THE EFFECTIVENESS OF BIOSORPTION ACTIVATED MEDIA (BAM) TO REDUCE NITRATE AND ORTHOPHOSPHATE IN STORMWATER RUNOFF
PART 1: Literature and Laboratory Results

Marty Wanielista, 2013
Why?

- Some groundwater and surface water supplies are decreasing in quantity and quality
- Stormwater runoff - medium of transport for nutrients and pollutants
- Stormwater runoff may impair groundwater and surface water
Why?

• Nitrate concentrations in Florida springs have been increasing for 50 years (USGS, 2008)

• Nitrate in Silver Springs has increased from 0.5 mg/L NO$_3$-N (1960) to 1.0 mg/L NO$_3$-N (2003) (Phelps, 2004)
Why?

- Springs and lakes are currently suffering from reduced water quality caused by excess nutrients.
- Elevated nutrient levels are responsible for approximately 45% of lakes and streams listed as impaired by the FDEP.
Nitrogen: One possible pathway

- Rain
- Animal Waste or Fertilizer containing NH₃
- Stormwater containing Organics + NH₃ yield NH₄⁺
- Nitrification occurs: NH₄⁺ + 2O₂ → NO₃⁻ + 2H⁺ + H₂O
- Permeable Earth
- Groundwater
- Nitrogen Species:
  - Ammonia Nitrogen
  - Nitrile or Nitrite Nitrogen
  - Ammonium Nitrogen
- Spring Head
- Groundwater: negligible Nitrogen species
- Spring water: contaminated with Nitrates and/or Nitriles
Problems

- Stormwater runoff and infiltration provides excess nutrients to lakes, rivers, springs and streams which may lead to Eutrophication
- Algal Growth, degraded aesthetics, lower water quality
Objectives

- Reduction of Nitrate and Phosphorus entering ground water and surface waters
- Reduction of Nitrate and Phosphorus in stormwater runoff
- Reduction of Nitrate and Phosphorus by specifically designed stormwater Biosorption Activated Media filter (BAM)
Background Information

- Nitrogen Removal: typical are filtration, and biological (such as: anammox and nit-denit facultative organisms).

- Nitrification and Denitrification
  - Facilitated by bacteria usually attached to a solid
  - Requires aerobic conditions for Nitrification
  - Requires anaerobic conditions for Denitrification
  - Requires an electron donor, examples C, CO₂ for nitrification, S, Fe, Mn
  - Can exist for a long time period given proper conditions

- \( \text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2 \) (Gas)
Background Information

- Phosphorus Removal: typical are sorption, precipitation, ion exchange, and filtration.
- Sorption
  - During infiltration Phosphorus tends to readily sorb onto many soils and media types (Crites, 1985)
  - May be removed in either aerobic or anaerobic conditions
  - Typically has a life expectancy
Objective

• Reduce Nitrogen (Nitrate) and Phosphorus (Orthophosphate) via BAM

• 4 Approached:
  1. Literature Review
  2. Batch Test Experimentation
  3. Material Characterization
  4. Column Test Experimentation
Literature Review

• 32 different types of media were investigated to reduce Nitrogen and or Phosphorus within stormwater runoff (Moberg, 2008)

• Performance assessment of each potential media using Multi-criteria Decision Making

• Qualitatively and Quantitatively evaluated
Literature Review

• **Multicriteria Decision Making:**
  1. Relevance (excellent, very good, good, fair, poor)
  2. Permeability (High, medium, low)
  3. Cost (High, medium, low)
  4. Availability in Florida (yes, no)
  5. Additional environmental benefit (yes, no)
Literature Review

- Top seven media from literature review move to the batch test
- Florida peat, sandy loam, woodchips, crushed oyster shell, crushed limestone, tire crumb and sawdust
- All selected media may sorb Phosphorus
<table>
<thead>
<tr>
<th>No.</th>
<th>Scopion Media</th>
<th>Criteria 1</th>
<th>Criteria 2</th>
<th>Criteria 3</th>
<th>Criteria 4</th>
<th>Criteria 5</th>
<th>Overall*</th>
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<tbody>
<tr>
<td>1</td>
<td>Florida Peat</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<td>2</td>
<td>Alkaline</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Activated carbon</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Carbon sand, Bedrock sand, or sand</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4a</td>
<td>Sandy Loam (SL), Loamy Sand (LS), and Sandy Clay Loam (SCL), Planting soil</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4.6</td>
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<tr>
<td>5</td>
<td>Sawdust (untreated wood)</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4.4</td>
</tr>
<tr>
<td>6</td>
<td>Lignocellulosic Materials: Wheat straw</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Tire Cumb (electron donor)</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4.1</td>
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<tr>
<td>8</td>
<td>Limestone/electron donor</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4.88</td>
</tr>
<tr>
<td>8a</td>
<td>Crushed oyster/electron donor</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4.88</td>
</tr>
<tr>
<td>9</td>
<td>Wood fiber/wood chips/compost</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4.88</td>
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</tbody>
</table>
Past Media Investigations: to illustrate successful removal

- Previous experimentation with sawdust and woodchips has shown Nitrate removals of 95% (Kim, 2000)
- Sand, peat and lime rock column removed approximately 41% of the TP (Debusk, 1997)
- Porous reactive media barriers that consisted of sand, silt, sawdust, peat and gravel and sand achieved between 72% and 97% Nitrate removal (Robertson and Cherry, 1995)
Past Media Investigations: to illustrate successful removal

- 89% to 96% reduction in ammonium and Nitrate within an infiltration bed comprised of sand and sawdust (Robertson, 1999)

- Average Nitrate removal of 80% for the sulfur/crushed oyster shell filter (Sengupta and Ergas, 2006)
Lab Batch Test Experimentation

