NC STATE UNIVERSITY

Ohio Workshops – Nov/Dec 2011

Bioretention Water Quality Performance & Design

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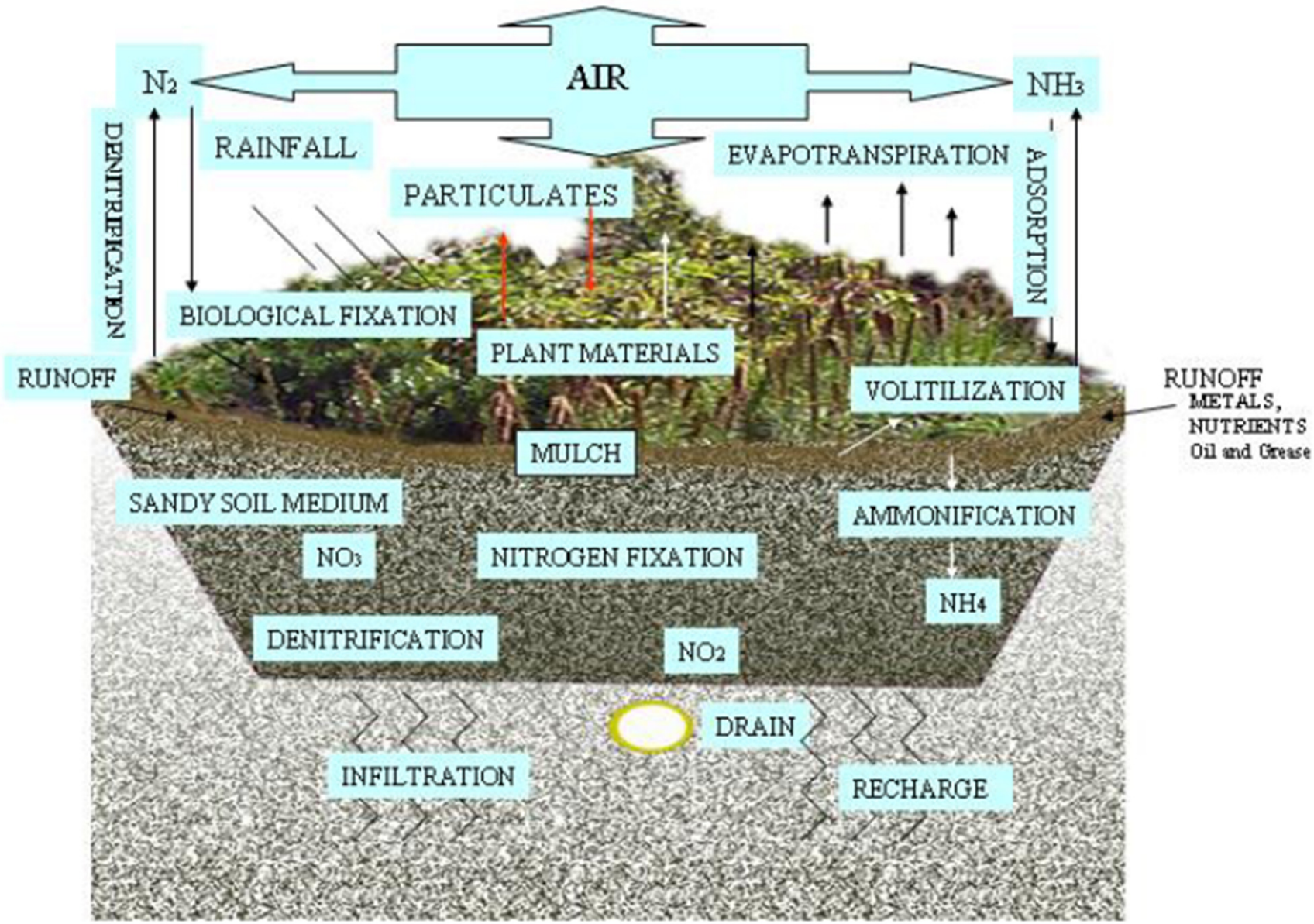
NC STATE UNIVERSITY Bio&Ag ENGINEERING

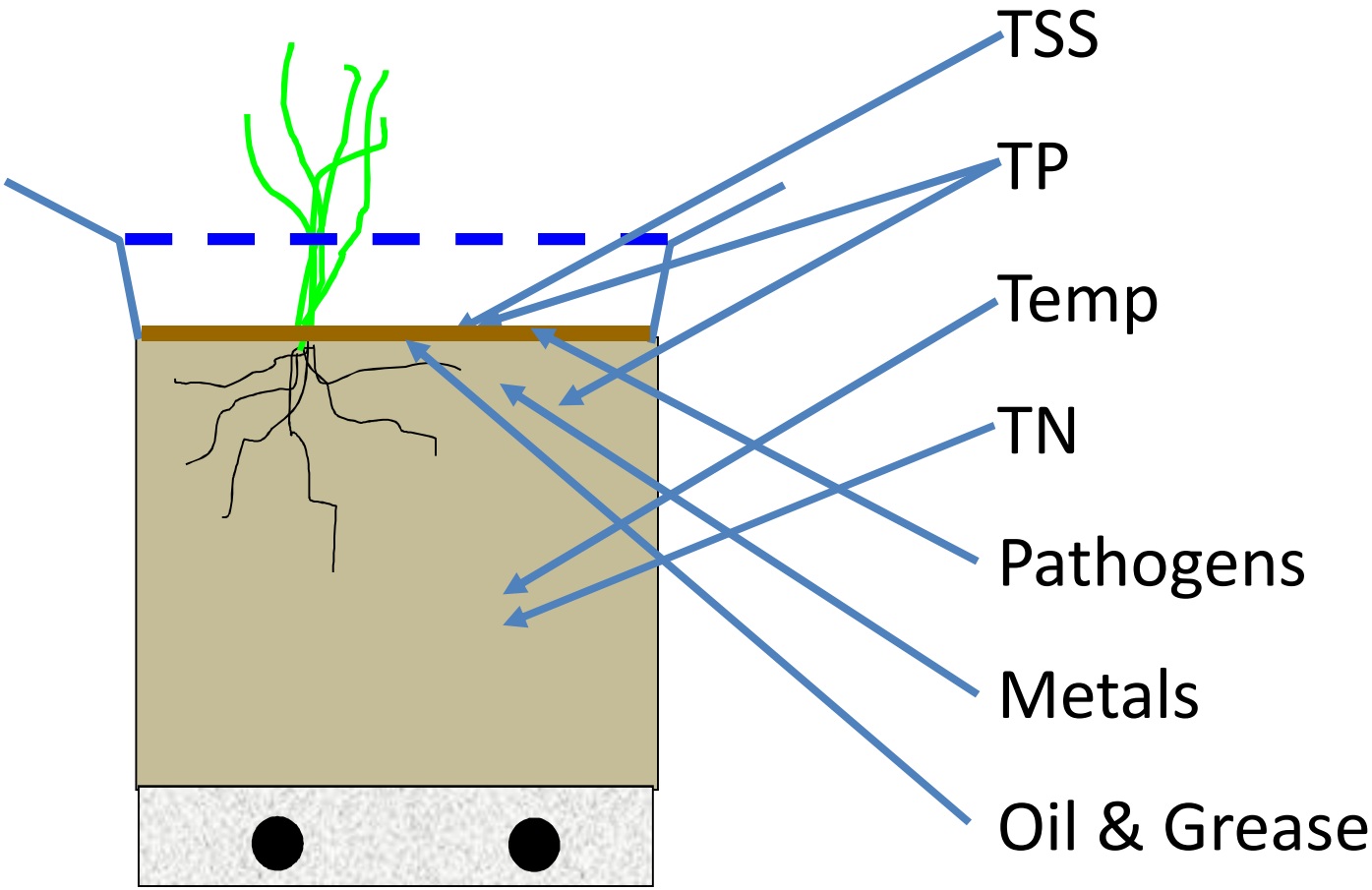
Q: How does Bioretention work: Pollutant Removal Mechanisms

- Sedimentation (temporary)
  - Trash, TSS, Phosphorus
- Microbial Processes
  - Nitrogen
- Chemical Processes & Media Filtration
  - Metals, Phosphorus
- Exposure to Sunlight & Dryness
  - Pathogens, Oil & Grease
- Infiltration

Biochemical Pollutant Removal Mechanisms in a Bioretention Cell



Stormwater Game Show: Where are pollutants removed?



Studies on Water Quality

College Park (CP) Site

Watershed	**Anacostia**
Year Built	**2004**
Watershed Size	**0.26 ha**
Surface to Drainage Area Ratio	**6%**
General Shape	**Trapezoidal**
Ponding Depth	**15 cm**
Fill Media Depth	**0.5-0.8 m**
Soil Texture[b]	**Sandy loam**

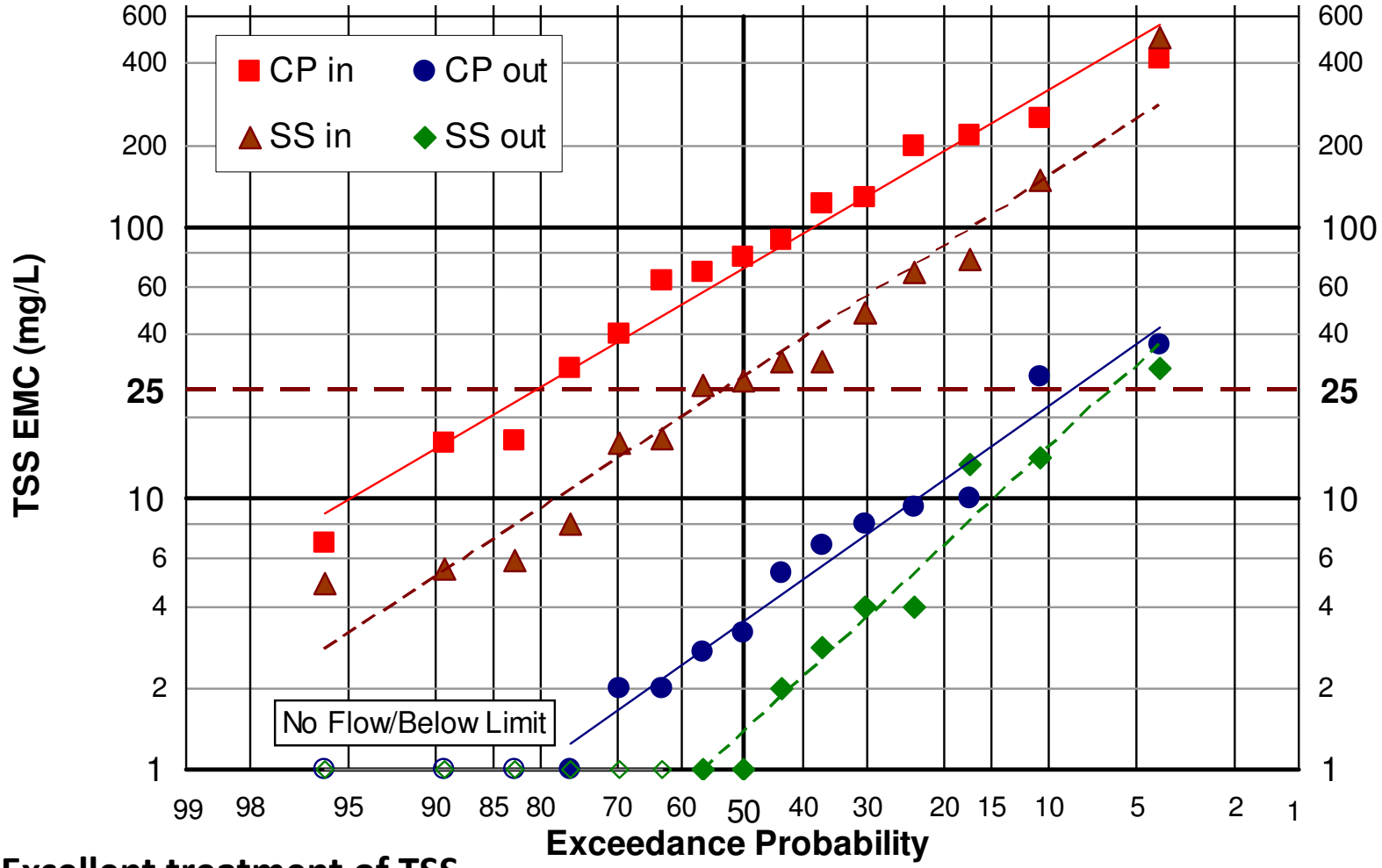
Underdrain discharge to Stream

Silver Spring (SS) Site

Watershed	Anacostia
Year Built	2006
Watershed Size	0.45 ha
Surface to Drainage Area Ratio	2%
General Shape	Triangle
Ponding Depth	30 cm
Fill Media Depth	0.9 m
Soil Texture	Sandy clay loam

