Soil Stability and Water Quality within Constructed Wetland Treatment Swales

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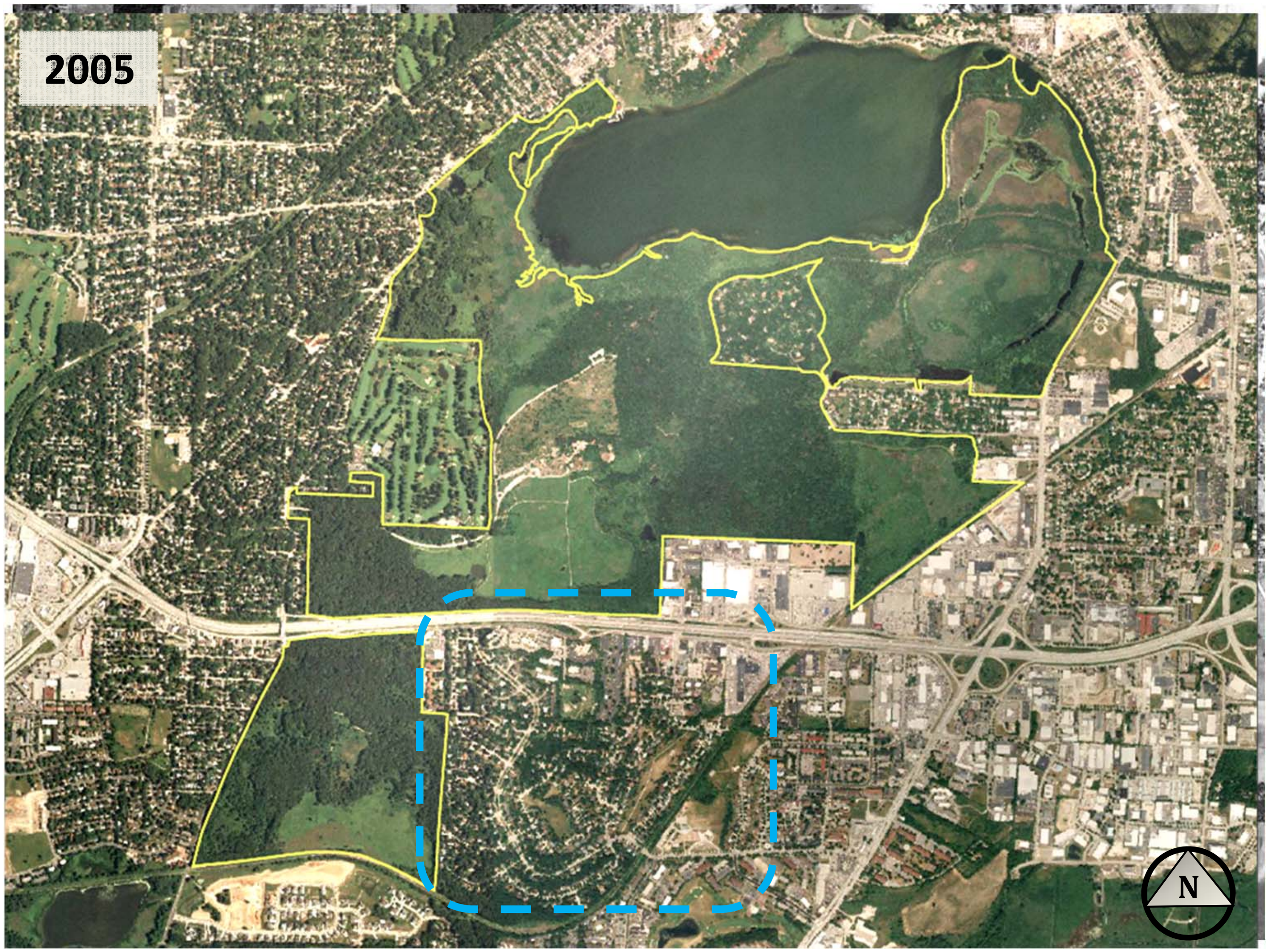
THE UNIVERSITY of WISCONSIN MADISON

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Great Lakes RESTORATION

Regional Urbanization



(USDA, 2005)

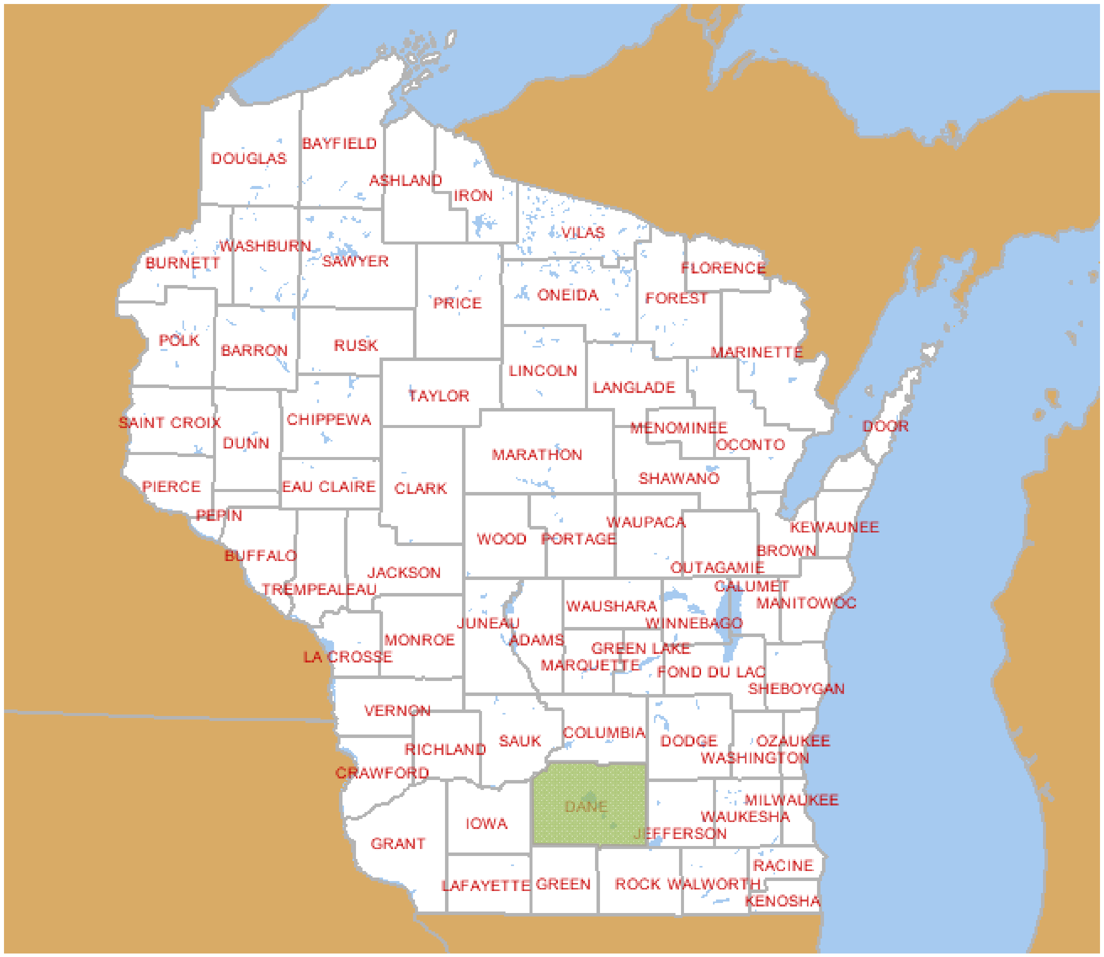
Stormwater Impacts

Carpenter et al. (1998)

Zedler and Kercher (2004)

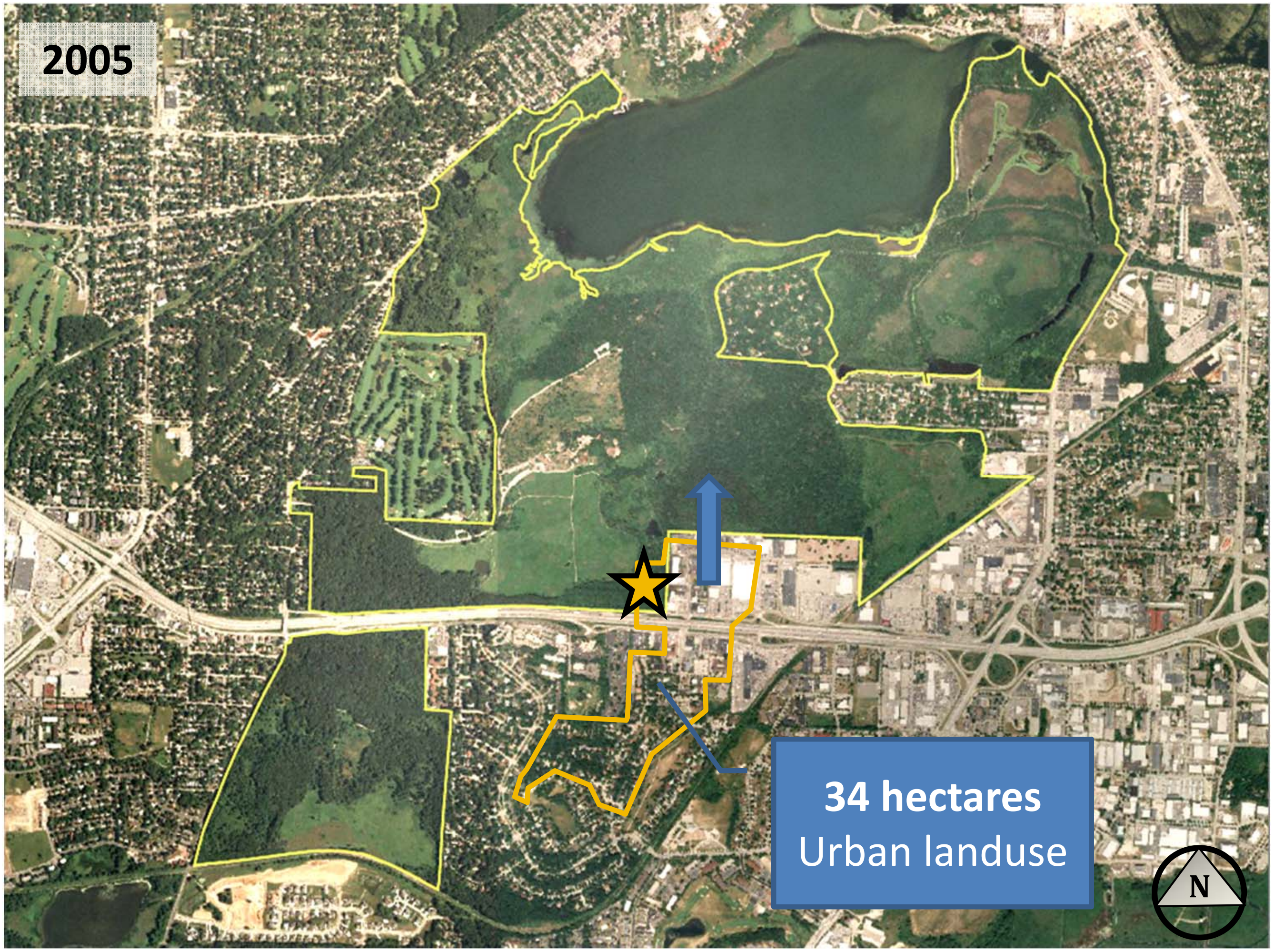
Allen et al. (2008)

