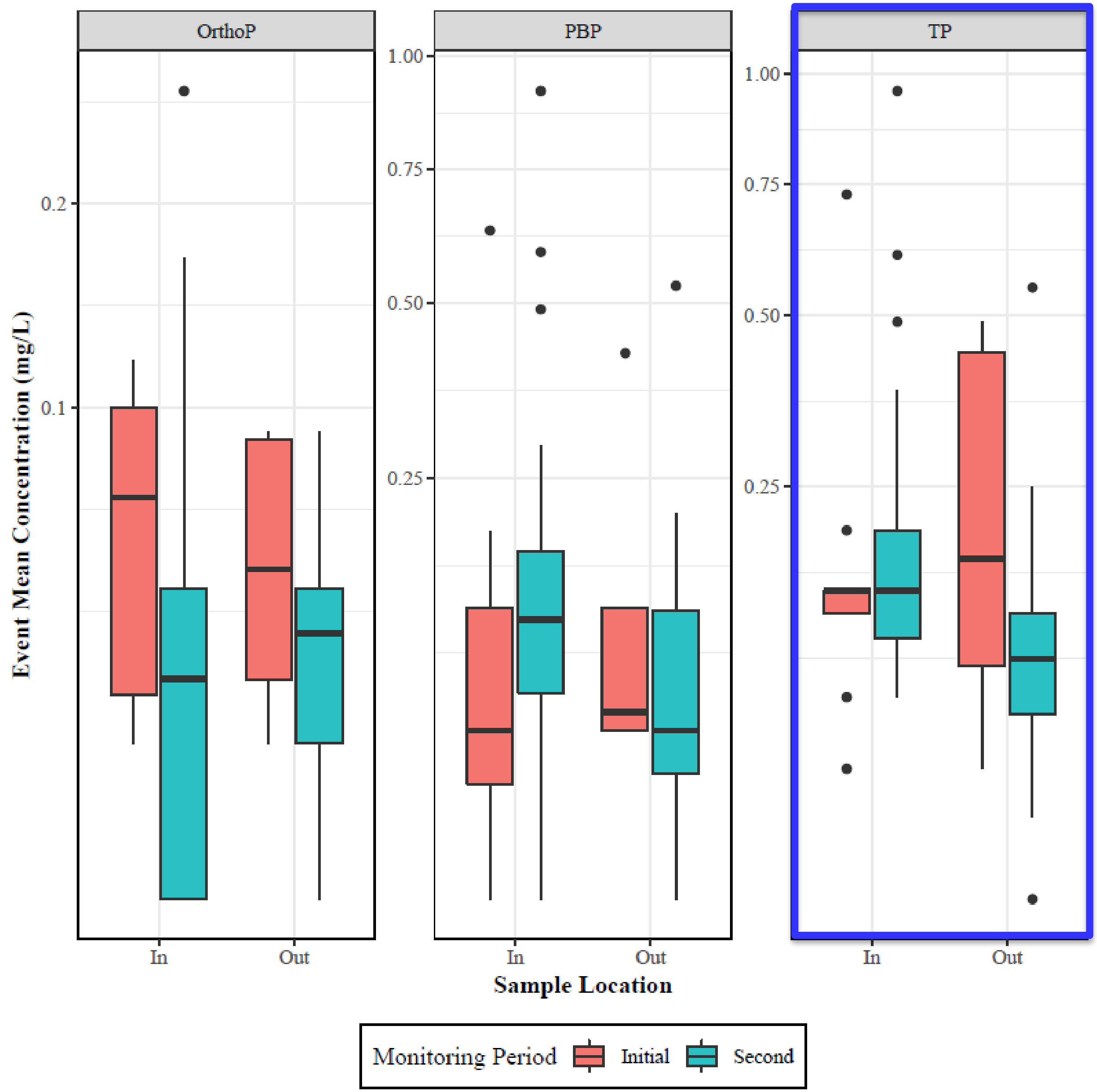
What's Different?

What's Different?

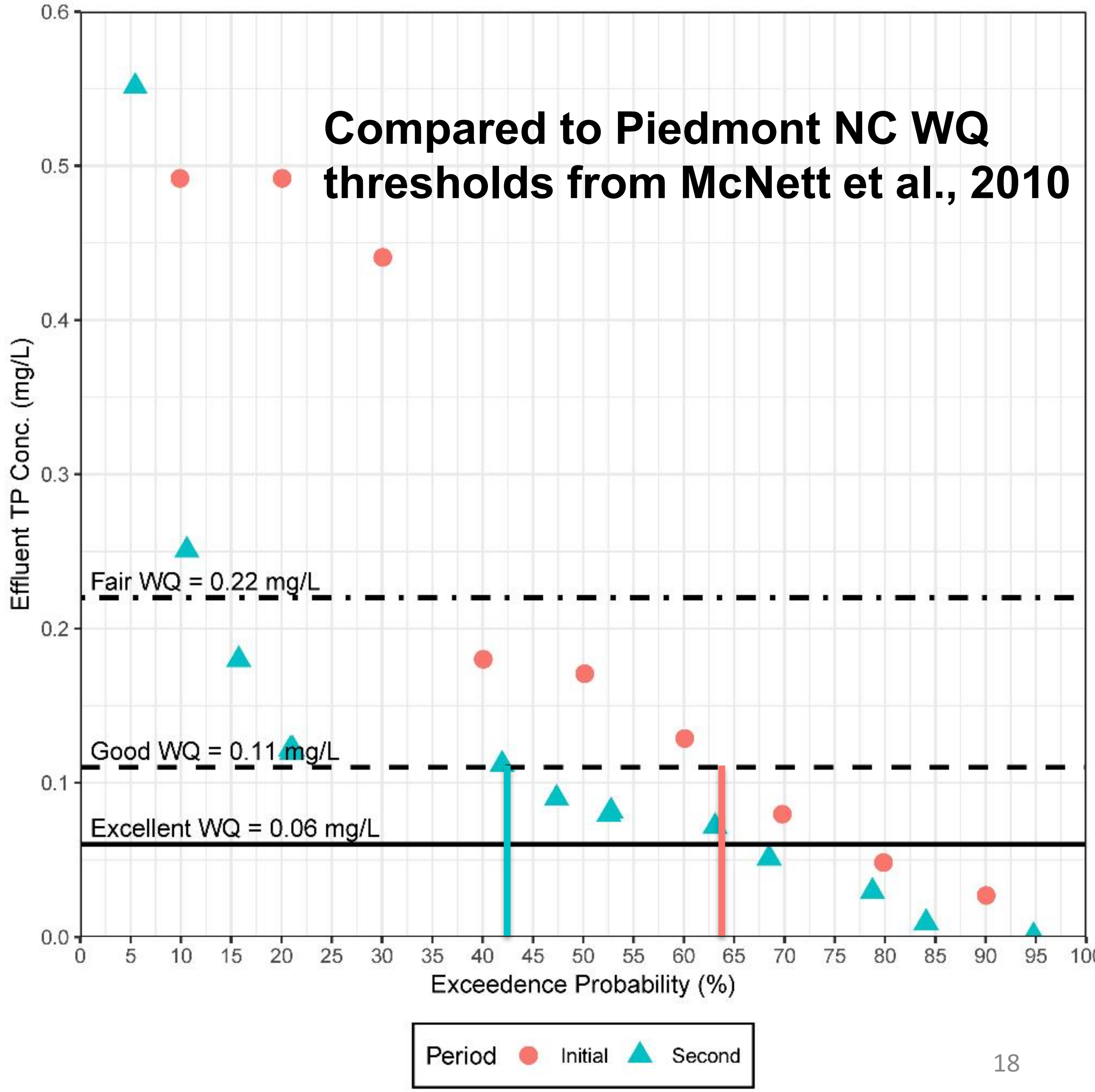
What's Different?

- **Collected soil media samples in February 2018**
  - **Average carbon content = 0.67% (665 mg/100 g media)**

Results – Phosphorus



Effluent TP Comparisons



Phosphorous Accumulation

Characteristic	Monitoring Period		
	Initial	Second	Sorption Capacity
Bulk Density (kg/m^3)	1023.7		
BRC Area (m^2)	90		
Media Depth (m)	0.2		
Media Volume (m^3)	18		
Media Mass (kg)	18,426		
M3P Conc. (mg/kg)	7.4	24.3	28
M3P Mass (g)	136	447	516

- At an average M3P accumulation rate of 19-20 g/yr, the top 20 cm of media will reach estimated sorption capacity in 3.5 years
  - Top 20 cm of media has an estimated 20 years of life, BUT
  - Media depth is 1.2 m

Take Home Points

- 2017-2018 monitoring period observed significant reductions in TAN, NO_3-N, TN, and TP
- Comparing monitoring periods:
  - TN removal sustained after 17 years
    - Increase in nitrate removal
      - Carbon source builds over time
  - TP removal improved
- High phosphorus concentrations building in the soil media
  - Elevated concentrations observed in the top 20 cm similar to Komlos and Traver (2012)
  - Media depth of 1.2 m should allow continued sorption capacity for future P removal

Take Home Points

- Median effluent concentrations are now below assigned values for TN and TP for nutrient reduction calculations from NC DEQ

Period	TN (mg/L)	TP (mg/L)
NC DEQ Credit	1.20	0.12
2002 – 2003	1.23	0.17
2017 – 2018	1.12	0.09

- Not only does bioretention work, it can get even better with time and may even be ***undervalued***

So for the Basin-wide Mega Model…

- Maybe an "Improvement Factor" should be implemented?
- Is this also true for other vegetated SCM's?

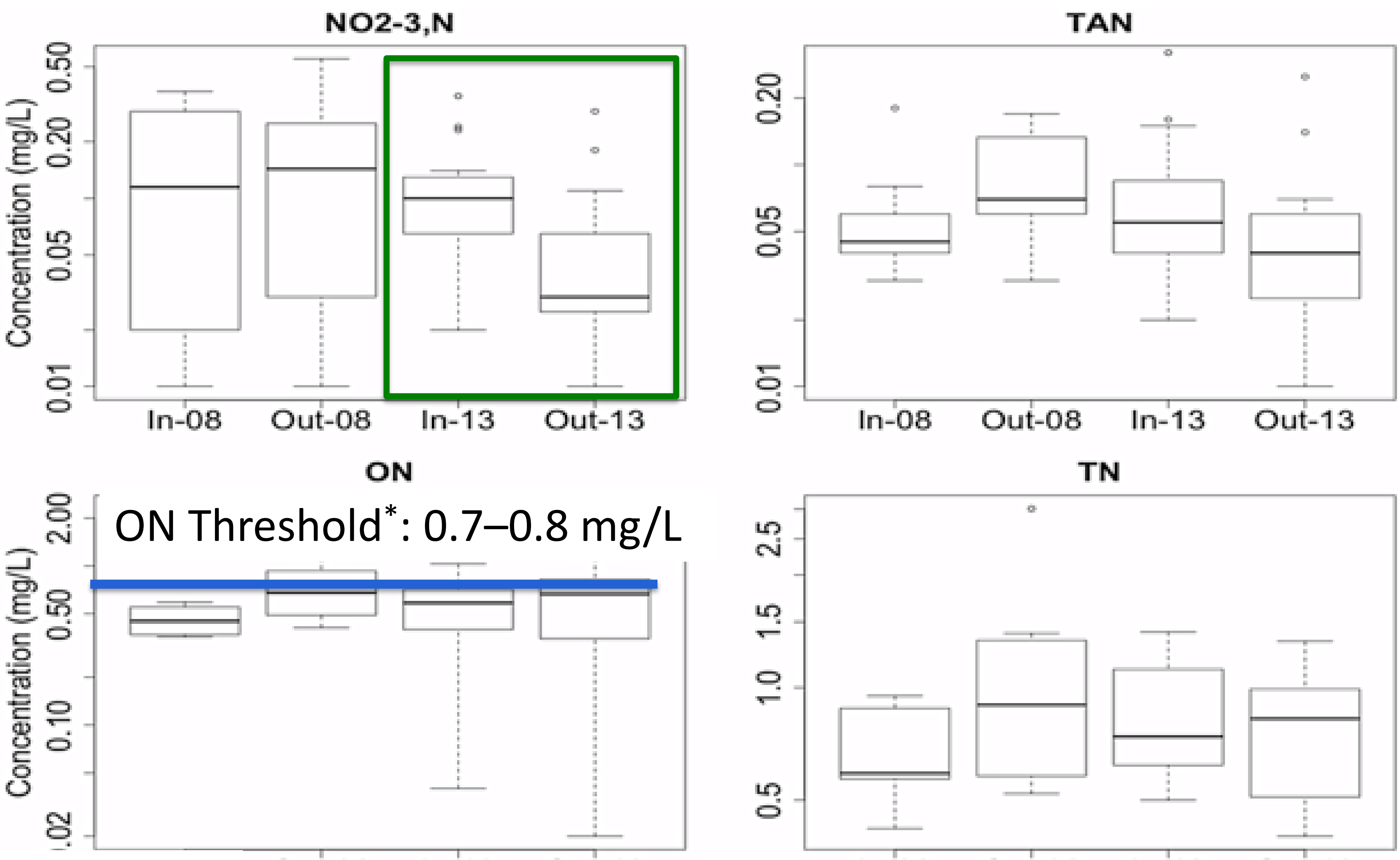
Monitoring Periods

2007 – 2008:
Lenhart and Hunt (2011)

2012 – 2013:
Merriman and Hunt (2014)

No Maintenance for
5 Years

Water Quality Services: Nitrogen



*Moore et al. 2011

So for the Basin-wide Mega Model…

- Maybe an "Improvement Factor" should be implemented?
- Is this also true for other vegetated SCM's?
- Do they, like wine, get better with age?

The first BRCs…

- 1990 – "Invention" in Prince George's County, MD
- 1993 – First BRC (rain garden) design guidance

ars…

e

Fast forward 24 years…

- We know that BRCs work
  - Hydrologic & nutrient benefits
    - (Davis et al. 2009; Hunt et al. 2012)
- And can continue to work for prolonged periods
  - If maintained…
    - (Komlos and Traver, 2012; Johnson and Hunt, 2016, 2019)

The catalysts for this research

Journal of Environmental Management 184 (2016) 363–370

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

ELSEVIER

Research article

Evaluating the spatial distribution of pollutants and associated maintenance requirements in an 11 year-old bioretention cell in urban Charlotte, NC

- Metal concentrations were well below remediation levels following 11 years of service
- Heavy accumulation of Mehlich-3 P, particularly in the forebay and areas near inlet
- Preferential flow is occurring in areas that are accumulating P → we're missing treatment

sustainability

MDPI

Article

A Retrospective Comparison of Water Quality Treatment in a Bioretention Cell 16 Years Following Initial Analysis

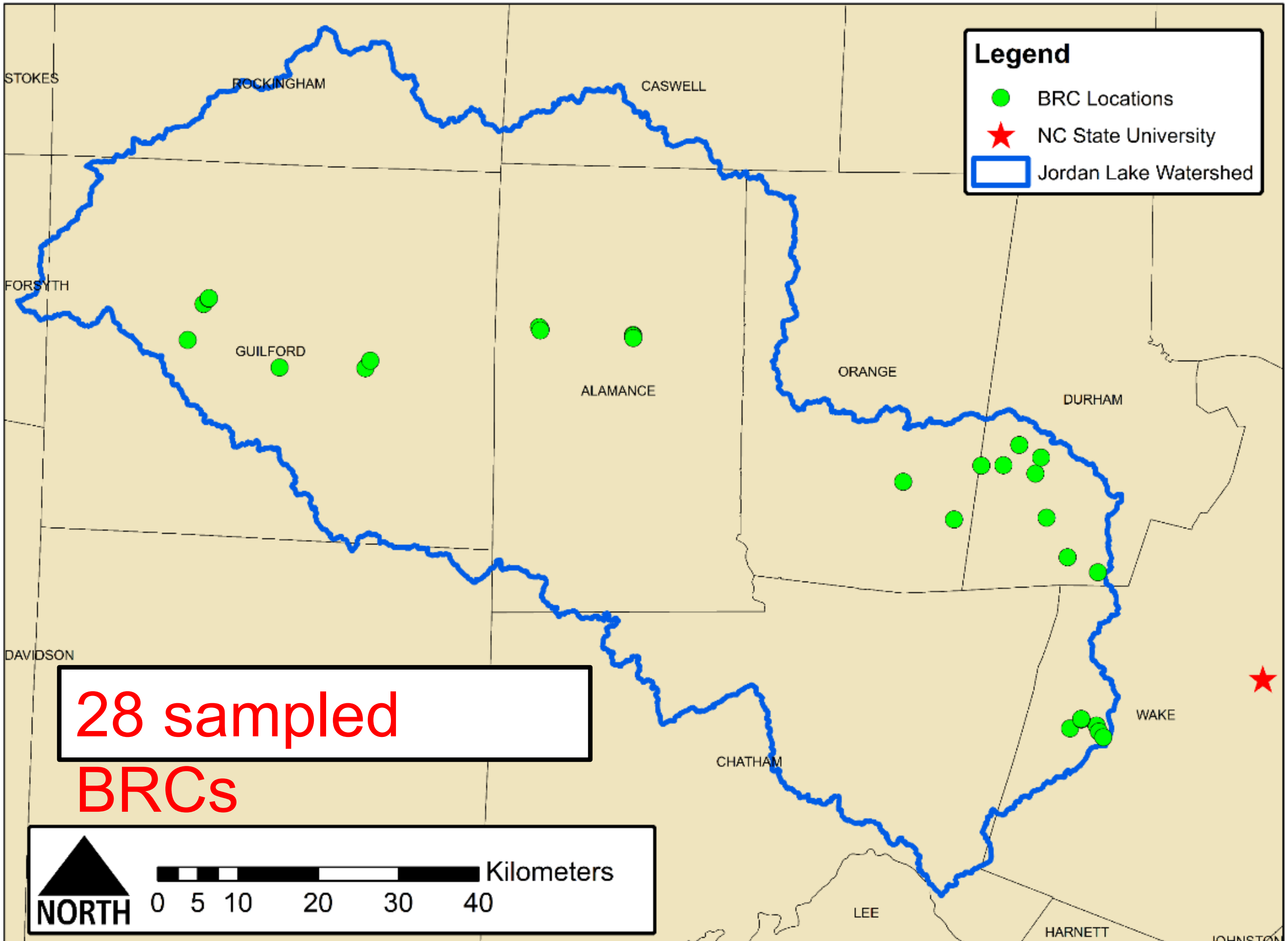
- After 17 years: significant reductions in TAN, NO_3-N, TN, and TP
- Comparing monitoring periods: increase in nitrogen removal
- P accumulating in the soil media
- Median effluent concentrations below assigned values for TN and TP for nutrient reduction calculations from NC DEQ

Sustainability 2019, 11, 1945; doi:10.3390/su11071945 www.mdpi.com/journal/sustainability

Research Questions

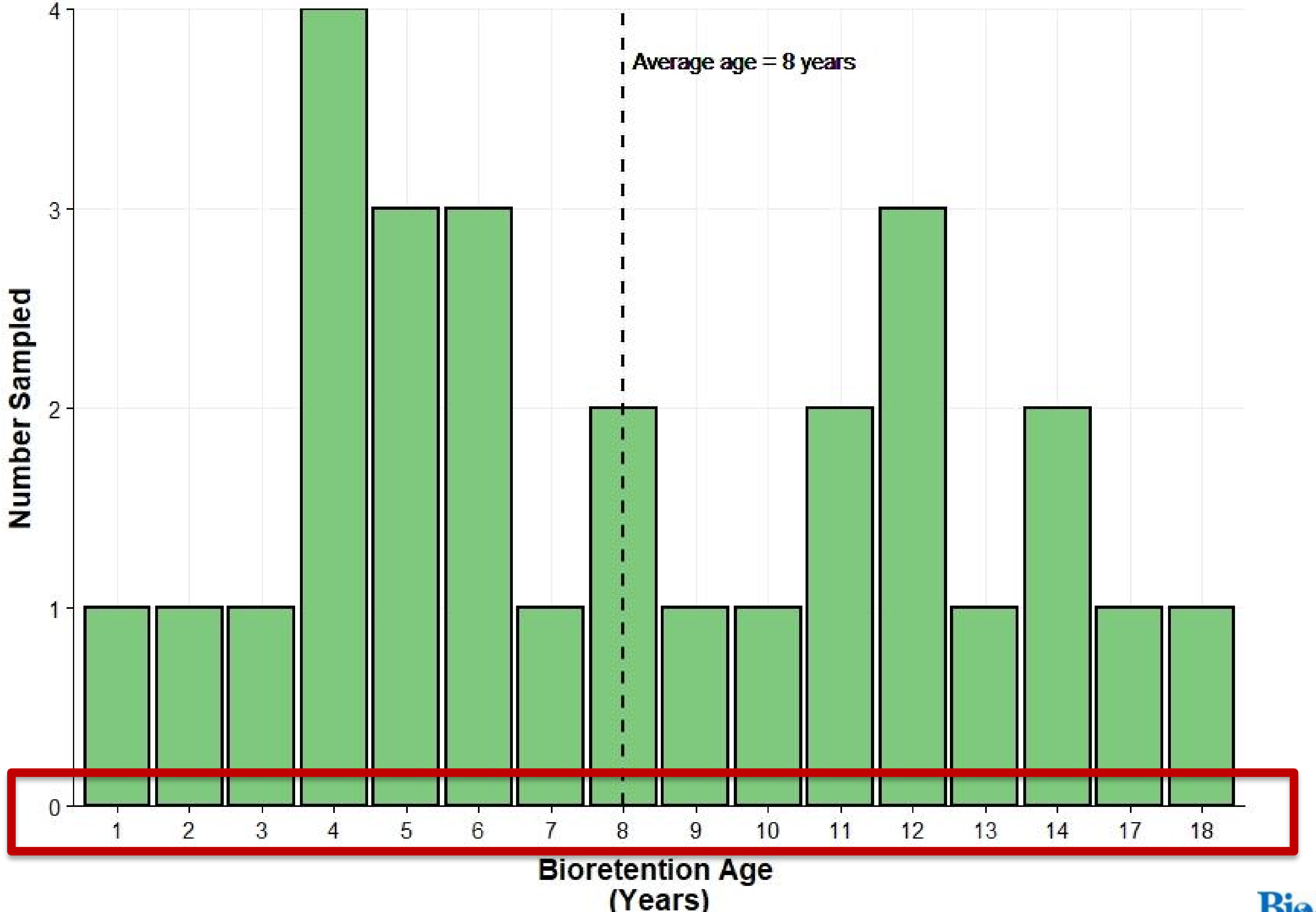
1. How do % sand, silt, and clay change with time?
   – Impacts hydrologic and water quality performance
2. What are the dynamics of carbon, organic matter, and nitrogen in BRC media?
   – Need to balance Carbon:Nitrogen ratio for treatment of N
3. How much Phosphorus is accumulating in BRC media?
   – Are older BRCs getting close to sorption capacity?
4. What design characteristics have the greatest impact on C:N and P?