Underdrain discharge to Storm Drain to Stream

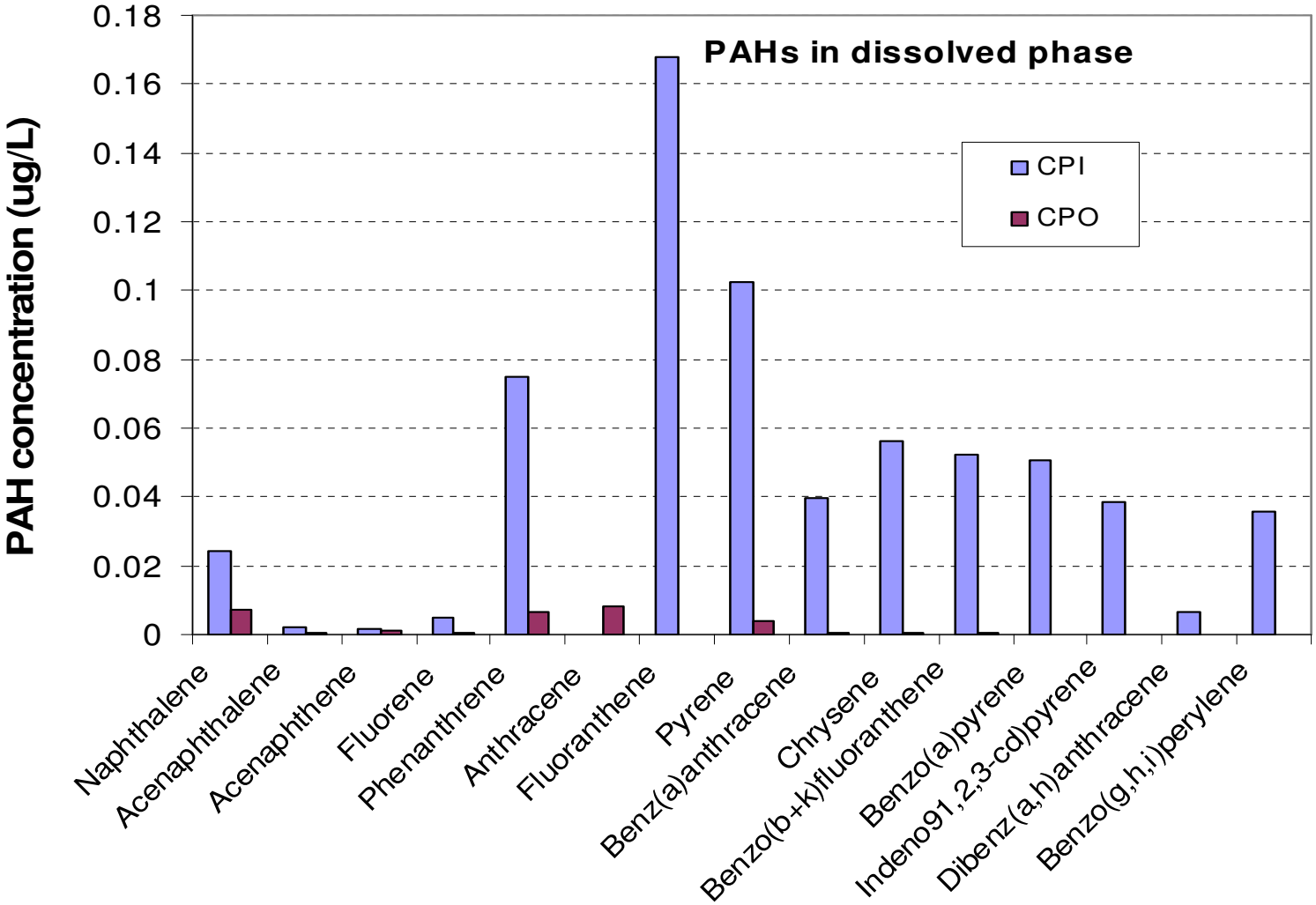
Bioretention TSS (CP & SS)



Excellent treatment of TSS

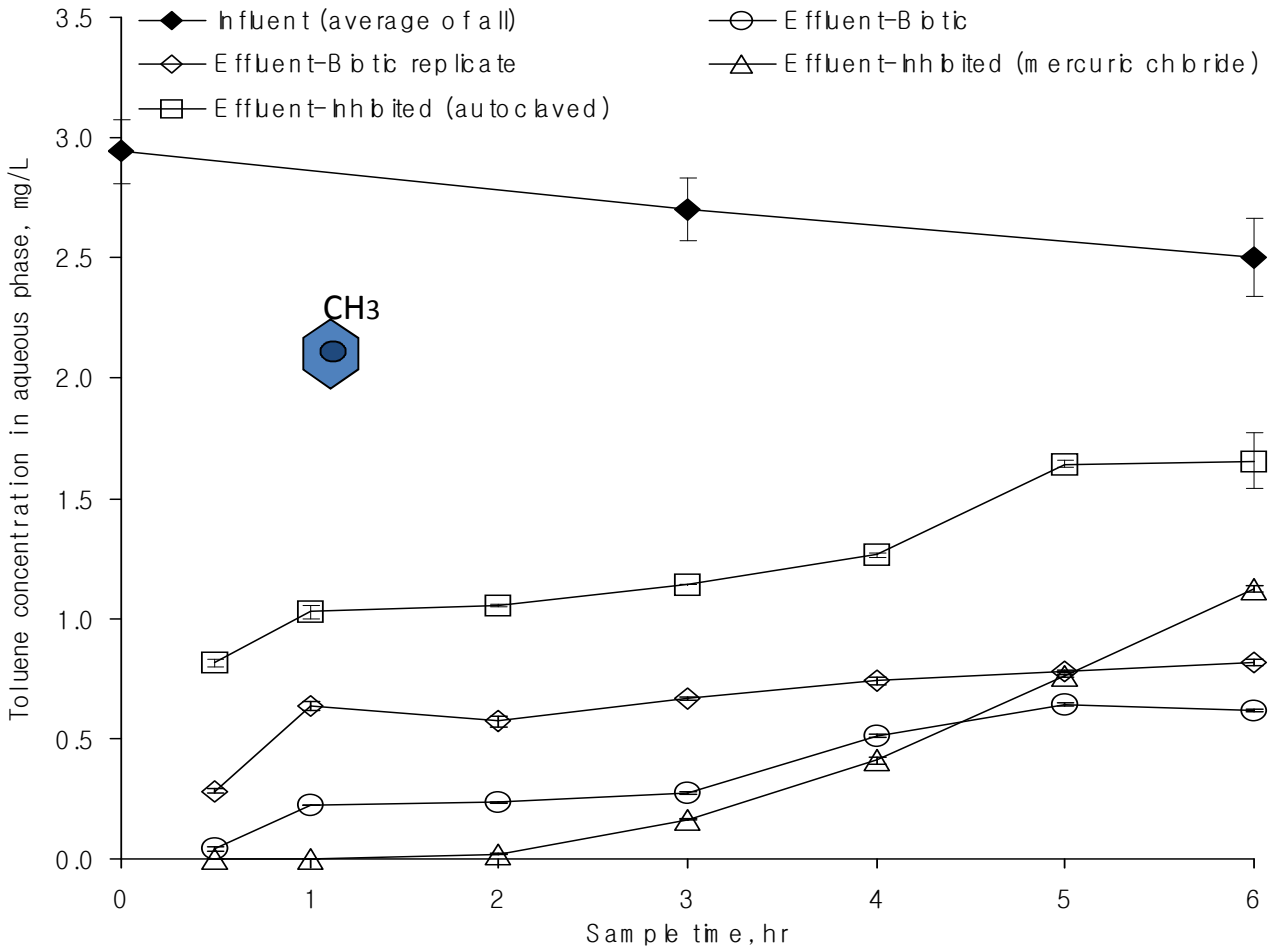
Li & Davis, J. Env. Eng. 2009

Bioretention PAH Field (CP)