Project Location



(DNR, 2012)

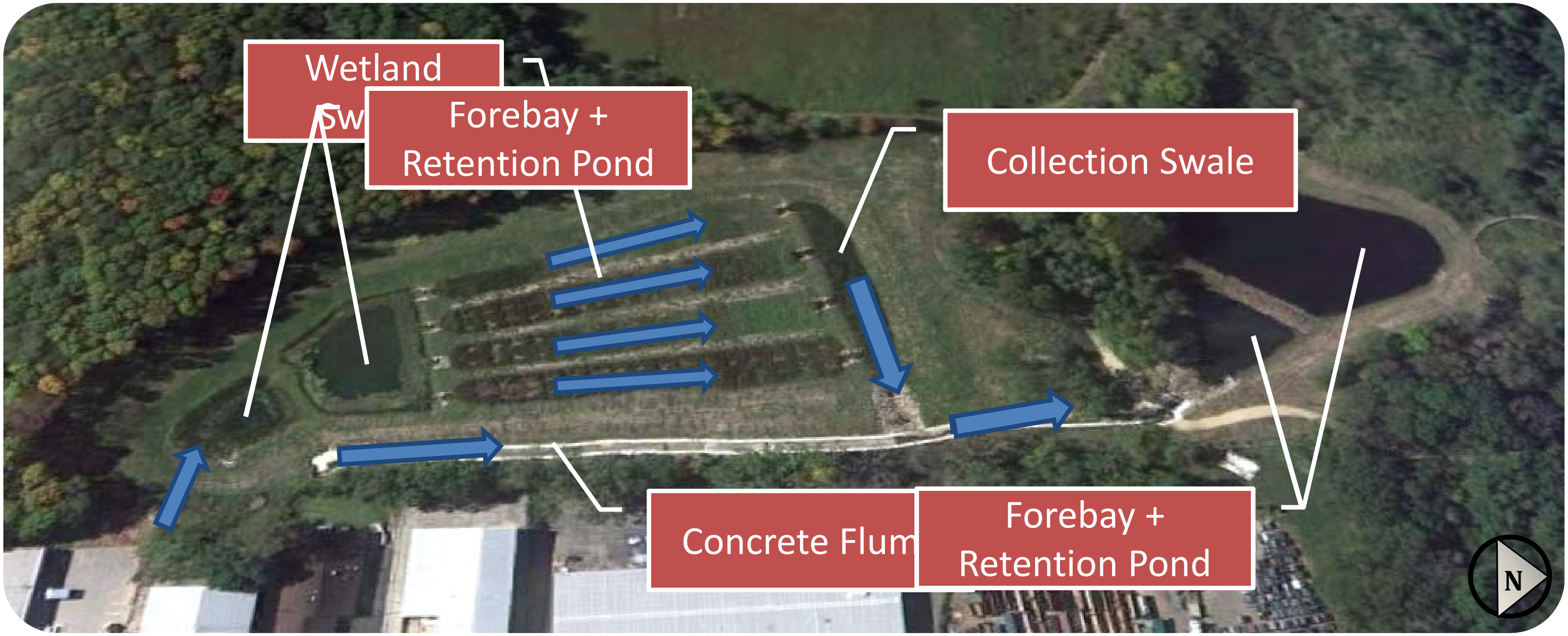
Regional Urbanization



(USDA, 2005)

Aerial View of SMRF

Stormwater Management Research Facility (SMRF)



(Google Maps, 2008)

Research Objective

Question

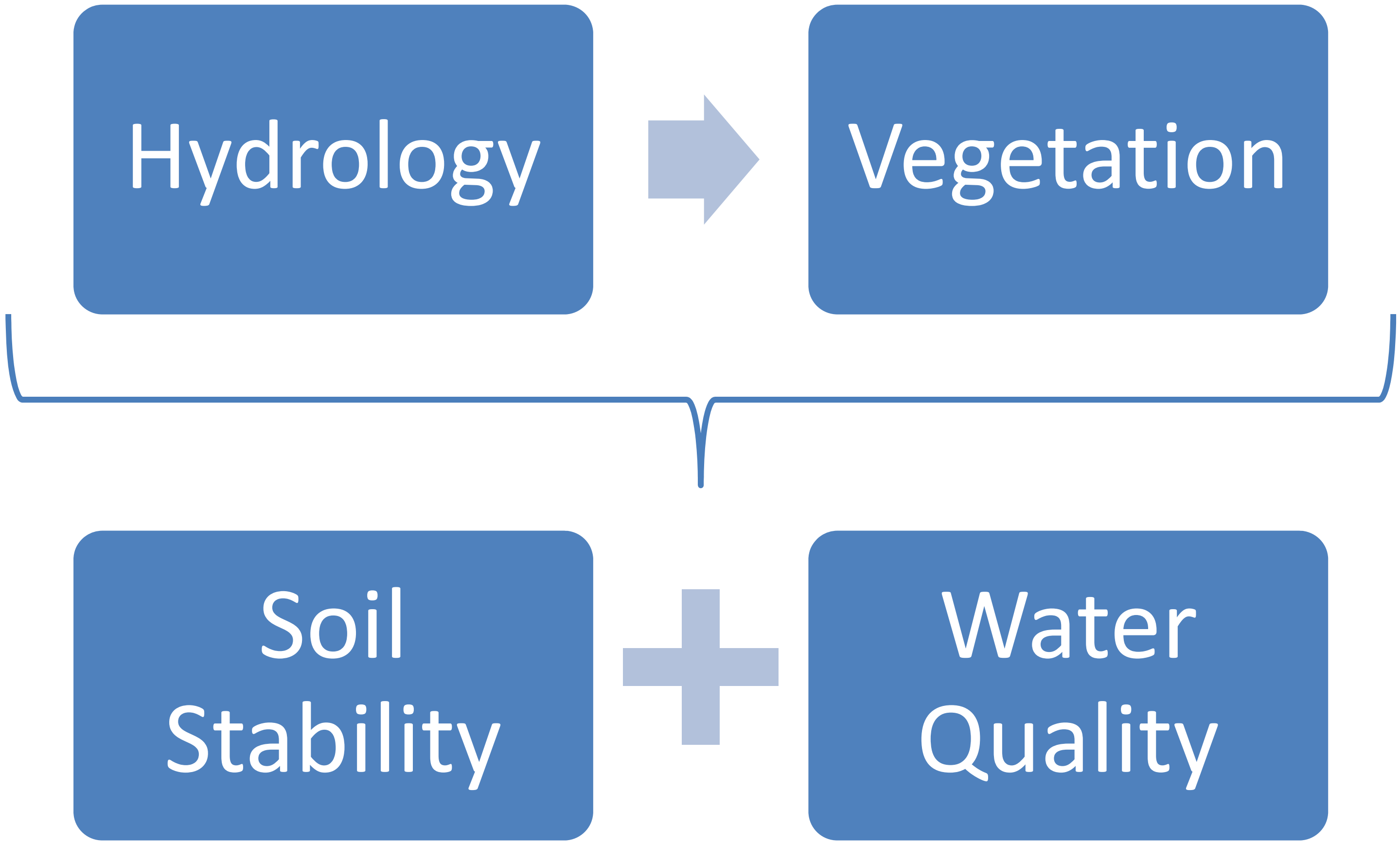
How does **hydroperiod** and **vegetation diversity** influence **stormwater treatment** and **soil stability** in a constructed wetland?

Hypothesis

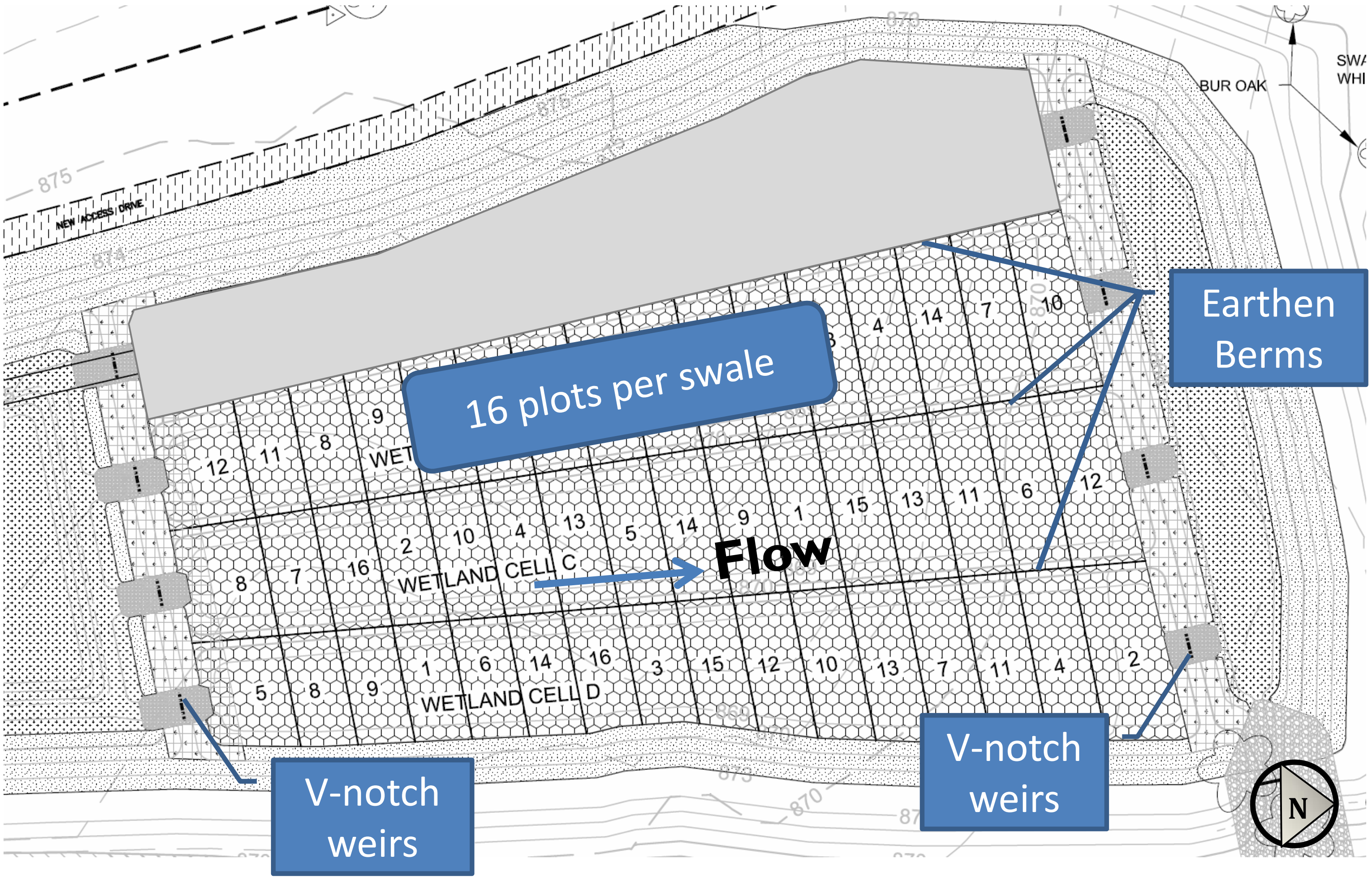
A combination of a **fluctuating hydroperiod** and **diverse vegetation** will be the most effective at stormwater treatment (TSS, N, and P) and soil stabilization.