Methods: Sample Collection

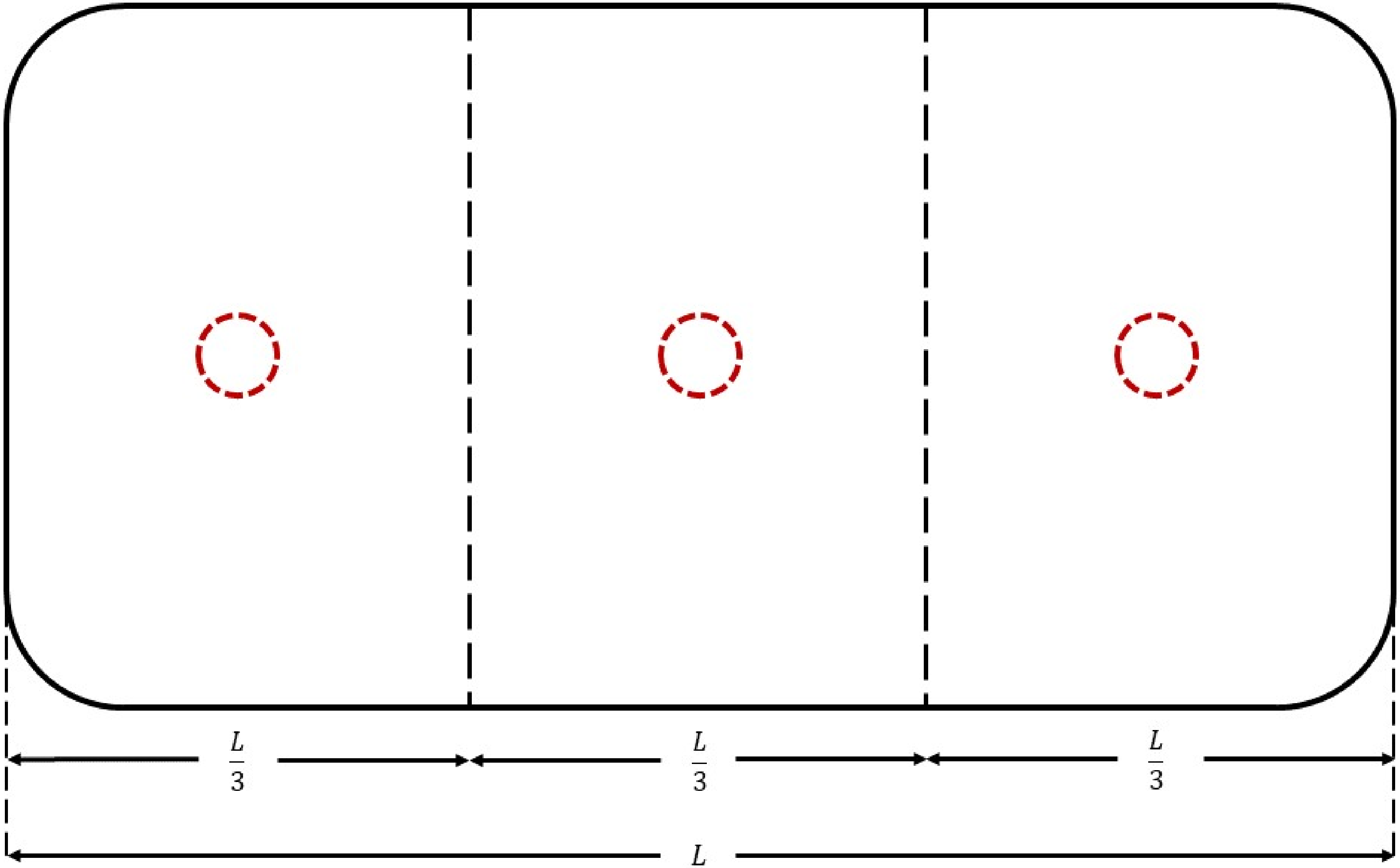


28 sampled BRCs

Methods: Sample Collection



Methods: Sample Collection



Legend

Sampling Location: 3 composited samples from top 20 cm at each location for nutrients
1 sample from top 60 cm at each location, composited for nutrients
1 sample from top 60 cm at each location, composited for particle size analysis

Sample Analysis

- Analyzed
  - TOC
  - TN
  - TP
- Calculated
  - Organic Matter = TOC x 1.724
    - (Nelson and Sommers 1996)
  - C:N = TOC/TN
  - P-Index = $\frac{0.117 \times TP \times Bulk\ Density}{1.2}$
    - (Hardy et al. 2014; Lammers & Bledsoe 2017)

- Particle Size Analysis
  - ASTM Hydrometer Method

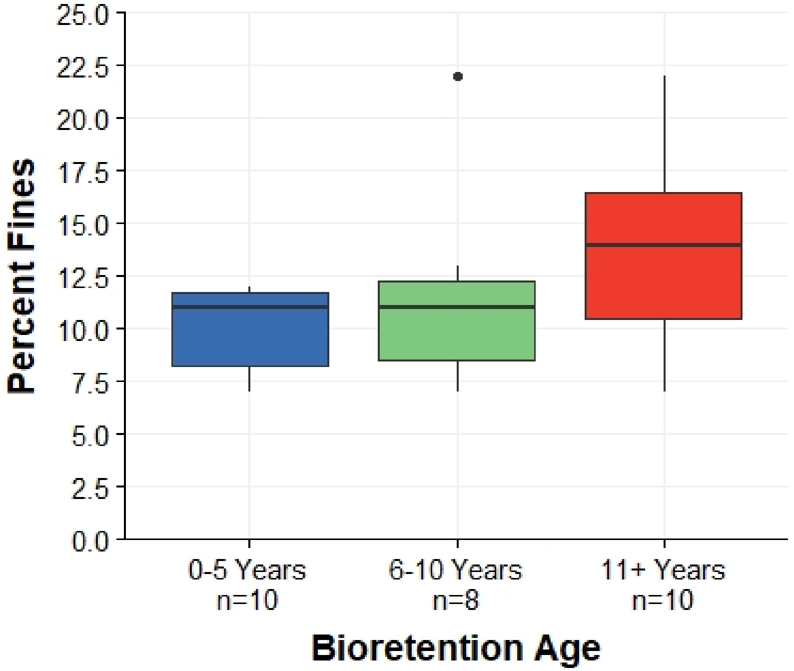
Random Forest Modeling

- Machine learning to assess importance of design and watershed variables on C:N and P-Index

Variable	Description
Land use type	Commercial, institutional, or residential
Drainage area imperviousness	Percentage of impervious area in drainage area
Jurisdiction	Jurisdictional subwatershed of each bioretention cell
Percent sand	Percent sand of bioretention media
Percent clay	Percent clay of bioretention media
Age	Age of bioretention cell at time of sampling
DA:SA	Ratio of drainage area to bioretention surface area
Forebay	Does bioretention cell include a forebay (Y/N)
Ponding Depth	Surface storage depth (cm)
Media Depth	Depth of filter media (m)
Vegetation type	Dominant vegetation type (Sod, shrubs, or trees)
Mulch	Does bioretention cell include a mulch layer (Y/N)

Physical Characteristics

- 22 sampled BRCs were sandier than NC specifications for BRC media (75-85% sand)
- 4 sampled BRCs exceeded fines maximum (15% fines)
- Fines content significantly increased in older BRCs (p=0.023)
- Changes likely due to:
  1. Sedimentation from watershed
  2. Changes in media specifications over time

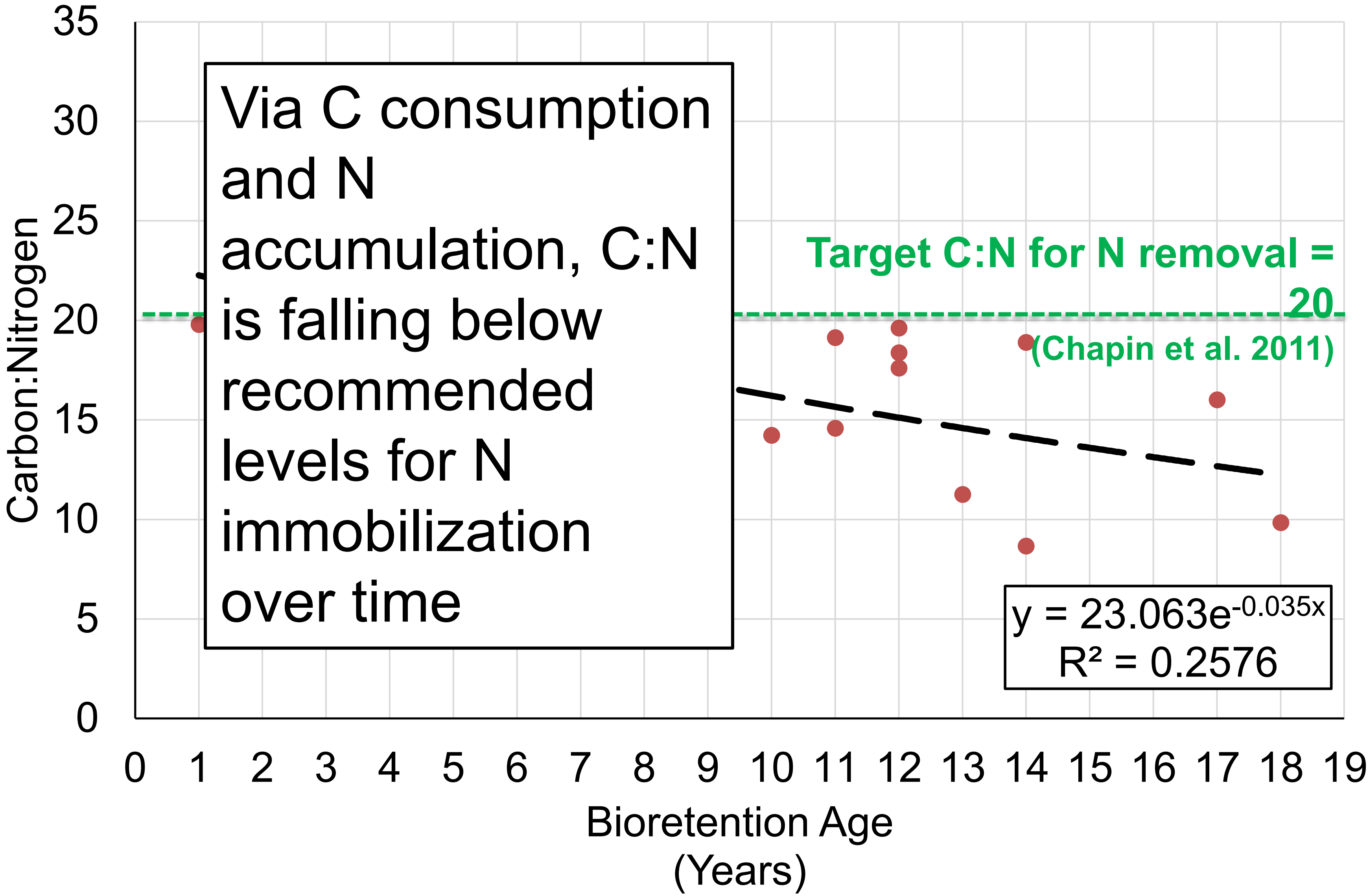


Organic Matter

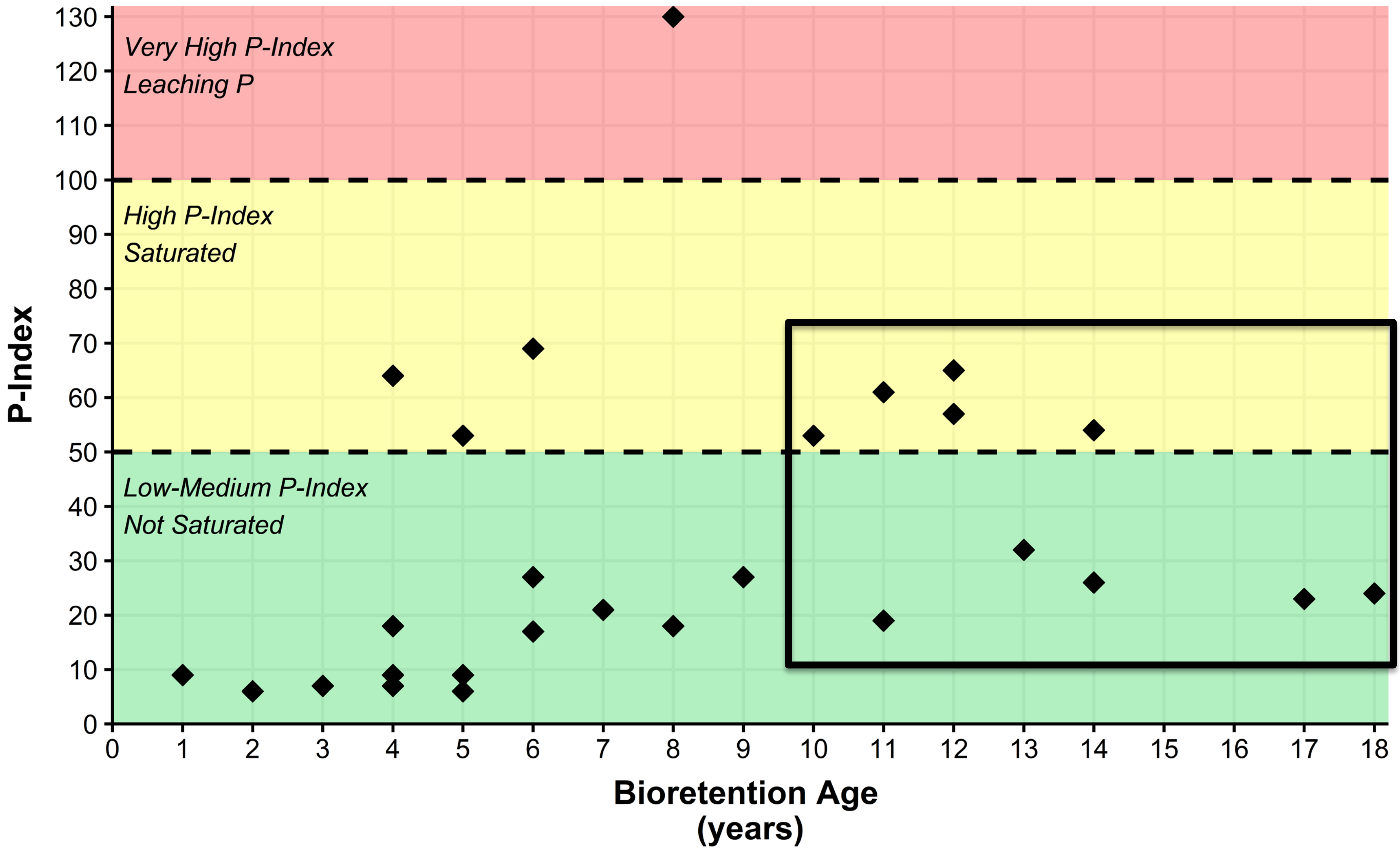
- Median OM = 2.3% by weight
- Bootstrapped 95% CI = 1.6% – 3.6%
- No significant trend in OM

- BUT…while calculated from TOC
  - 95% CI less than recommended 5% OM in media for removal of metals, hydrocarbons, and nutrients
    - (Hunt et al. 2012; Peterson et al. 2015)

Carbon:Nitrogen

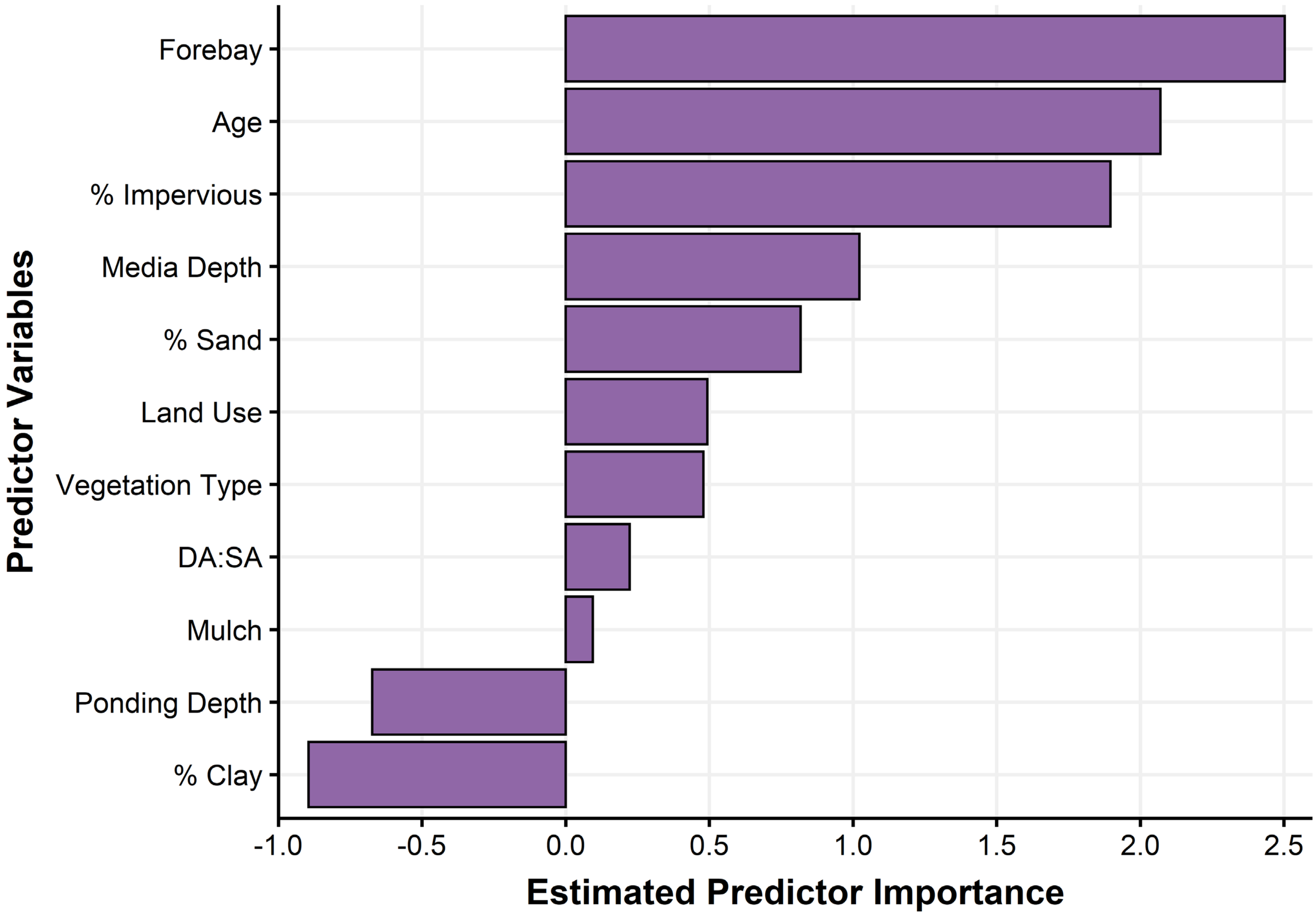


P-Index

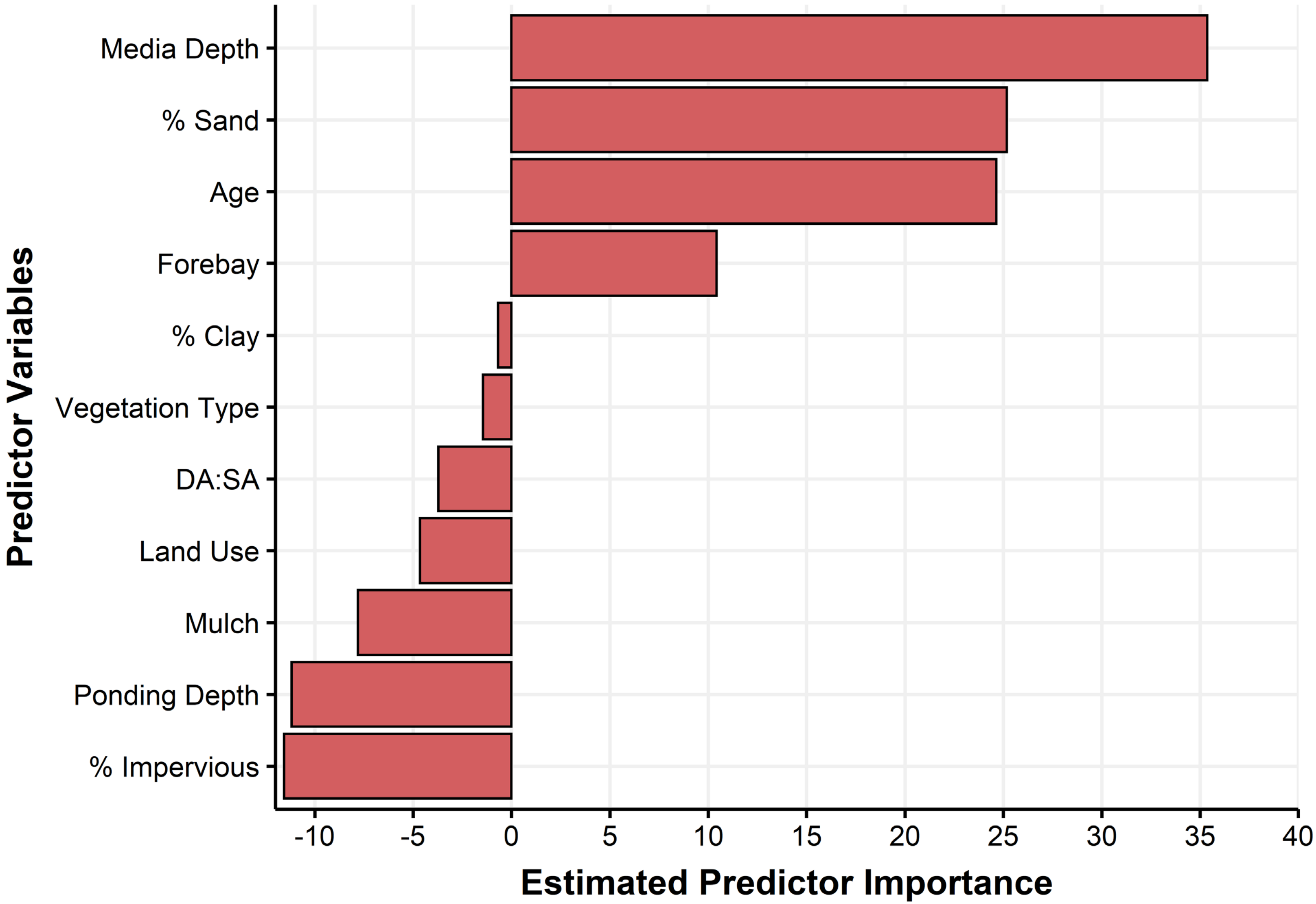


- Note: P-Index estimated from TP

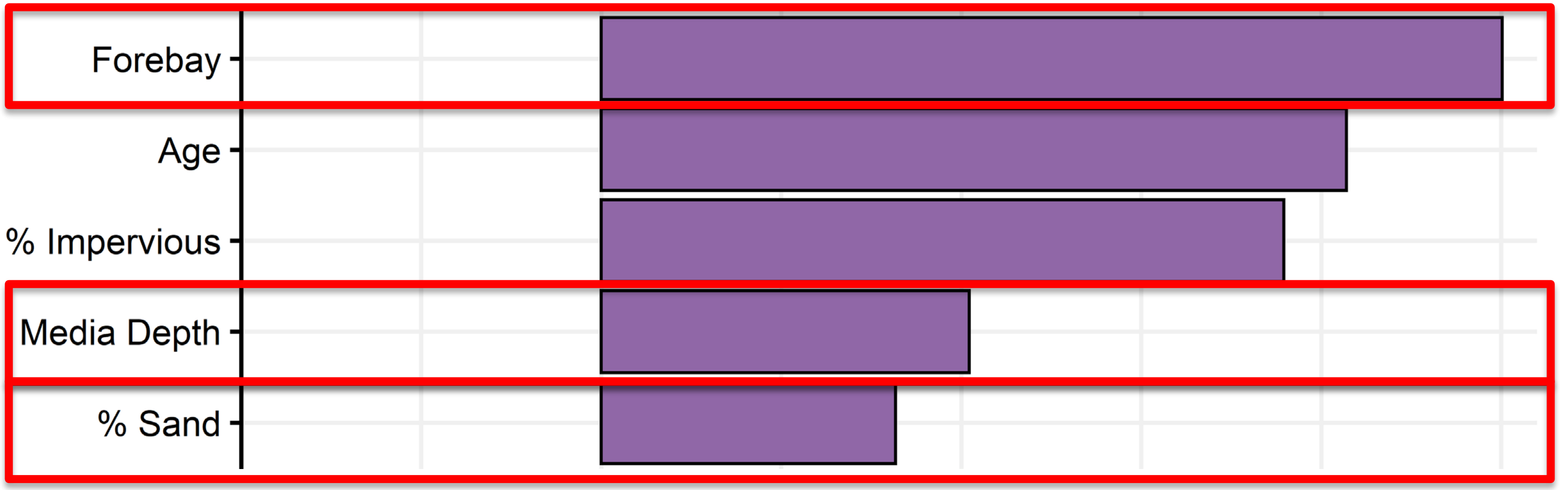
Random Forest: C:N



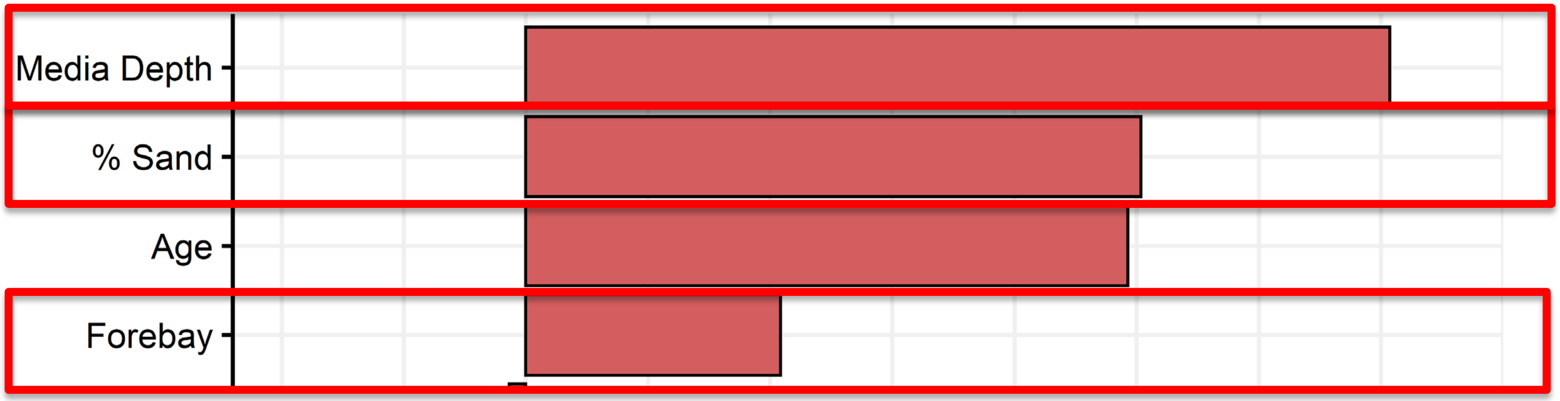
Random Forest: P-Index



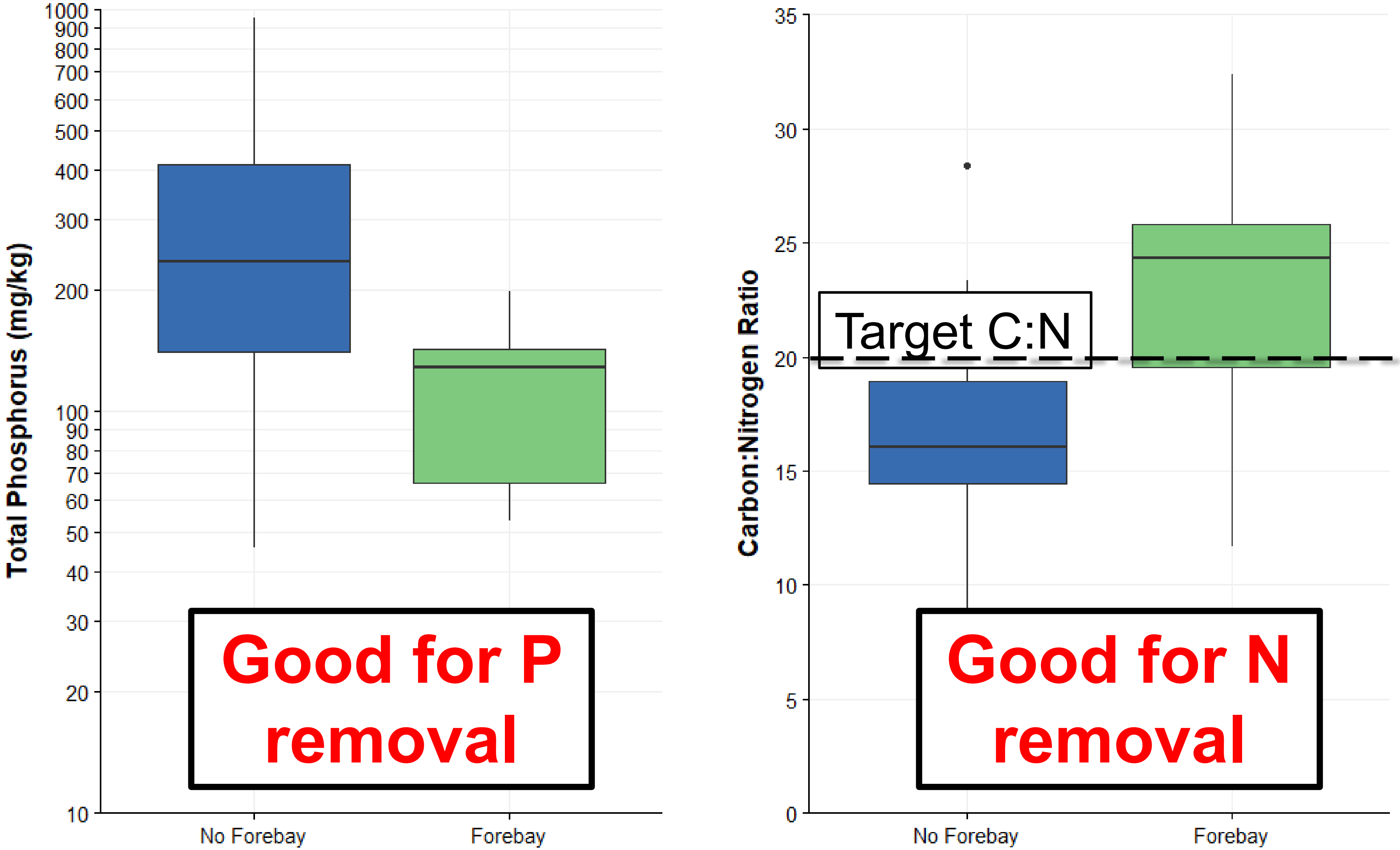
Top Variable Importance: C:N



Top Variable Importance: P-Index



Forebays: A Difference Maker



Forebays

Recommendations

BIORETENTION RECOMMENDATION 1: DISPERSE FLOW OR ENERGY DISSIPATION.
Flow should enter the bioretention cell via disperse flow or an energy dissipater.

