The Potential to Enhance Nutrient Removal in Bioretention and Sand Filters

USWG

6-27-2017

Chesapeake Stormwater Network

Center for Watershed Protection

Hirschman Water & Environment, LLC

National Fish and Wildlife Foundation

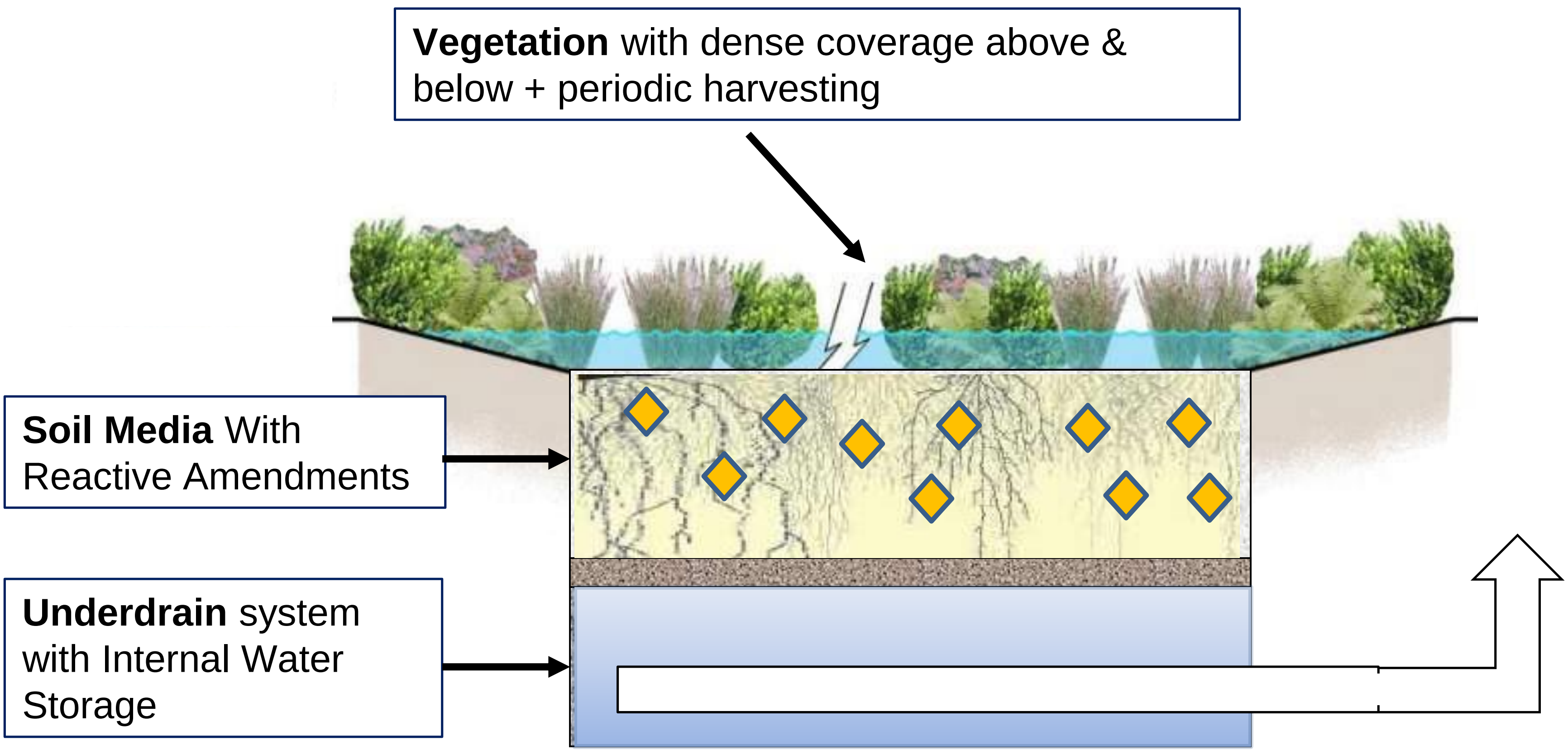
Presentation

• Project Background	Tom Schueler
• Initial Monitoring Results	Brian Siepp
• Research Synthesis	Dave Hirschman
• Question and Comments	All
• Proposed Credit Approach and Next Steps	Tom Schueler

Project Background

- NFWF Innovative Nutrient and Sediment Removal (INSR) Grant to CWP
- Two PED monitoring sites in MD
- Extensive Literature Synthesis by HWE
- Peer Review by MD and NC Researchers
- Two Watershed-Wide Webcasts in Late 2016
- Final Recommendations released in May
- Looking for USWG Feedback today

Bioretention: With Performance Enhancing Devices



Design Modifications

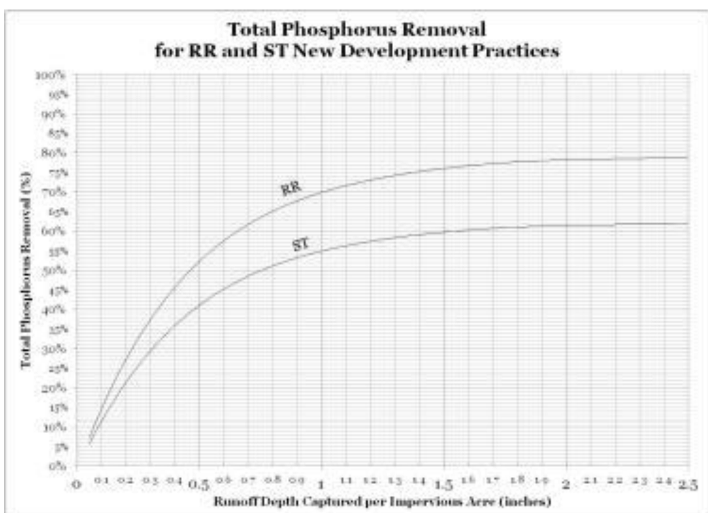
- Alternative media layers (e.g., iron filings, activated carbon, wastewater treatment residuals, activated carbon, biochar, wood chips, fly-ash)

- Internal design configurations that promote denitrification (e.g., upturned elbows, carbon seeding, anaerobic layers, subsurface ponding, biofilms, controlled subsurface releases)

- Plant species to maximize nutrient uptake and/or evapotranspiration rates.