This is one component of a joint project between BSE, Botany, and Civil-Environmental Engineering departments aimed at testing relationships between **native plant diversity**, **hydrology**, and a **range of ecosystem services** over multiple growing seasons.

Project Development

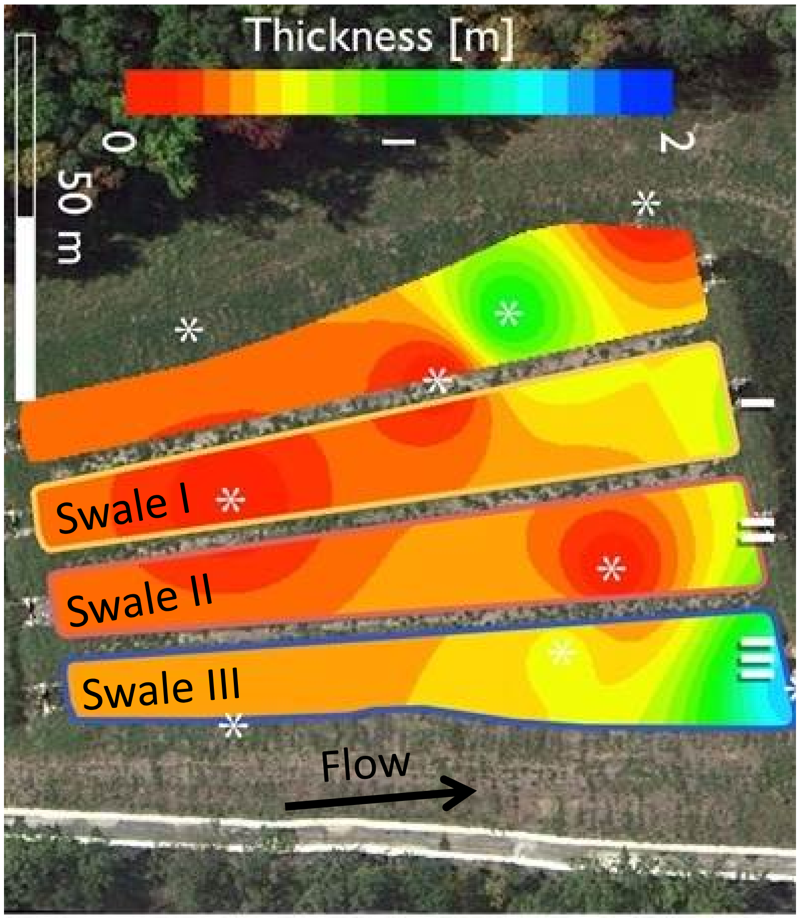


Wetland Swale Plots



Plots seeded November 2009 with 3 or 9 species of native plants

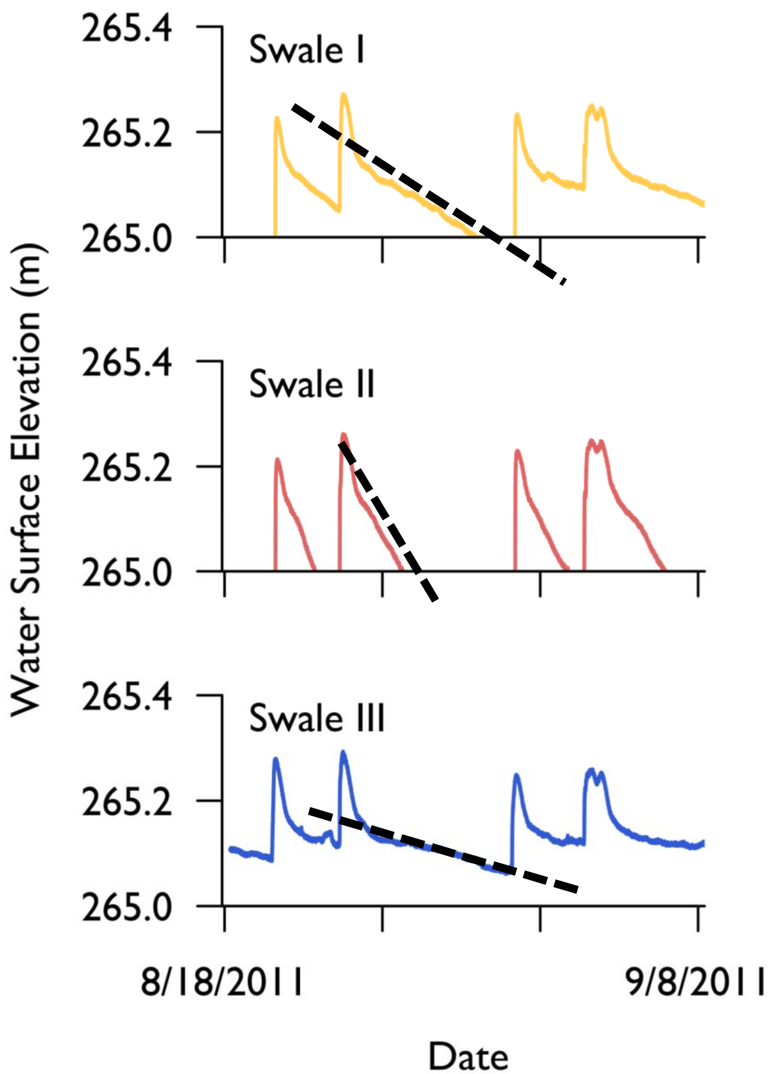
Subsurface Heterogeneity



Jeff Miller, *unpublished*

- 9 soil borings taken in 2006 & 2007
- Clay layer discontinuities
- Thicker clay in Swale III