Diblasi, Li, Davis & Ghosh, Environ. Sci Technol., 2009

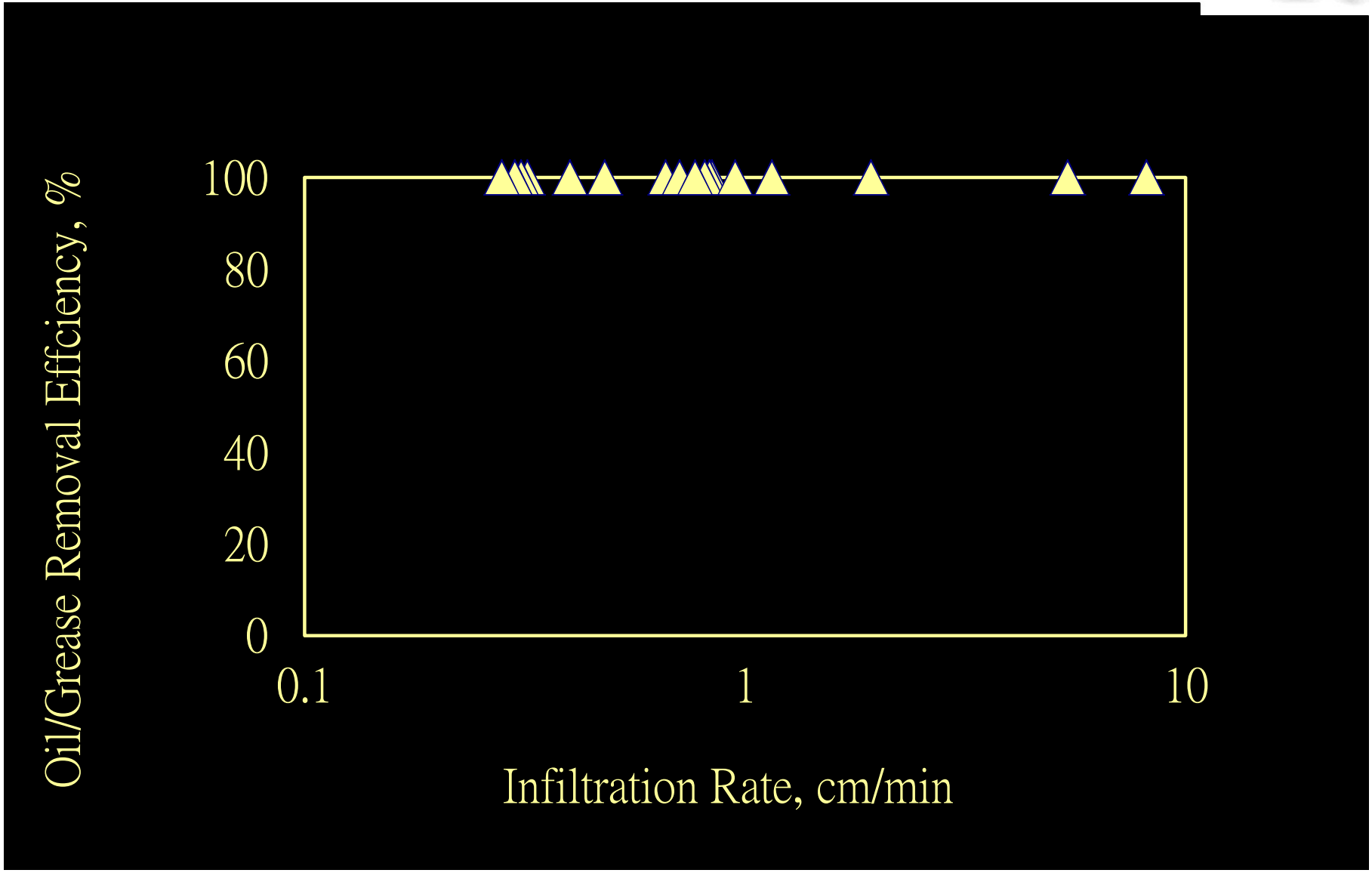
Toluene Removal w/ Mulch



Hong, Seagren, Davis, Wat. Environ. Res., 2006

Toluene, gasoline component, well removed by mulch layer

Results: Oil and Grease

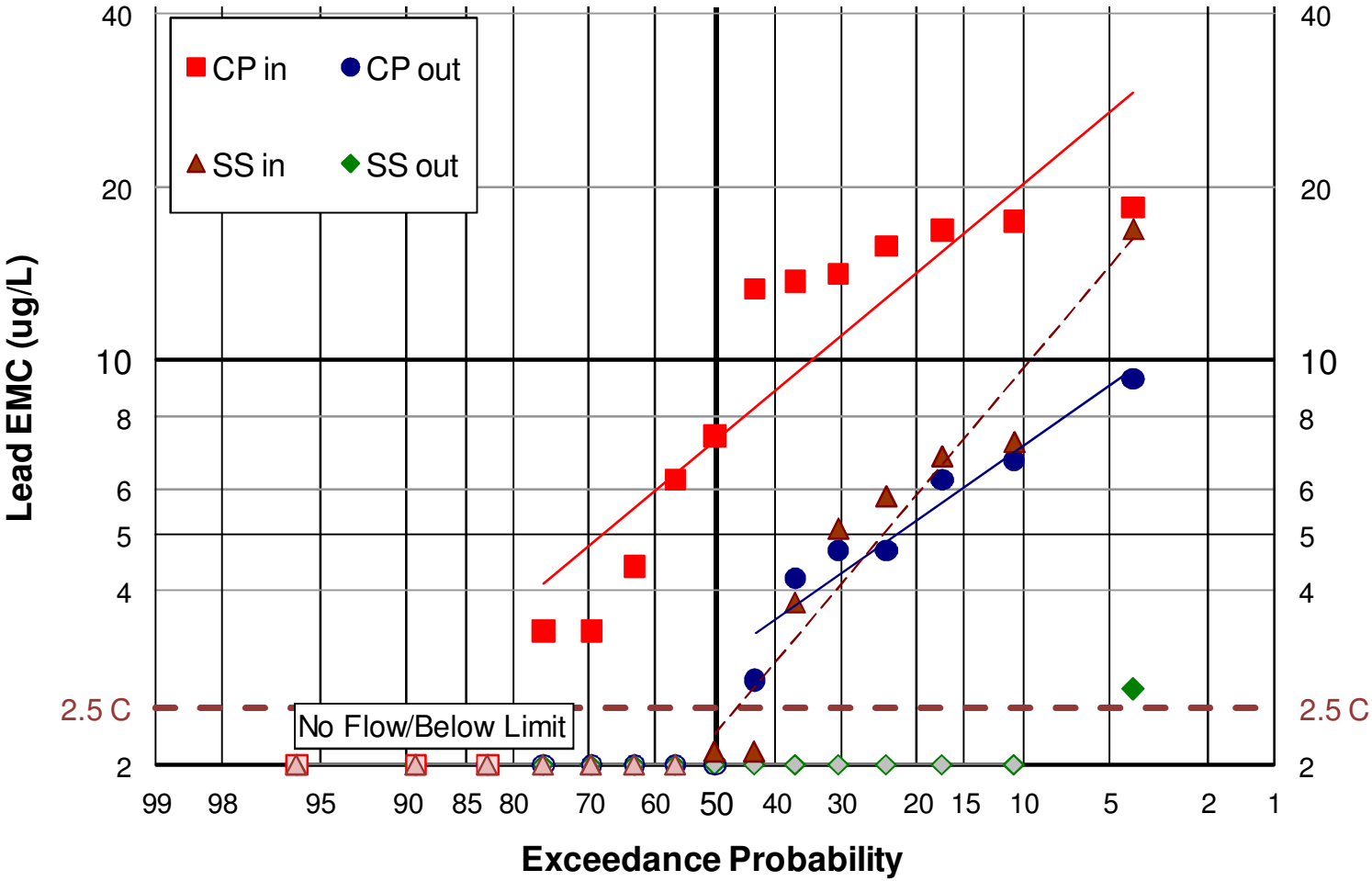


100% O/G removal. Type of Media has no impact.

Hsieh & Davis J. Environ. Engg. 2005

Mulch Matters!

Lead (CP & SS)

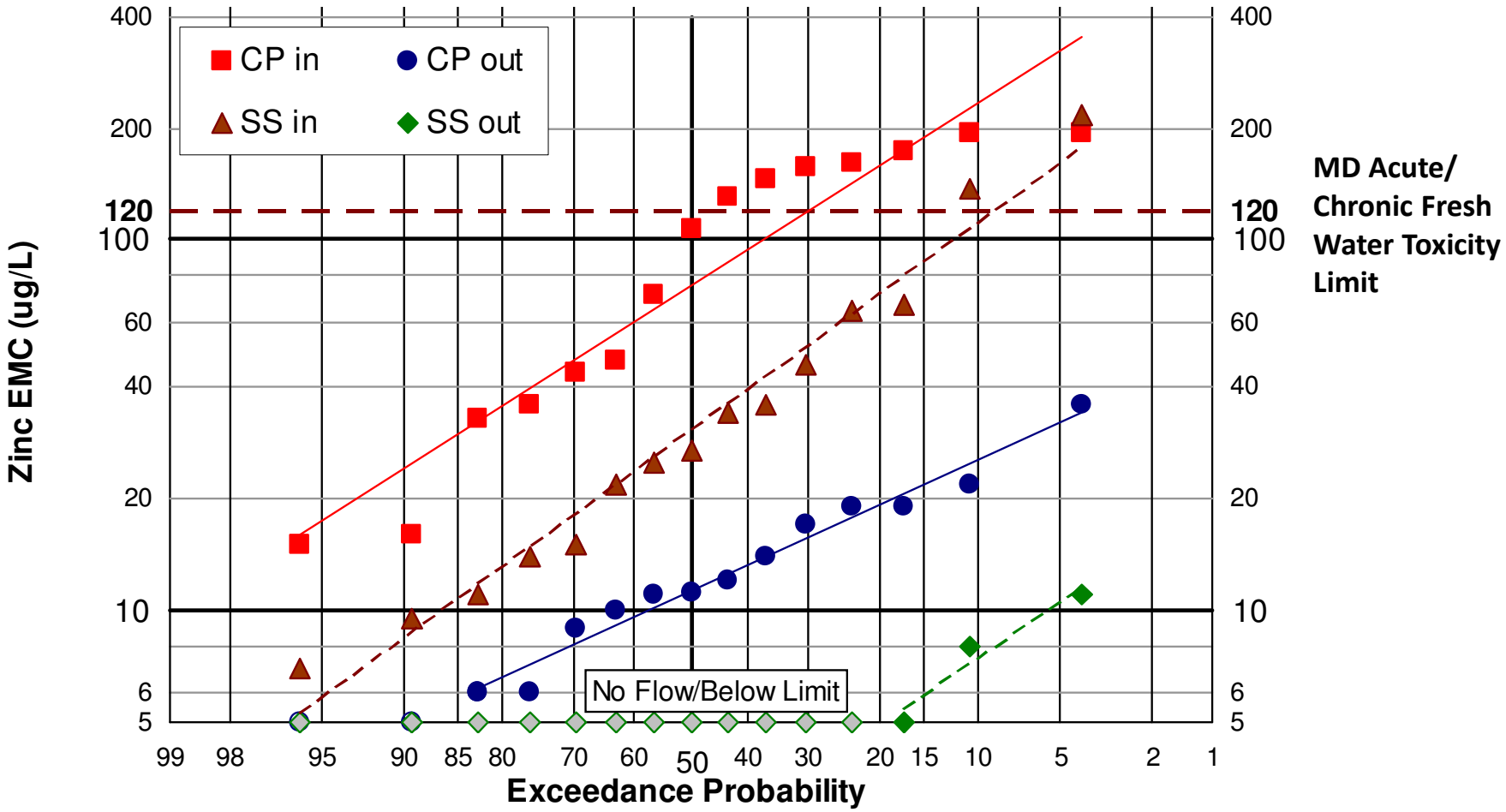


MD Chronic Fresh Water Toxicity Limit

Lead is very well removed as evidenced by field bioretention data.