Goal of Project

- Evaluate recent literature on mechanisms to boost nutrient removal in bioretention and sand filters
- Collect more field monitoring data on PEDs in the watershed
- Make a recommendation whether baseline N and P removal rates can be increased for bioretention and related runoff reduction practices



Field Monitoring of Biochar

CENTER FOR WATERSHED PROTECTION ASSOCIATION

Photo Credit: biochar.ucdavis.edu

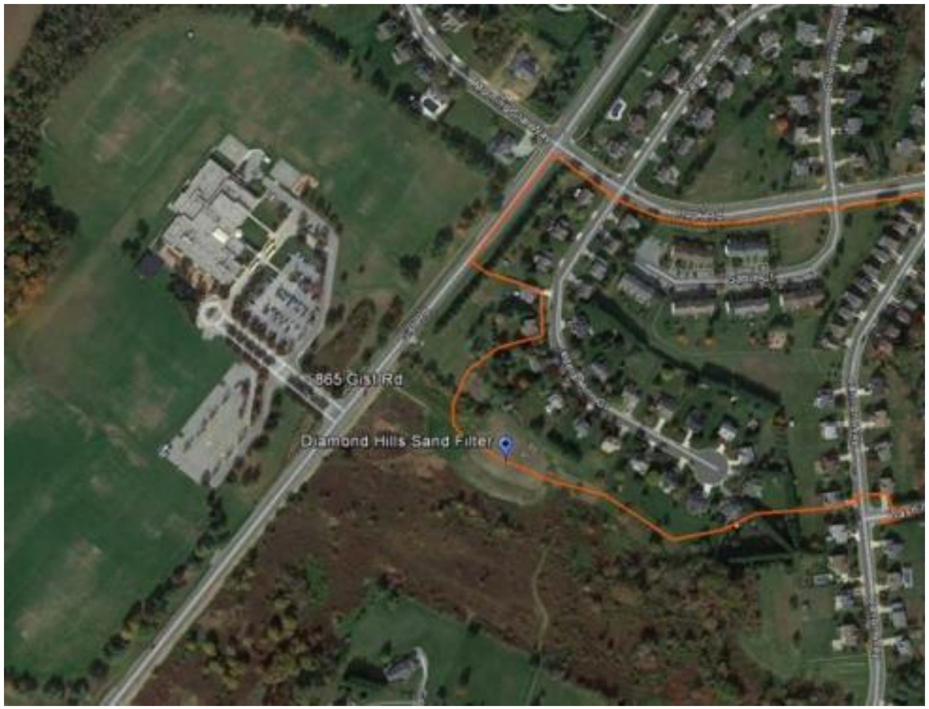
Monitoring Objectives

- Evaluate and document the procedures for incorporating Biochar into Stormwater Management BMPs (Bioretention & Sand Filters)

- Measure the impact to the performance of stormwater management BMPs to remove TN, TP, and TSS

Bethel Korean Presbyterian Church

Diamond Hills Community

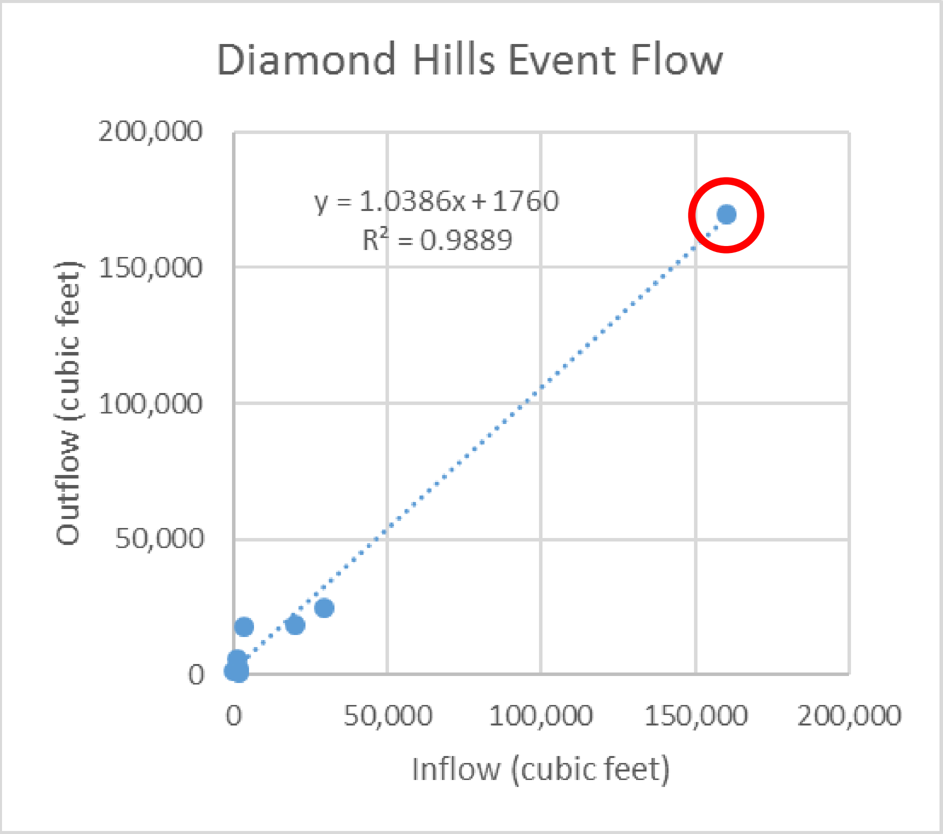


Carroll County Maintenance Center

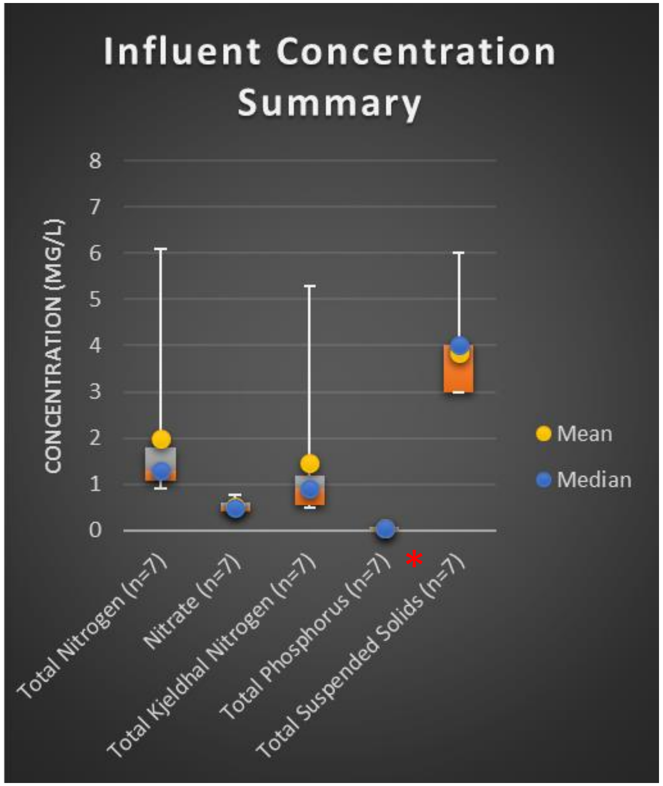
Monitoring Equipment

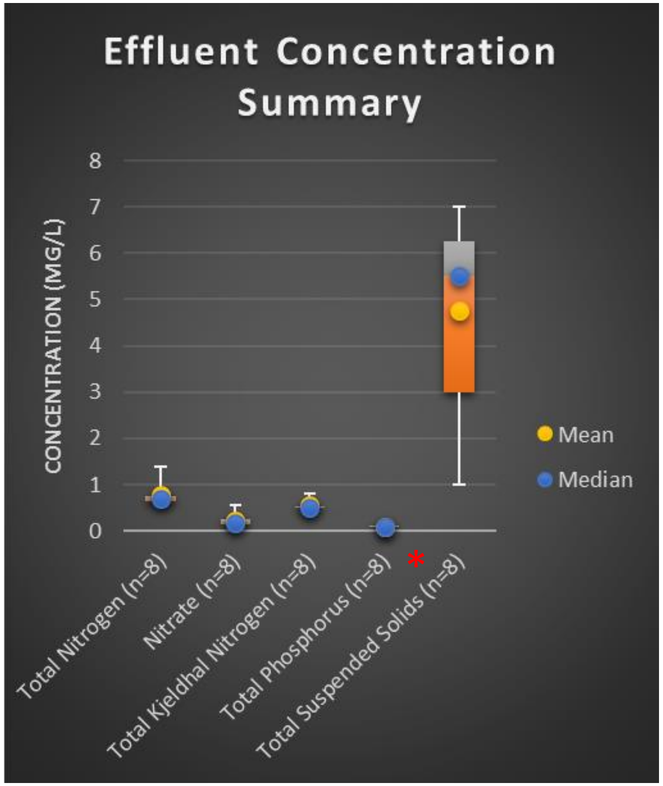
Diamond Hills Flow

- Flow mass balance is good
  - Less than 6% difference between in and out for large storm.
- Scatter at low end
  - Initial moisture
    - Is the underdrain still running?
    - Available water storage capacity in sand media