Inflow should enter a bioretention cell via disperse flow with a velocity less than 1.0 foot per second for mulched cells or 3.0 feet per second for grassed cells to prevent erosion. Disperse flow can be provided via a gently sloping parking lot that drains toward a bioretention cell. If inflow is concentrated in a pipe or swale, then a rip rap lined entrance, a forebay, or other energy-dissipating device should be used. If a forebay is used, it can both dissipate energy and provide pre-treatment.

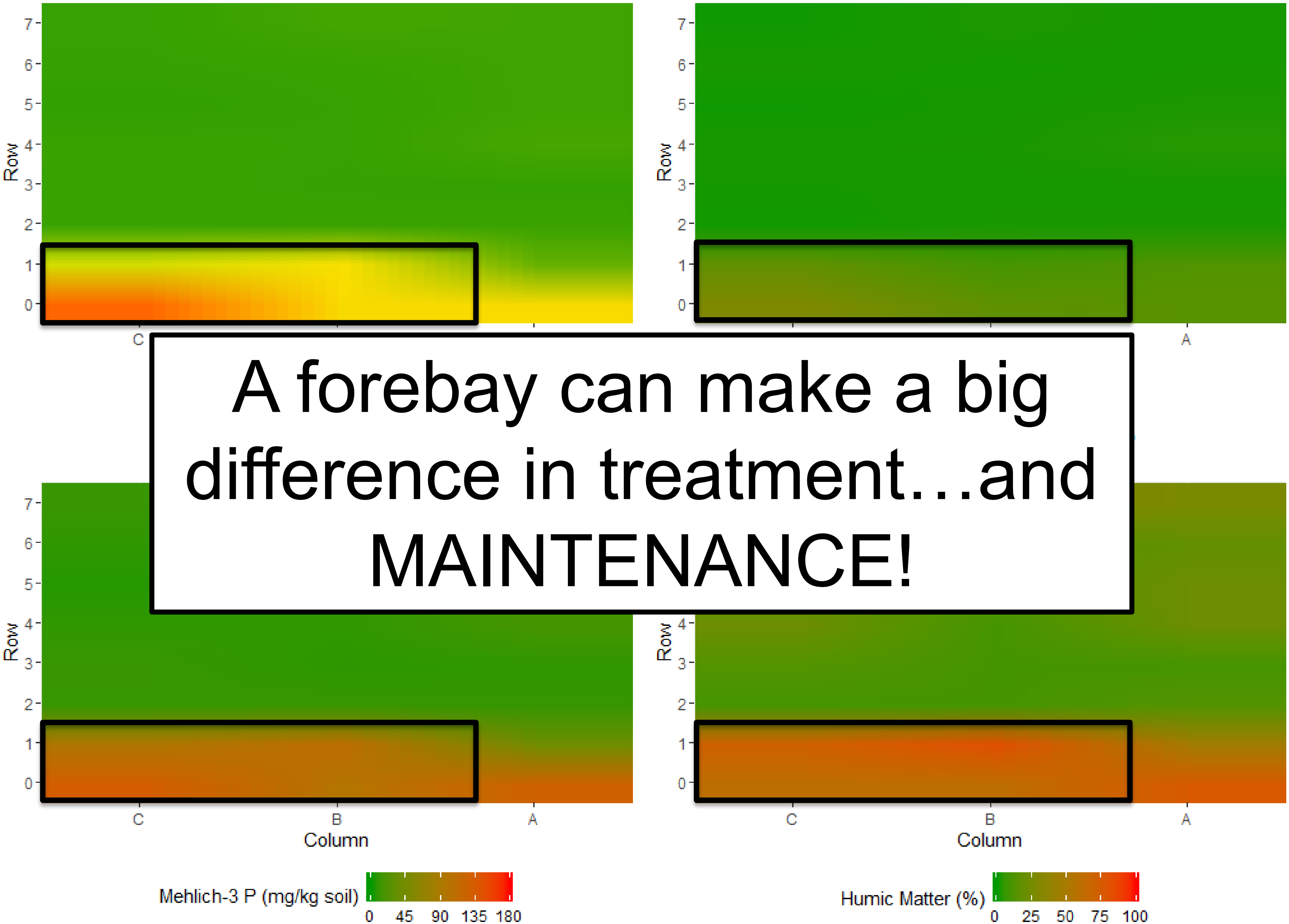
BIORETENTION RECOMMENDATION 2: PRETREATMENT.
Pretreatment should be provided.

A bioretention cell should have a pretreatment area. The most commonly used pretreatment devices are:

- ***A grass and gravel combination:*** This should consist of 8 inches of gravel followed by 3 to 5 feet of sod. In eastern and central North Carolina, hybrid Bermuda and centipede have been used successfully. In the mountains, fescue and bluegrass are appropriate.

- ***A forebay:*** The forebay should be 18-30 inches deep and used only in areas where standing water is not considered a safety concern. The forebay should be deepest where water enters, and more shallow where water exits in order to dissipate hydraulic

Forebays



A forebay can make a big difference in treatment…and MAINTENANCE!

Take Home Points

- BRC media is sandier than it should be (in NC)
  - Careful attention needed to BRC media ticket with PSD during installation
  - Particle size specifications are made to balance infiltration for hydrologic goals with HRT needed for WQ goals
- C:N is significantly decreasing in BRCs with age
  - C:N is important component in N treatment
  - Amend top layer of BRCs with a high C:N material (woodchips, sawdust, etc) when performing maintenance (e.g., scraping)

Take Home Points

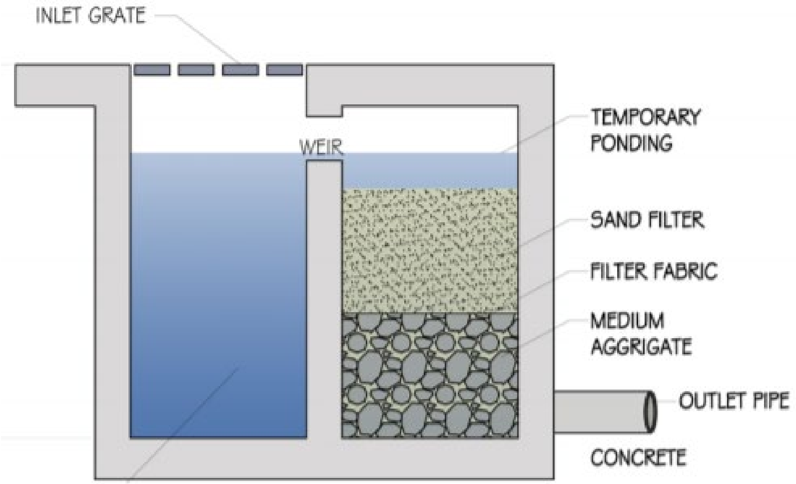
- P-Index is significantly increasing in BRCs with age
  - Although increasing, lower depths of media should continue providing treatment
- Forebays are a difference maker in C:N and P-Index
  - Retrofit opportunity!
  - Consider requiring forebays on new BRCs
- Vegetation type? Not so much.

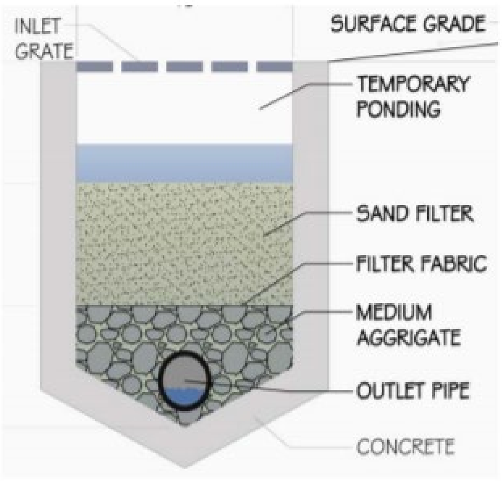
Parting Thoughts…

- Am I saying ignore these practices and they'll work better?
  - NO!
- Am I saying that vegetated systems have self-healing mechanisms? That that are resilient?
  - YES! YES!
- Human Intervention/Maintenance is needed
  - Keep SCMs looking good, Prevent Mosquito proliferation, and maintain flow
- Vegetated SCMs kinda help us out.

Stormwater Sand Filters

The "Setting": Folks want to use them here, but scant data exist regionally to assign removal credits





NCDEQ Stormwater Design Manual Section C-6. Sand Filter

Treatment Efficiencies (%)

Study	TSS	TP	TN	TKN	Fecal Coli.	T Zn	T Pb
(Zarezadeh et al., 2018)	93					43	79
(Kandasamy et al., 2008)	32-76	39-41	39-61	70	65-79	79-83	
(Barrett, 2003)	90	39	22	51	65	80	87

Pollutant Removal Efficiencies from 8 Sand Filters in Sydney, Australia, Central Texas, and Southern California

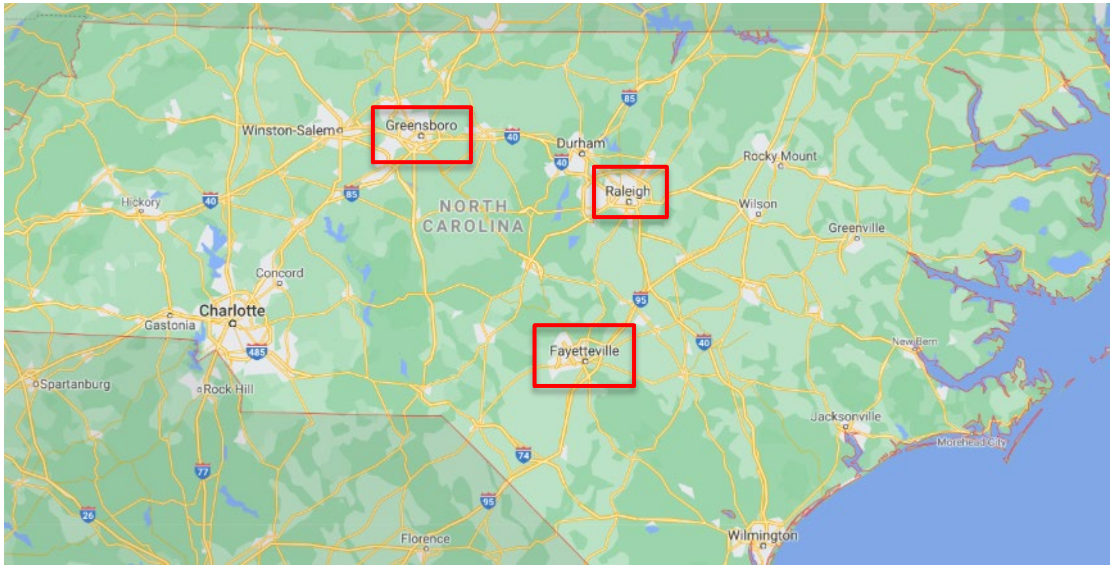
Research Questions

- Sand filter performance in NC's humid subtropical climate?
- Performance comparison to NCDEQ stormwater credits?
- Internal water storage impact on treatment performance?

Methods

- 4 sand filters total in Fayetteville and Greensboro
- Modification to one filter in each city
- Lab analysis for removal efficiency of TSS, TN (NO_3 + NH_3), TP (OP)

Image of North Carolina from Google Maps



RNR Tire Express
Fayetteville, NC

Cape Landing Apartment Complex, Fayetteville

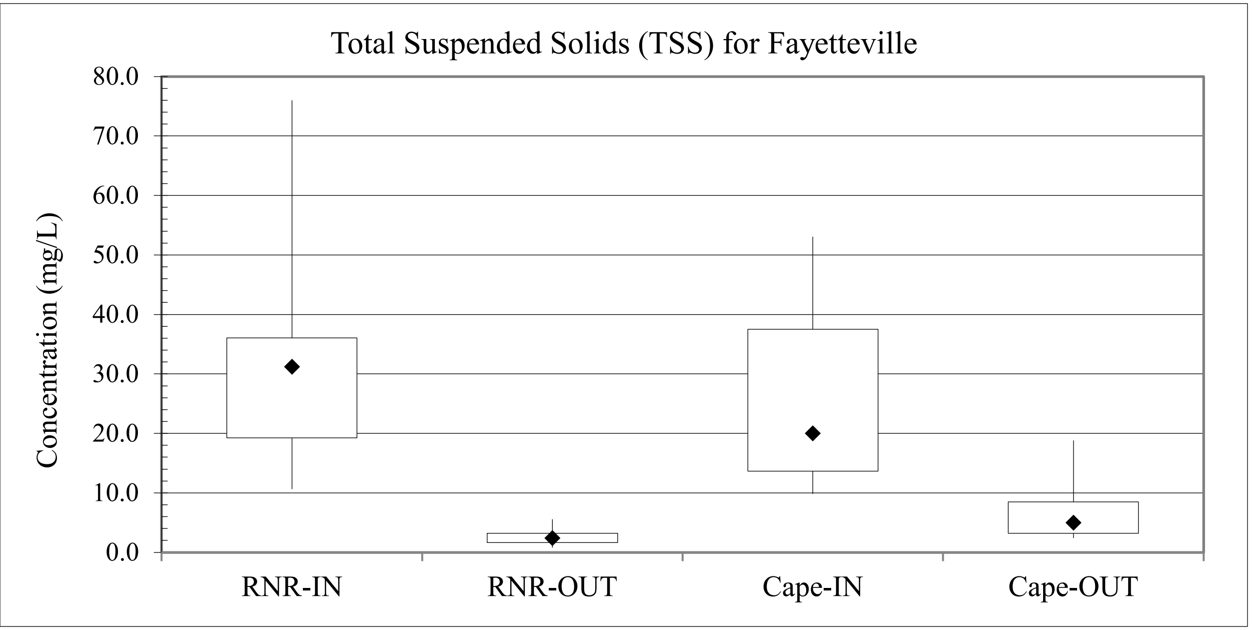
Park Place Salon, Greensboro

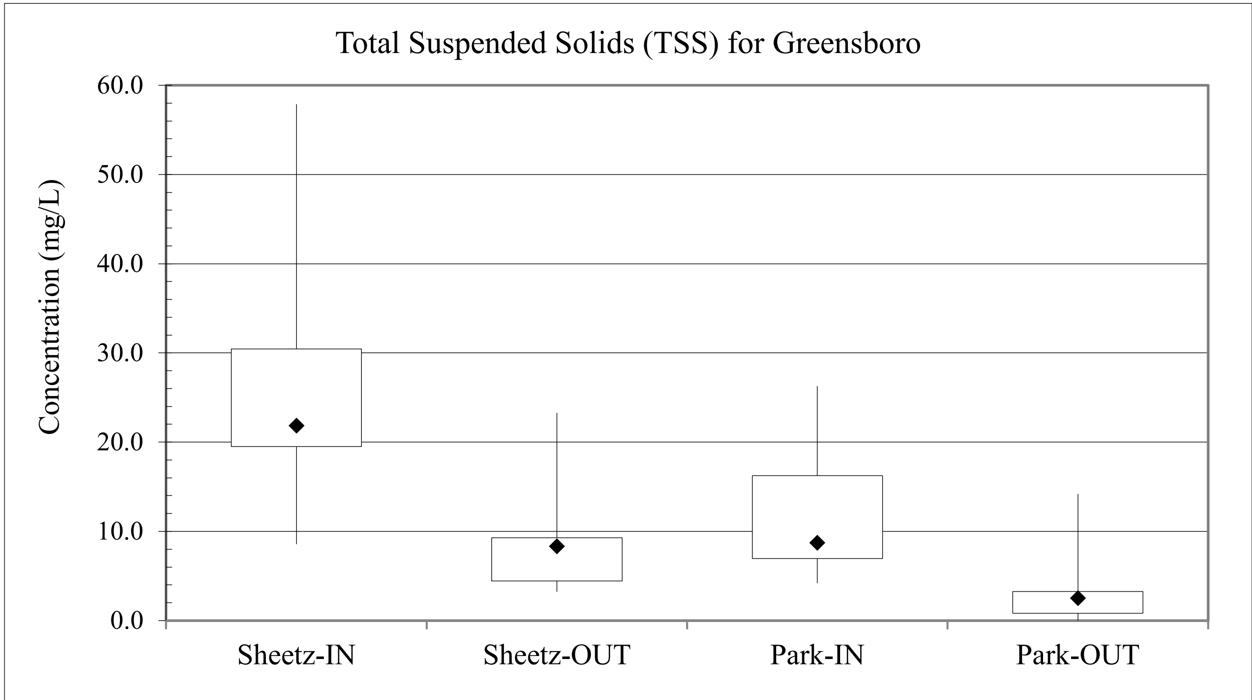
Sheetz Greensboro

Phase One Treatment Efficiencies (%)

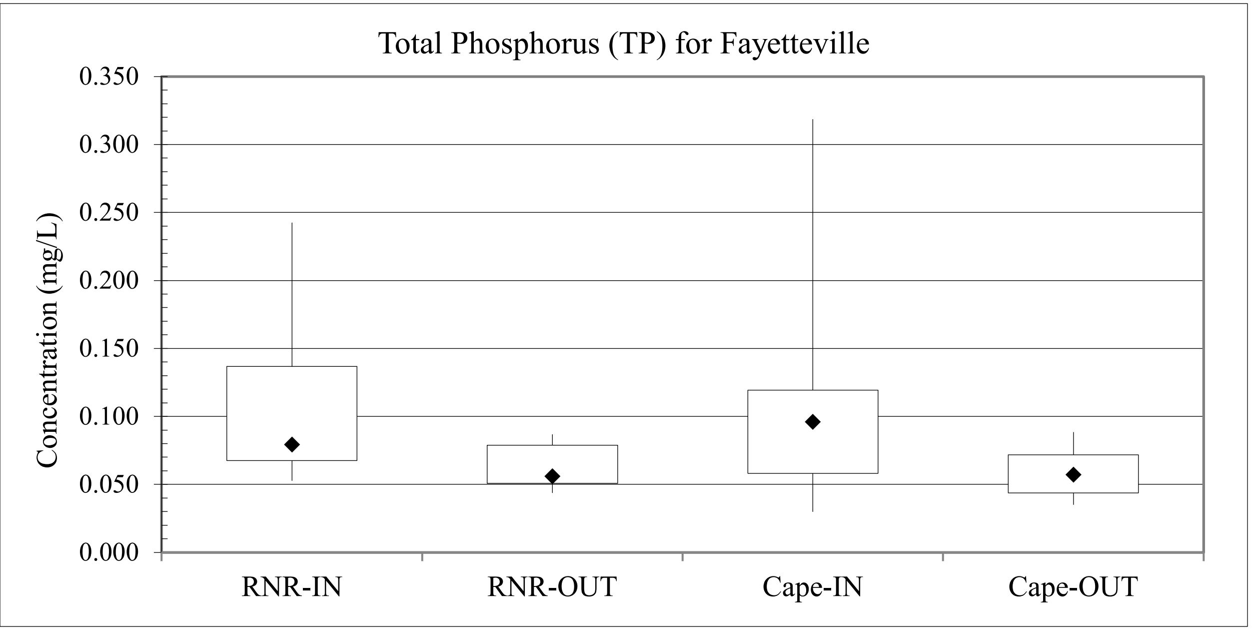
Site	TKN	NO3-N	NH3	TP	OP	TSS
Sheetz	58	-80	6	-2	-54	58
Park Place	-26	-296	-204	20	28	71
Cape Landing	31	-98	76	32	-4	67
RNR	42	-20	52	23	-51	89
Range	-123 to 82	-722 to 64	-675 to 97	-153 to 79	-268 to 84	-15 to 98