Li & Davis, J. Env. Eng. 2009

Zinc (CP & SS)



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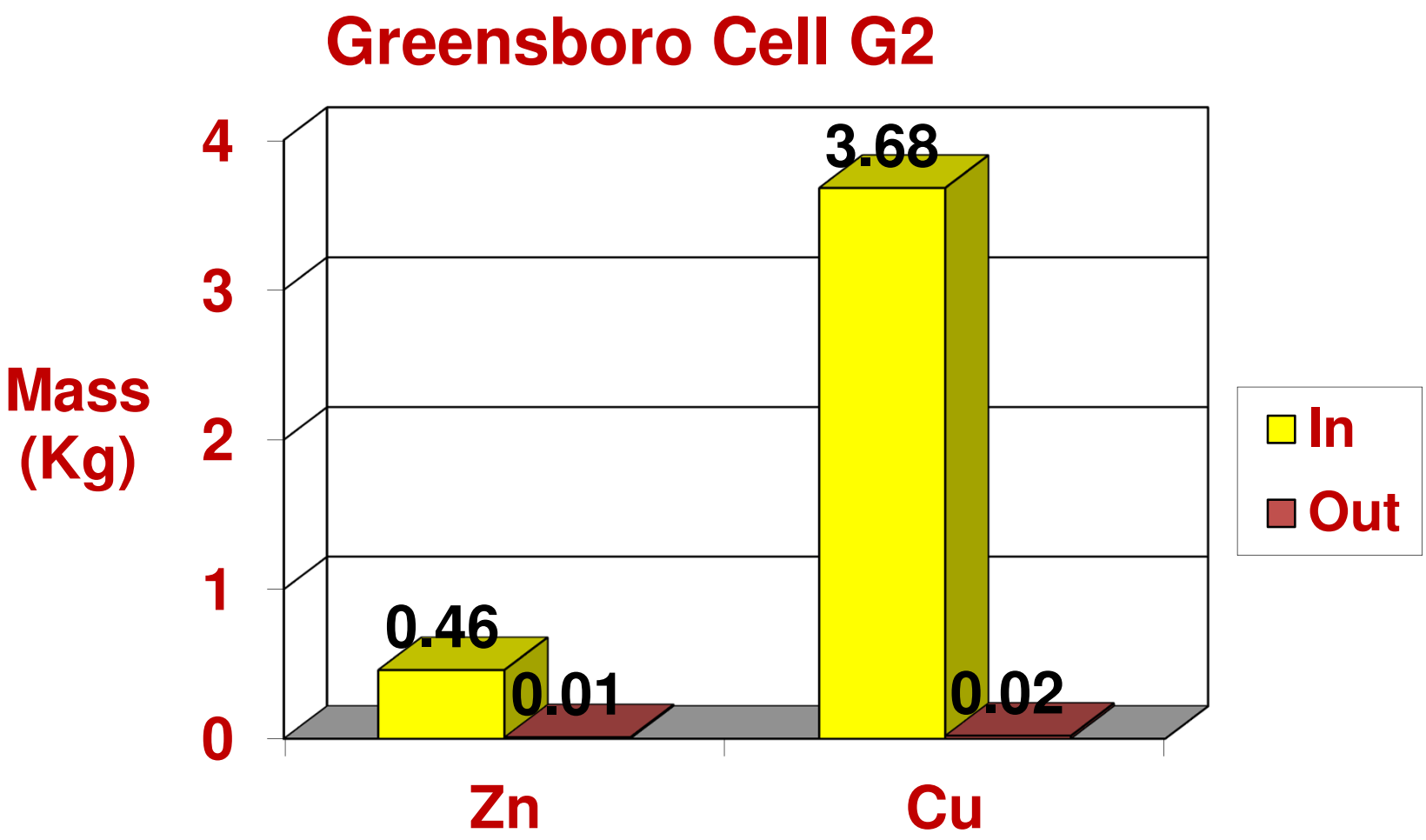
Li & Davis, J. Env. Eng. 2009

Similar Data from NC

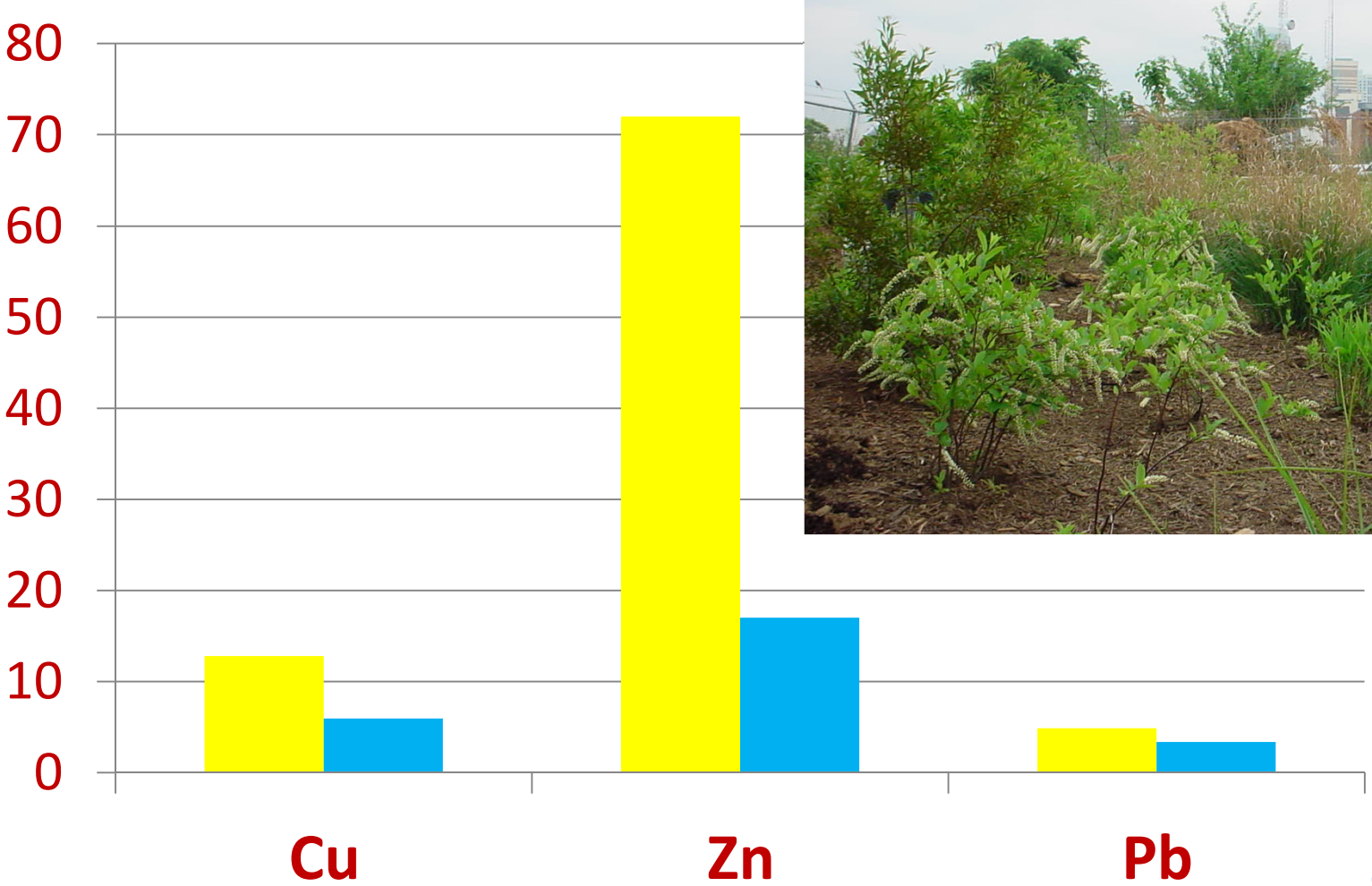
(Hunt et al. 2006)

Annual Loadings (2002-2003)



And Charlotte, too

(Hunt et



Take Home Point

- The Mulch and Upper Media Layers are critical for removal of…
  - Metals
  - Hydrocarbons
  - TSS
- Performance appears to be independent of type of media used

Blame it on the Media…

Phosphorus Index (P-Index) is a measure of how much phosphorus is already in the soil media.

Low P-Index: Can capture more phosphorus

High P-Index: Soil is "saturated" with phosphorus

Very High: > 100

High: 50-100

Medium 25-50

Low: 0-25

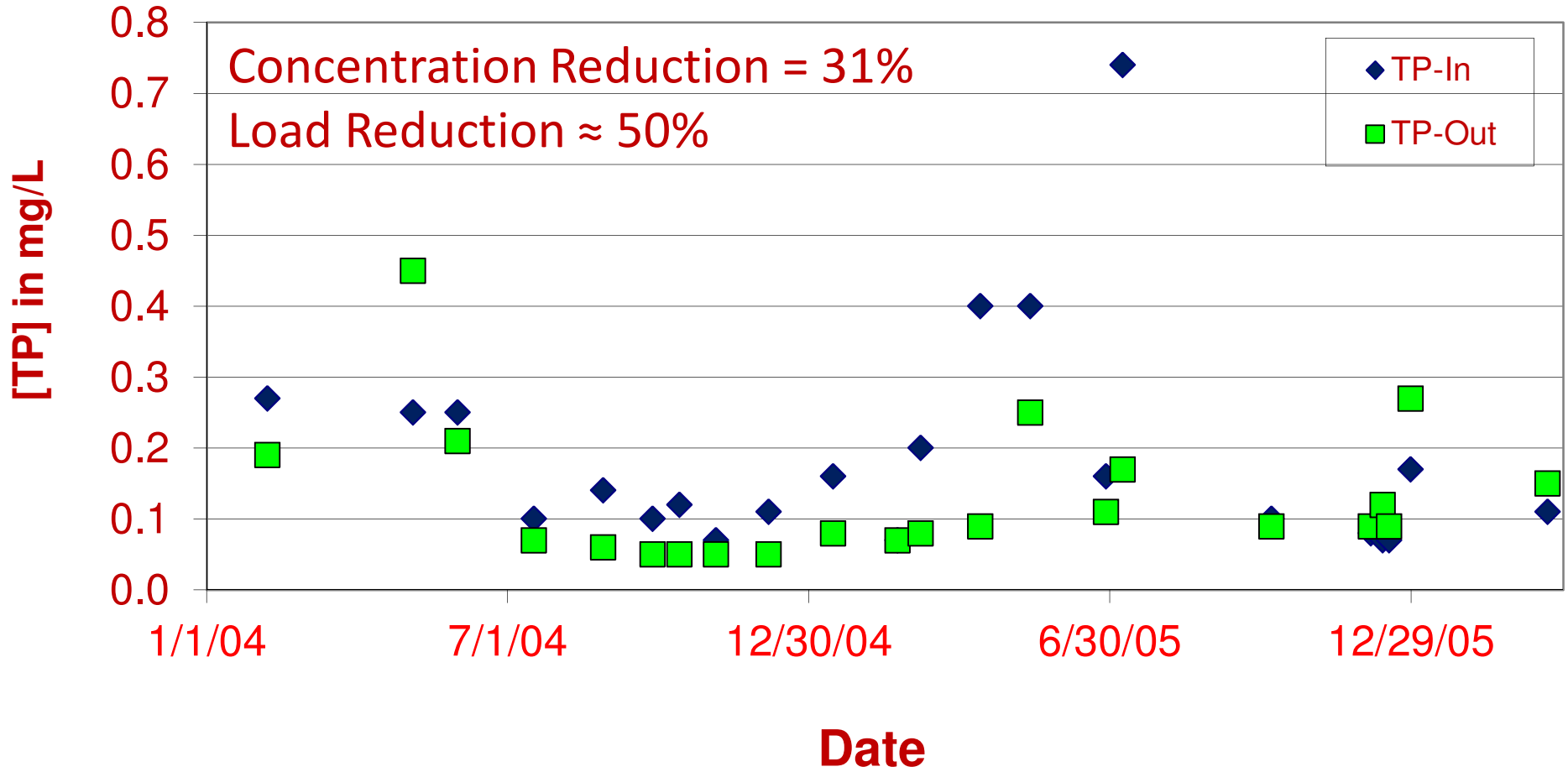
Mecklenburg Co. Hal Marshall Bioretention Cell (2004-2006)