Water Level Recession Rate



Jeff Miller, *unpublished*

Water Level Recession Rate

Swale I

1.7 cm/day
Intermediate Water Recession

Swale II

6.0 cm/day
High Water Recession

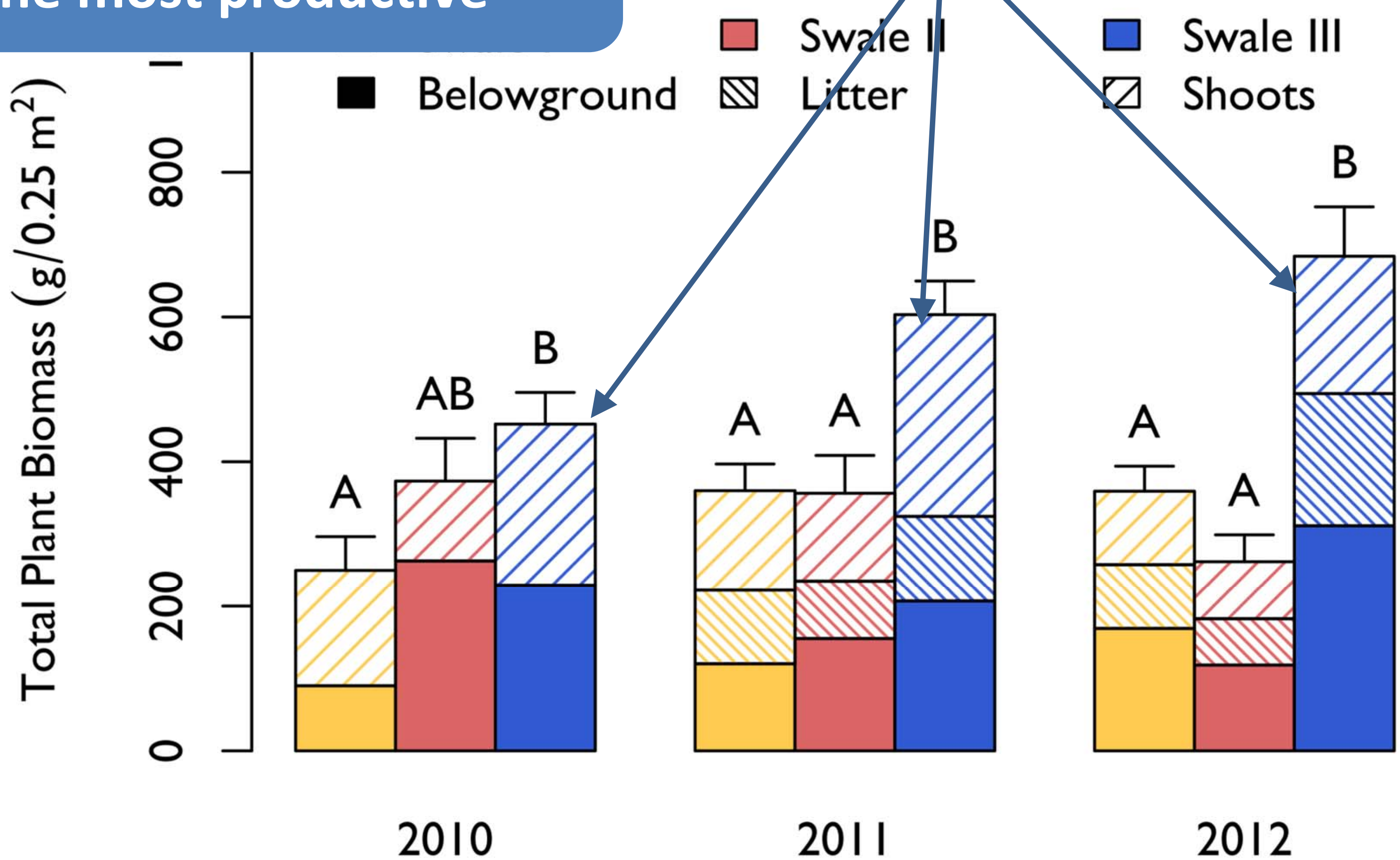
Swale III

1.2 cm/day
Low Water Recession

Jeff Miller, *unpublished*

Plant Productivity

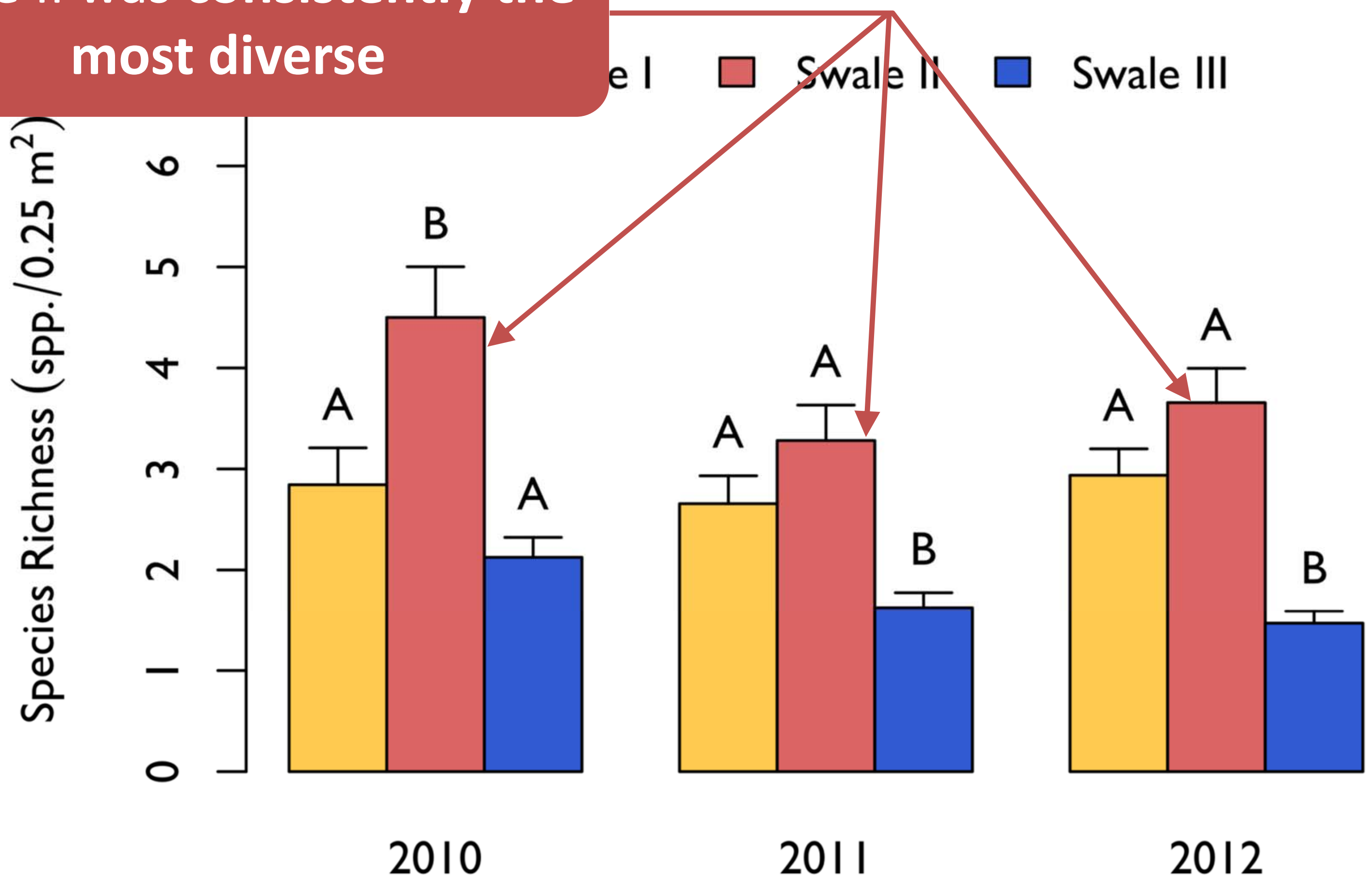
Swale III was **consistently the most productive**



Doherty and Zedler, *in review*
Graph by Jeff Miller

Plant Diversity

Swale II was **consistently the most diverse**



Doherty and Zedler, *in review*
Graph by Jeff Miller

Results | Soil Stability

Cohesive Strength Meter (CSM)