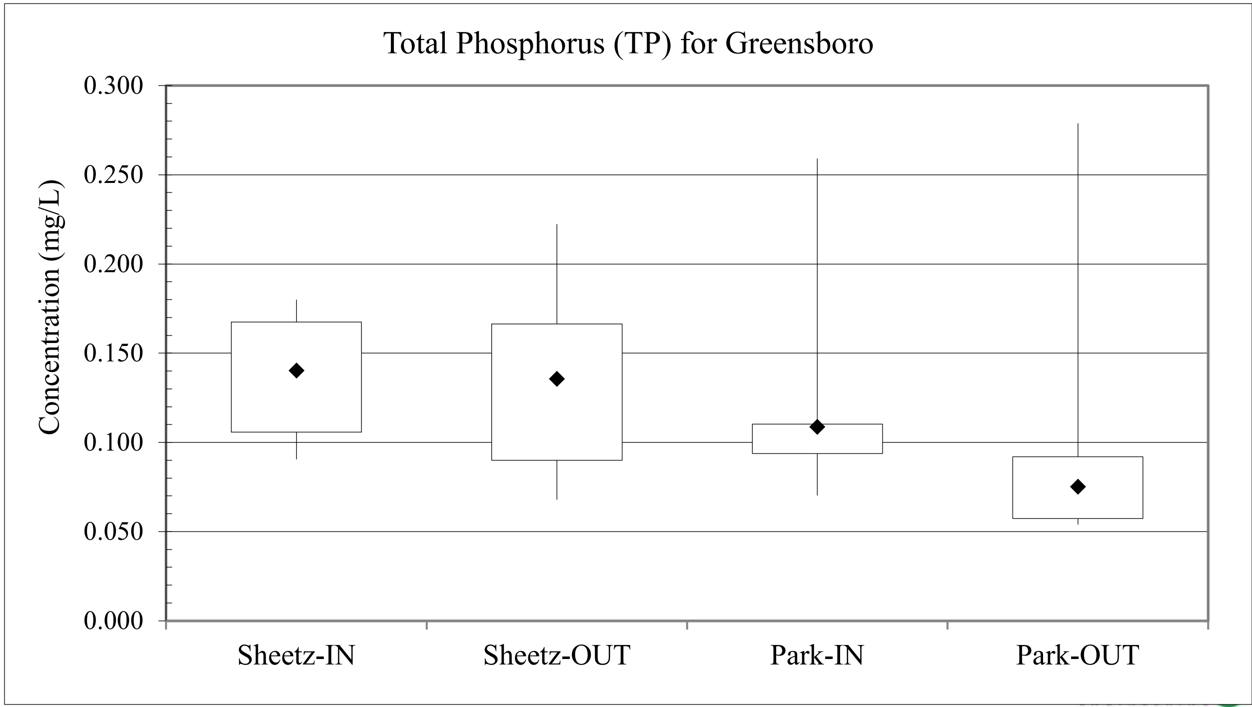
TSS Trapping



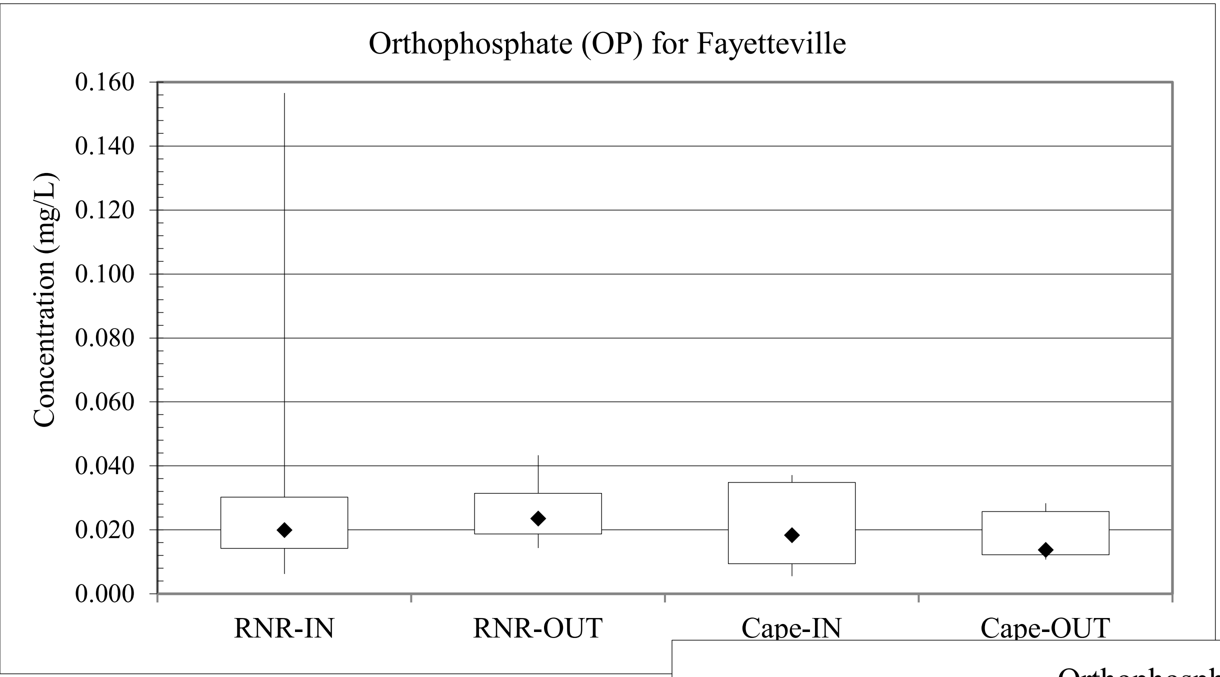


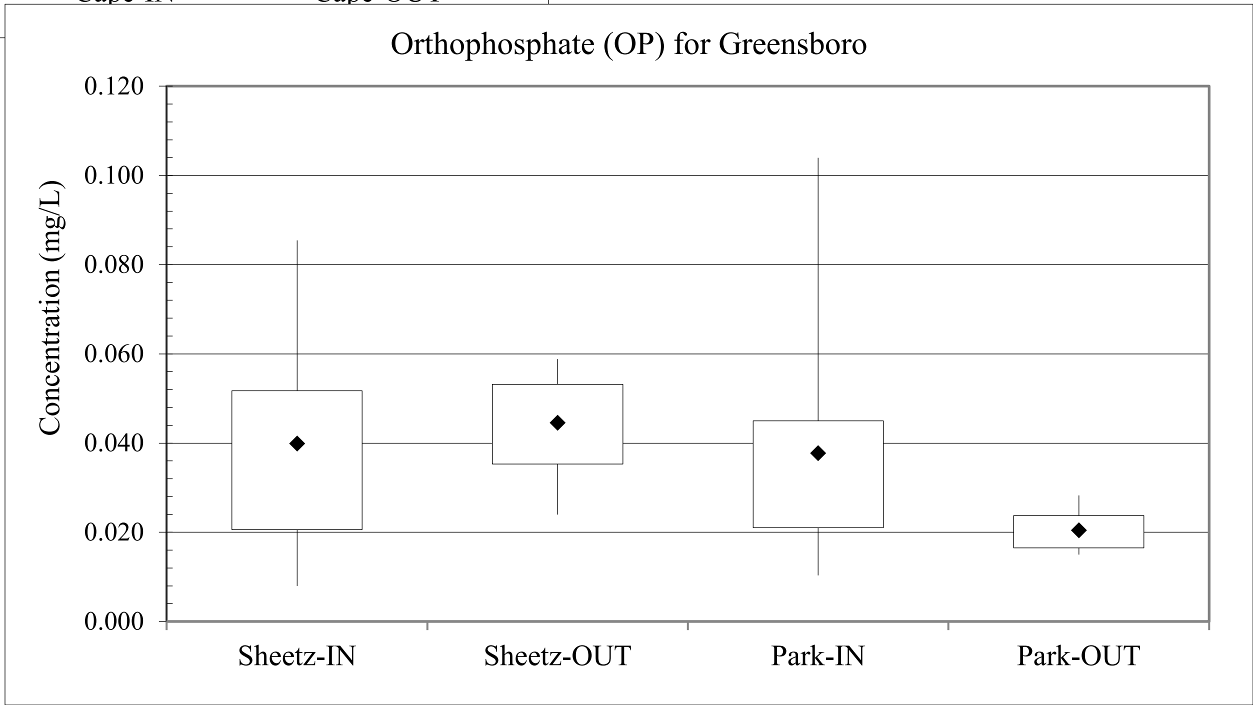
Phosphorus Capture



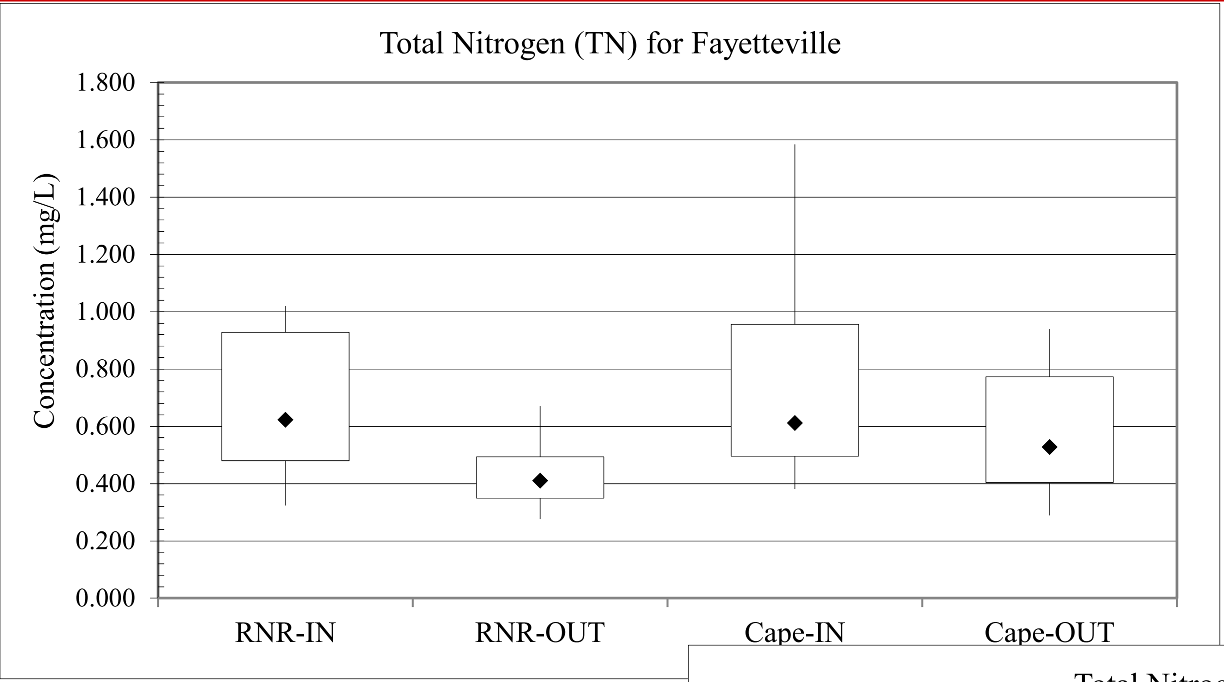


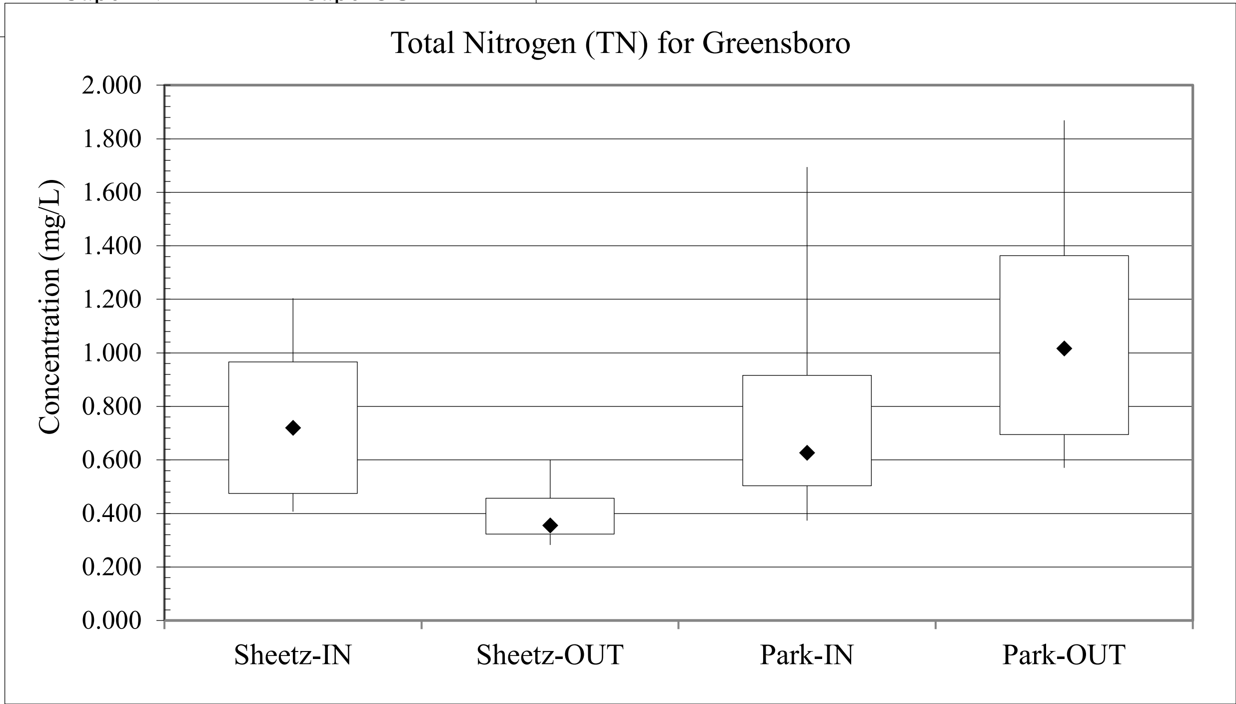
Ortho-P Sorption





TN "Reduction"





So, what do we know?

- As expected, great TSS removal across all sites
  - Confirmed this is a primary SCM
- TP results generally good
  - Little Ortho-P removal
- TN “removal” varies rather widely
- Inflow concentrations have been generally low

Previous: Phase I
Now Phase II: Internal Water Storage

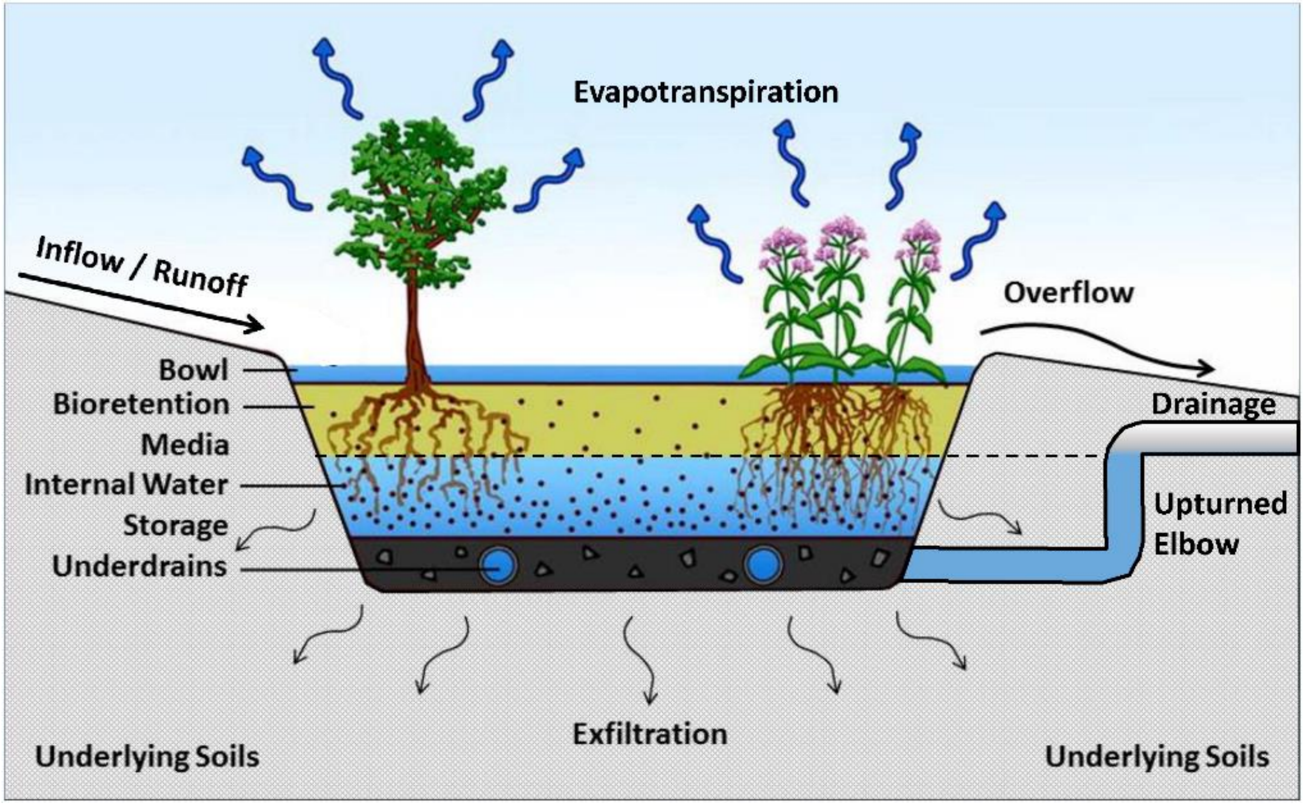
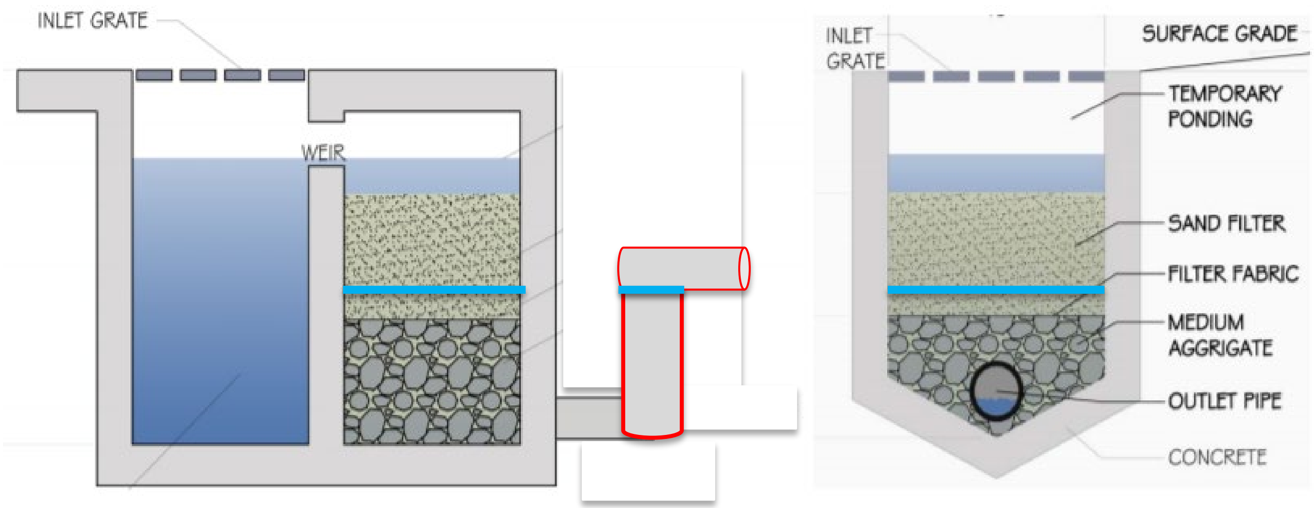


Diagram of Internal Water Storage in a Bioretention Cell

Stormwater Sand Filters – with IWS



NCDEQ Stormwater Design Manual Section C-6. Sand Filter

Internal Water Storage Installed

Sheetz (Greensboro)

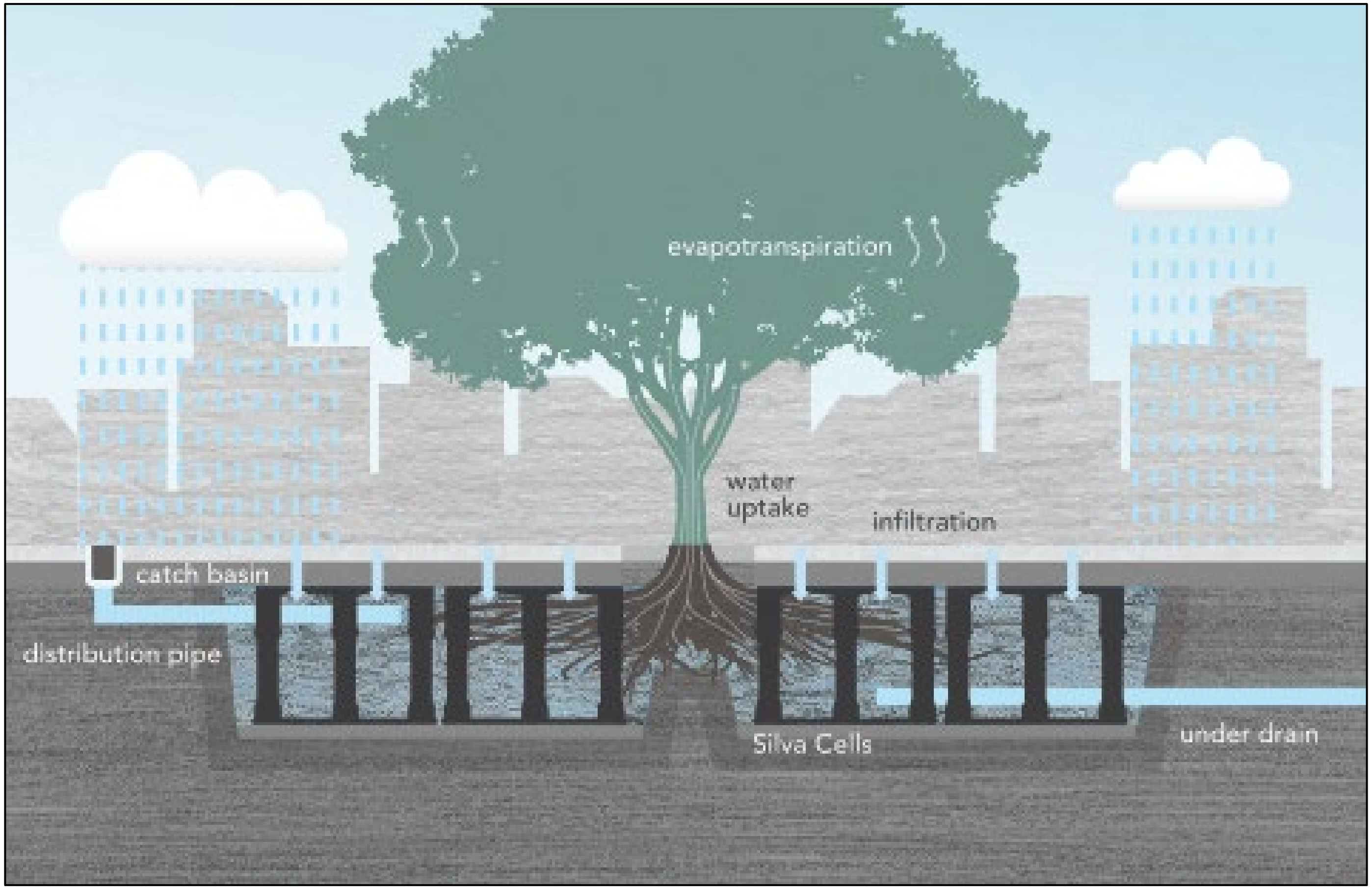
Cape Landing (Fayetteville)

Urban Trees

Are these happy little trees?