Soil

- 80% Mason Sand
- 20% Fines + Compost
- P-Index = 6
- 4 ft (1.2 m) Depth

TP Charlotte, NC (2004-2006)

Hunt et al., 2008



Louisburg Bioretention Cells

- Soil Media:
  - Nominally 0.75 m Deep
  - 60% Sand
  - 40% “Ballfield Mix”
- Low PI (1-2) fill
  - 85% Sand
  - 10% Fines
  - 5% Organics
- Constructed Spring 2004

Load Reductions: Louisburg

Cell	TN	TP
L-1 (unlined)	64%	66%
L-2 (lined)	68%	22%

June 2004- February 2005

Concentration vs. P-Index

Site	P-Index	Depth (in)	Outflow (mg/L)
C-1	6	48	0.13
L-1	1-2	30	0.16
L-2	1-2	30	0.18
G-1	35-50	48	0.57
G-2	85-100	48	1.85

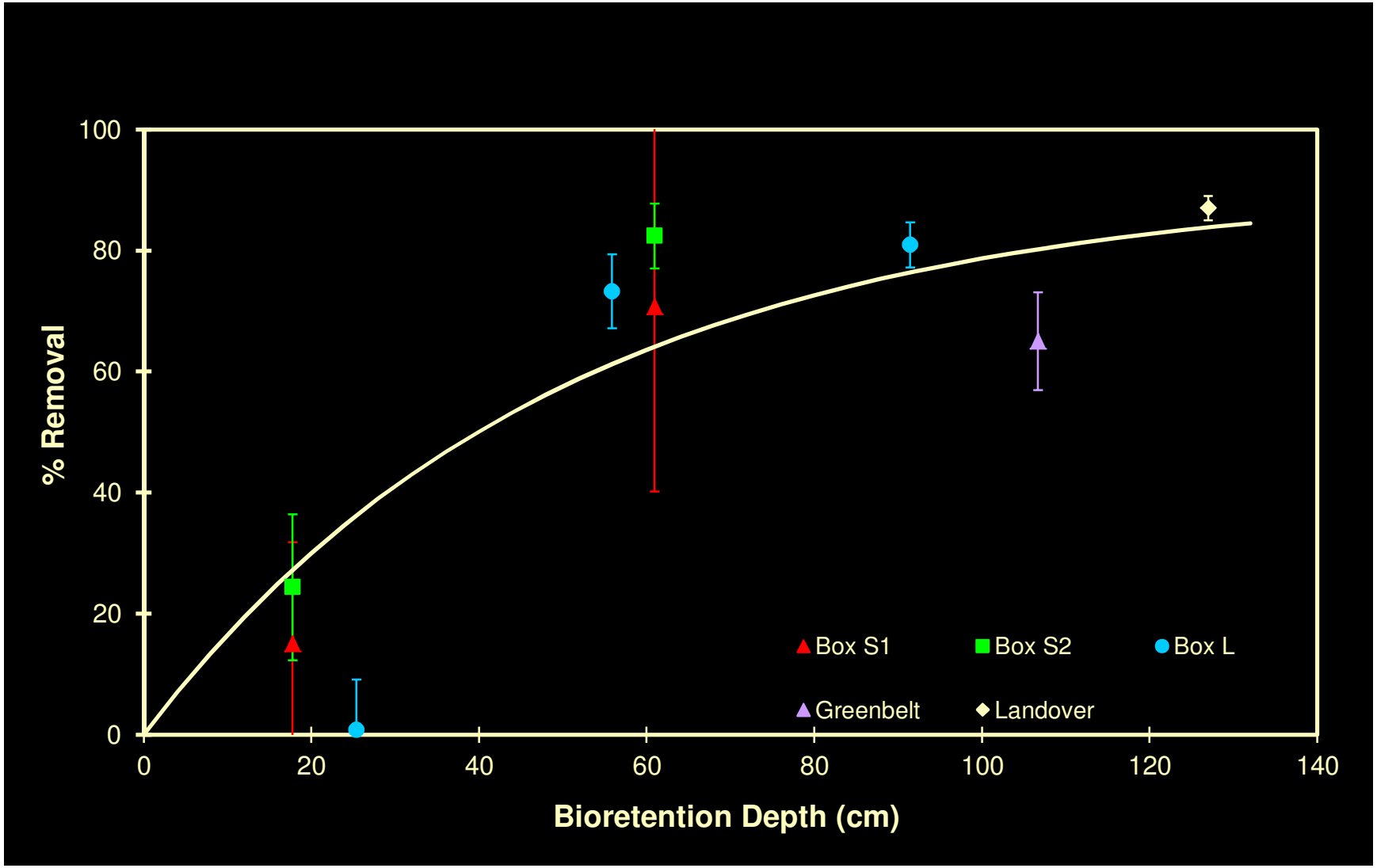
LOW

Mass Loads (kg/ha/yr)

	CP		SS	
	In	Out	In	Out
TSS	1190	37	570	38
Chromium	0.09	0.015	0.02	~0.007
Copper	0.26	0.073	0.12	0.045
Lead	0.09	0.013	0.03	~0.005
Zinc	1.0	0.063	0.36	0.017
Chloride	6800	458	320	25
TN	27	7.2	9.6	3.6
Nitrate	12	2.5	3.7	~0.19
TKN	15	4.1	6.0	3.6
TP	3.6	0.72	0.9	0.38
TOC	44	154	43	78

Li & Davis, J. Env. Eng. 2009

Overall Results: Phosphorus



Phosphorus removal increases gradually with bioretention depth.

Davis, Shokouhian, Sharma, Minami, Wat. Environ. Res. 2006

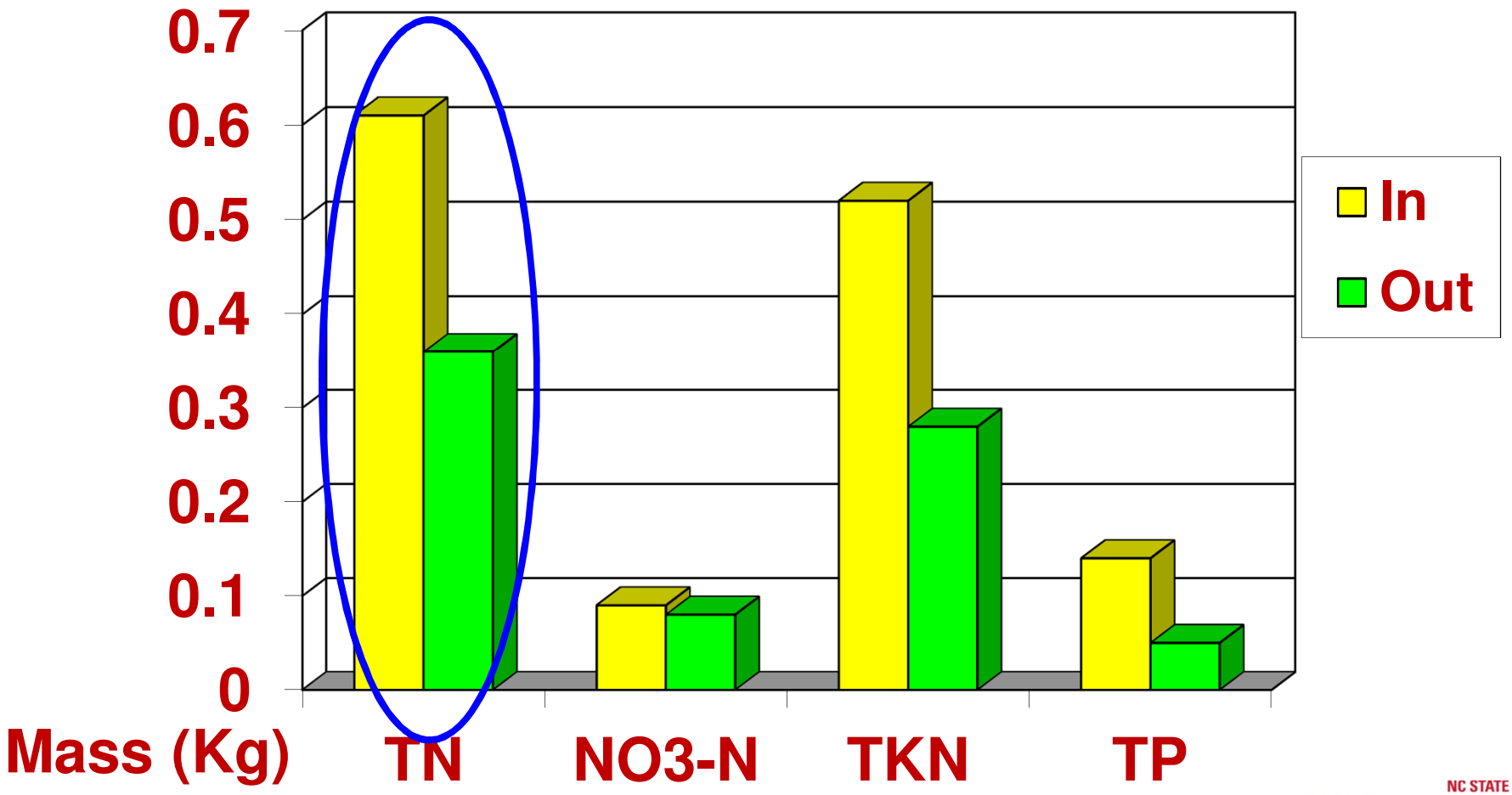
Take Home Point: Phosphorus

- Proper Media Selection is Critical
- With good media, TP sequestration is high.
- Most appears to occur in the upper layers of media

Chapel Hill Cell, C1
STP/WS = 0.14
Conventional Drainage

Annual Loadings (2002-03)