Soil Substrates

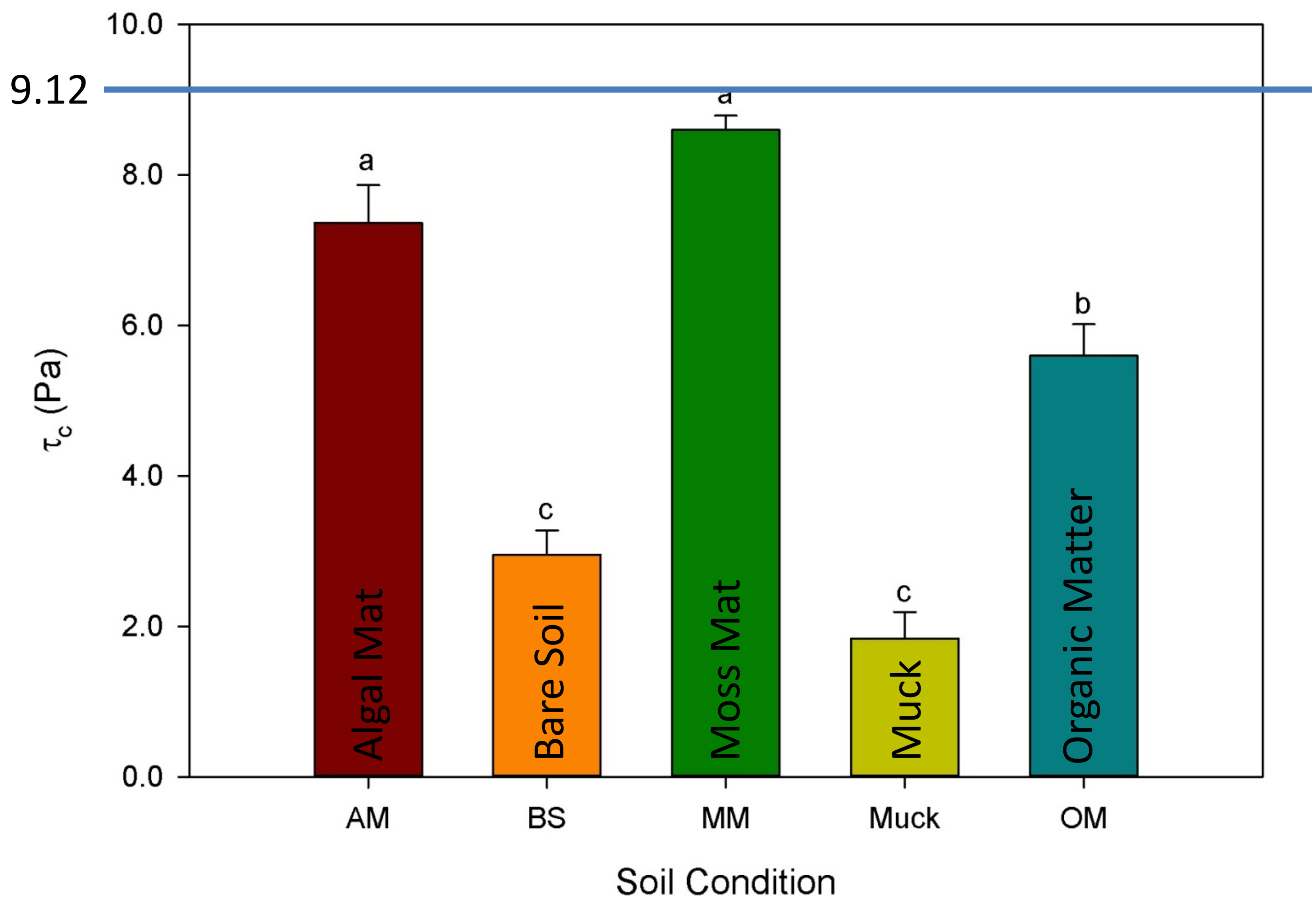
Moss Mat

Algal Mat

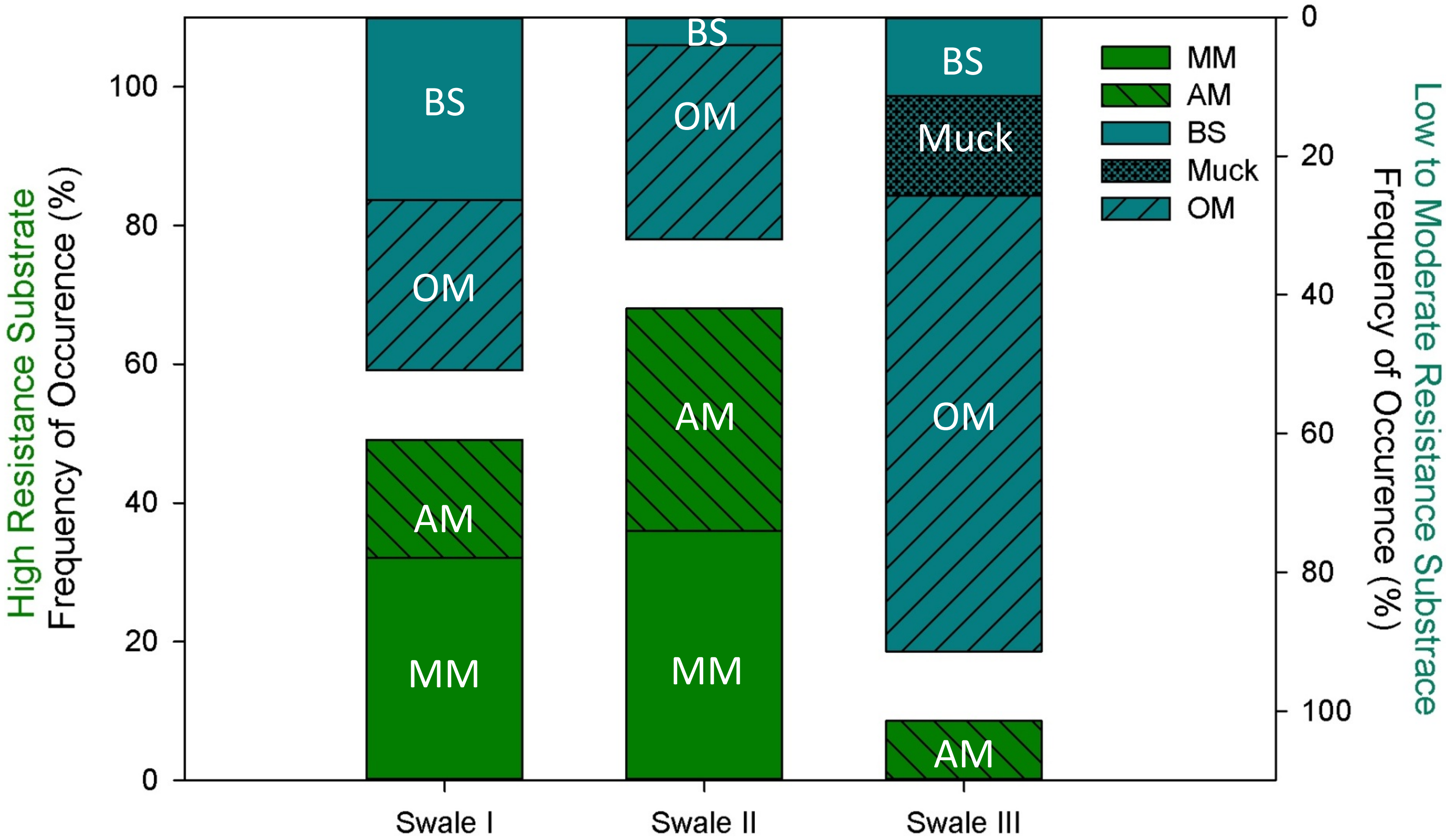
Bare Soil

Organic Matter

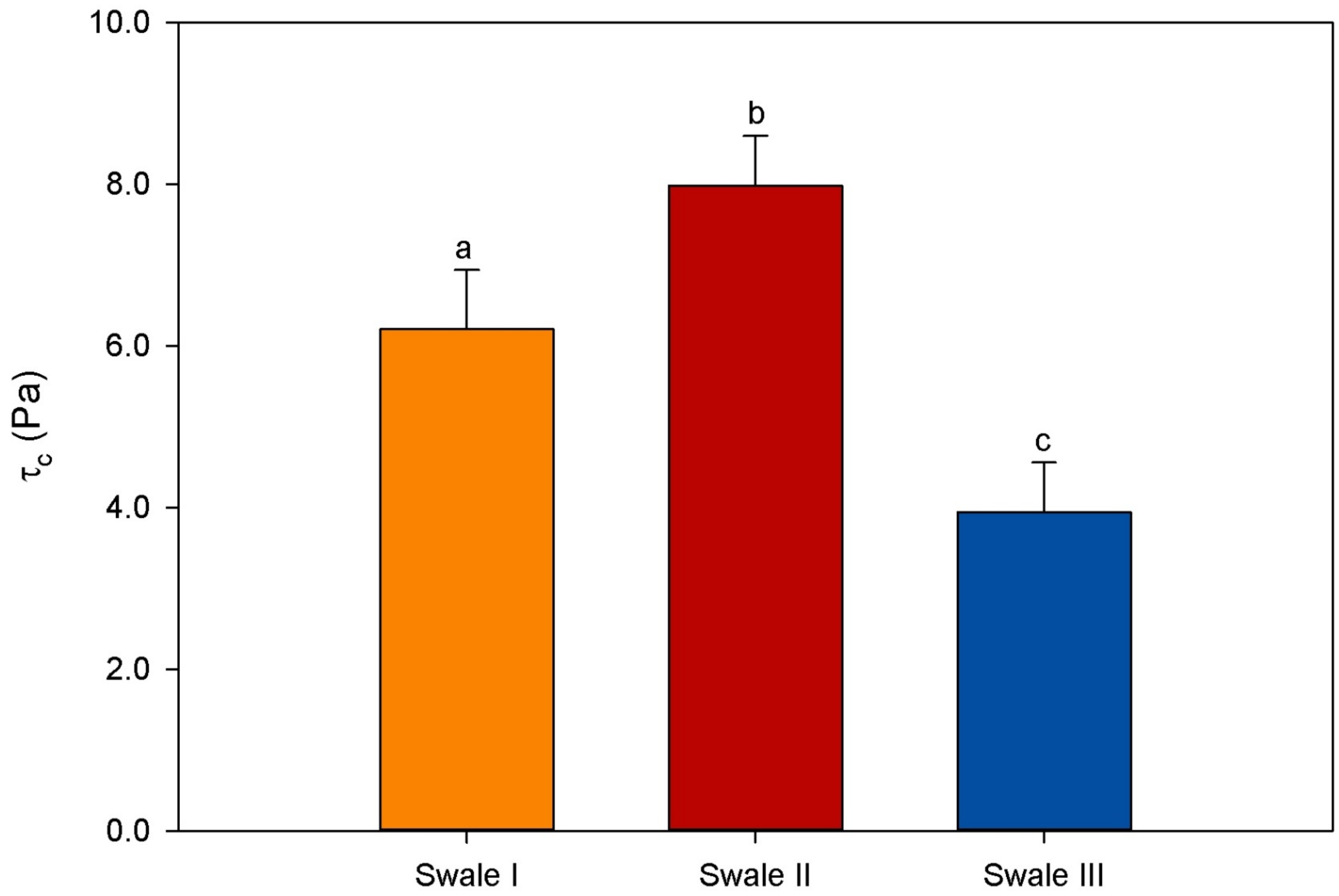
Critical Shear Stress by Substrate



Frequency of Soil Substrate

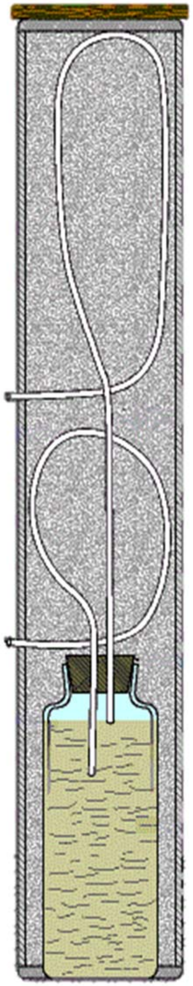


Soil Stability by Swale

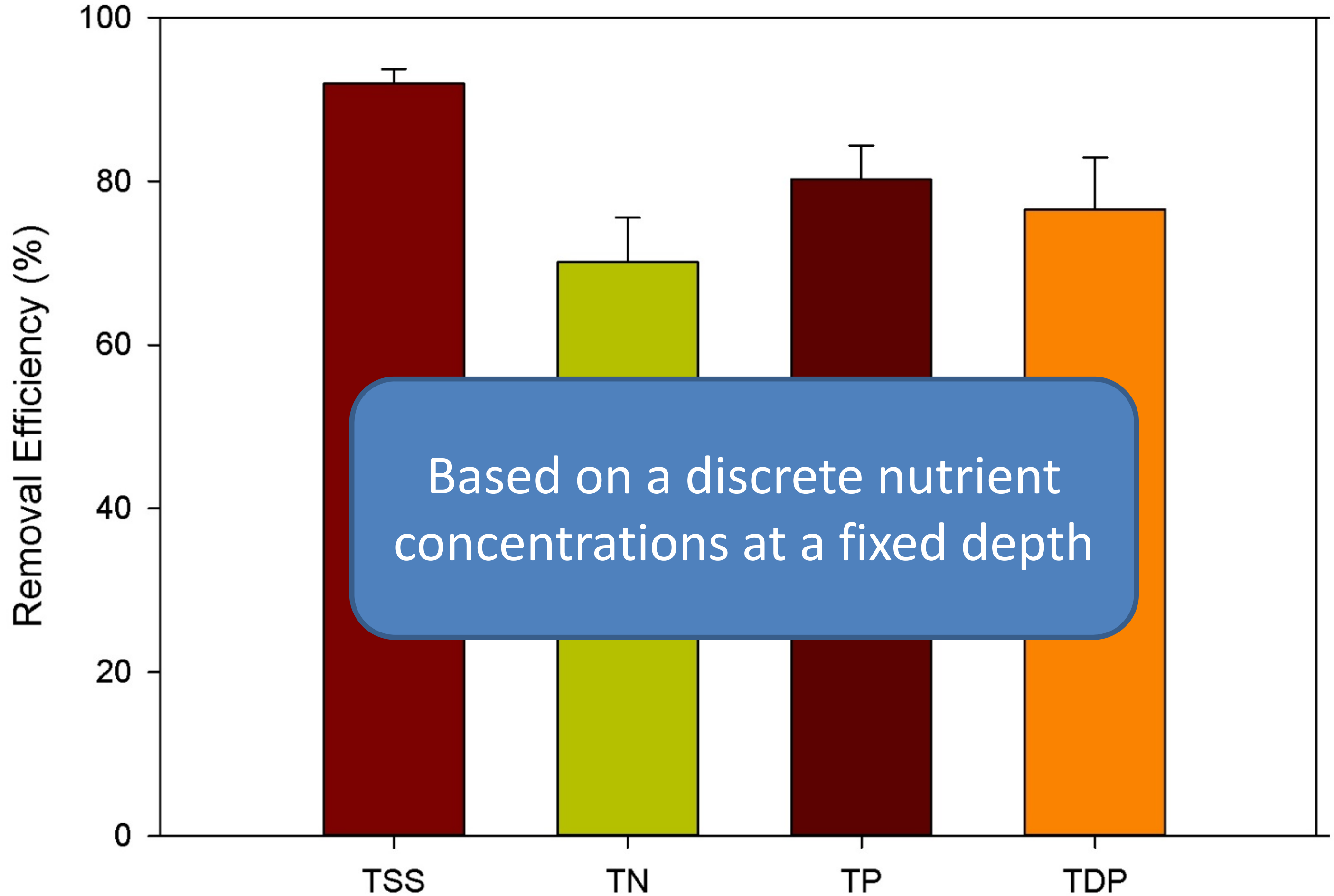


Results | Water Quality

Siphon Sampler Locations



Pretreatment in Retention Pond

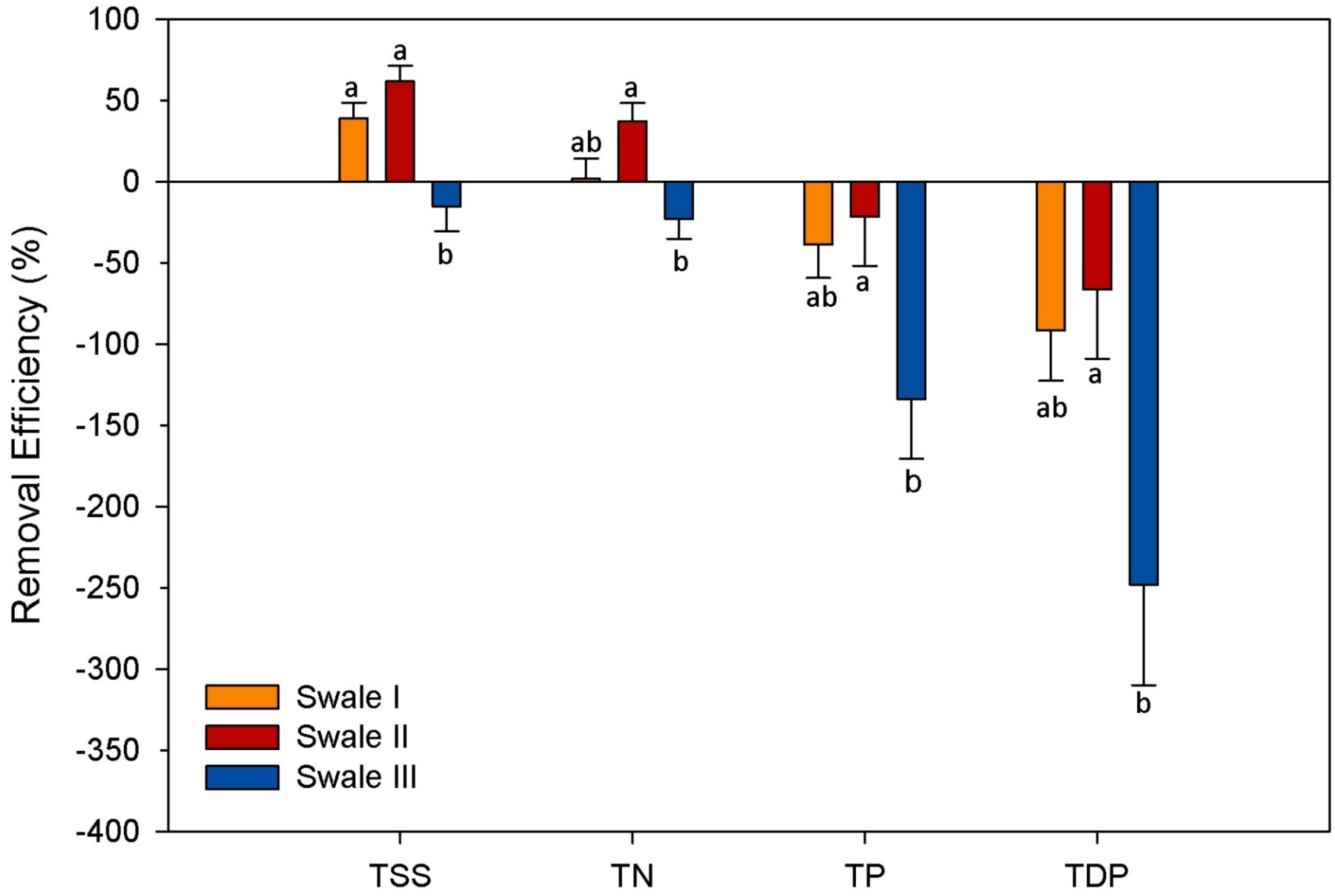


Stormwater Sampling Regime

- Multiple samples over storm hydrograph
- 13 select storms
  - September 18, 2011 to October 13, 2012
  - 6 to 65 mm of precipitation

ISCO Sampler Locations

Swale Nutrient Removal



Conclusions

Influence of Hydrology

- **Fluctuating** Hydroperiod
  - Promoted establishment of highly-resistant, biotic assemblages
  - Enhanced nutrient removal
- **Inundated** Hydroperiod
  - Facilitated the development of highly-erodible, abiotic substrates
  - Contributed to the mass export of nutrients