Bethel Treatment Chemical Data





*At the lower margins of TP and TS detection

Effluent TN, NO3, TKN conc. statistically lower (t-Test @ alpha = 0.05)

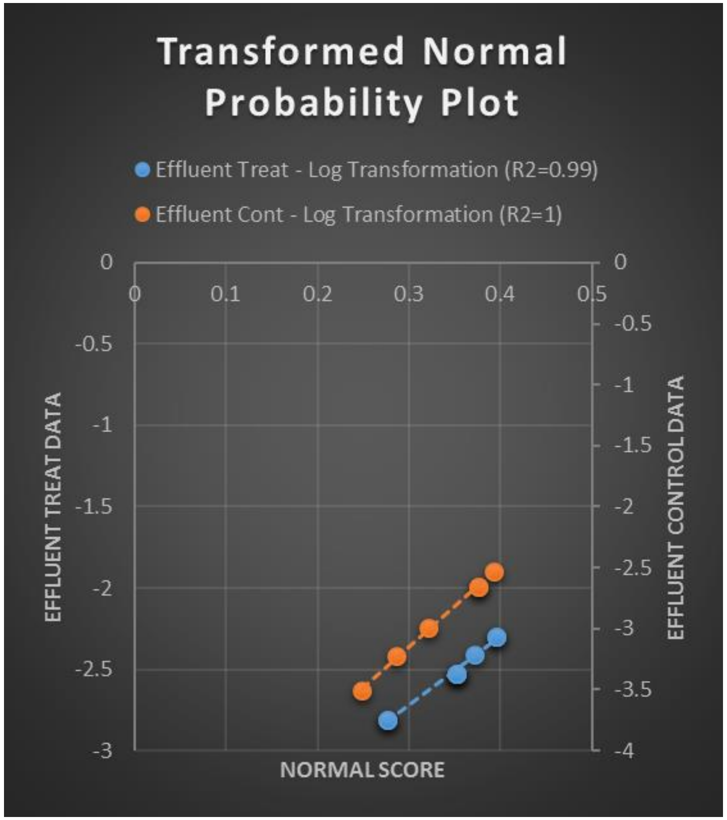
Effluent TP conc. statistically higher (t-Test @ alpha = 0.05)

Effluent TS conc. no statistical difference

Control is similar but no significant differences

Inflow and Outflow

- Statistical differences
  - Treatment Influent and Control Influent
    - Nitrate (t-Test, alpha = 0.1 [P=0.06])
    - Treatment influent is higher
  - Treatment Effluent and Control Effluent
    - Total Phosphorus (t-Test, alpha = 0.1 [P=0.03])
    - Treatment effluent is higher
      - Treatment n = 8
      - Control n = 6



Early Indications

- Dependent on daily flow
  - Do not always have outflow with inflow
- Have not yet accounted for true zero outflow conditions
- TP in treatment – Inflow loads are statistically lower
- TP in control – No statistical differences
- TS in either – No statistical differences

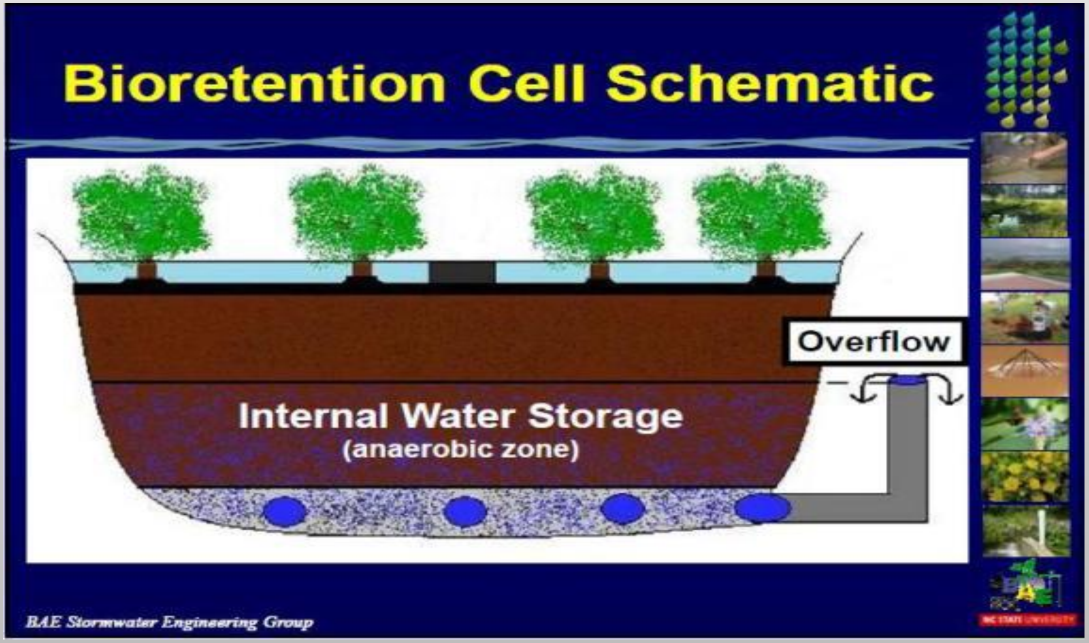
Summary

- Our initial findings appear to support R. Winston
  - Benefits are mostly in runoff reduction
- Bioretention current standard design does a good job
- Samples from both treatment and “basic” bioretention are often near the limits of detection.