Chapel Hill Cell C1 *Hunt et al., 2006*

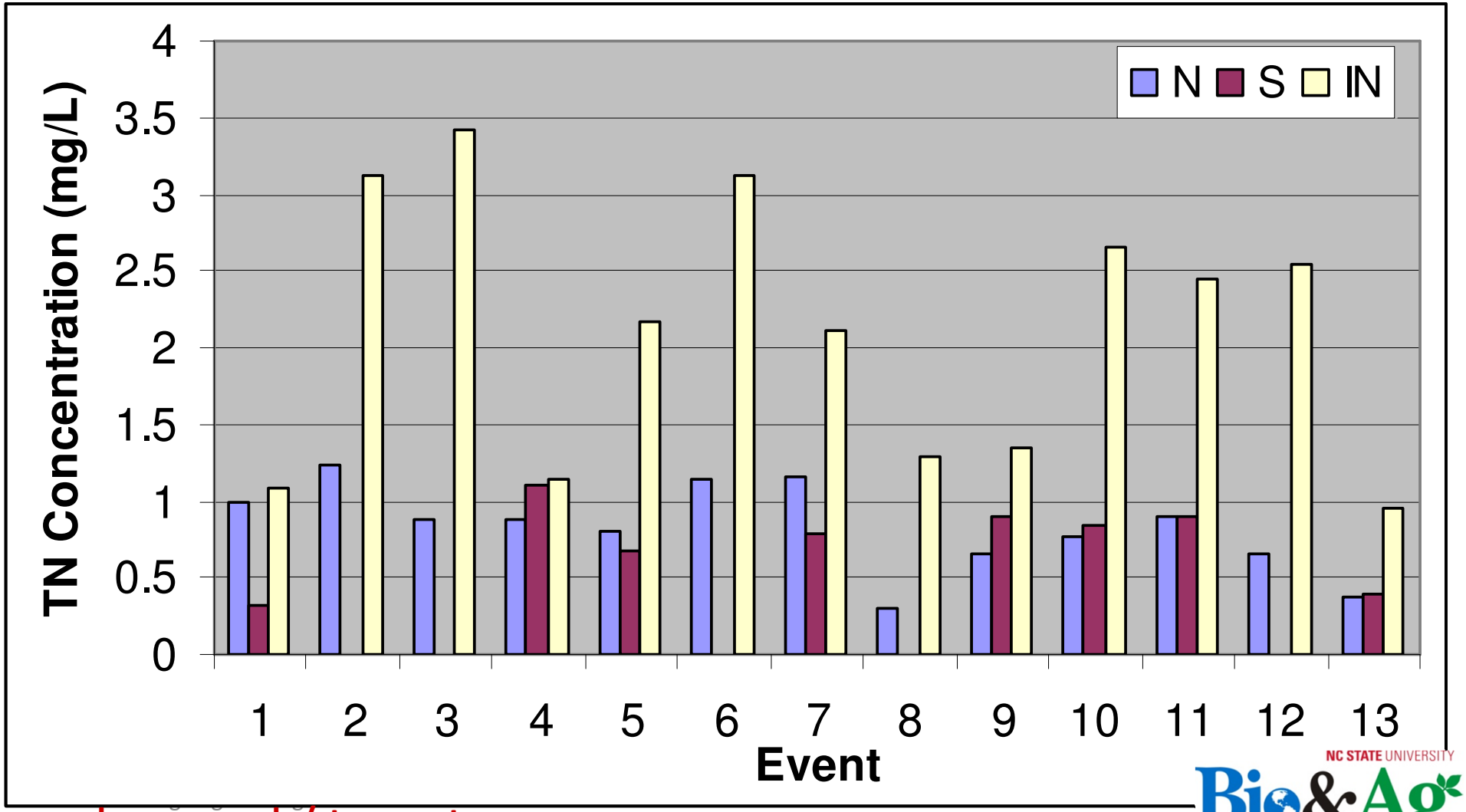


Graham High School (2006-2007)

Passeport et al. 2009

- Watershed area = 0.69 ha
- Bioretention Cells Area = 204m^2
- Fill Media/ Soil
  - 90% Expanded Slate Byproduct
  - 10% Top Soil
  - P-Index: Low
  - 0.6 m & 0.9 m (2 & 3 feet) depth
- Both Cells Covered in Turf (Hybrid Bermuda)

TN concentrations: Grassed Graham HS Bioretention (2006)



Mass Loads (kg/ha/yr)

	CP		SS	
	In	Out	In	Out
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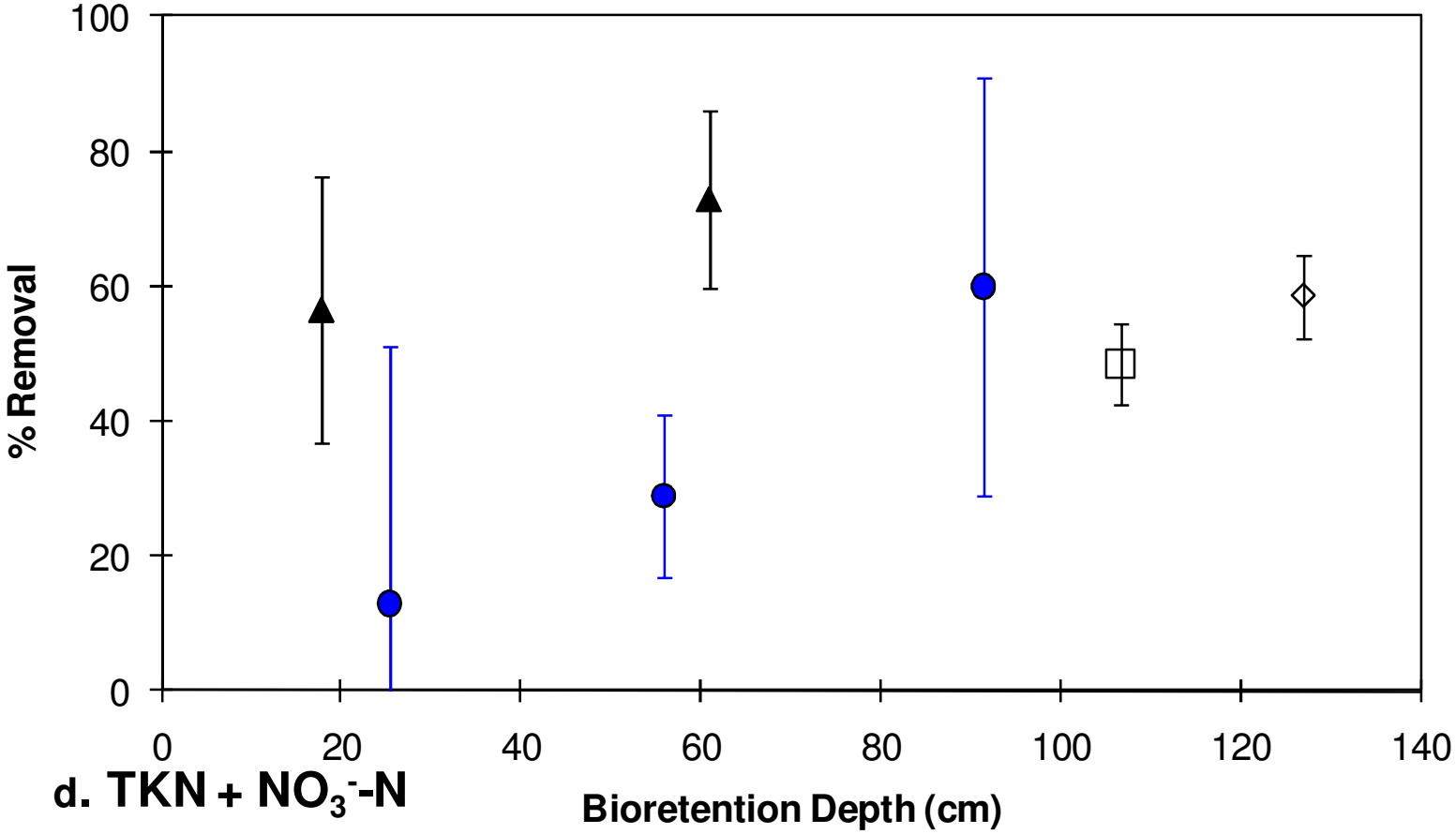
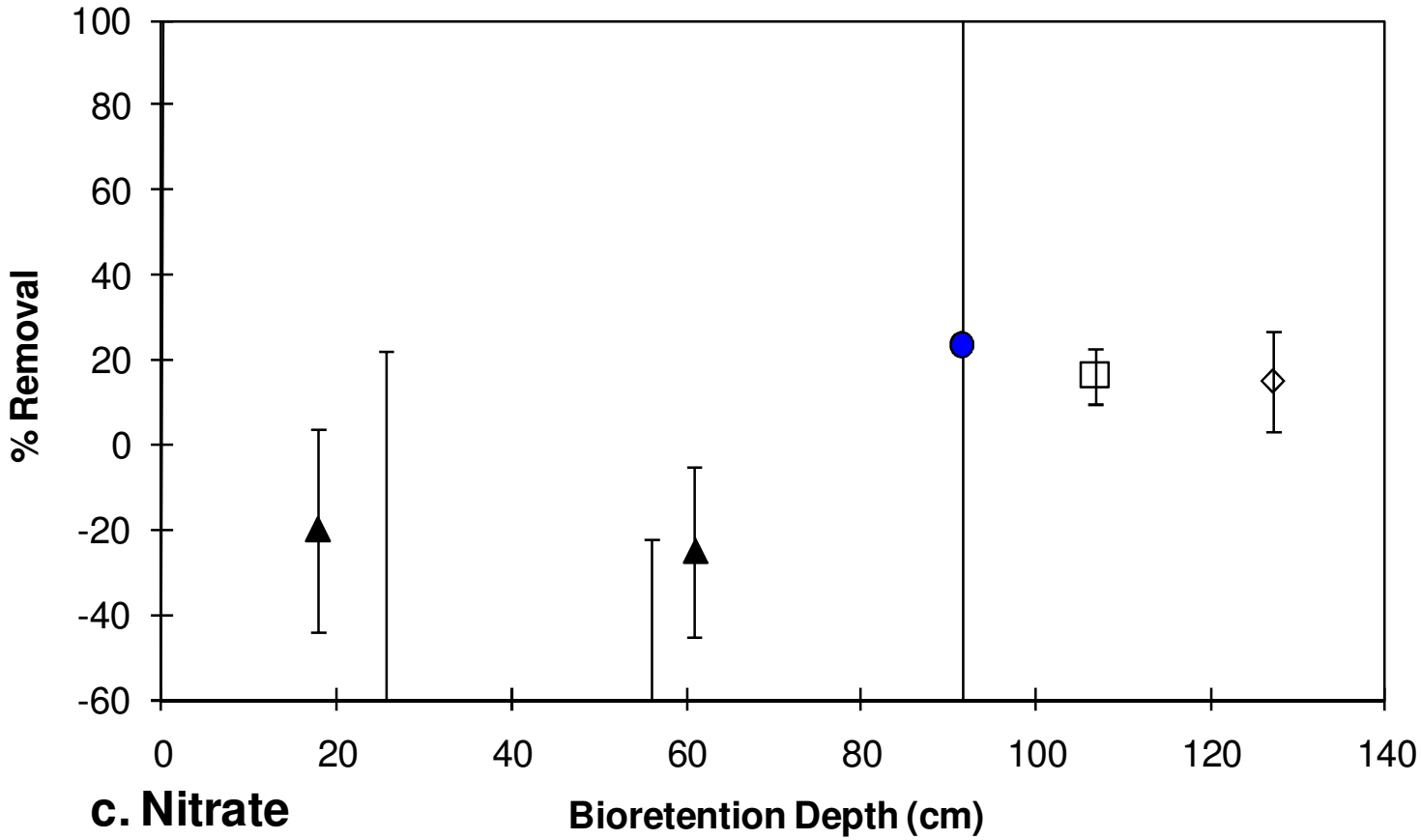
Li & Davis, J. Env. Eng. 2009