DeepRoot Silva Cells®

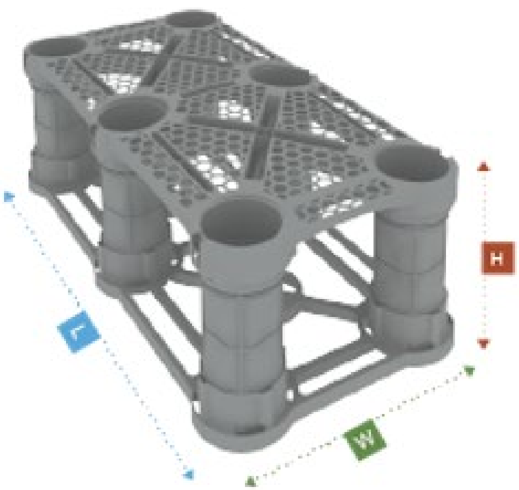
- Modular suspended pavement system using soil volume to support **large tree growth** and **stormwater management**



DeepRoot Silva Cells®

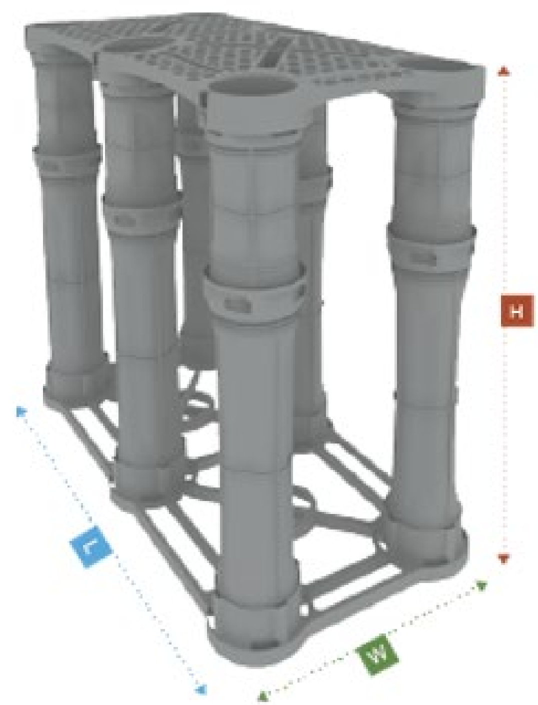
H Height: 16.7" (424 mm)	H Height: 30.9" (784 mm)	H Height: 43" (1092 mm)
W Width: 24" (600 mm)	W Width: 24" (600 mm)	W Width: 24" (600 mm)
L Length: 48" (1200 mm)	L Length: 48" (1200 mm)	L Length: 48" (1200 mm)

1x

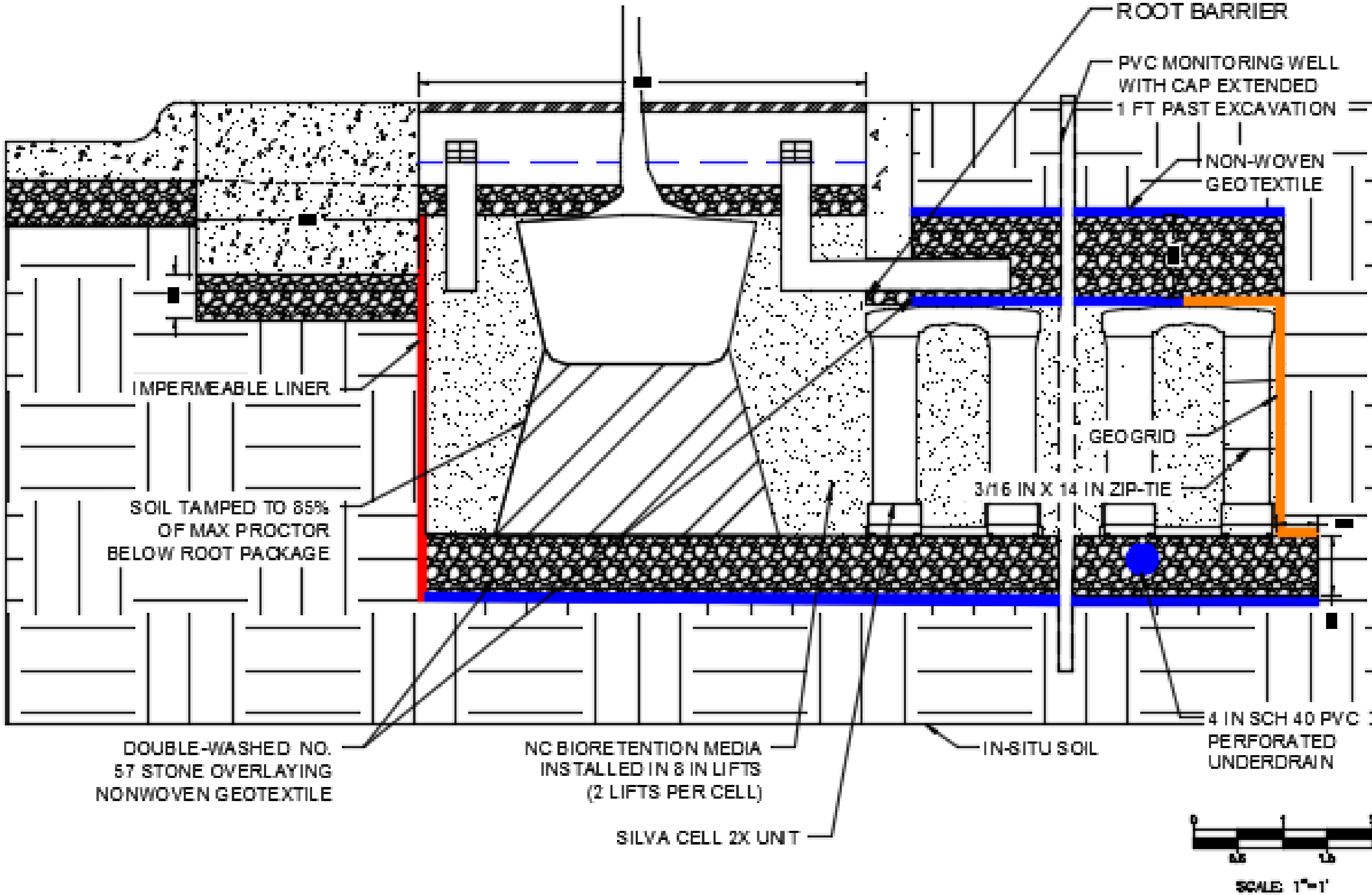


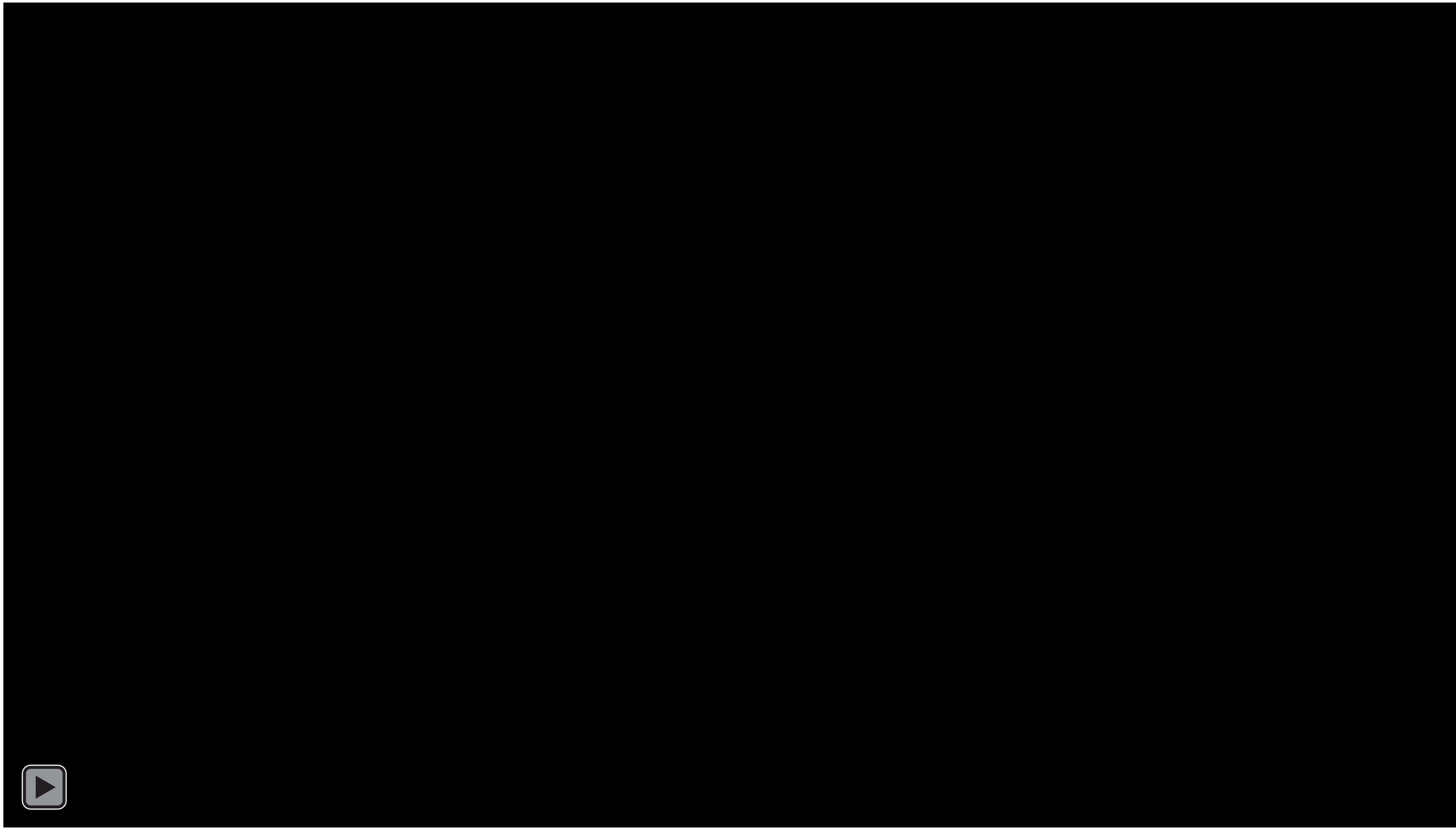
2x

3x

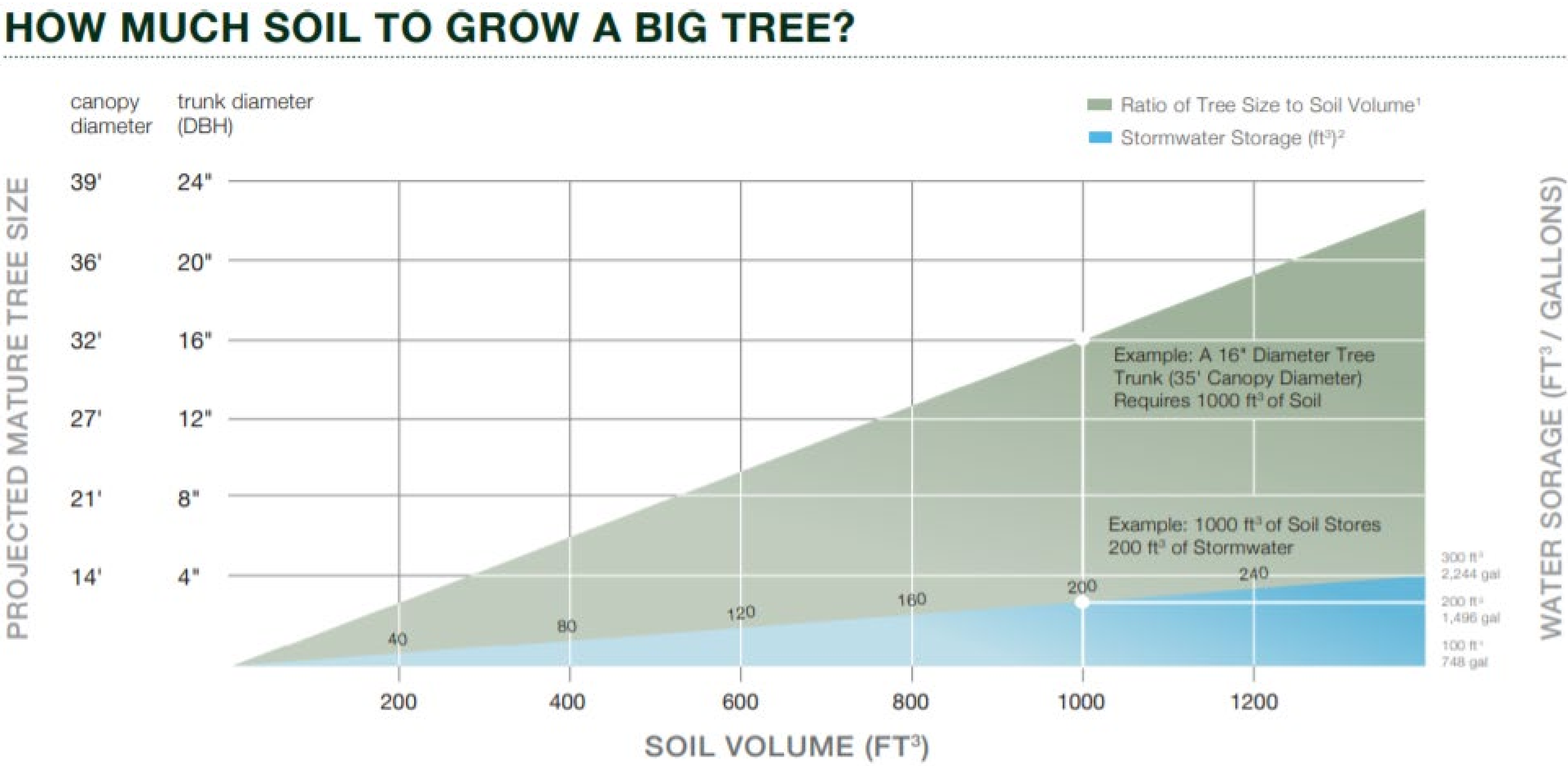


DeepRoot Silva Cell® Components





DeepRoot Silva Cells®

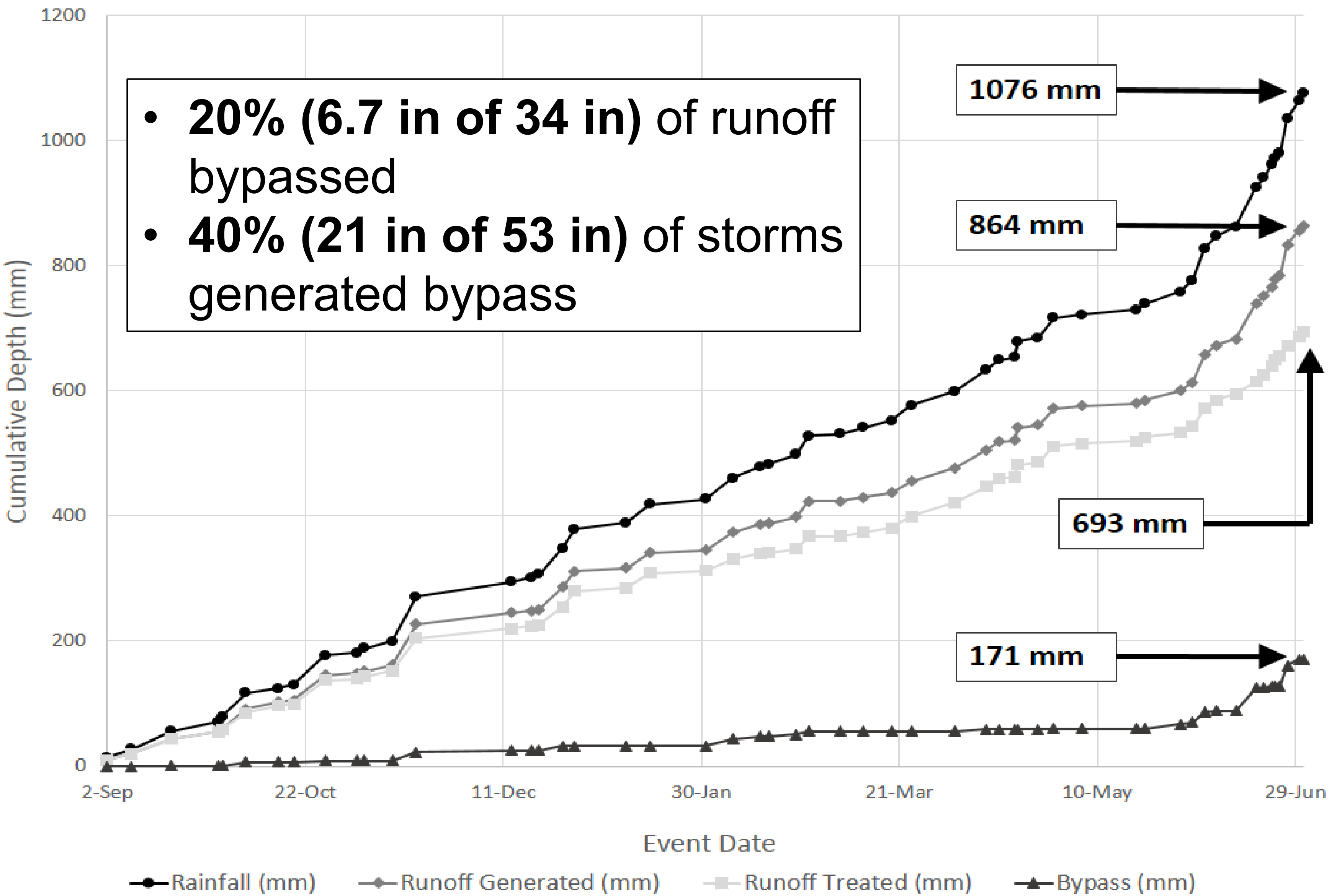


Bio&Ag ENGINEERING

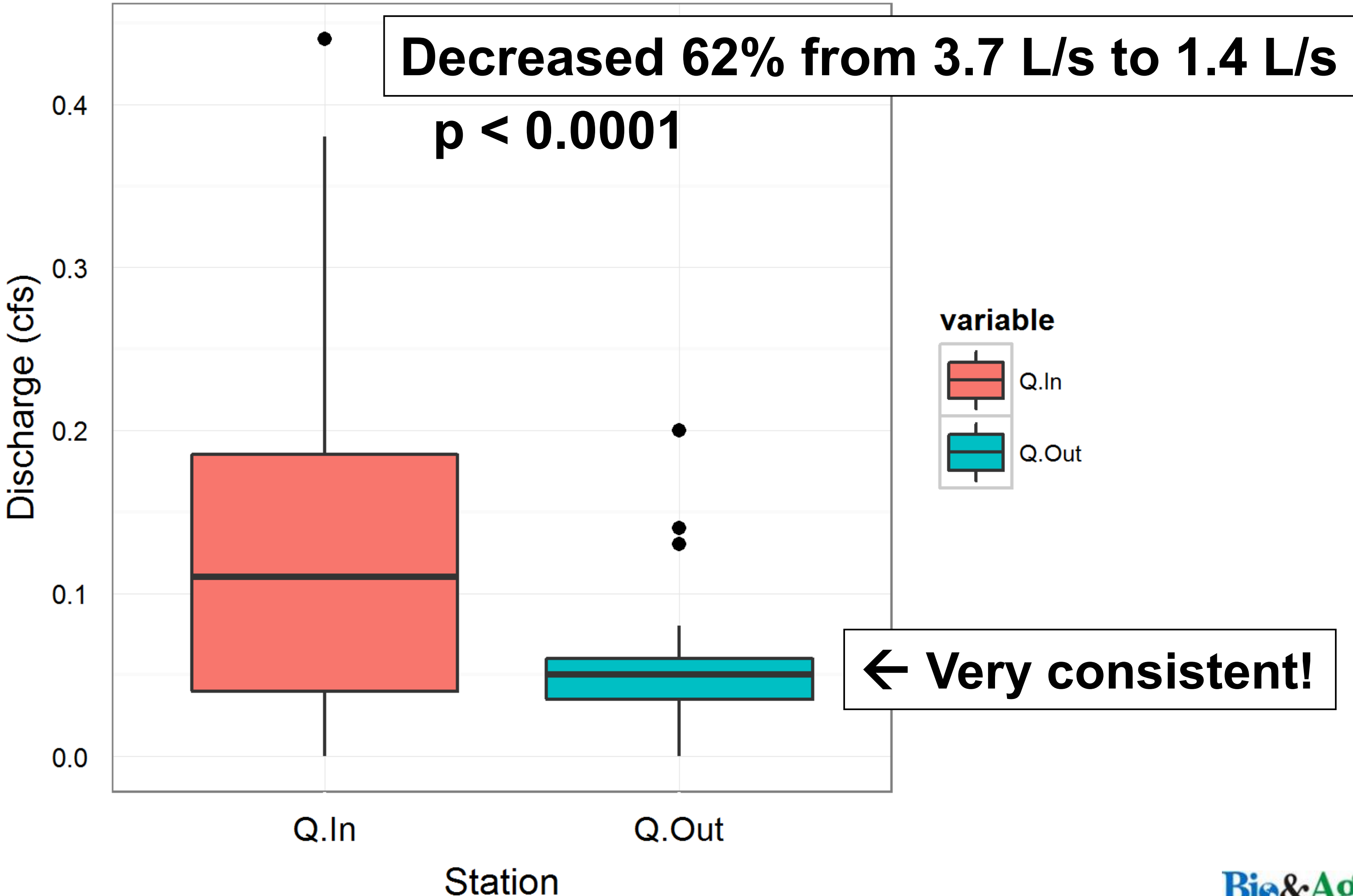
Wilmington Silva Cell Data

Wilmington Silva Cells®

- **20% (6.7 in of 34 in)** of runoff bypassed
- **40% (21 in of 53 in)** of storms generated bypass



Wilmington Silva Cells® Flow Rates



Wilmington Silva Cells® Water Quality

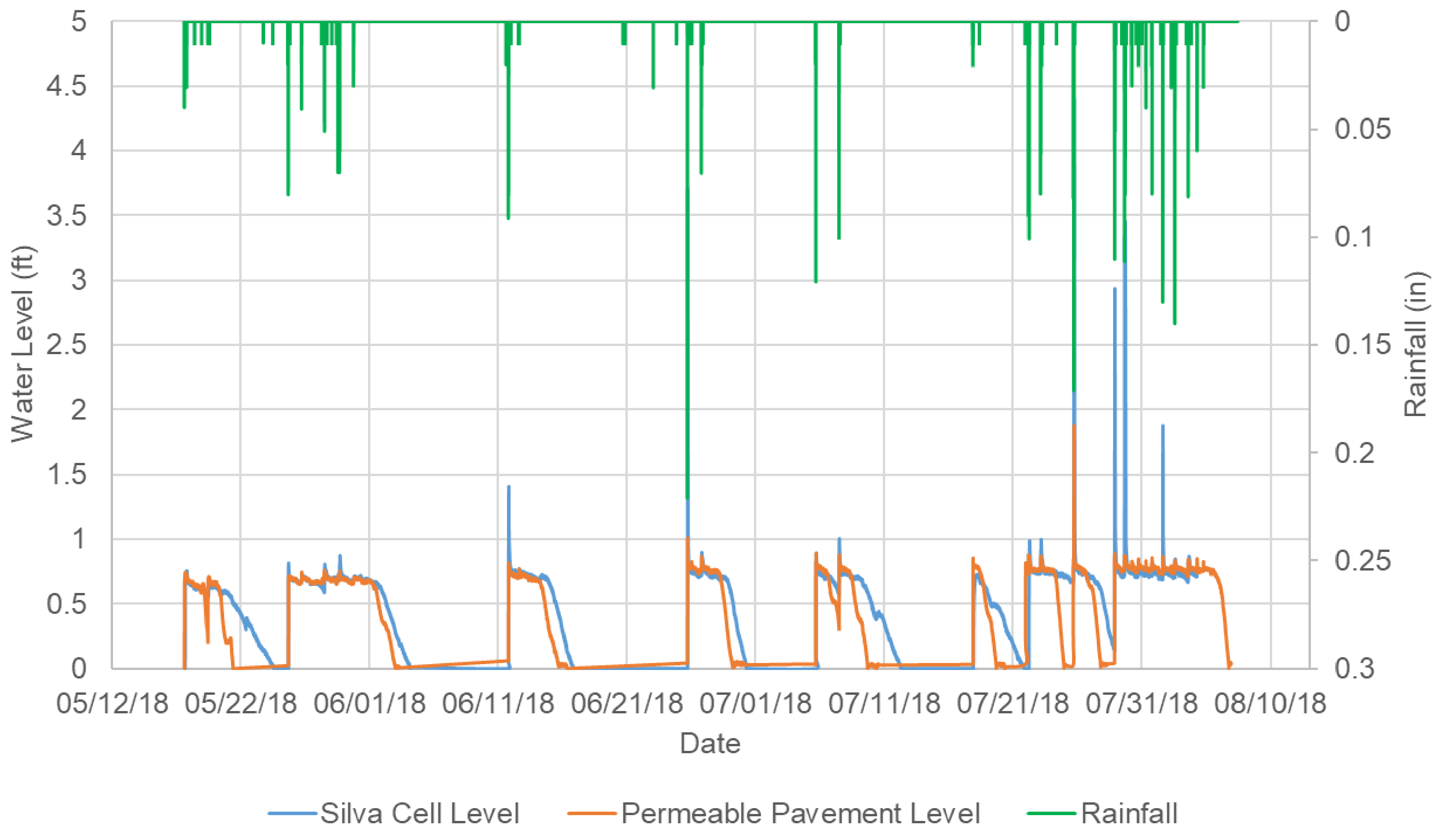
Pollutant	Ann Street Pollutant Load Summary (kg/ha/yr)			
	Pre-Retrofit	Post-Retrofit	Mass Retained	% Retained
TN	8.47	4.02	4.45	53%
TP	1.43	0.51	0.92	59%
TSS	556	170	416	69%
Cu[a]	0.18	0.04	0.15	70%
Pb[a]	0.14	0.06	0.07	58%
Zn[a]	0.86	0.35	0.51	60%

- No volume reduction
- Recall: 20% of total runoff volume bypassed

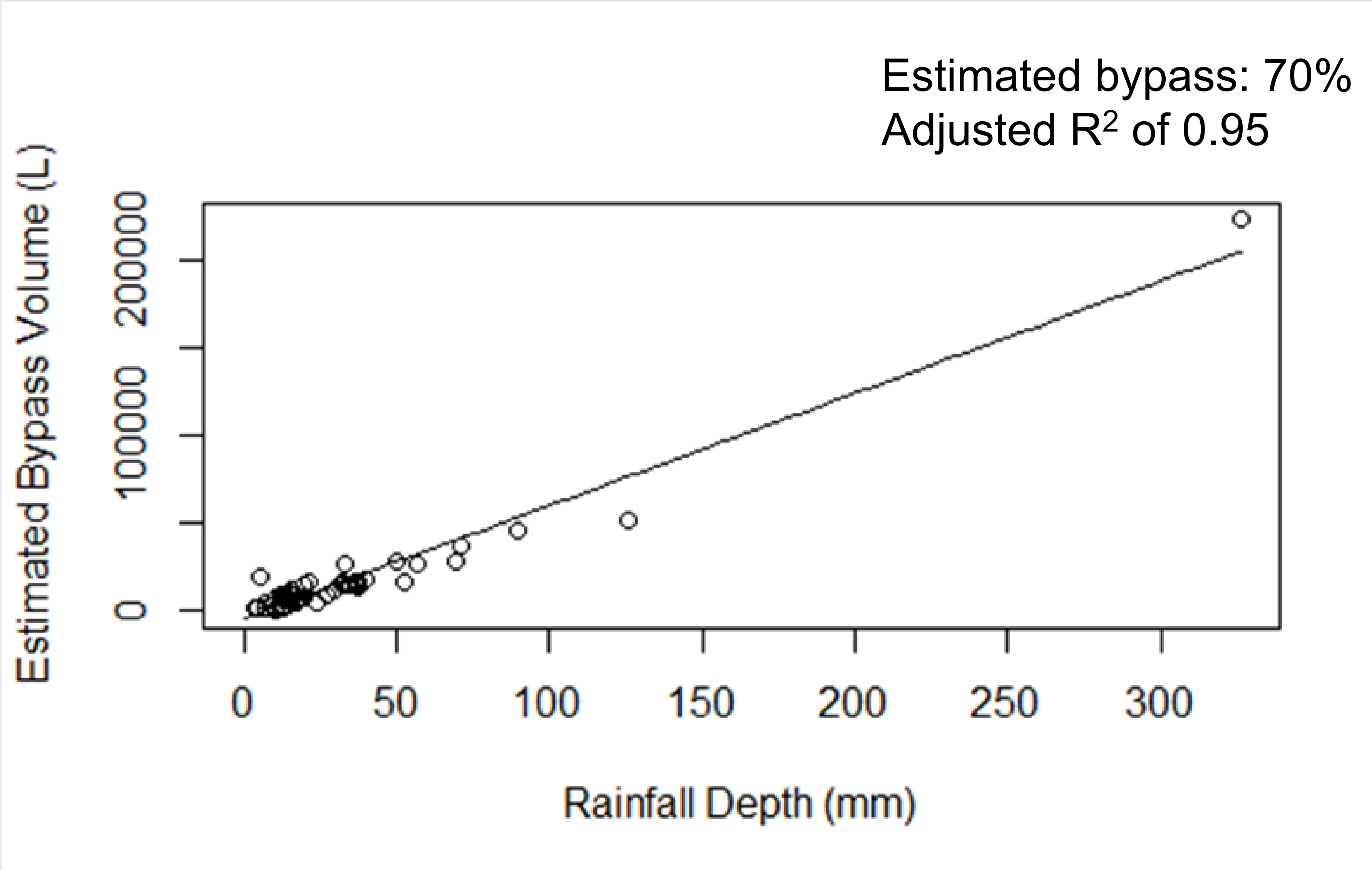
Let’s just say… We were stoked.