Performance Enhancing Devices for Stormwater BMPs

Literature Review & Recommendations

David J. Hirschman
Hirschman Water & Environment, LLC



Presentation Overview

- Generations of Bioretention Design & Performance
- PEDs Research Review
- Reactive Media Amendments for bioretention, sand filters
- BMP Configurations: internal water storage, sizing/storage
- Vegetation

"Generations" of BMP Design & Performance

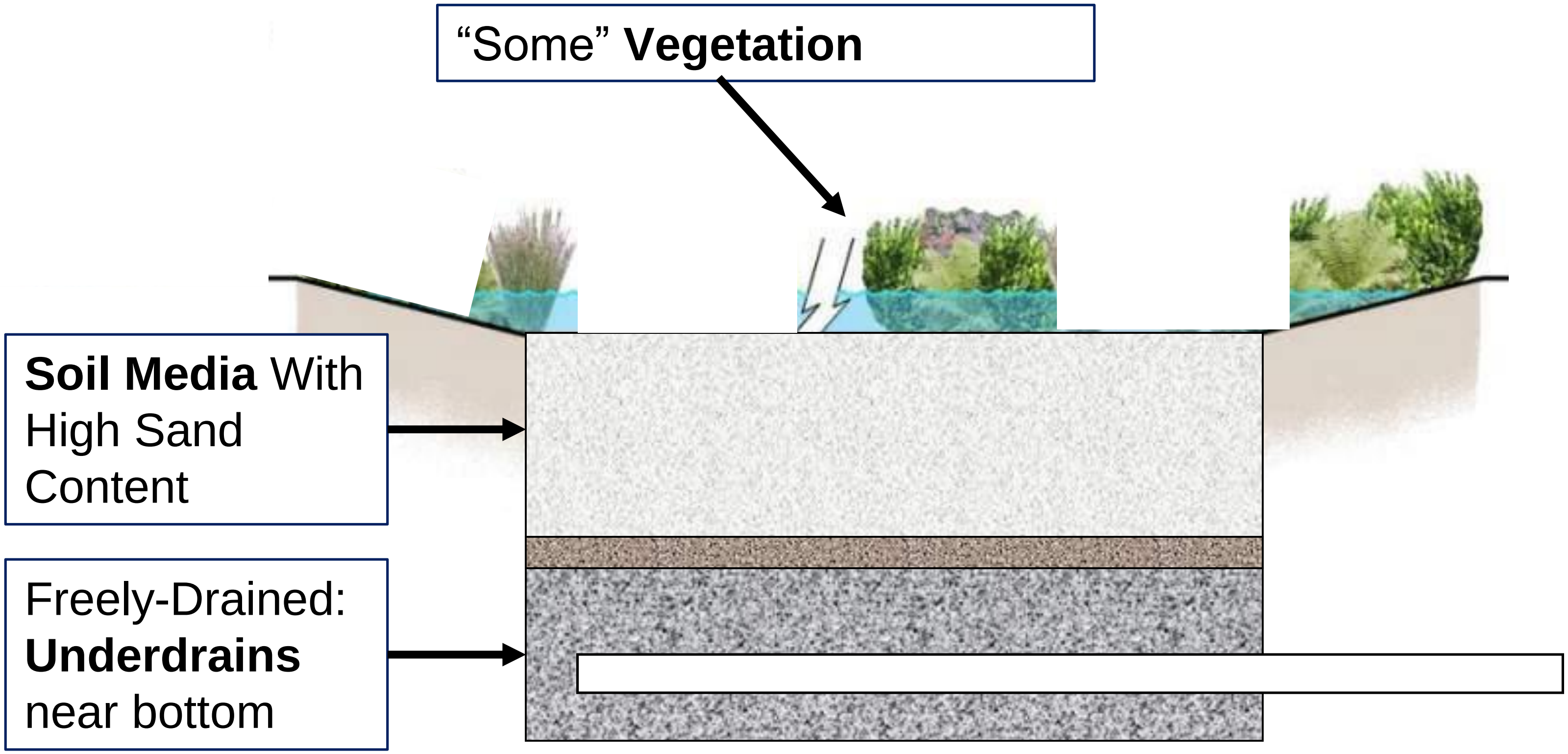
Generation of Bioretention Design	General Nutrient Removal Rates
1990s: **Early Bioretention**	• Limited TP removal – around 25%, with leaching of dissolved P • Moderate TN removal: 55%, but negligible or negative capture of dissolved N
2000s: **Mainstreaming Bioretention**	• TP: 45-55%, but very wide range of results, including negative removals • TN: 25-70%
Late 2000s to present: State-specific standards and Chesapeake Bay Performance Curves	• TP: 55-70% • TN: 45-60%

Are We Ready For A 4th Generation With PEDs?

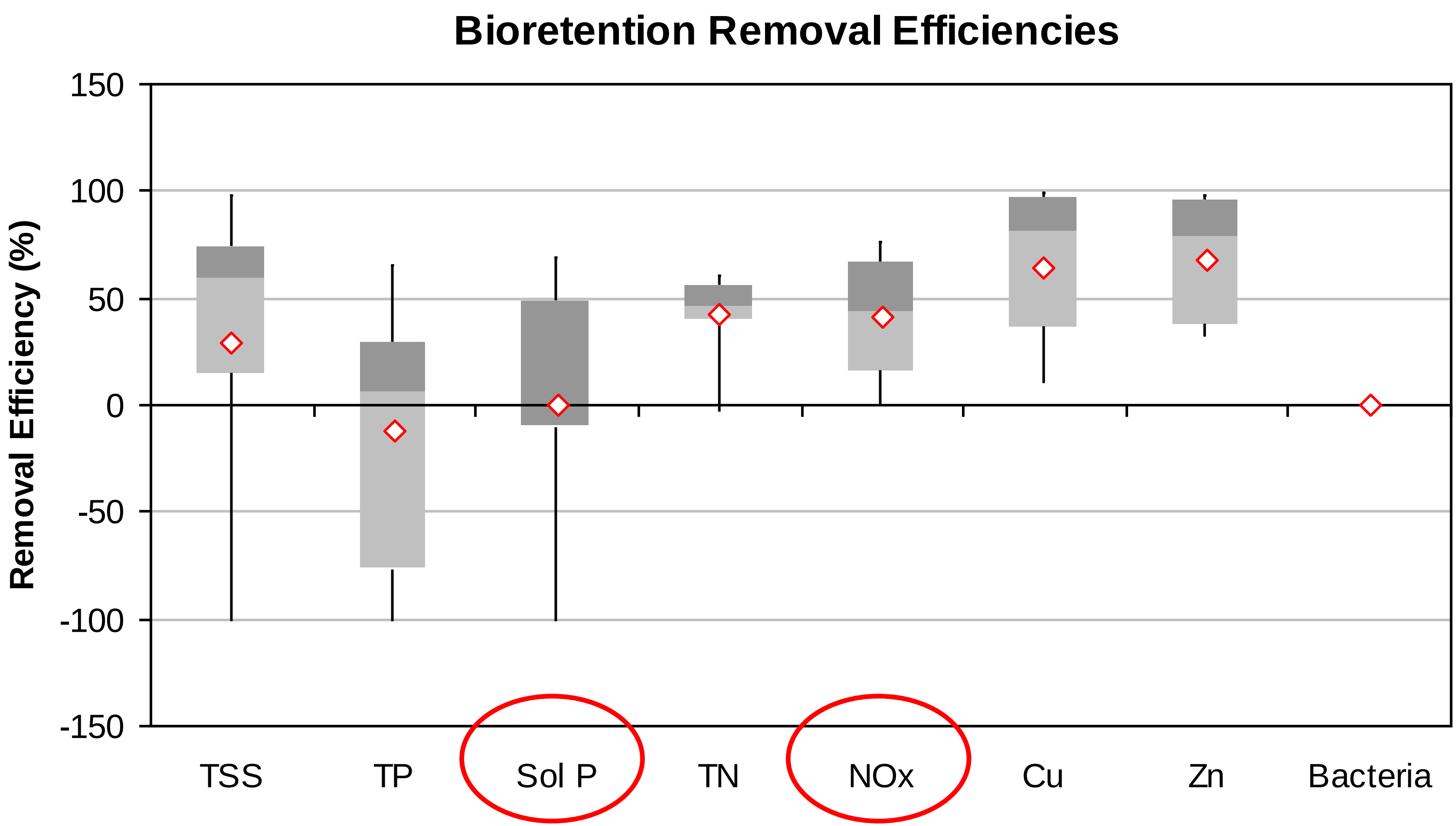
PEDs Research Review

- 138 papers, journal articles, technical reports
- Stormwater-focused + agricultural & wastewater applications
- Half of nutrient-oriented studies were for bioretention
- Many studies in lab, where variables can be controlled; about 30% of nutrient studies in field
- Many studies since 2010 – PEDs are growing research area
- Geographically distributed in Australia, U.S., New Zealand, and other countries