Influence on Vegetation

Swale II

↓ Biomass production
↑ Soil stability
↑ Nutrient removal

Swale III

↑ Biomass production
↓ Soil stability
↓ Nutrient removal

Conclusions

- Macrophyte productivity ≠ Stormwater treatment
- Need direct assessment, not rapid assessment

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Committee Members

Anita Thompson | Biological Systems Engineering, Advisor

Joy Zedler | Botany and Arboretum

Steven Loheide | Civil & Environmental Engineering

Research Colleagues

Jim Doherty | Botany

Jeff Miller | Civil & Environmental Engineering

Project Support

Zach Zopp, John Panuska, Josh Accola, Kristi Freitag, Jasmeet Lamba, Daniel Mossing, Michael Nied, Michael Polich, Harsh Vardhan Singh, Ryan Stenjem, Mike Hansen, Brad Herrick, Mark Wegener

Photo by Jim Doherty

Additional Material

- Untreated Stormwater
- Bryophyte Cover
- CSM Operation
- Development of Substrate
- Swale Treatments
- Low Nutrient Removal
- Abiotic vs. Biotic Substrate
- TSS Removal Mechanisms
- TN Removal Mechanisms
- TP Removal Mechanisms
- TDP : TP

Wetland Swale Treatments

Swale I
Intermediate recession rate
Moderate plant biomass
Moderate plant diversity

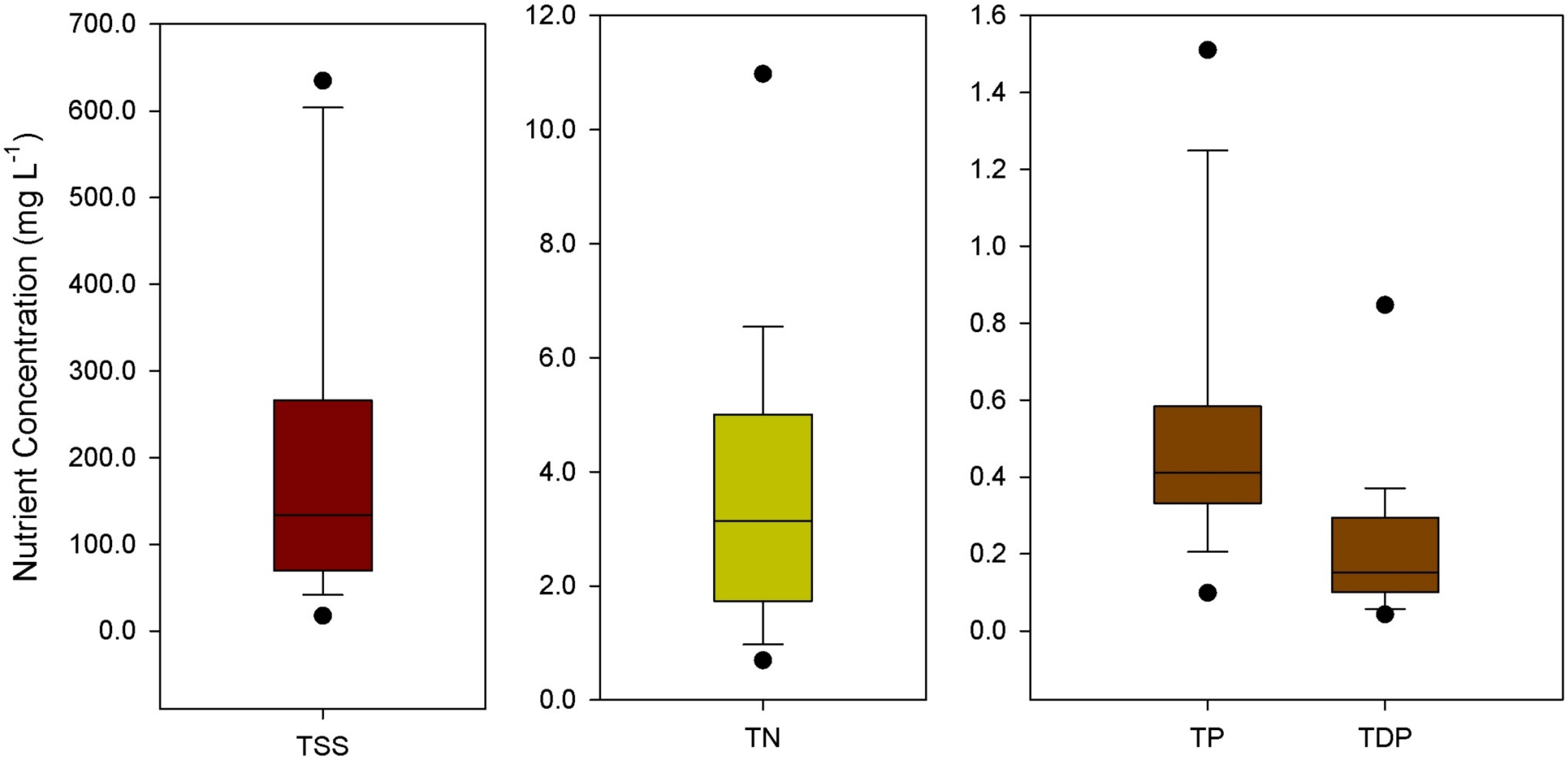
Swale II
High recession rate
Lowest plant biomass
Highest plant diversity