Fayetteville (Person Street) Silva Cells®

Fayetteville Silva Cells®

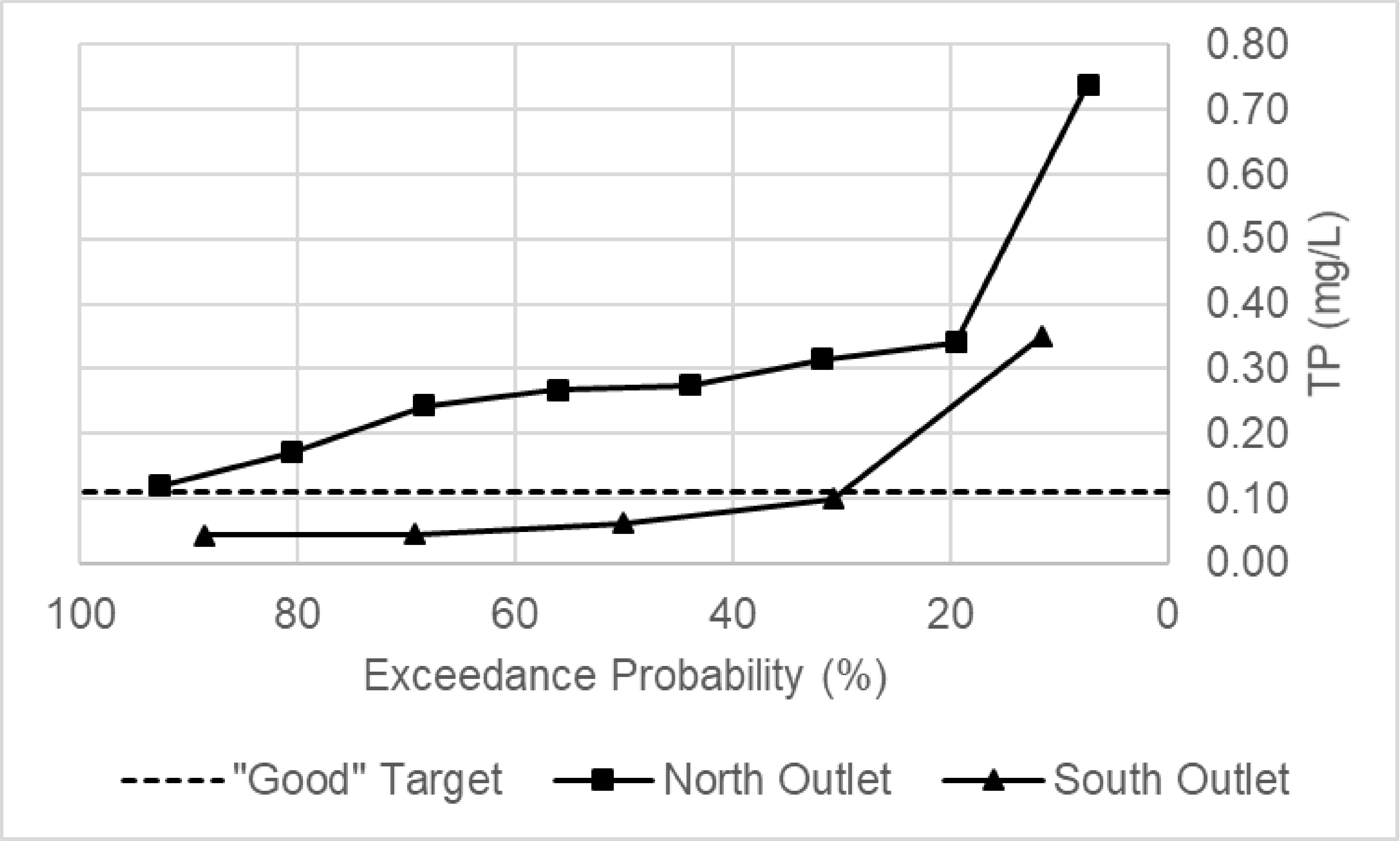


Fayetteville Silva Cells®



Fayetteville Silva Cells®

Fayetteville Silva Cells®

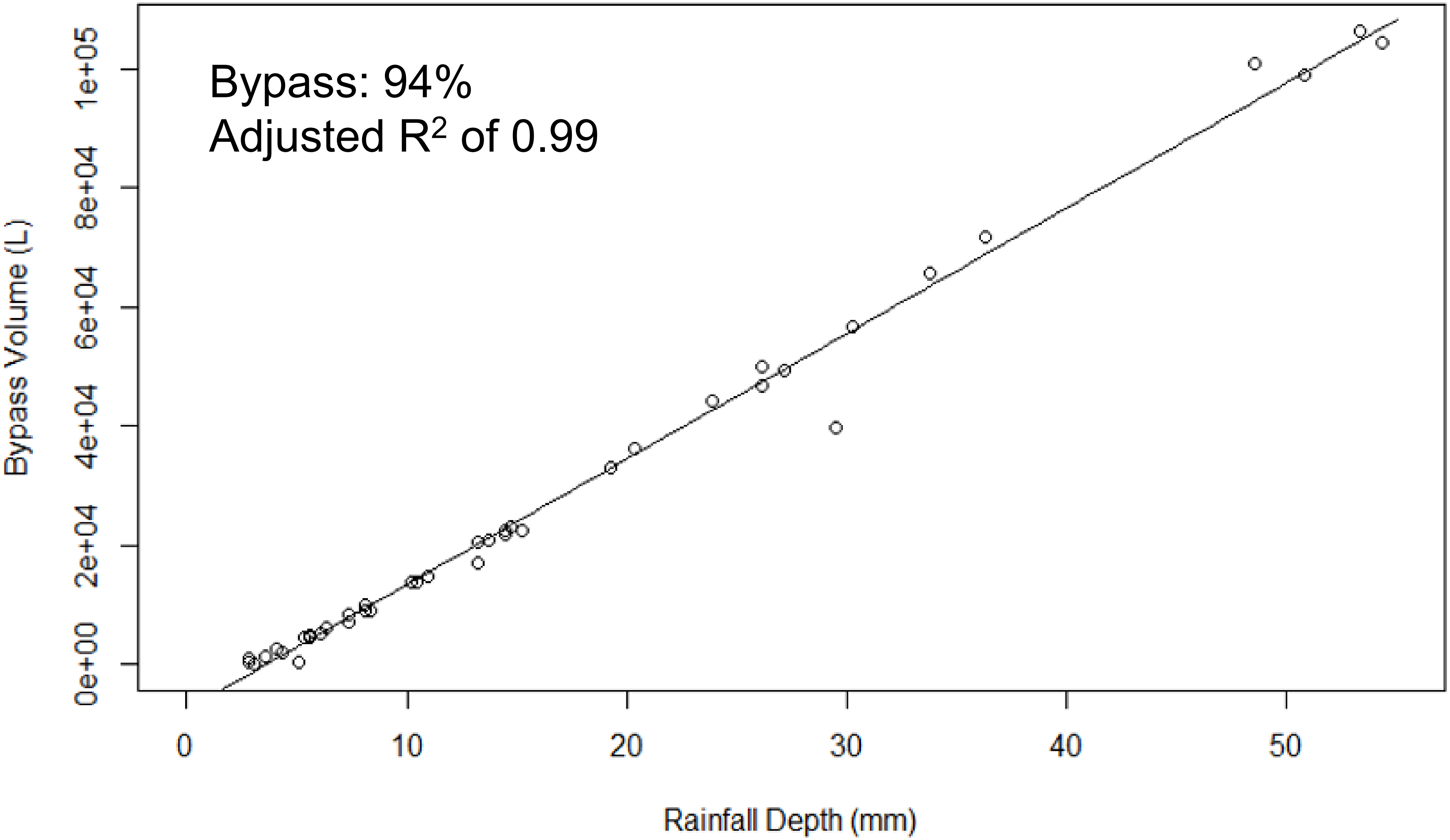


Let’s just say… We were surprised.

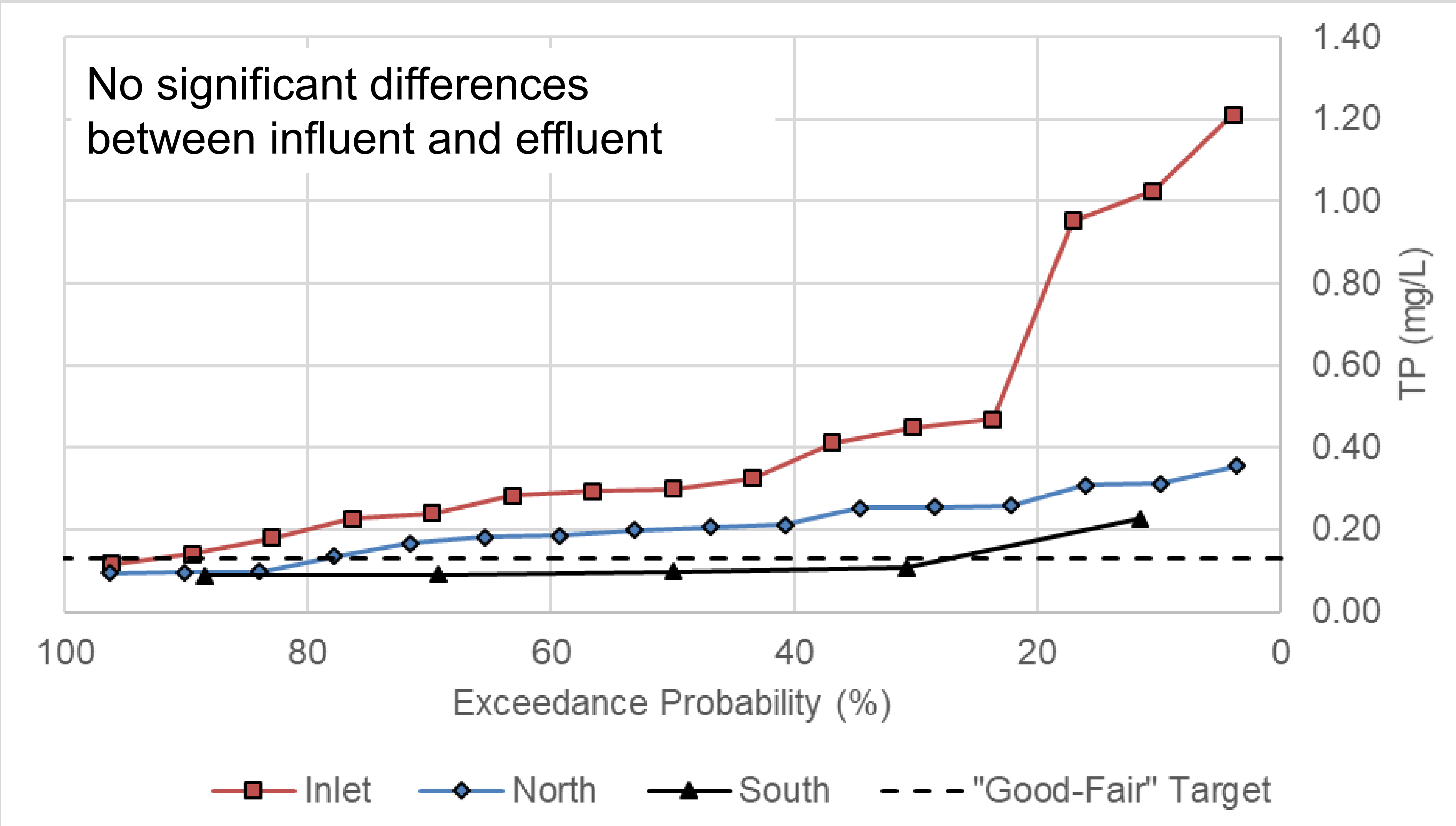
But… had they been maintained…

Durham Silva Cells®

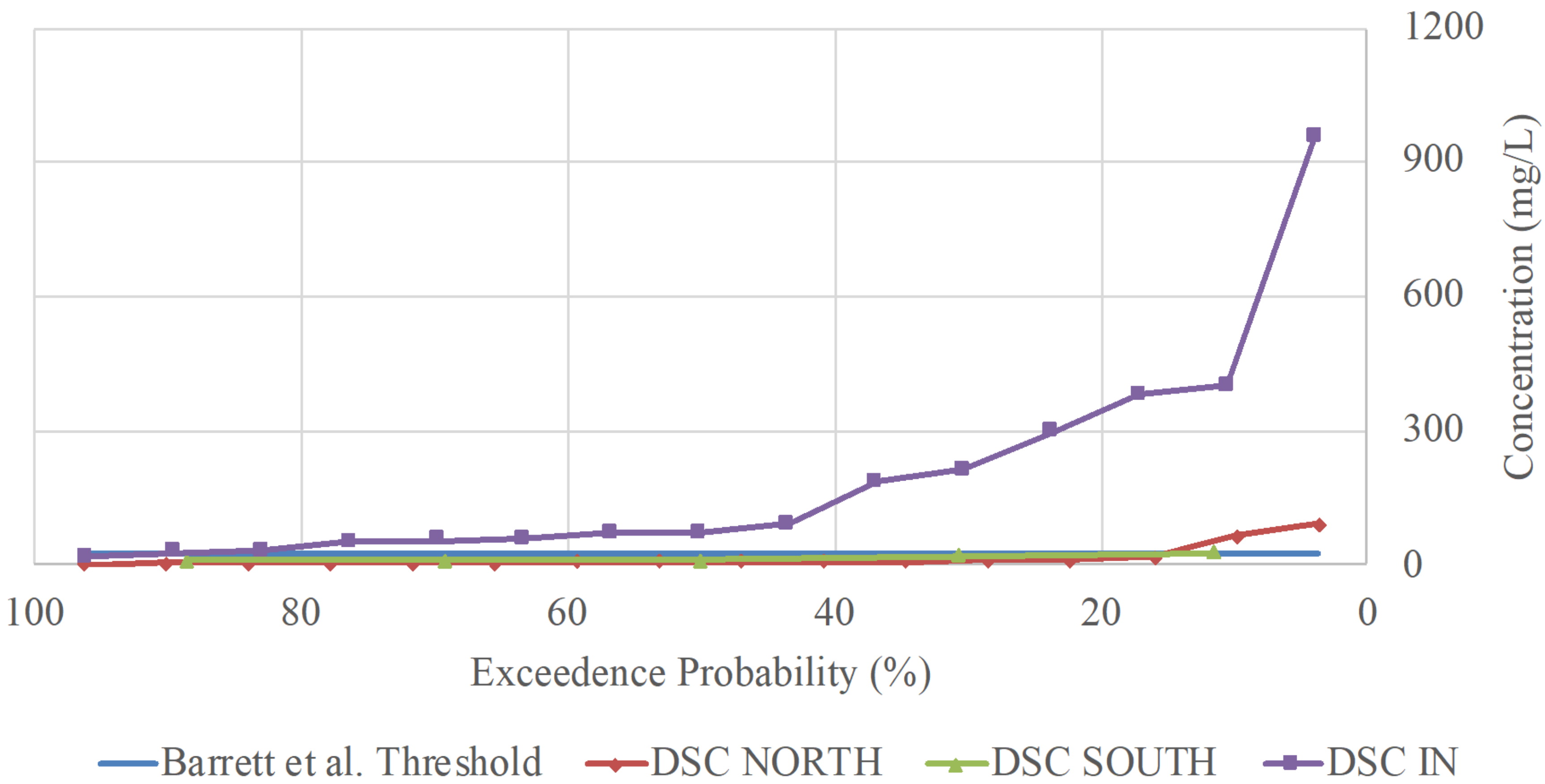
Durham Silva Cells®



Durham Silva Cells® TP



Total Suspended Solids Trapping – Durham Silva Cells



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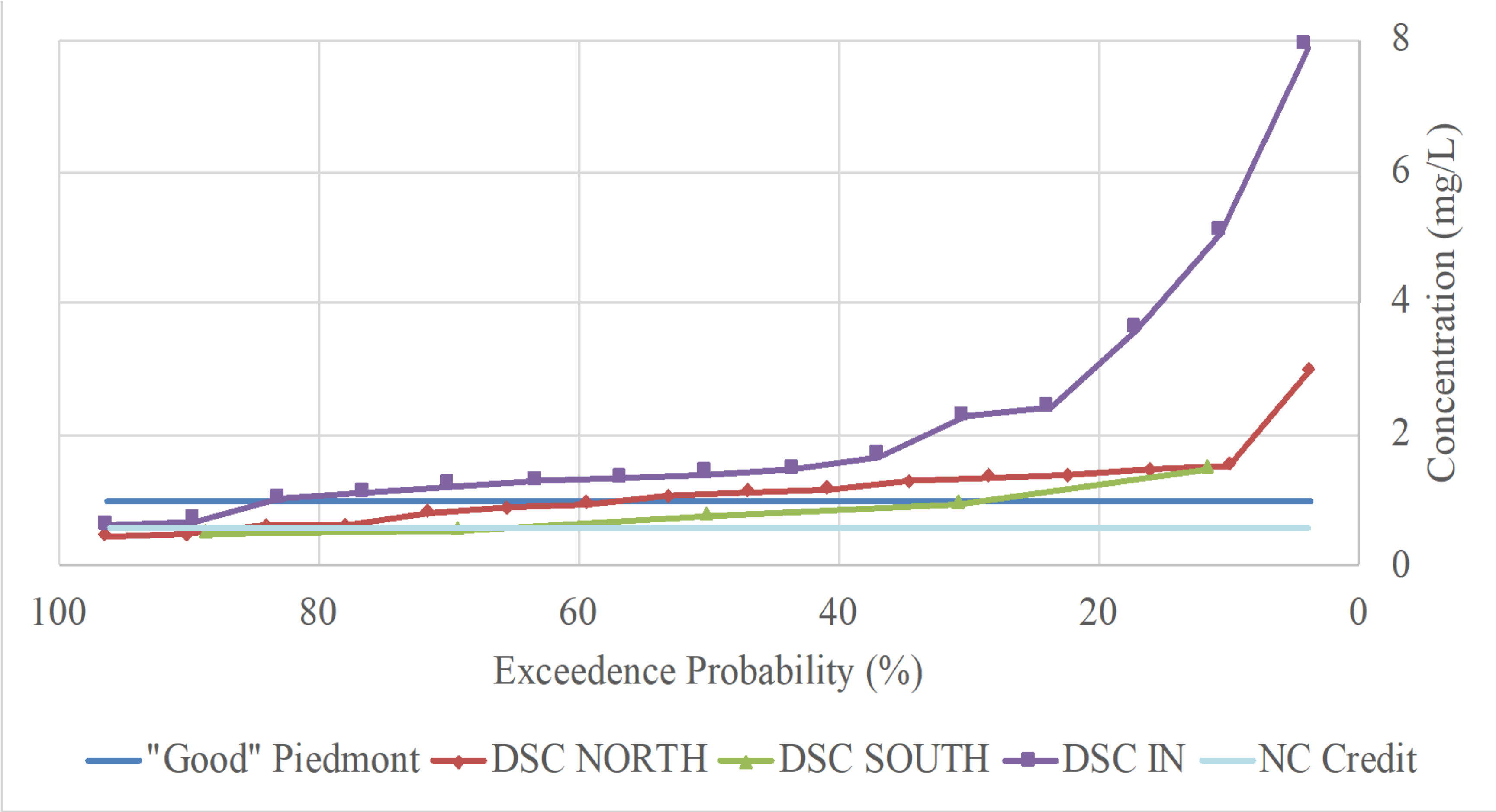
Durham Silva Cells – Nitrogen



Let's just say… We were disappointed.

(By all the bypass)

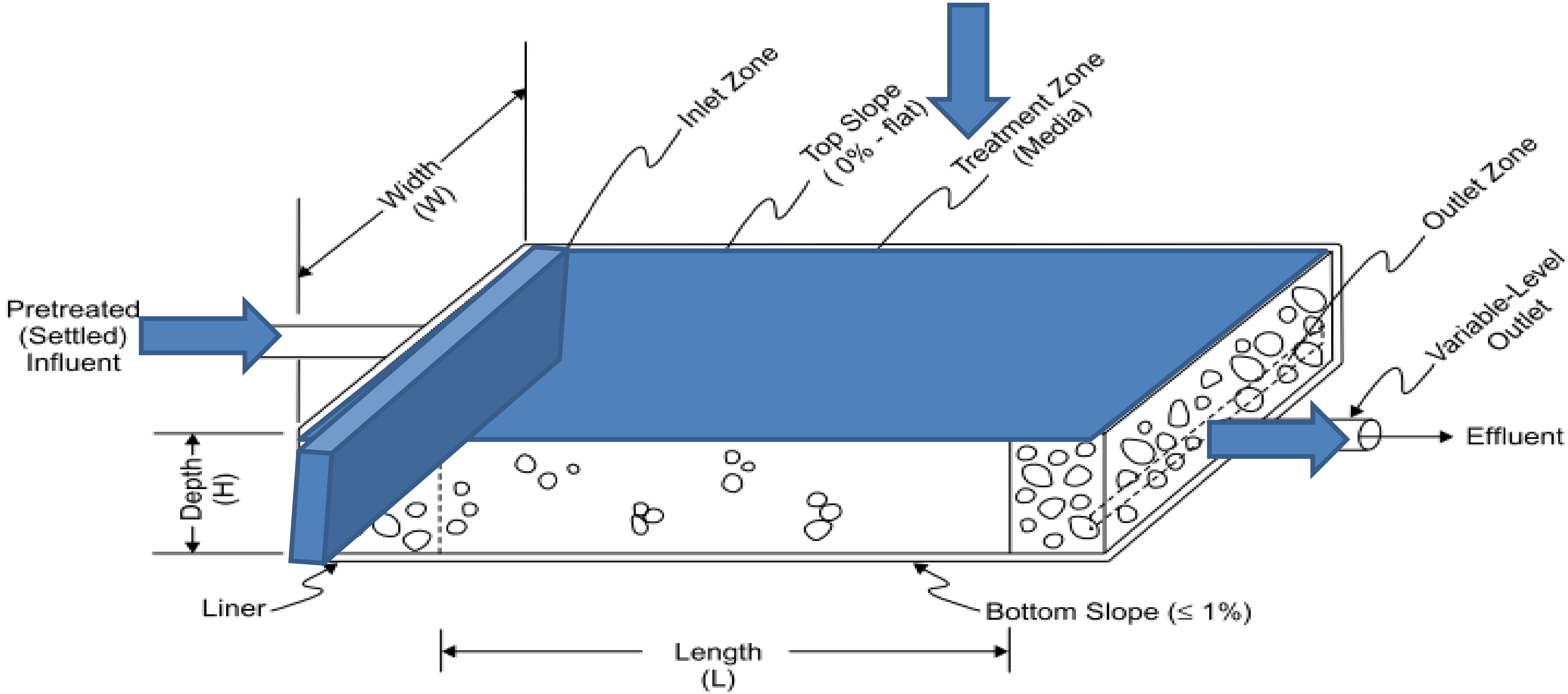
But still hopeful… because treated water concentrations were lower than influent

Stormwater-Treating Tree Systems: Take Home Message

- Get the water into the media, good treatment seems likely.
- Bypass of runoff? Appears to be an issue associated with inlets.

What is a

Subsurface-flow Gravel Wetland (SSGW)?