Current Bioretention Design



Focus of PEDs Research: Improved Performance for Particulate & Dissolved Forms



Laboratory: Multiple Columns or Mesocosms to control multiple variables & flow rates

Photos: Virginia Tech Research Station, Virginia Beach: Mesocosms Testing Various Bioretention Soil Media Recipes & vegetation, Liu et al 2014. Thanks to David Sample.

Field: Real-World Conditions

Photo: Bill Hunt, North Carolina State University, Bio&Ag Engineering, Stormwater: **www.bae.ncsu.edu/stormwater**

1. Reactive Media Amendments

- Metal Cations: **Iron**/Aluminum, Calcium/Magnesium
- Carbon: Biochar, activated carbon*
- Adsorption of Dissolved P onto reactive surface
- Removal factors: reactive surface area, contact time, adsorption capacity & lifespan, pH of media

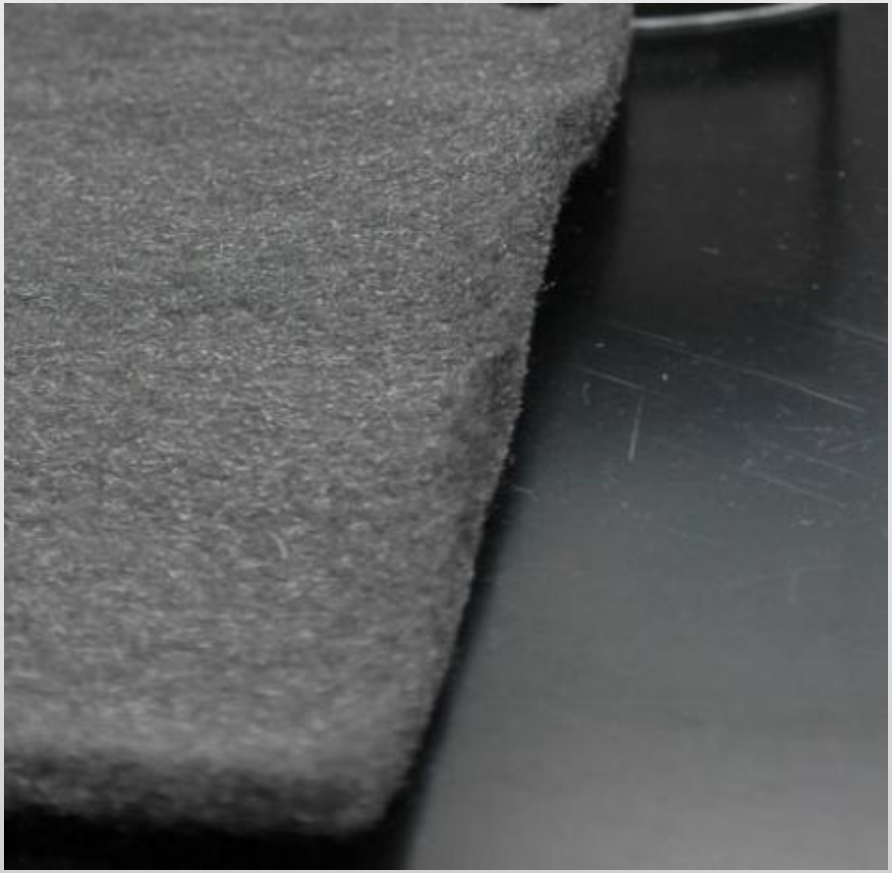
* Compost is typically used as a component of bioretention soil media, but also is a source of leaching of nutrients

Metal Cations: Materials Tested

- Water treatment residuals
- Steel wool, iron filings
- Slag
- Acid mine drainage residuals
- Fly ash
- TARGET POLLUTANT: Dissolved **P**

Steel Wool

Iron Filings



~½ inch thick

~C33 Concrete Sand

Source: Andy Erickson, Saint Anthony Falls Laboratory, Univ. of Minnesota

MN (Iron Enhanced) Filter
(5% iron filings, Maplewood, MN)

Source: Andy Erickson, Saint Anthony Falls Laboratory, Univ. of Minnesota

Water Treatment Residuals

Photo Credit: Washington Stormwater Center

Summary of Field Research on Iron Amendments

Bioretention & Stormwater Filters		
Source	Material	P Removal *
Roseen & Stone 2013; Stone 2006 [2]	WTR [1]	20 – 55%
Liu and Davis, 2013	WTR	60 – 84%
Ahmed et al. 2014	Iron filings	65%
Erickson et al.2012	Iron filings	29-91%
Erickson and Gulliver 2010	Iron filings	72-90%
Erickson et al. 2011	Steel wool	80-90%

*Ranges for Total P and Dissolved P

Considerations for Mass Deployment

- Hydraulic conductivity, clogging: research shows good results for Fe, but not Ca. Some concern with WTR if it is not processed/dried.
- Leaching of metals (e.g., Al): research shows that it is potential concern if $pH < 5$, generally not an issue for stormwater applications.
- Construction costs: MN examples had 3-5% increase, but lessons will be learned in C.B. Watershed.

Carbon -- Biochar

Photo Credit: UC Davis Biochar Database

Many Types:

- Biomass used
- Combustion temperature
- Size/surface area
- Porosity

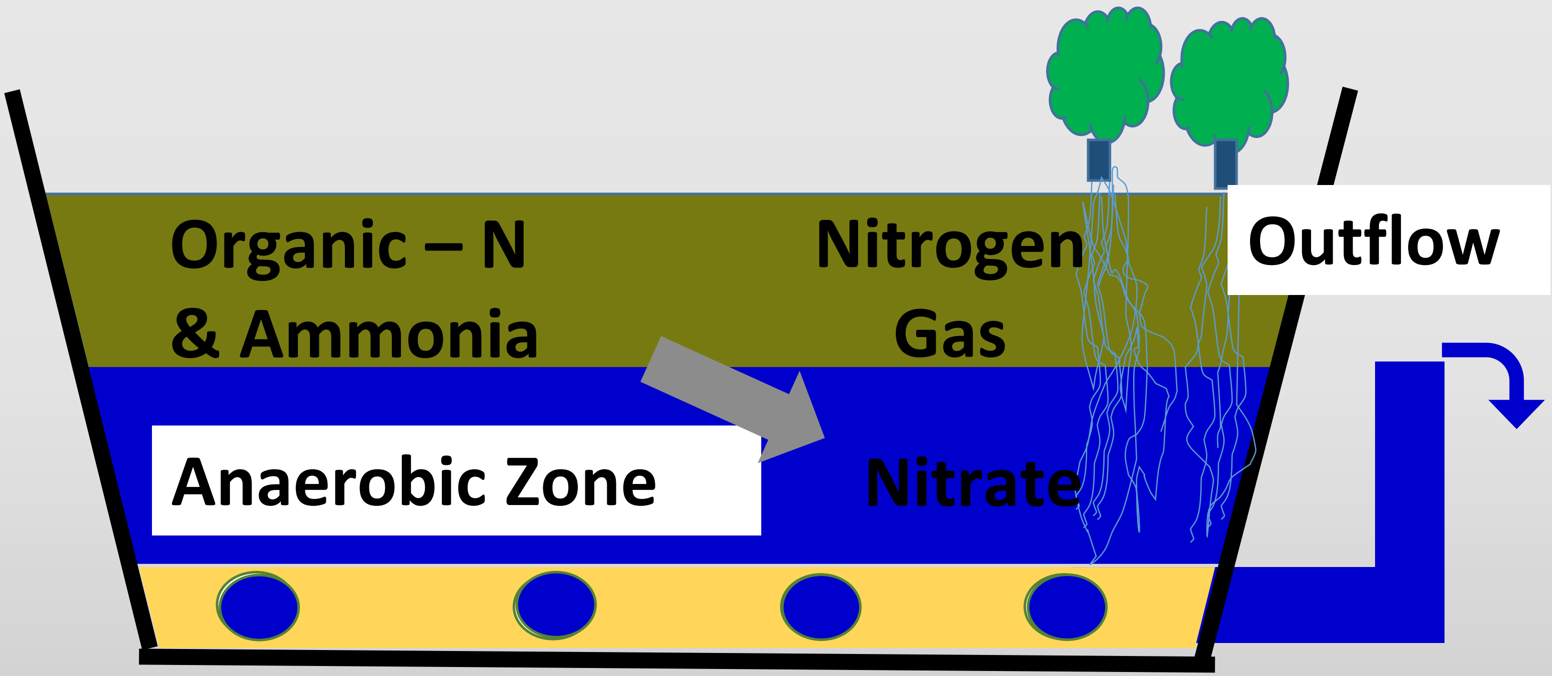
As Media Amendment:

- Adsorption of P & N
- C donor for denitrification

Lab Findings for Biochar & Other Carbon Sources

Source	Material [1]	P Removal	N Removal
Beneski 2013	Biochar	**N/A**	50%
Tian et al. 2014	Biochar		37-74%
Kim et al. 2003	Various carbon sources		30-100%
Reddy et al. 2014	Biochar	47% [3]	86%
Al-Anbari 2008	GAC, zeolite	20-60% [2]	20-60%
Schang et al. 2011	Zinc-coated GAC	80-90% [2]	75-85%

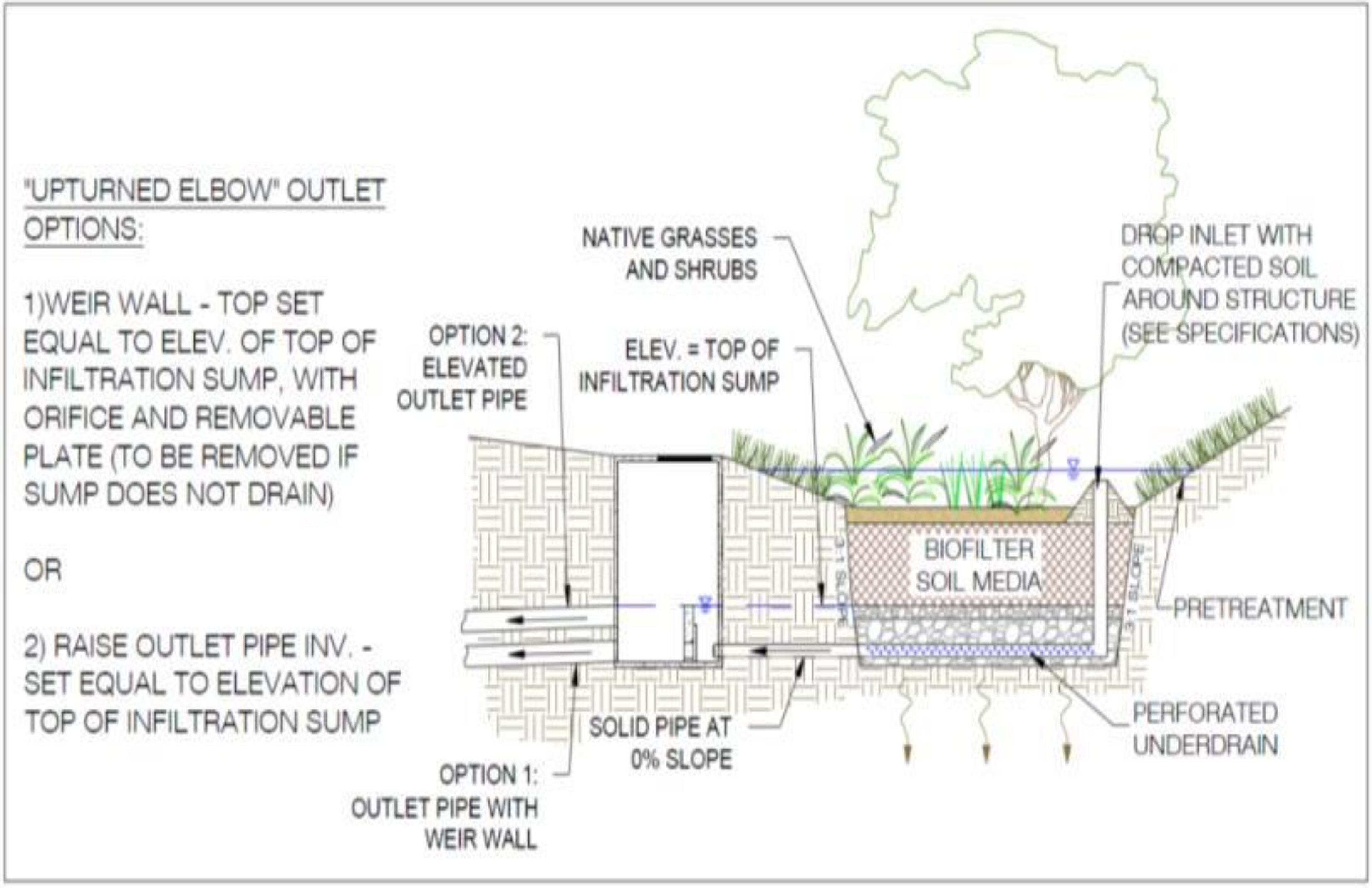
2. Internal Water Storage (IWS)



Creation of a Saturated Zone

Graphic: Bill Hunt, North Carolina State University, Bio&Ag Engineering, Stormwater:
www.bae.ncsu.edu/stormwater

WV Stormwater Manual Spec



Field Research on IWS

Source	P Removal	N Removal
Roseen & Stone 2013; Stone 2006	20-55% [1]	36-60% [1]
DeBusk & Wynn 2011	99% [2]	99% [2]
Brown & Hunt 2011	N/A	>50%
Gilchrist et al. 2013		75% [2]
Passeport et al. 2009	58-78% [1]	47-88% [2]
Winston et al. 2015	Negative removals due to organic content in media	

[1] Range of values show removals for Total P or N and Dissolved P or N.