Swale III
Low recession rate
Highest plant biomass
Lowest plant diversity

Doherty and Zedler, *in review*; Jeff Miller, *unpublished*

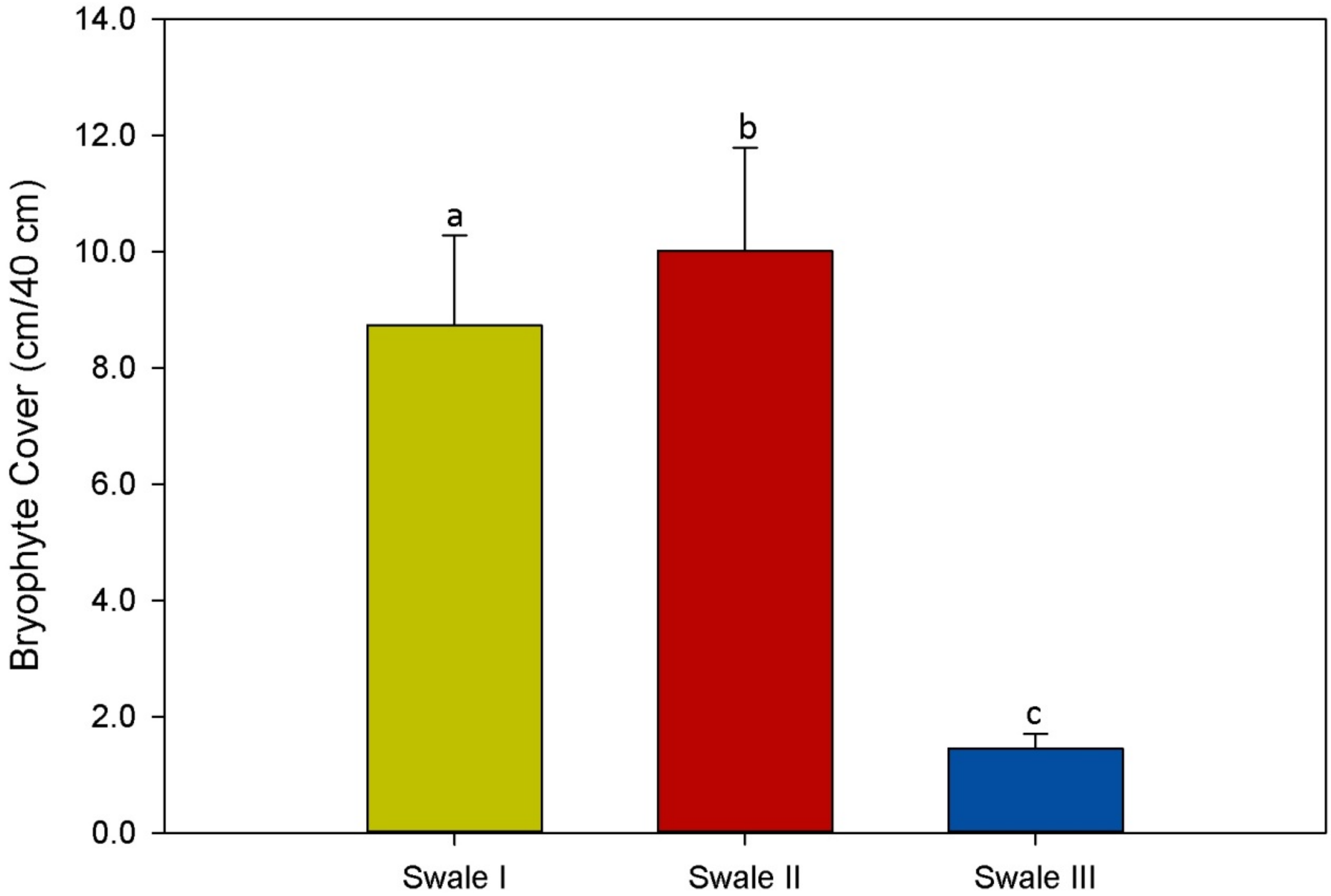
Additional Material

Untreated Stormwater



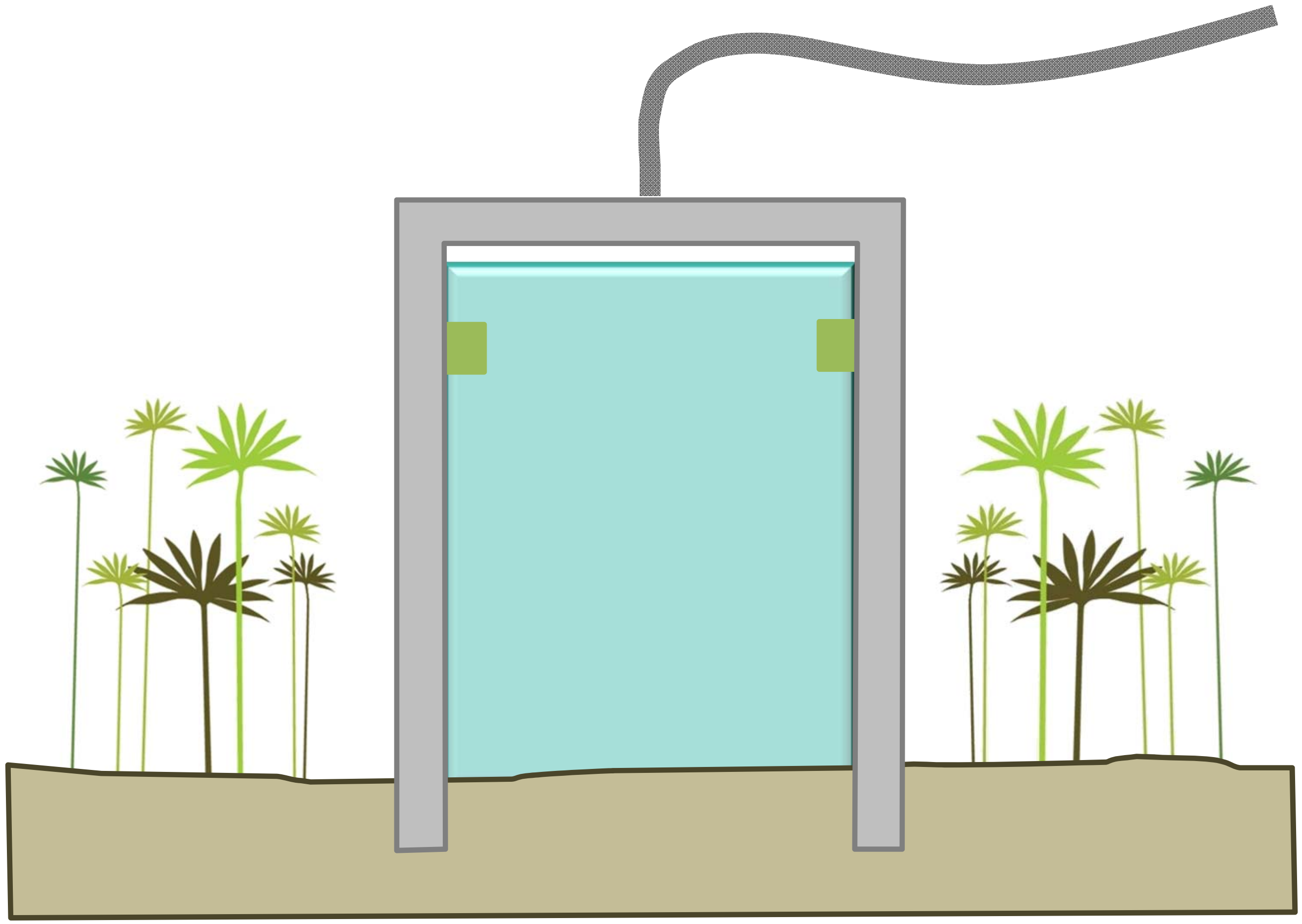
Additional Material

Bryophyte Cover

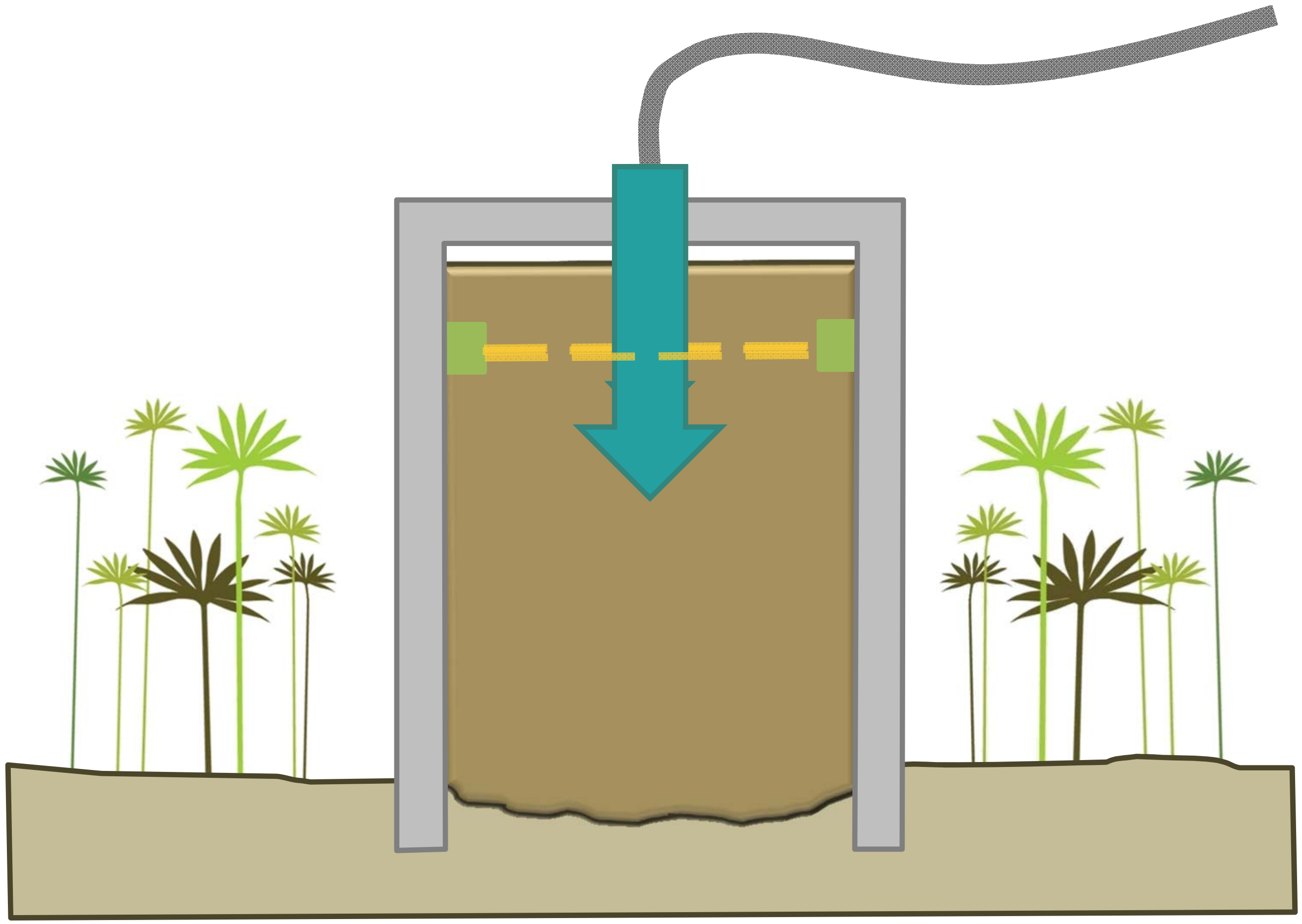


Additional Material

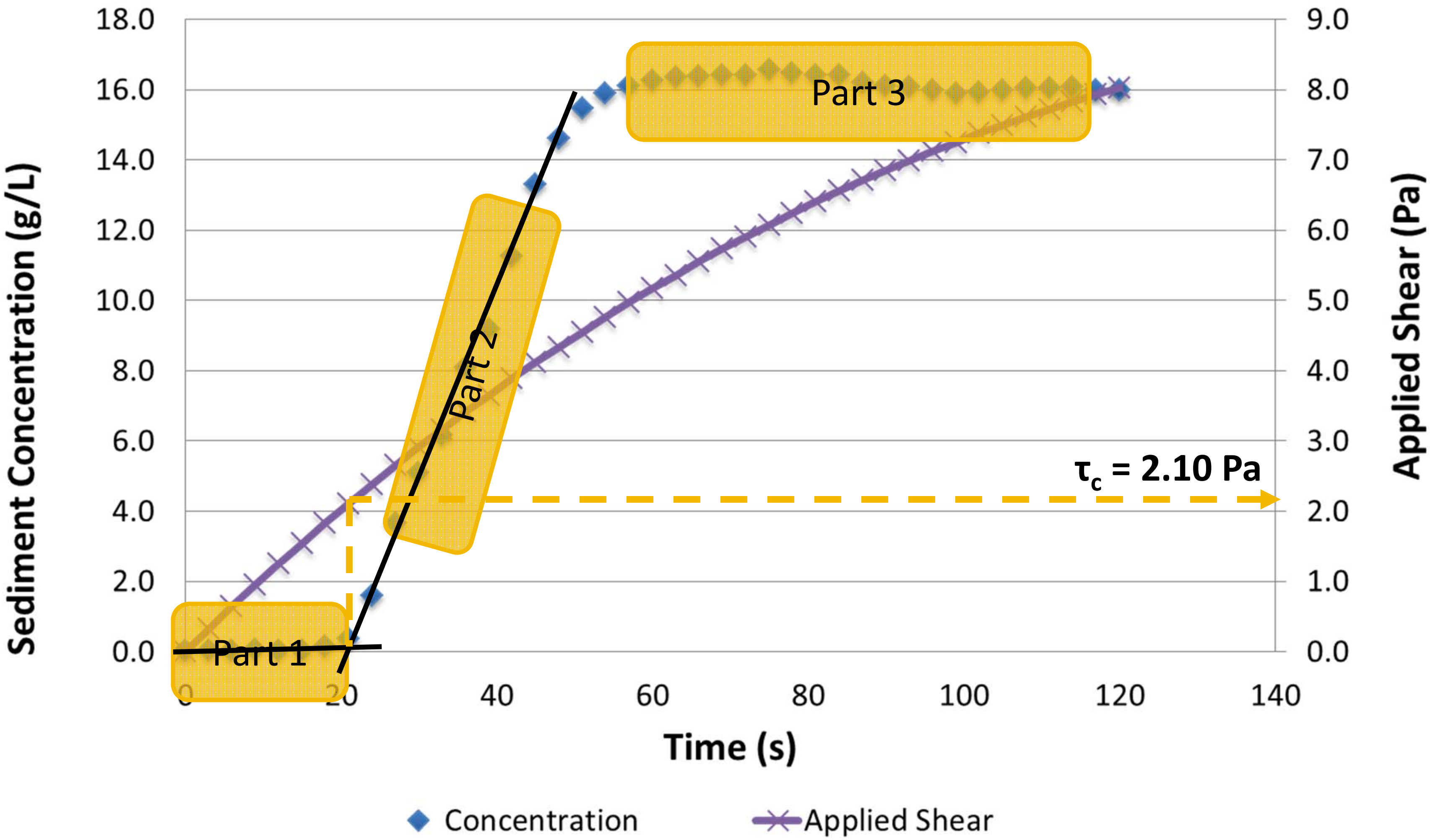
Cohesive Strength Meter



Cohesive Strength Meter



Critical Shear Stress (τ_c) Estimation



Additional Material

Development of Substrate

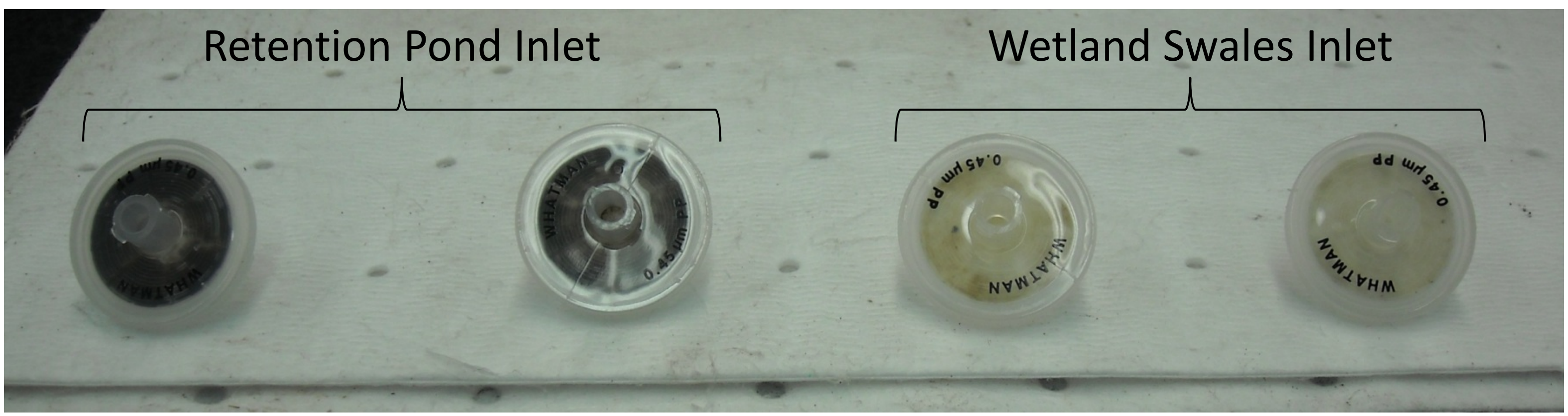
- Swales I and II
  - More open canopies = Surface light penetration (Timofeev 1959)
  - Fluctuated between wet and dry conditions
  - Supported establishment of algae and moss