Manual Constructed Wetlands Treatment of Municipal Wastewaters
(US EPA , 2000)

Gravel Wetlands vs. Stormwater Wetlands

- Stormwater wetlands:
  - Constantly ponded water
  - Varying topography
  - Plant specific zones

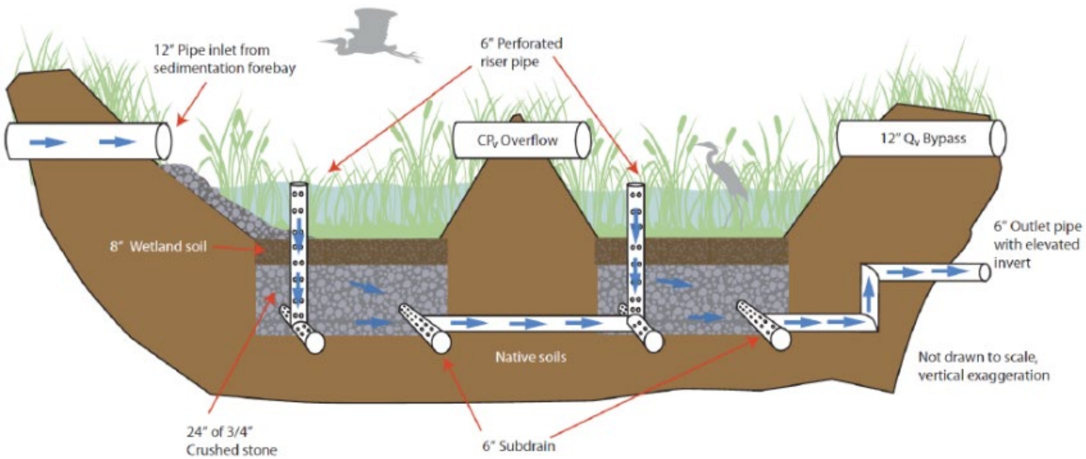
- Gravel wetlands:
  - Temporarily ponded water
  - Saturated gravel layer
  - Little variation in topography

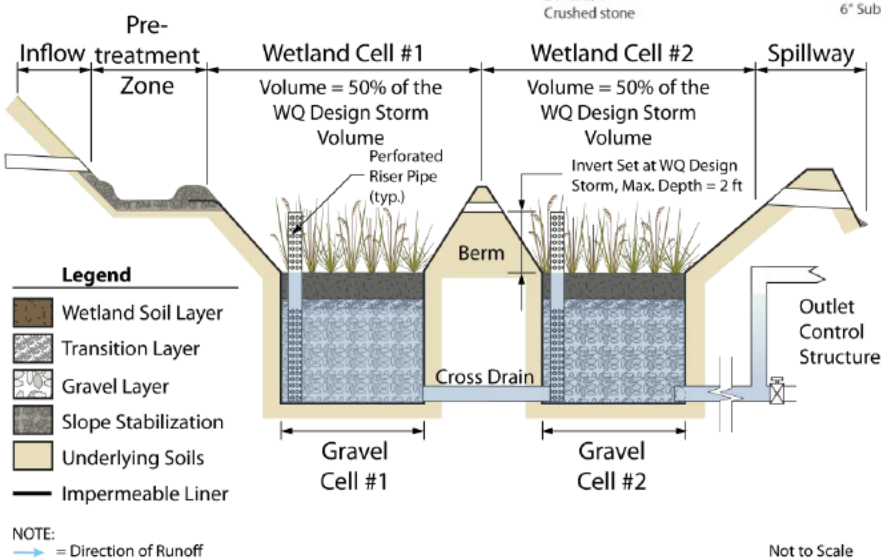
Gravel Wetlands vs. Stormwater Wetlands

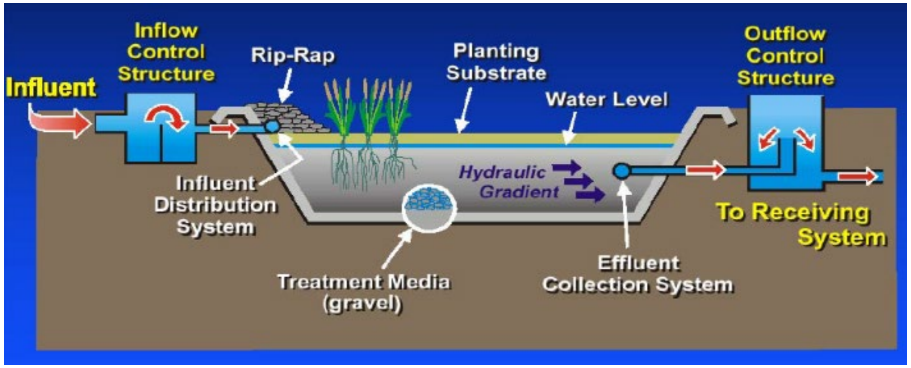
- NC stormwater wetlands (Hathaway and Hunt 2010; Line et al. 2008; Mallin et al. 2012):
  - TN removal: 39 to 59%
  - TP removal: 27 to 68%
  - TSS removal: 58 to 83%
- Gravel wetlands:
  - Wastewater: up to 96% TN and 71% TP removal (Van de Moortel et al. 2009); < 20 mg/L effluent TSS (Reed and Brown 1995)
  - Stormwater: 54% TP and 99% TSS removal (Roseen et al. 2009)

Current Design Guidance

- Gravel wetlands approved/installed SCM in: MD, NH, NJ, TN, and VT



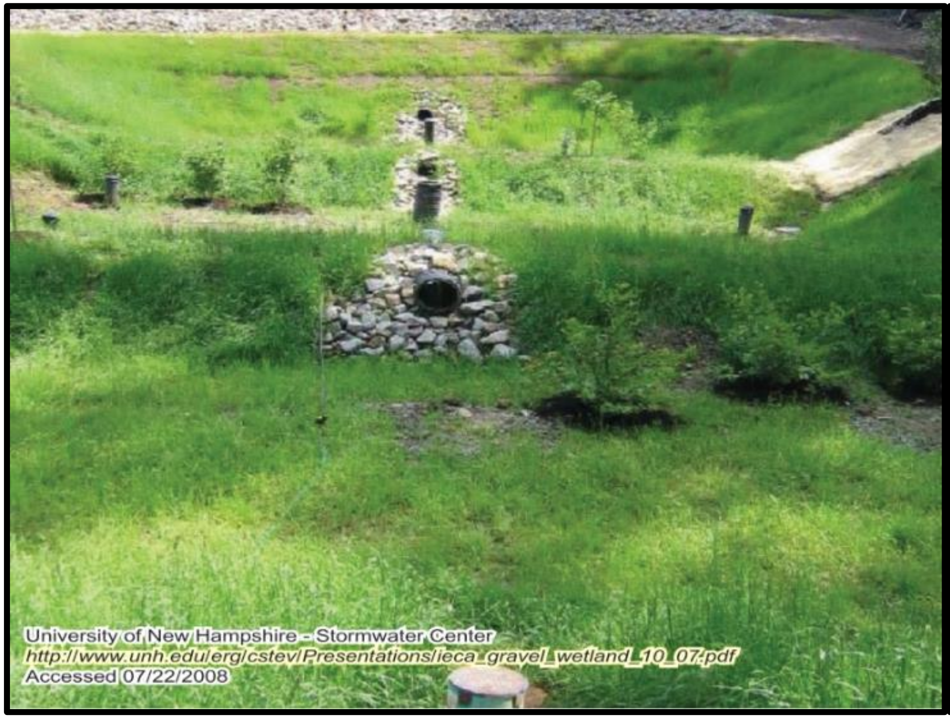




Current Design Guidance – New Hampshire

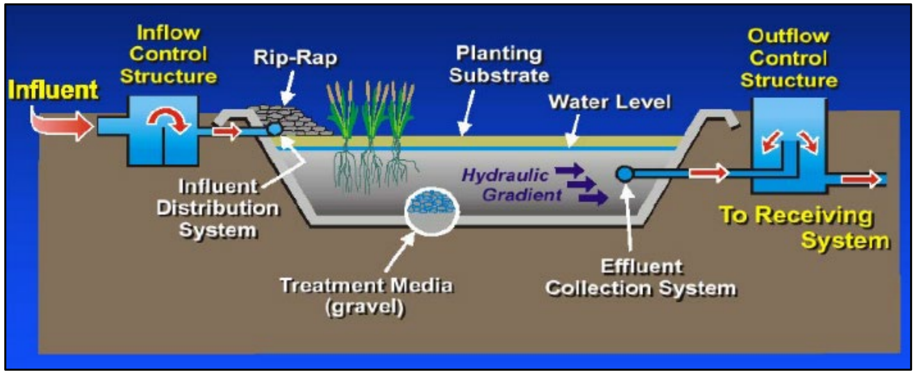
- Pioneer of gravel wetlands for stormwater treatment
- Guidance (UNHSC 2016):
  - Saturated gravel within 4 to 8 in of soil surface
  - Minimum of: 8 in wetland soil, 3 in intermediate aggregate, 24 in gravel layers
  - Geotextile fabric if in-situ conductivity > 0.3 ft/day
  - Size primary orifice for 24 to 30 hr storage in gravel layer
  - Two cell system where length of each cell is ≥ 15 ft and holds 50% of WQV
  - Pre-treatment basin or forebay that is well-drained

Current Design Guidance – New Hampshire



Current Design Guidance – Tennessee (Knox County)

- Guidance (Knox County 2018):
  - Drainage area ≤ 5 ac with ≥ 50% impervious cover
  - SHWT separation ≥ 2 ft
  - Pre-treatment required and accounts for WQV storage
  - Minimum of 20 ft wide easement for maintenance



Current Design Guidance Summary

- General consensus:
  - Pre-treatment is necessary
  - Permeable in-situ soils should be avoided
  - Saturation within 4 to 8 in of wetland soil surface
  - Temporarily ($\leq$ 72 hrs) pond water at surface
  - Drainage pipes incorporated into cell(s) to encourage infiltration into gravel layer
  - At least 8 in soil, 3 in intermediate aggregate, 2 ft gravel

Research Questions

How do SSGWs reduce peak stormwater flows, increase basin lag time, provide channel protection, and reduce annual runoff volume?

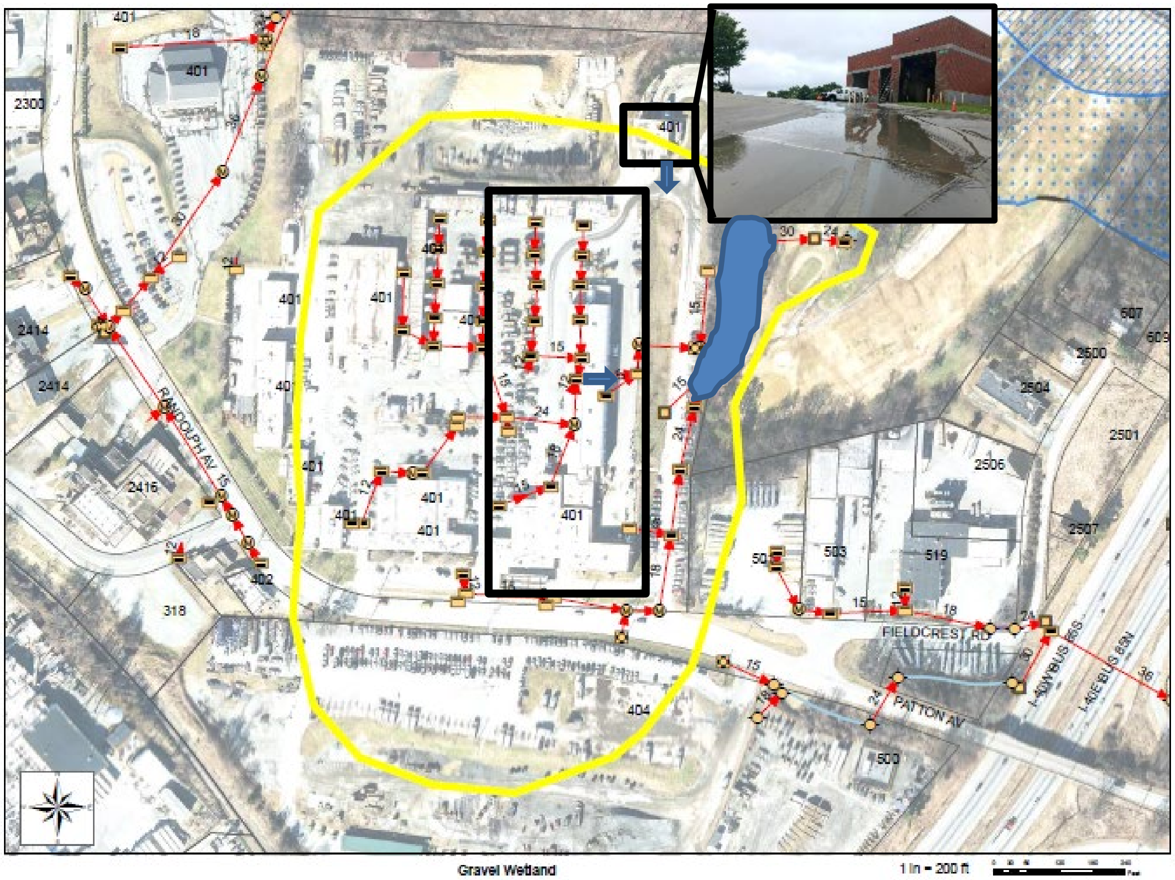
- Storage volume (temporarily ponded water)
- Orifice control (or clogging of media)
- Evapotranspiration
- No exfiltration

How do SSGWs remove stormwater pollutants (specifically nutrients)?

- Hydraulic retention time (HRT)
- Vegetation uptake, microbial transformation and immobilization
- Gravel media adsorption, filtration, and storage

Can these answers inform the design, construction and maintenance of SSGWs ensuring long term efficiency?

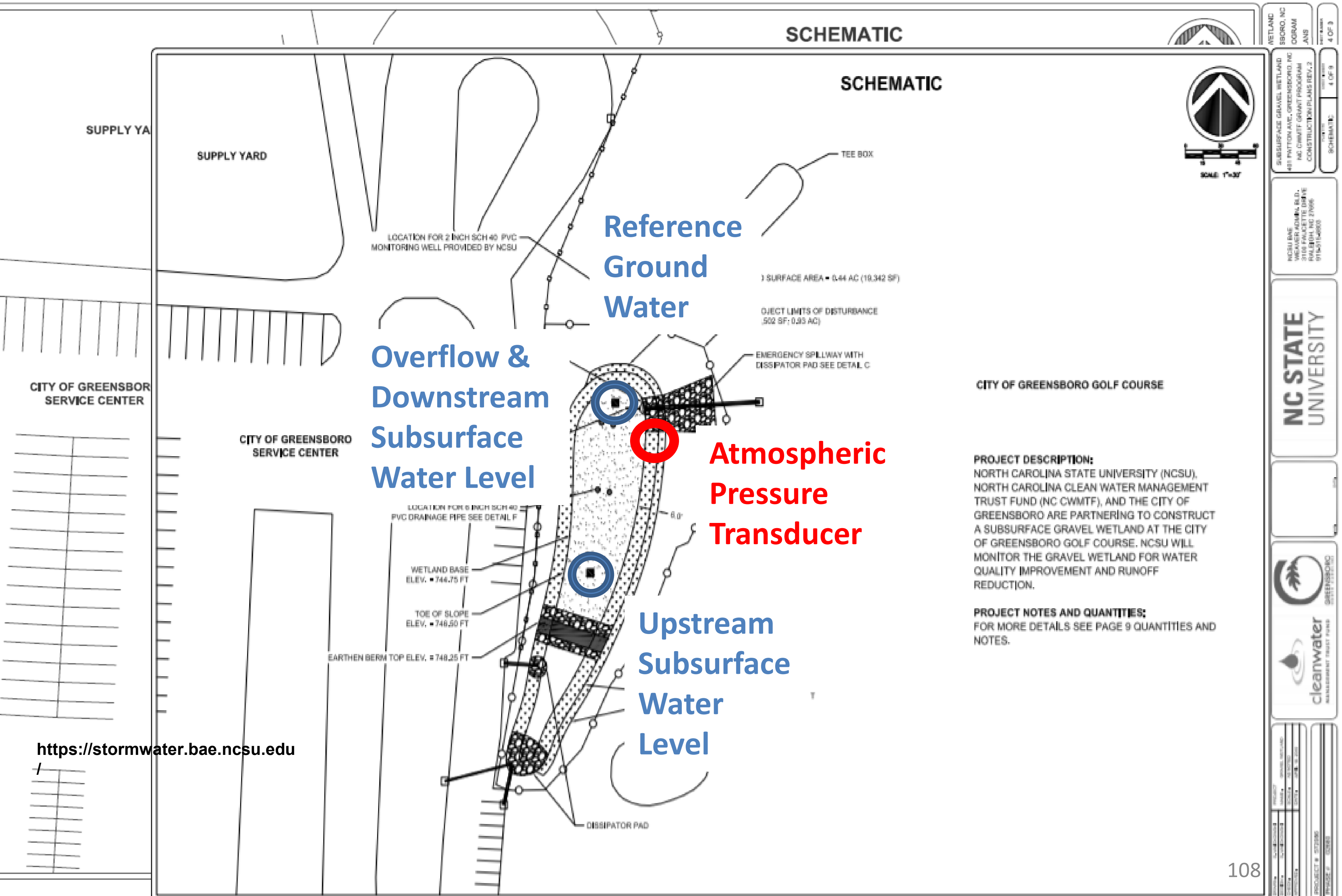
401 Patton Ave Greensboro, NC, Watershed



Watershed Activities and Specs

- 12.6 acres (VERY LARGE)
- 98% impervious
- City vehicle service center
- City garbage truck wash
- Baseflow from truck wash water
- Pulses of baseflow from upstream service center

Meet the Watershed


SCHEMATIC
SUPPLY YARD
CITY OF GREENSBORO SERVICE CENTER
LOCATION FOR 2 INCH SCH 40 PVC MONITORING WELL PROVIDED BY NCSU
Reference Ground Water
TEE BOX
SURFACE AREA = 0.44 AC (19,342 SF)
EMERGENCY SPILLWAY WITH DISSIPATOR PAD SEE DETAIL C
Overflow & Downstream Subsurface Water Level
Atmospheric Pressure Transducer
CITY OF GREENSBORO GOLF COURSE
WETLAND BASE ELEV. = 744.75 FT
TOE OF SLOPE ELEV. = 746.50 FT
EARTHEN BERM TOP ELEV. = 748.25 FT
Upstream Subsurface Water Level
DISSIPATOR PAD
PROJECT DESCRIPTION:
NORTH CAROLINA STATE UNIVERSITY (NCSU), NORTH CAROLINA CLEAN WATER MANAGEMENT TRUST FUND (NC CWMTF), AND THE CITY OF GREENSBORO ARE PARTNERING TO CONSTRUCT A SUBSURFACE GRAVEL WETLAND AT THE CITY OF GREENSBORO GOLF COURSE. NCSU WILL MONITOR THE GRAVEL WETLAND FOR WATER QUALITY IMPROVEMENT AND RUNOFF REDUCTION.
PROJECT NOTES AND QUANTITIES:
FOR MORE DETAILS SEE PAGE 9 QUANTITIES AND NOTES.
NC STATE UNIVERSITY
cleanwater
https://stormwater.bae.ncsu.edu/

Construction of the City of Greensboro SSGW

https://stormwater.bae.ncsu.edu/

Construction of the City of Greensboro SSGW

Planting of the City of Greensboro SSGW

Species	Common Name	Wetland Indicator Status	Survival/Presence During 1st Growing Season
Herbaceous Species (Planted as Plugs on 3-foot centers (9 ft^2))			
Acorus americanus	Sweet flag	OBL	TBD
Andropogon gerardii	Big bluestem	FAC	TBD
Asclepias tuberosa	Butterfly weed	UPL	TBD
Chasmanthium latifolium	River oats	FACU	TBD
Eragrostris spectabilis	Purple lovegrass	UPL	TBD
Eupatorium perfoliatum	Boneset	FACW	TBD
Helianthus angustifolius	Swamp sunflower	FACW	TBD
Hibiscus coccineus	Scarlet rose mallow	OBL	TBD
Muhlenbergia capillaris	Sweet grass	FACU	TBD
Ratibida columnifera	Prairie coneflower	FACU	TBD
Rudbeckia fulgida 'Goldsturm'	Goldsturm black-eyed susan	FAC	TBD
Schizachyrium scoparium	Little bluestem	FACU	TBD
Scirpus cyperinus	Woolgrass	FACW	TBD
Sorghastrum nutans	Indian grass	FACU	TBD
Stokesia laevis	Stokes aster	FAC	TBD
Symphyotrichum novae-angliae	New England aster	FACW	TBD
Tridens flavus	Purpletop tridens	FACU	TBD
Verbena hastata	Blue Swamp verbena	FACW	TBD
Vernonia noveboracensis	Ironweed	FACW	TBD
Shrub Species (Planted as Tublings on 5-foot centers (25 ft^2))			
Callicarpa americana	American beautyberry	FACU	TBD
Calycanthus floridus	Sweetshrub	FACU	TBD
Clethra alnifolia	Sweet pepper bush	FAC	TBD
Cornus amomum	Silky dogwood	FACW	TBD
[illegible]	[illegible]	FACW	TBD

Hydrology of the City of Greensboro SSGW

Before any storms

Drawdown following a storm (>1 inch)

Monitoring SSGW Post-construction Hydrology: Volume & Flowrate

Monitoring SSGW Post-construction Hydrology: Clogging

Development of a Schmutzdecke after only a couple “frog-choking gully-washers”?

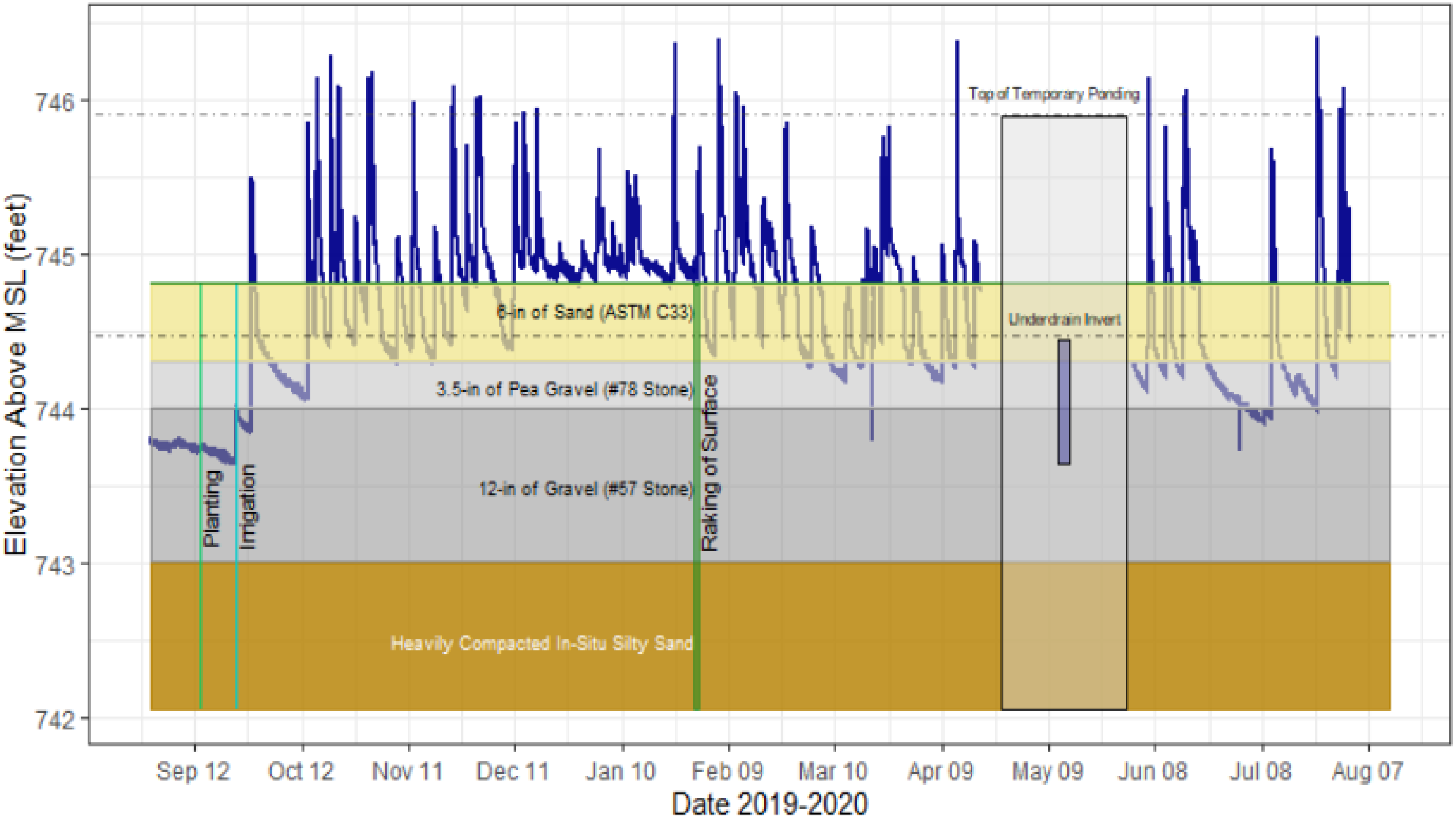
Reason: LARGE LOADING RATIO (i.e., 50:1 (Watershed Area : Media Area)
And VERY (VERY) DIRTY WATERSHED