[2] Mass load reduction with a majority of reduction attributable to runoff reduction processes.

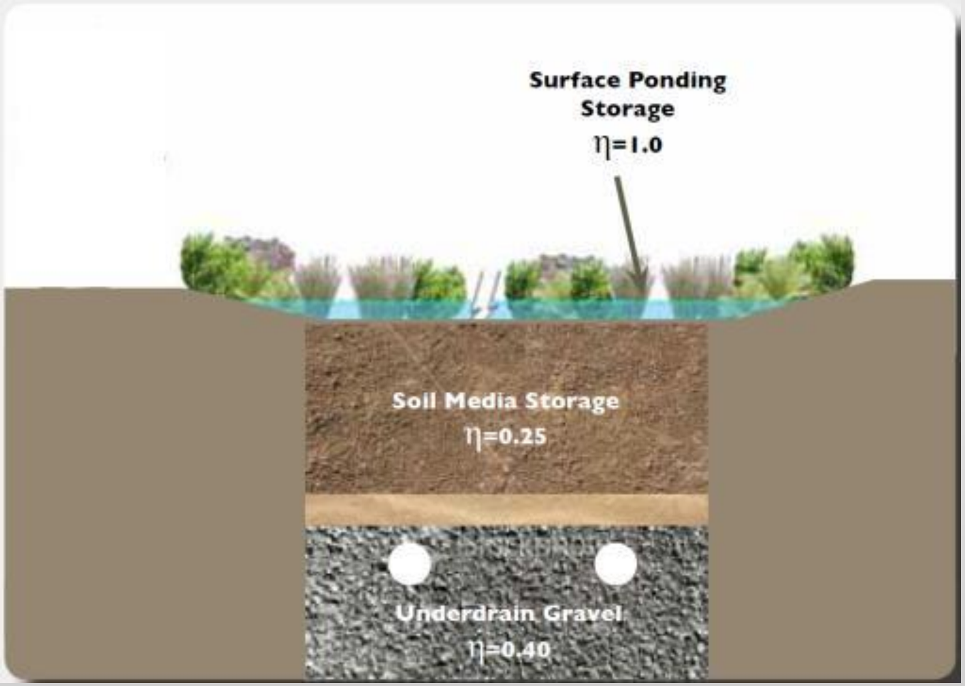
Lab Research on IWS

Source	P Removal	N Removal
Roseen & Stone 2013; Stone 2006	50-99% [1]	N/A
Caruso 2014	50-90% (47-67% for no IWS)	43-92% (negative for no IWS)
Zhang et al. 2011	>70%	83%
Zinger et al. 2013	IWS increased Dissolved N removal 1.8 to 3.7X from no IWS, but also decreased P removal	
Glaister et al. 2012	50-95% [1]	70-77% (negative for no IWS)
Lucas & Greenway 2011b	N/A	53-94% [1] (negative to 50 for no IWS)

[1] Range of values show removals for Total P or N and Dissolved P or N.

Runoff Reduction Rocks the BMP!

- ✓Infiltration
- ✓Canopy Interception
- ✓Evaporation
- ✓Transpiration
- ✓Rainwater Harvesting
- ✓Extended Filtration



3. Vegetation

Research Shows:

- Type of vegetation is important: factors include root thickness/density, coverage, above & below-ground biomass, leaf area, etc.
- Vegetation plays a role in other performance measures: microbial activity in media (immobilization of nutrients), hydraulic performance, etc.
- Periodic harvesting may help with nutrient removal from system.
- Not much insight on C.B.-specific plants. Some to consider: *Carex*, *Switchgrass*, *Big Bluestem*, *Joe Pye Weed, some trees with high stomatal conductance.*

layered structure of plant communities

Thick, Dense, Above & Below-Ground Biomass

Source of Graphic: Claudia West, North Creek Nurseries, http://www.northcreeknurseries.com/

Vegetation Results (selected)

Source	Vegetation	P Removal/Retention	N Removal/Retention
Henderson 2008	Various	85-94% (31-90% for non-vegetated)	63-77% (negative to 25% for non-vegetated)
Lucas & Greenway 2008	Native grasses & shrubs from Australia	67-92% (39-56% for non-vegetated)	51-76% (maximum of 18% for non-vegetated
Barrett et al. 2013	Buffalograss, Big Muhly (native to TX)	77-94%	59-79% (negative for non-vegetated)
Read et al. 2008	20 Australian species	From 2 to >150 fold change in removal for N and P, depending on species of vegetation.	
Scharenbroch et al. 2016	7 tree species from the Midwest	Study focused on water cycle and transpiration rather than nutrient removal; trees account for 46-72% of total water budget	

Considerations for Mass Deployment

- BMP planting & maintenance plans have to become more sophisticated, including periodic harvesting.
- More work to I.D. good C.B. Watershed species (by State, eco-region?).