TN with Depth



d. TKN + NO_3^--N

Nitrate with Depth

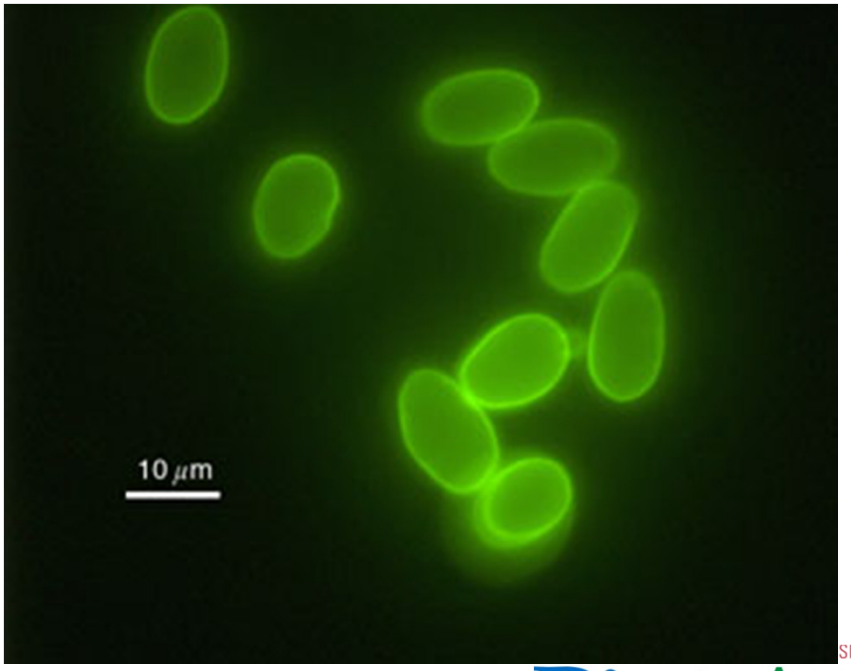


Take Home Points: Nitrogen

- Proper Amts of Organic Matter is Critical
- With good media, TN sequestration is high.
- Somewhat deeper media (> 90 cm) may be best (esp. for $NO_{2\text{-}3}$-N)

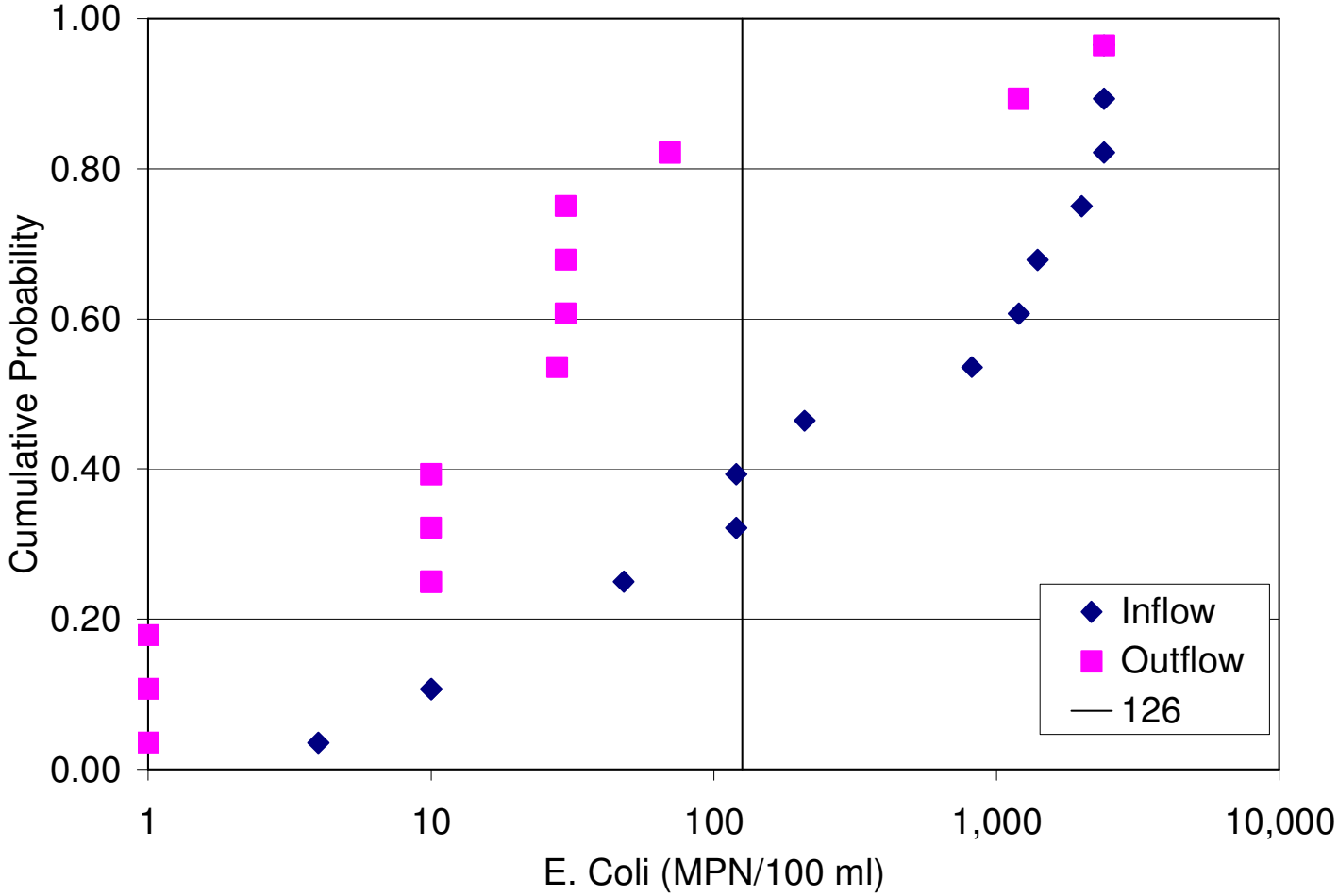
Indicator Bacteria

- Testing for pathogens is expensive and time consuming
- Epidemiology studies associate sickness to indicator bacteria
- Indicator bacteria
  - Total coliform
  - Fecal coliform
  - *E. coli*
  - *Enterococci*

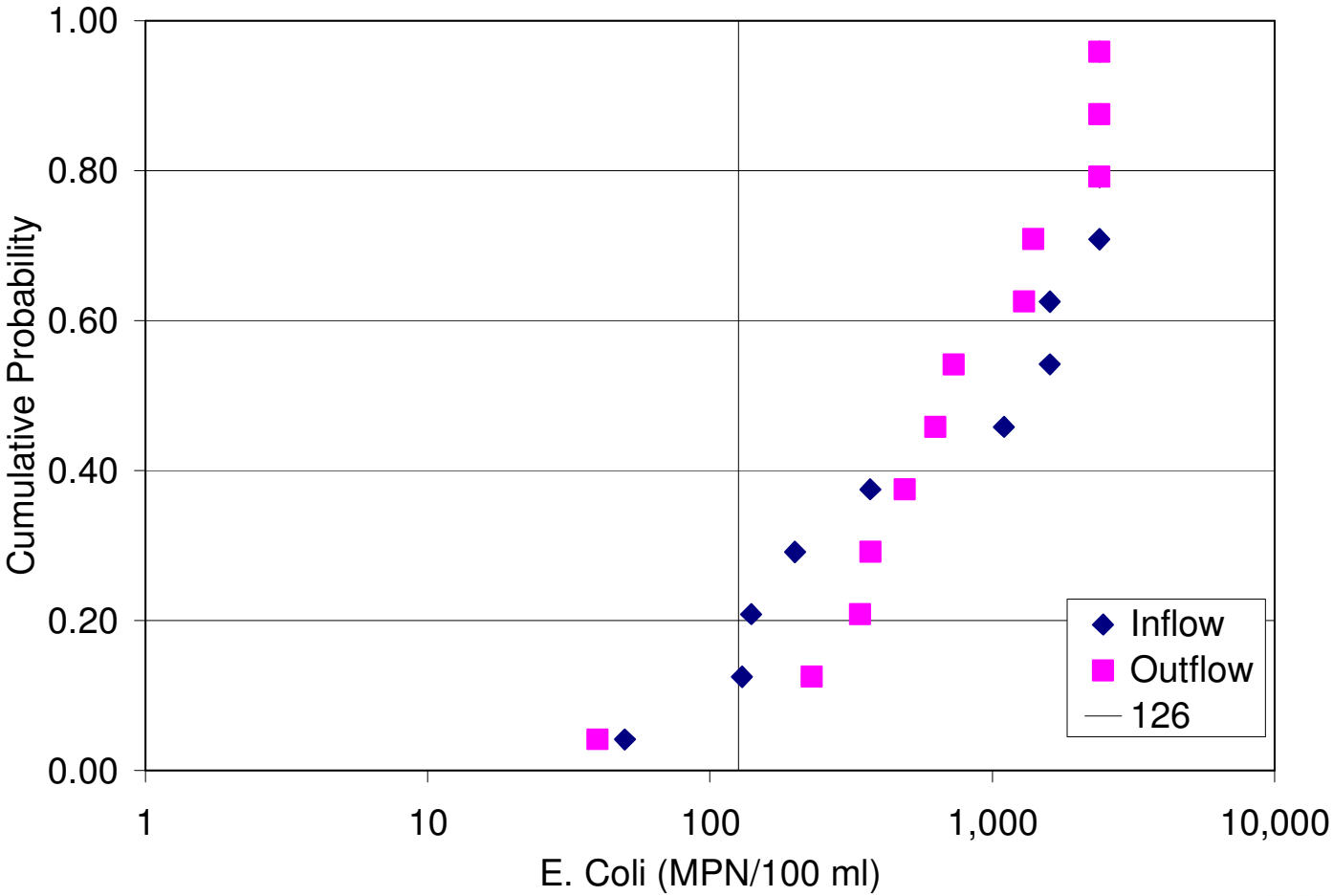


Hal Marshal (Bioretention)

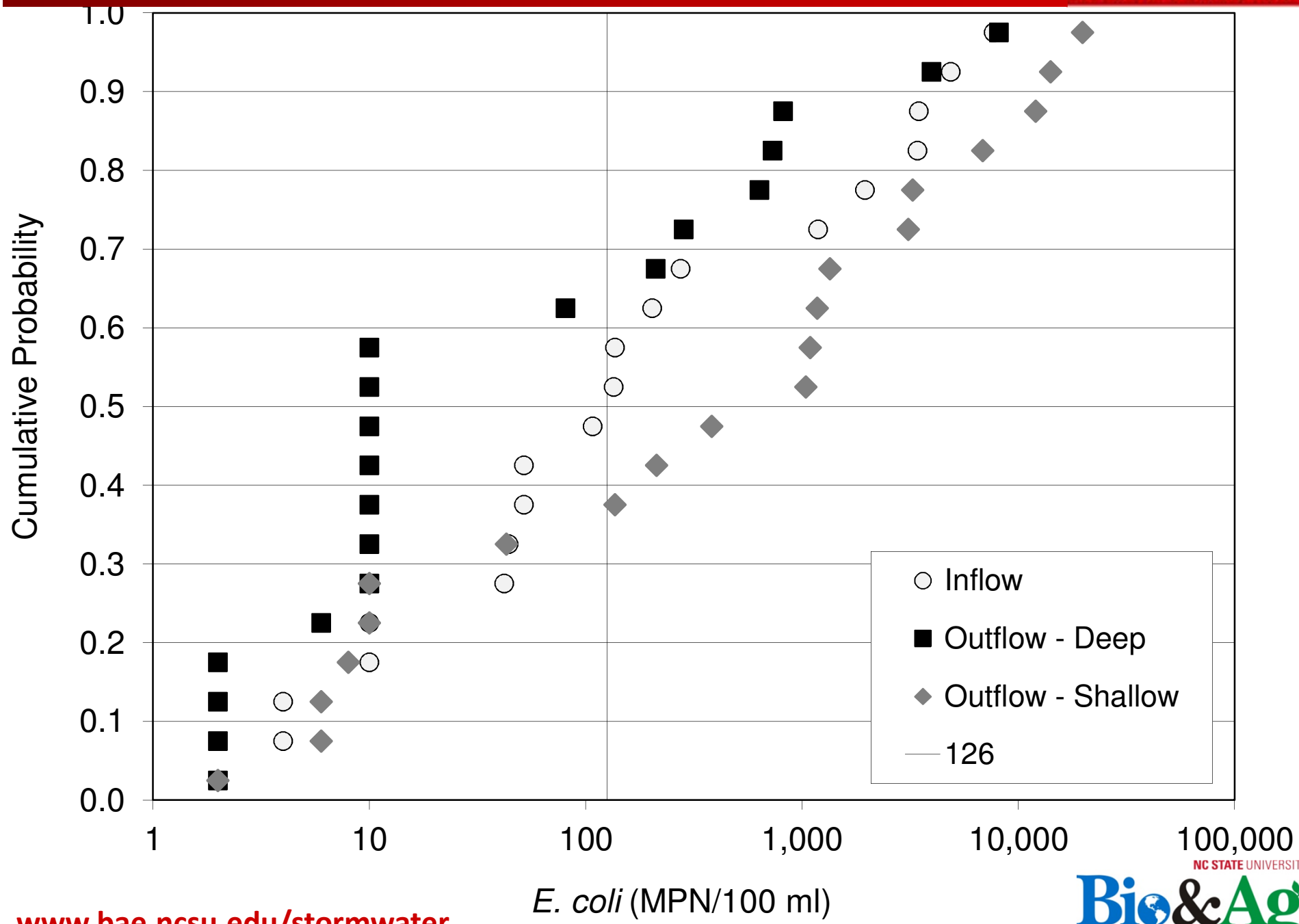
Cumulative Probability Plots – Bioretention