120

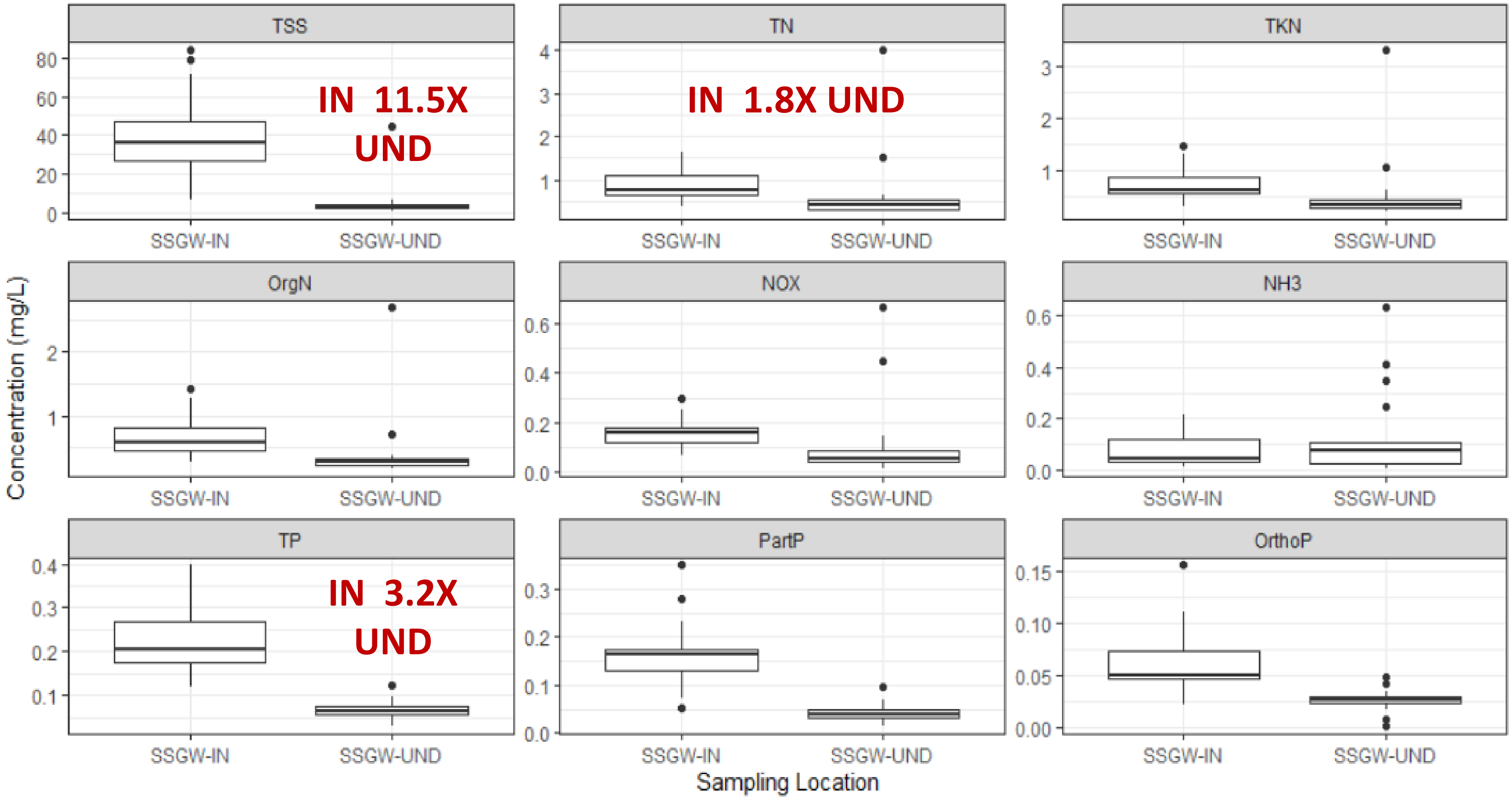
Photo Taken: August 10th 2020

https://stormwater.bae.ncsu.edu/

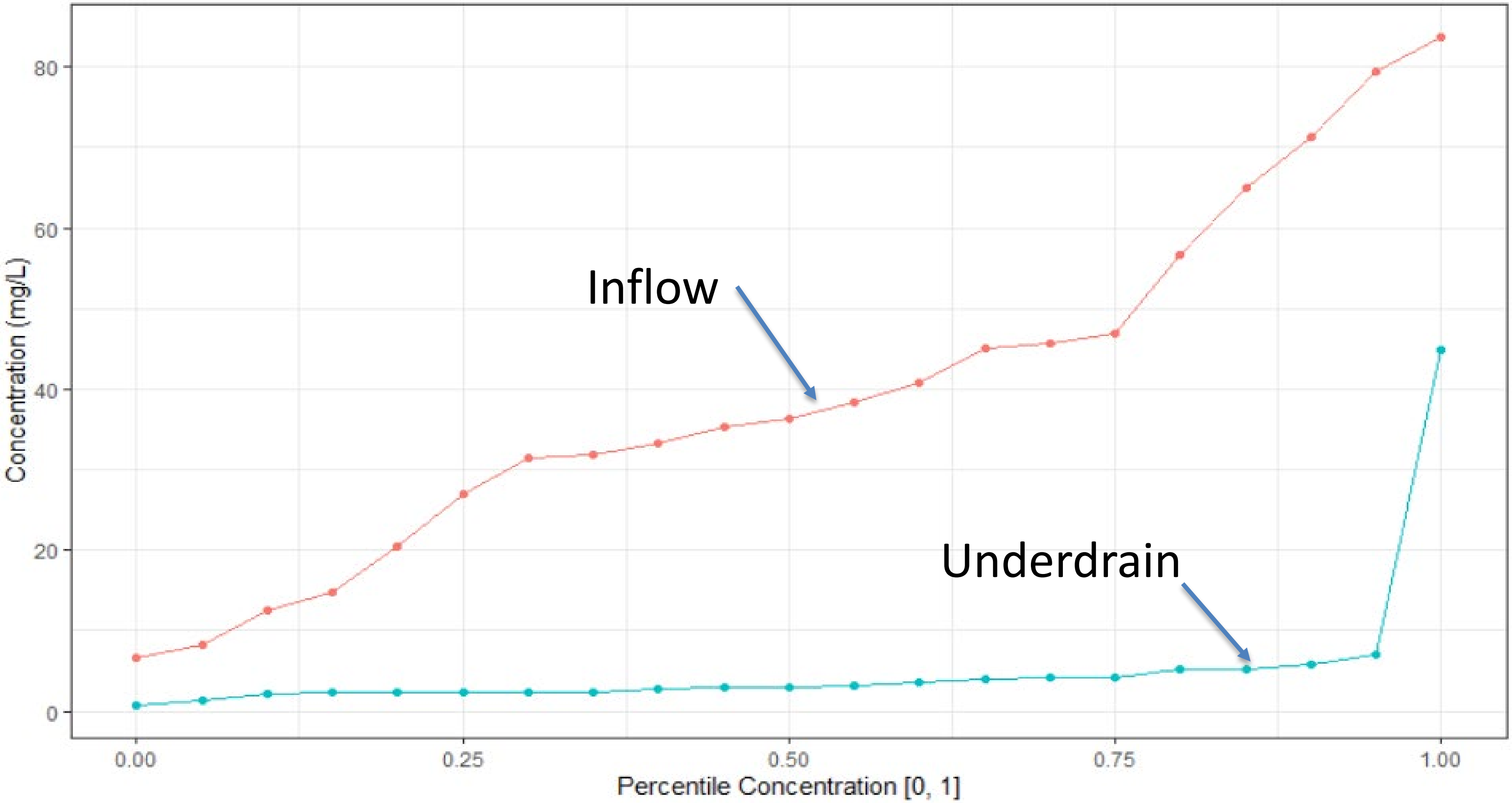
Monitoring SSGW Post-construction Hydrology: Volume



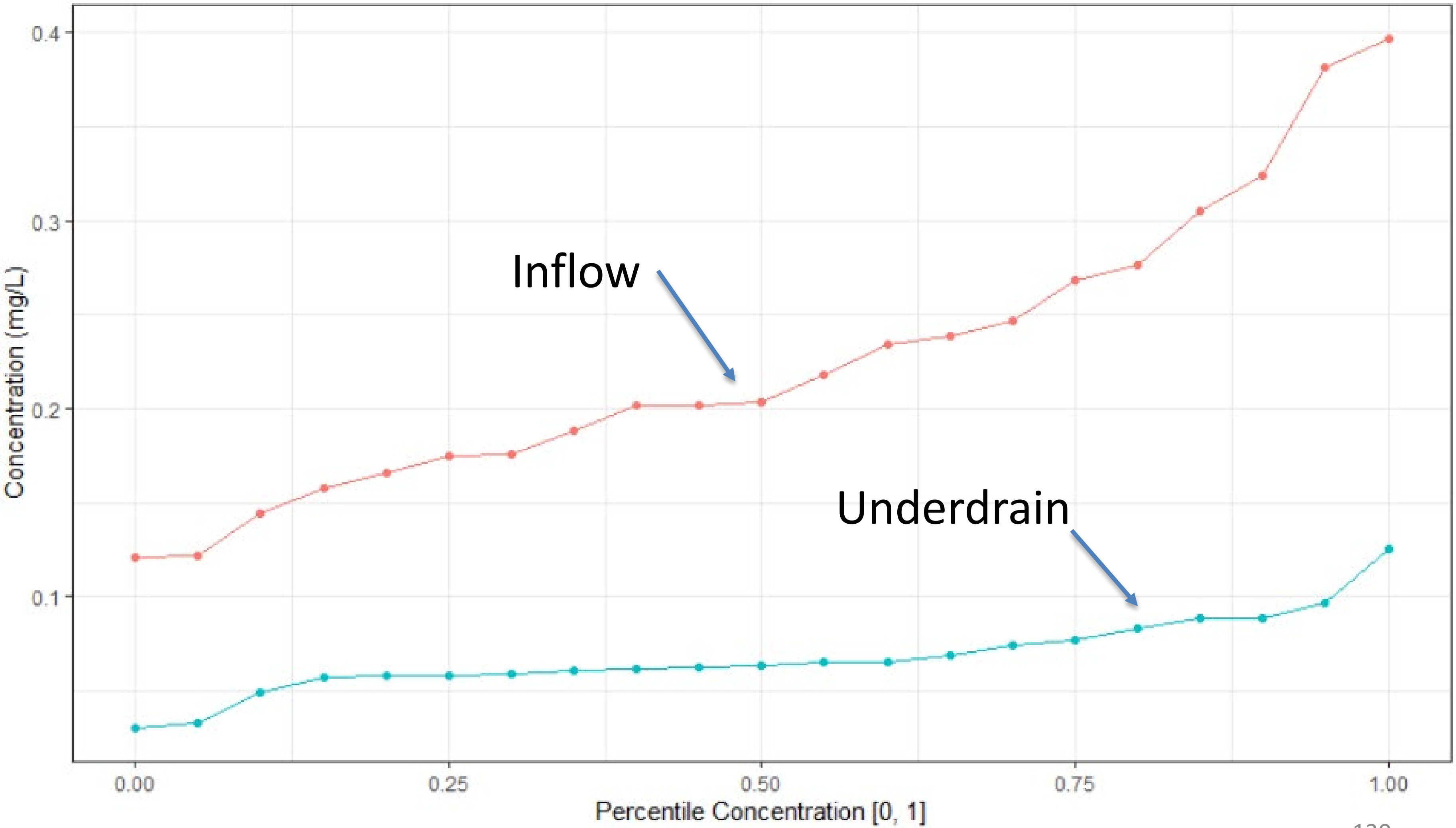
Monitoring SSGW Post-construction Water Quality: Boxplots



Monitoring SSGW Post-construction Water Quality: TSS Percentile Ranks:
En Route to Primary SCM



Monitoring SSGW Post-construction Water Quality: TP Percentile Ranks



Summary of GSO SGW

1. Baseflow contributes 28% of total flow. Minimal Volume Mitigation

2. Plants need to be resilient to slime.

3. Maintenance is hydrologically important

4. Median Treatment Efficiencies (n=21):
   - TN = 45%
   - TP = 68%
   - TSS = 92%

Floating treatment wetlands (FTWs)

- Relatively common retrofit option to improve wet pond performance
- Provide advances in
  - water quality treatment
  - wildlife habitat
  - aesthetic benefits

Image source: Winston et al. (2013)

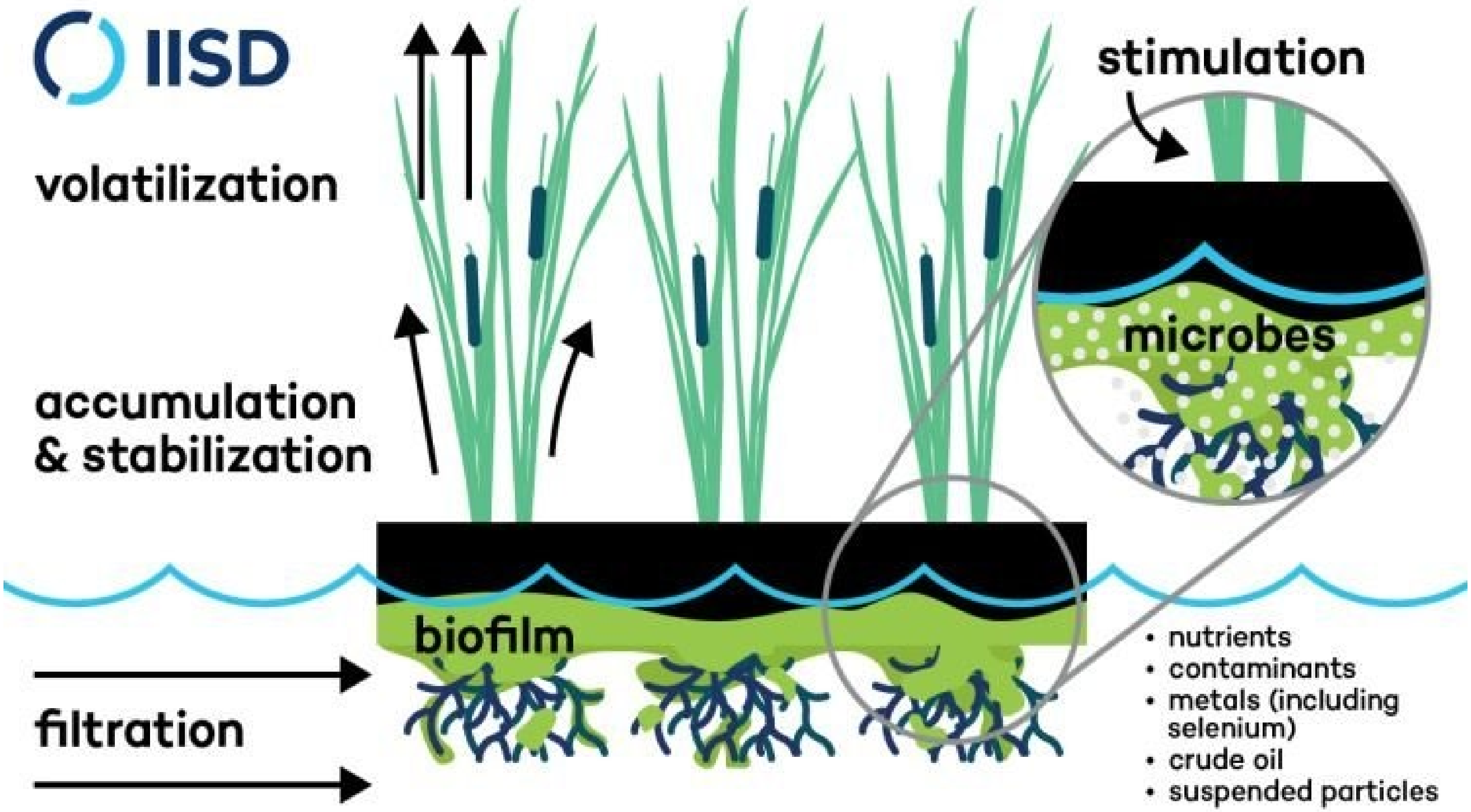


Image source: International Institute for Sustainable Development. (2017)

FTW Design Criteria & Costs

- Current design approach: target **20%** percent water surface area covered by floating wetlands (Winston et al., 2013)
- FTW retrofit cost:
  - $1-24 per sq ft of mat
  - cost of plants & installation
  - ~$100 per sq ft total

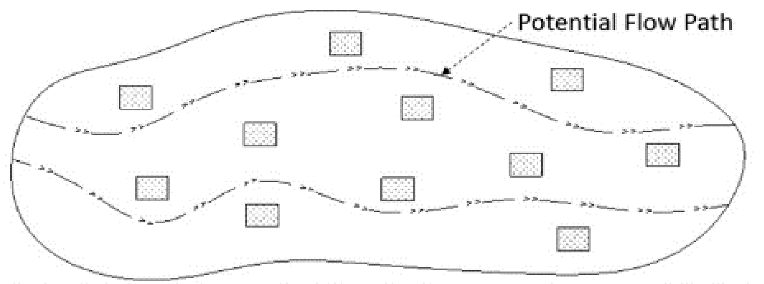
  (I think this is high, but I did not check with student)

Image source: Winston et al. (2013)

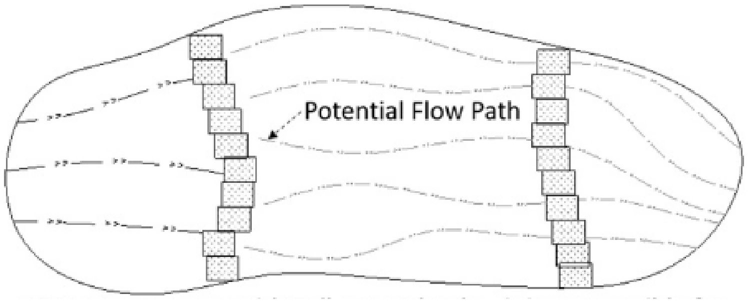
Research Gaps

- Lack of research on **optimal FTW placement** for optimized hydraulic performance (Khan et al., 2013; Lucke et al., 2019)

Random placement



Strategic Placement



- Forces runoff through the root matrix, **maximizing contact** and reducing risk of short-circuiting (Glenn and Bartell, 2008)

Research Questions and Objectives

Can strategic FTW placement at the outlet structure improve Wet Pond water quality treatment?

- Determine the additional total phosphorus (**TP**), total nitrogen (**TN**), and total suspended solids (**TSS**) removal achieved by FTWs
- Quantify the nutrient uptake of the wetland plants

How will optimized FTW placement affect design recommendations?

- Determine the minimal FTW surface area coverage needed to achieve desired pollutant removal
- Provide an update to the NC Stormwater Design Manual and SCM credit document

Site Selection

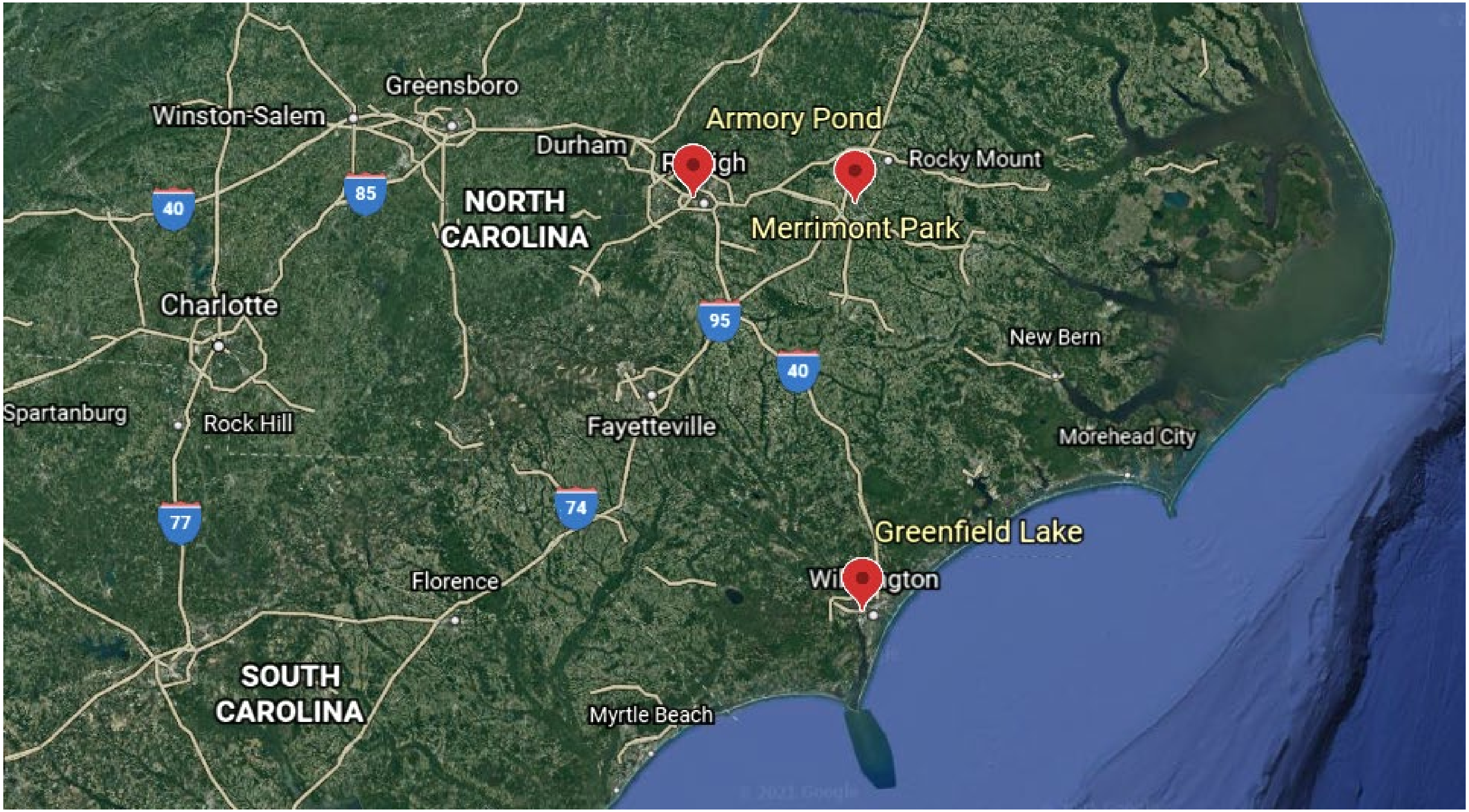
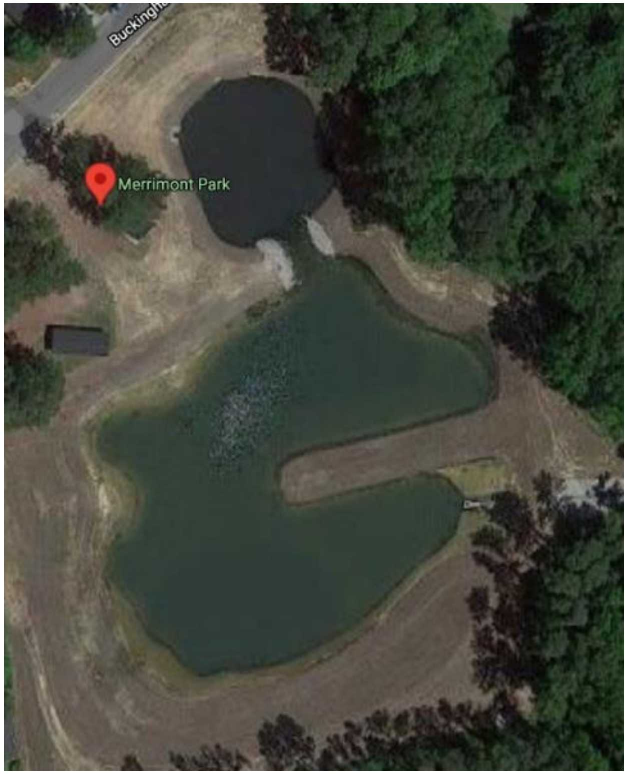


Image source: Google Earth

Site Selection



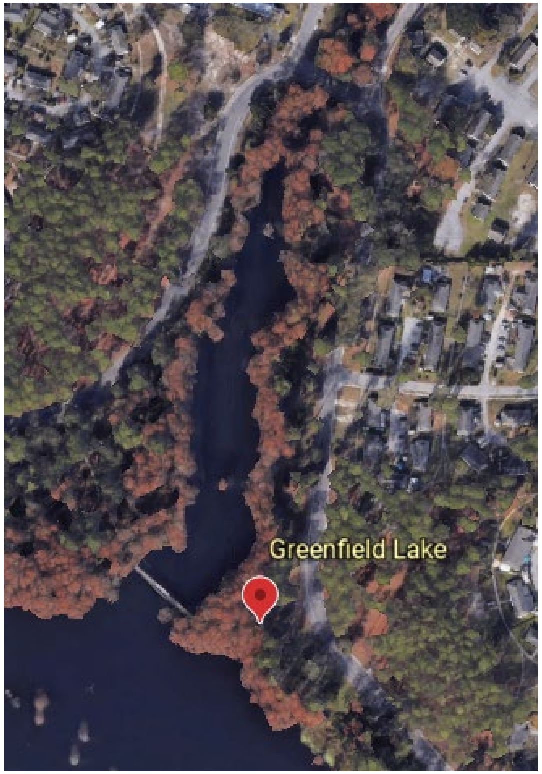


Image sources: Google Earth, Google Maps

We will retrofit the ponds with: Beemats Floating Islands

Image source: Beetmats Floating Wetlands

FTW Design Layout

Image sources: Google Earth, Google Maps

Sampling Methods

- Collect flow-weighted samples following storm events at each site using automatic ISCO 6712 samplers

<u>Armory pond</u>

- Two monitoring periods: pre- and post-retrofit
- Collect samples at the inlet and outlet

<u>Merrimont Park & Greenfield Lake</u>

Image source: Teledyne ISCO

- No pre-retrofit monitoring
- Collect samples at the inlet, directly before FTWs, directly after FTWs, and at the outlet

Wetland Plant Sampling and Analysis

- Collect 9 plant **root biomass** samples upon FTW installation and seasonally thereafter at each project site
- Samples will be analyzed by for **nutrients** by the NC Department of Agriculture and Consumer Services (NCDA&CS) Plant Laboratory

Image source: Beetmats Floating Wetlands

Take Home Points: Floating Wetland Islands

- This research is in early stages.
- We'll talk more in a year!

Thank you for your attention!