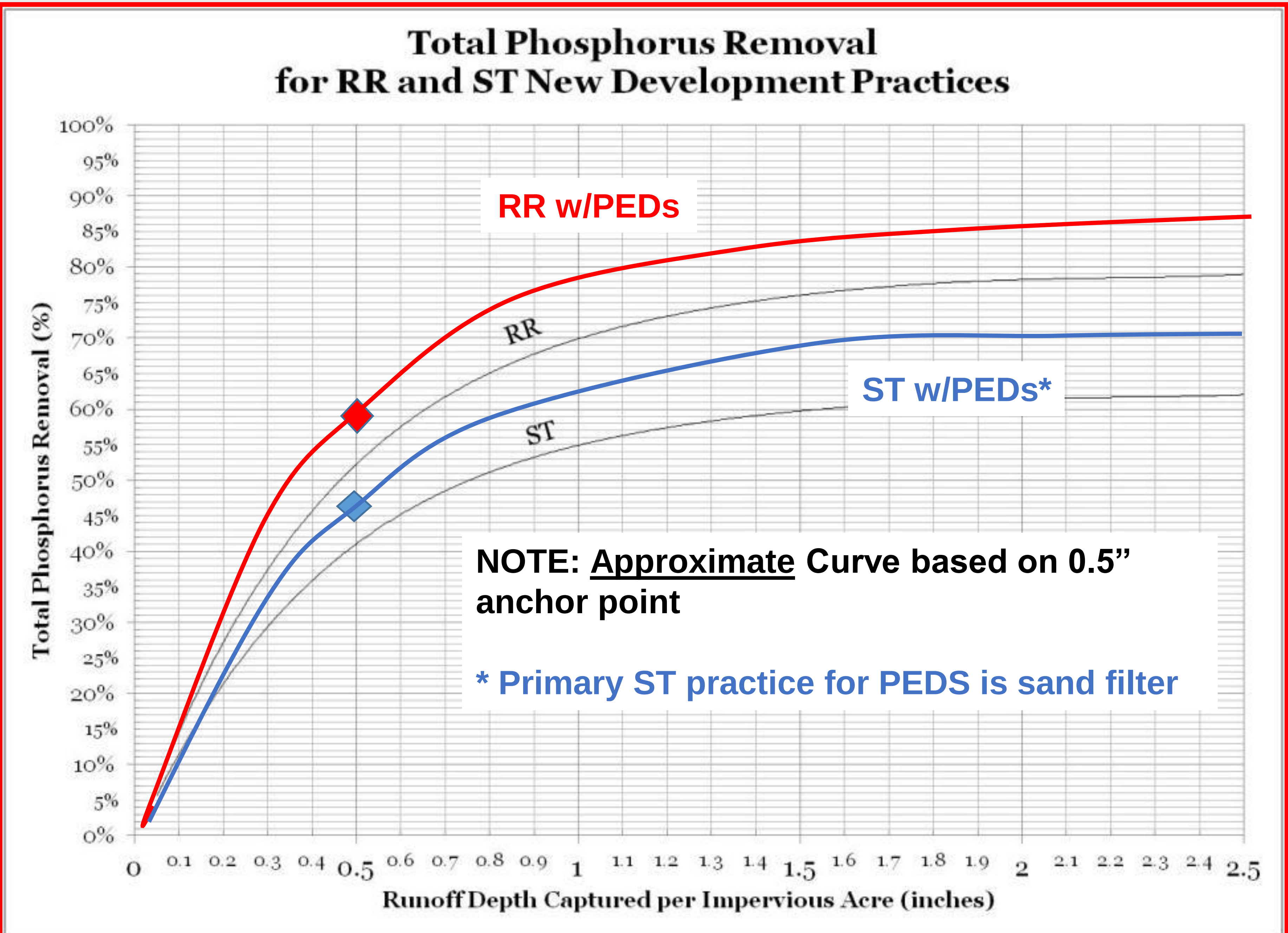
Summary

- PEDs include: reactive media, IWS, enhanced vegetation.
- Sizing/storage/optimization also important; Runoff Reduction remains key performance metric.
- PEDs are new frontier for stormwater research: primarily lab, but also some field examples.
- Research indicates performance enhancements for reactive media & IWS.
- Conditions apply to applying enhanced credit.

PEDs Performance Crediting Recommendations to the USWG

- Provide credit after design and implementation issues are solved
- Use existing performance curves for retrofit applications
- Media Amendments: Add 10% at anchor point for both RR and ST curves
  - Applicable RR practices = bioretention, dry swale, permeable pavement w/media, maybe vegetated filter strip
- IWS: Add 10% at anchor point for RR curve
  - Applicable ST practice = sand filter, other filtering practices

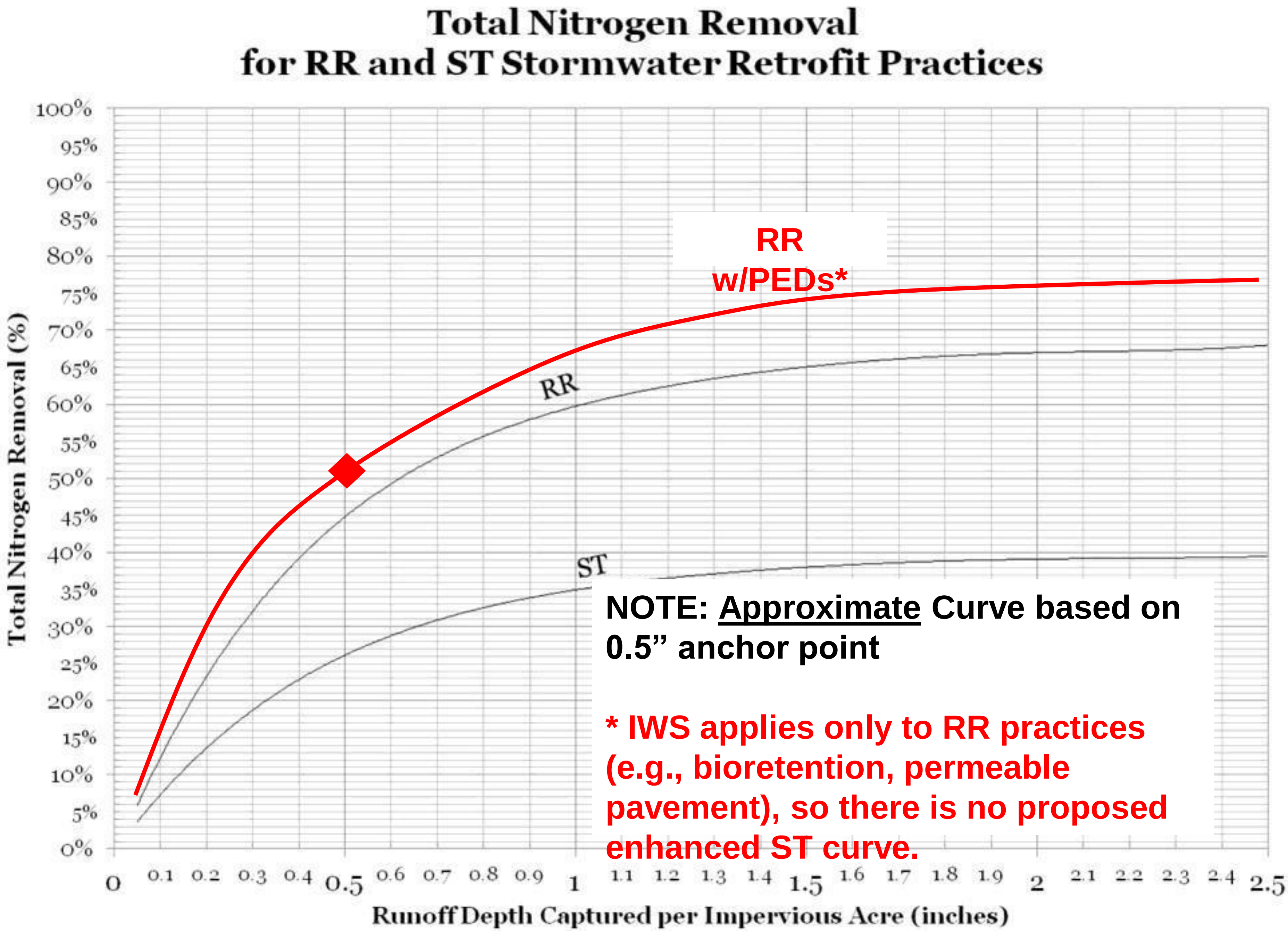
- Consider PEDs for new an redevelopment projects as individual Bay states update their design manuals



Total Phosphorus Removal
for RR and ST New Development Practices
RR w/PEDs
RR
ST w/PEDs*
ST
NOTE: Approximate Curve based on 0.5” anchor point
* Primary ST practice for PEDS is sand filter
Total Phosphorus Removal (%)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3 2.4 2.5
Runoff Depth Captured per Impervious Acre (inches)

Key Design and Implementation Issues

- “Standard” PED media specification and recipe
- PED media testing procedures to certify consistent PED sources
- Proper procedures for drying and incorporating amendments into media
- Additional guidance on PED retrofit construction methods and ongoing maintenance
- Design guidelines for IWS including depth, intersection with media layer and potential need for carbon seeding
- Appropriate landscaping template, recommended plant species and minimum surface cover
- Other PED delivery issues, as identified by states and USWG



NOTE: Approximate Curve based on 0.5” anchor point

*** IWS applies only to RR practices (e.g., bioretention, permeable pavement), so there is no proposed enhanced ST curve.**

Q&A