- Swale III
  - Inundation = Anaerobic conditions
  - Inhibited establishment of moss and algae (Miller and Zedler 2003, Day and Megonigal 1993)
  - Supported accumulation of OM

Additional Material

Low Nutrient Removal

- Facilities in series (Hathaway and Hunt 2010)
- Irreducibly low concentrations (Schueler and Holland 2000)
- Baseline concentration of nutrients (Moore et al. 2011)
- Nutrient-rich topsoil
- RE as a metric for treatment (Strecker et al. 2001, Lenhart and Hunt 2011)



Additional Material

Stabilization by Soil Substrate

- Biotic > Abiotic Substrate
  - Biotic: Physical, biological, chemical processes
    (Paterson et al. 2000, Whitehouse et al. 2000)
  - Abiotic: Physical mechanisms
    (Lundkvist et al. 2007)
- Algae: Extracellular Polymeric Substances (EPS)
  (Sutherland et al. 1998)

Additional Material

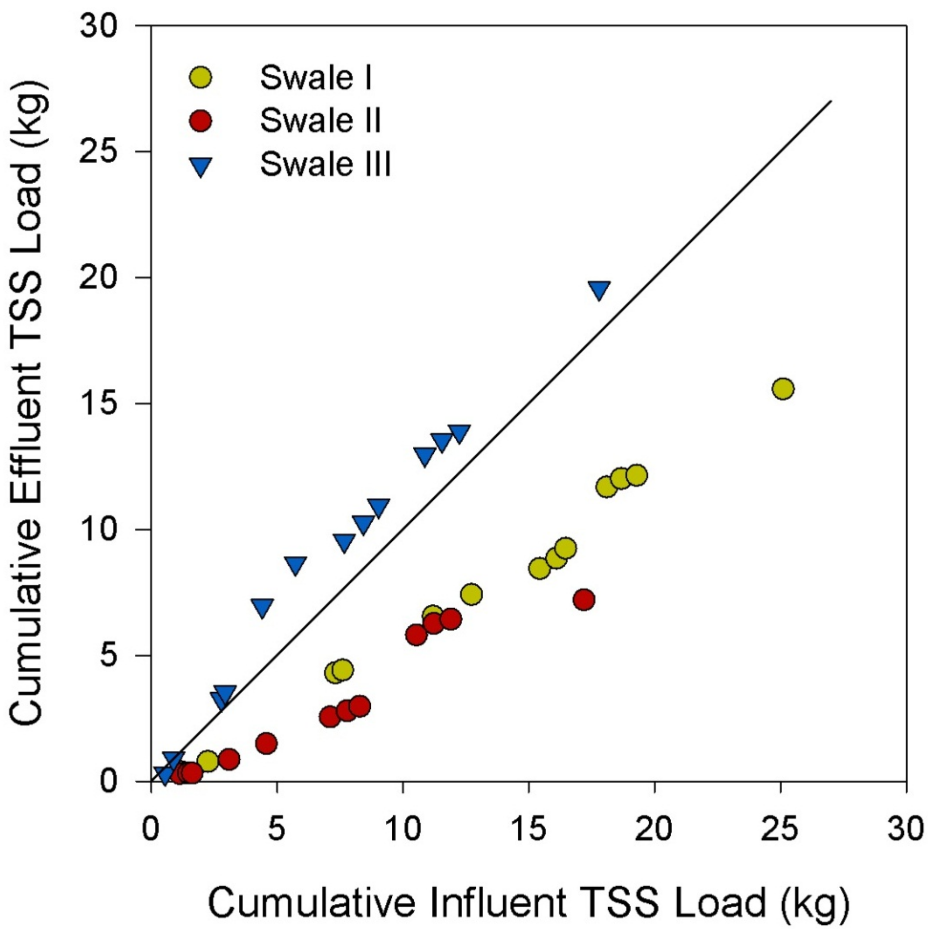
Removal of Total Nitrogen

- Removal mechanisms:
  - Mineralization: organic nitrogen → ammonia
  - Volatilization: ammonia → atmospheric N_2
  - Denitrification: nitrate → atmospheric N_2
  - Plant uptake
  - Particulate Settling
- Export mechanisms:
  - Nitrogen fixation: atmospheric N_2 → ammonia
  - Particulate resuspension
  - Diffusion of dissolved forms

Additional Material

Removal of TSS

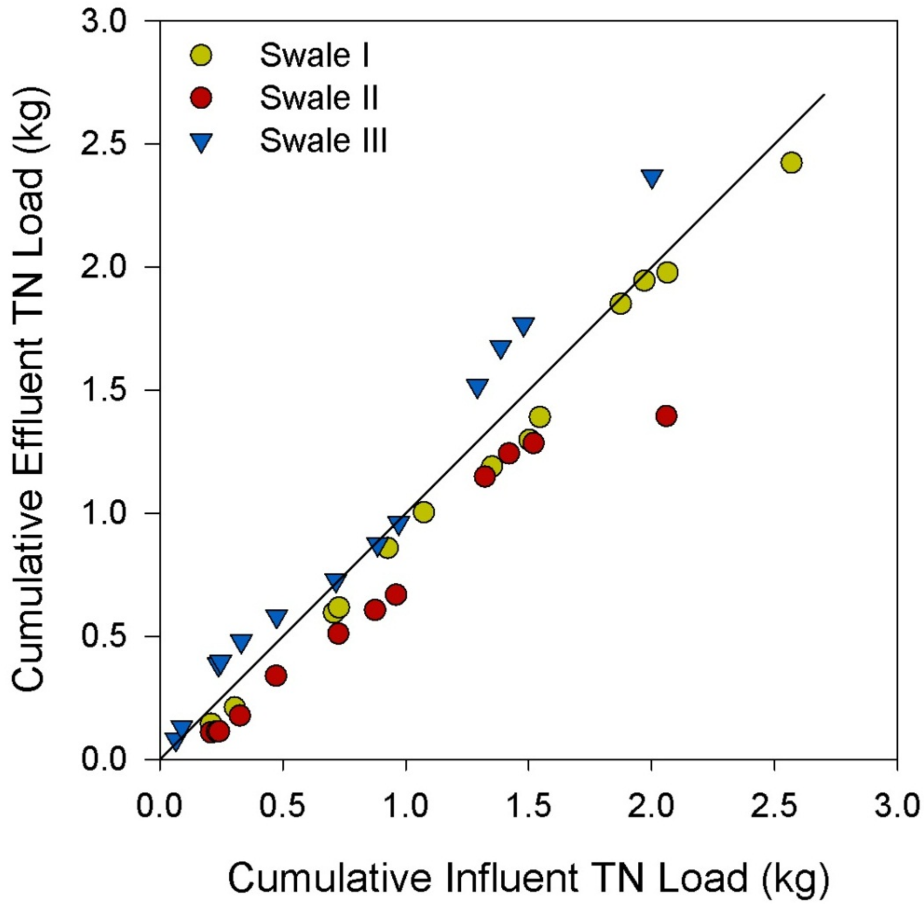
- Deeper inundation, greater settling (Nichols 1983)
- Swale III
  - Frequent inundation, greater TSS export
  - Resuspension of OM
  - High soil moisture (Grabowski et al. 2011)
- Swales I and II
  - Moss and algal mats (Turetsky 2003)
  - Diverse stem architecture (Vermaat et al. 2000)



Additional Material

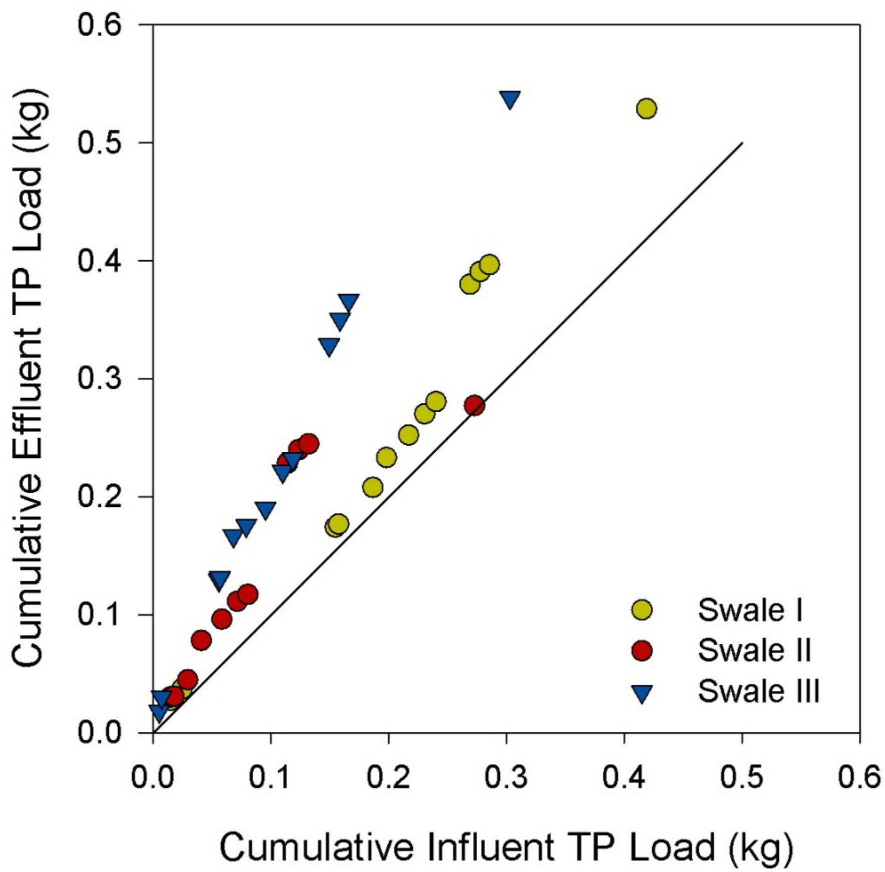
Removal of TN

- Highest removal with fluctuating hydroperiod
  (Busnardo et al. 1992, Jordan et al. 2011)
  – Nitrification (aerobic) + denitrification (anaerobic)
- Swale III
  – Inundated conditions; average export of TN
  – Increased particulate resuspension
  – OM accumulation, increases TN export
  (Thoren et al. 2004)



Additional Material

Removal of TP



- Fischer (2004): 10%-25% of studied wetlands exported P
- Highest removal with **fluctuating hydroperiod** (Busnardo et al. 1992)
  - Increased oxygen sediment concentrations (Fisher and Acreman 2004)
- Prolonged inundation: mobilization of Fe and Al (Boers and Zedler 2008)

Additional Material

TDP : TP

- TDP:TP = 42% → 52% over retention pond
- Good et al. (2012)
  - Phosphorus solubilization can be described as a linear relationship between soil phosphorus concentration and an extraction coefficient (0.006)
  - Average soil phosphorus = **49.1** mg L^{-1}
  - Dissolved phosphorus loss (DP_{soil}) = **0.03** mg L^{-1}

Additional Material

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