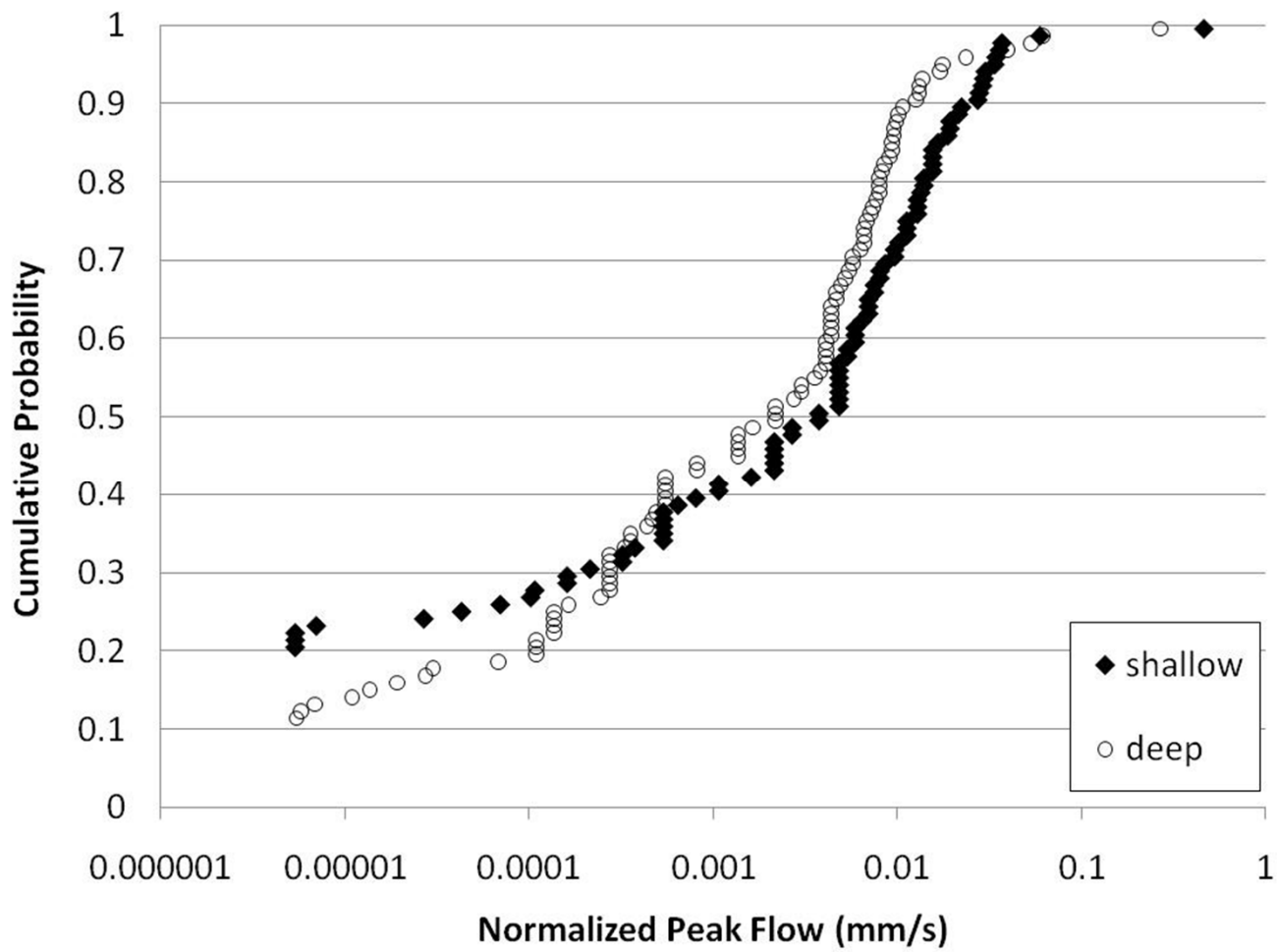
Cumulative Probability Plots – Dry Detention



Wilmington Bioretention


Cumulative Probability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
10
100
1,000
10,000
100,000
E. coli (MPN/100 ml)
Inflow
Outflow - Deep
Outflow - Shallow
126

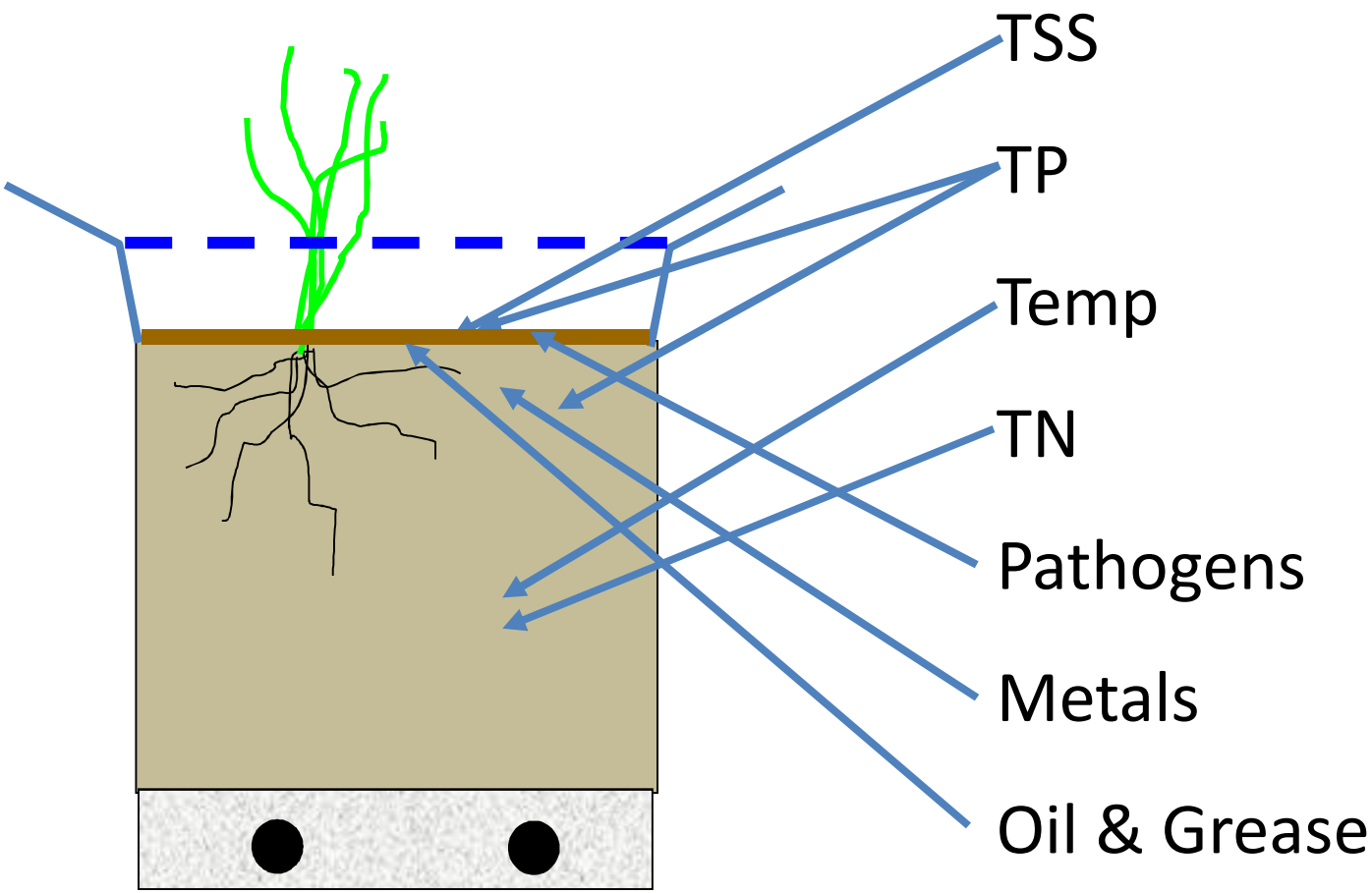
Hydrology


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Cumulative Probability
0.000001
0.00001
0.0001
0.001
0.01
0.1
1
Normalized Peak Flow (mm/s)
shallow
deep

Take Home Points

- Soil depth matters
  - Cost vs. performance balance
- Bioretention design can be manipulated for indicator bacteria removal
- Bioretention shows promise
  - Better than other practices
- There are minimum bioretention depths
  - 60 cm or greater seems safe

Where are pollutants removed?



Literature/Research Justification for Minimum Media Depths: WQ

Pollutant	Depth (ft)	Studies
TSS	1	Diblasi et al. 2009, Li et al. 2008
Metals	1	Li and Davis 2008, Hatt et al. 2009
O&G	1	Diblasi et al. 2009,
Phosphorus	2 (min); 3 (conservative)	Hatt et al. 2009, Hsieh and Davis 2007, Passeport et al. 2009
Nitrogen	0.9	Passeport et al. 2009
Temperature	3 (min); 4 (optim)	Jones and Hunt 2009

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

Question: What's the Ideal Fill Media Composition?

Infiltration Rate:

- Varies: Contact Time
- Temperature reduction and N removal
  - More Contact Time
  - 25-50 mm/hr
- TSS, High Sat K is OK
  - > 150 mm/hr
- Heavy metals… jury is out

Final Take Home Points: from Bioretention Research…

- Improve Hydrology
  - Modest Peak Flow Mitigation
  - Long-term Hydrology Balance
  - Leads to Pollutant Load Reduction
- Reduce Pollutant Concentrations / Release Low Pollutant Concentrations
  - TSS
  - Metals & Hydrocarbons
  - TP & TN
  - Bacteria

But, must be careful with Media Selection.