Soil Stability and Water Quality
within Constructed Wetland Treatment Swales

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2013 Wisconsin AWRA Annual Conference

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March 7, 2013
Regional Urbanization

(USDA, 2003)
Stormwater Impacts

- Algal Blooms: Carpenter et al. (1998)
- Eutrophication

- Flooding: Allen et al. (2008)
- Reduced Baseflow
- Stream Incision
Project Location

(DNR, 2012)
Regional Urbanization

(USDA, 2005)
Aerial View of SMRF

Stormwater Management Research Facility (SMRF)

(Wetland Swale)

(Concrete Flume)

(Forebay + Retention Pond)

(Collection Swale)

(Forebay + Retention Pond)

(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.
Wetland Swale Plots

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

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

Jeff Miller, unpublished
Water Level Recession Rate

Swale I

Swale II

Swale III

Date

8/18/2011

9/8/2011

Jeff Miller, unpublished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Jeff Miller, unpublished
Swale III was consistently the most productive

Doherty and Zedler, in review

Graph by Jeff Miller
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

![Bar chart showing critical shear stress by substrate.](image)

- **Algal Mat**: 9.12 Pa (a)
- **Bare Soil**: 6.00 Pa (c)
- **Moss Mat**:最高 (a)
- **Muck**: 最低 (c)
- **Organic Matter**: 6.00 Pa (b)
Frequency of Soil Substrate
Soil Stability by Swale

![Bar chart showing soil stability by swale](chart.jpg)
Results | Water Quality
Siphon Sampler Locations

Flow
Swale I
Swale II
Swale III
Pretreatment in Retention Pond

Based on a discrete nutrient concentrations at a fixed depth.
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

![Graph showing nutrient removal efficiency for TSS, TN, TP, and TDP in Swales I, II, and III. Different letters (a, b, ab) indicate statistical differences among treatments.](image)
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
Funding
This research is funded by the US EPA Great Lakes Restoration Initiative
(Award # GL-00E00647; PIs: Zedler, Thompson, Loheide)

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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
Questions?

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
Untreated Stormwater

Nutrient Concentration (mg L\(^{-1}\))

- TSS
- TN
- TP
- TDP

Additional Material
Bryophyte Cover

Additional Material
Cohesive Strength Meter
Cohesive Strength Meter
Critical Shear Stress ($\tau_c$) Estimation

Part 1

Part 2

Part 3

$\tau_c = 2.10$ Pa

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
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)
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 $\rightarrow$ ammonia
  – Volatilization: ammonia $\rightarrow$ atmospheric $\text{N}_2$
  – Denitrification: nitrate $\rightarrow$ atmospheric $\text{N}_2$
  – Plant uptake
  – Particulate Settling

• Export mechanisms:
  – Nitrogen fixation: atmospheric $\text{N}_2$ $\rightarrow$ 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)
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)
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)
TDP : TP

- TDP:TP = 42% \rightarrow 52\% \text{ 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}
Works Cited


USDA. 1937. Orthorectified mosaic of 1937 (spring) aerial photos.