- Aerobic conditions
- Denitrification is not possible within batch test experimentation
- Media performance is based on Orthophosphate (OP) and Ammonia Nitrogen removal
- Top performing media mixes for the 48 hour batch test move to column test experimentation
Batch Test Experimentation

- **Results:**
  - Florida peat, woodchips and sawdust add substantial Ammonia Nitrogen to sample
  - Cause and effect electron donor and nutrients
  - Sawdust adds the least Ammonia
  - Tire crumb substantially reduces Orthophosphate
  - Crushed oyster shell added considerable Orthophosphate
Batch Test Experimentation

- Media Selection:
  - Optimization of electron donor
  - Media Mix 1: 50% sand, 30% tire crumb, 20% sawdust by weight
  - Media Mix 2: 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight
  - Control: from Hunters Trace pond in Ocala, FL
Hunter’s Trace Location
Hunter’s Trace Pond

• ~ 0.8 ac
• 10 ft deep
• Water table ~10 ft below pond bottom
Materials Characterization

- ASTM D-421-85 Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis

- ASTM C29/C29M-07 for measuring the bulk density ("unit weight")

## Material Characterization Summary

<table>
<thead>
<tr>
<th></th>
<th>Hunter’s Trace (dry sample)</th>
<th>Hunter’s Trace (moist sample)</th>
<th>Media Mix 1</th>
<th>Media Mix 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.56</td>
<td>1.73</td>
<td>1.41</td>
<td>1.44</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>0.67</td>
<td>0.51</td>
<td>0.56</td>
<td>0.62</td>
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<tr>
<td>Porosity</td>
<td>0.40</td>
<td>0.34</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>Specific Gravity (Gs)</td>
<td>2.62</td>
<td>2.62</td>
<td>2.19</td>
<td>2.33</td>
</tr>
<tr>
<td>Surface Area (m²/g)</td>
<td>-</td>
<td>-</td>
<td>0.129</td>
<td>0.242</td>
</tr>
<tr>
<td>Permeability (cm/hr)</td>
<td>62.48</td>
<td>4.47</td>
<td>4.38</td>
<td>3.62</td>
</tr>
</tbody>
</table>
Gradation Curve: the soil in vadose zone at Hunters Trace site
Gradation Curve: Media Mix 1

Media 1:
Particle-Size Distribution

Percent Finer

Grain Size, D (mm)
Gradation Curve: Media Mix 2

Media 2:
Particle-Size Distribution

Percent Finer

Grain Size, D (mm)
Six Column Test Setup

CONTROL

MEDIA MIX 1

MEDIA MIX 2

Reservoir (influent)
Column Test Setup
Column Test Experimentation

- Augmented stormwater Nitrate concentration: 0.38, 1.26, 2.53 mg/L NO$_3$-N
- Average land use Nitrate values: 1.24 - 3.1 mg/L NO$_3$-N (Pitt, 2004)
- Overall average Nitrate: 2.66 mg/L as NO$_3$-N (Pitt, 2004)
Column Test Experimentation

- Augmented stormwater Orthophosphate concentration 0.125, 0.361, 0.785 mg/L PO$_4$-P
- Average land use Orthophosphate values: 0.123 - 0.613 mg/L PO$_4$-P (Pitt, 2004)
- Overall average Orthophosphate 0.40 mg/L PO$_4$-P (Pitt, 2004)
Column Test Experimentation

- Column test flow rate 10mL per minute
- 1.38 inches per hour
- Typical retention basin infiltration 0.25 - 2 inches per hour (Wanielista, et.al. 2011)
- 3 runs for each Nitrate and Orthophosphate concentration
## Overall Nitrate Reduction

<table>
<thead>
<tr>
<th></th>
<th>Initial Concentration (mg/L NO₃-N) Top Column 1</th>
<th>Final Concentration (mg/L NO₃-N) Bottom Column 2</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column 1,2</td>
<td>Average n=3 0.382</td>
<td>0.233</td>
<td>38.9</td>
</tr>
<tr>
<td></td>
<td>Average n=3 1.269</td>
<td>0.380</td>
<td>70.0</td>
</tr>
<tr>
<td></td>
<td>Average n=3 2.529</td>
<td>1.529</td>
<td>39.5</td>
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<tr>
<td><strong>MEDIA MIX 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column 3,4</td>
<td>Average n=3 0.382</td>
<td>0.022</td>
<td>94.2</td>
</tr>
<tr>
<td></td>
<td>Average n=3 1.269</td>
<td>0.023</td>
<td>98.2</td>
</tr>
<tr>
<td></td>
<td>Average n=3 2.529</td>
<td>0.021</td>
<td>99.2</td>
</tr>
<tr>
<td><strong>MEDIA MIX 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column 5,6</td>
<td>Average n=3 0.382</td>
<td>0.023</td>
<td>94.1</td>
</tr>
<tr>
<td></td>
<td>Average n=3 1.269</td>
<td>0.024</td>
<td>98.1</td>
</tr>
<tr>
<td></td>
<td>Average n=3 2.529</td>
<td>0.023</td>
<td>99.1</td>
</tr>
</tbody>
</table>
## Unsaturated Nitrate Changes

<table>
<thead>
<tr>
<th>Control Column</th>
<th>Initial Concentration (mg/L NO3-N) Top Column</th>
<th>Final Concentration (mg/L NO3-N) Bottom Column</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column 1</td>
<td>Average n=3, 0.382</td>
<td>0.626</td>
<td>-63.9</td>
</tr>
<tr>
<td>Column 3</td>
<td>Average n=3, 0.382</td>
<td>0.362</td>
<td>5.2</td>
</tr>
<tr>
<td>Column 5</td>
<td>Average n=3, 0.382</td>
<td>0.141</td>
<td>63.1</td>
</tr>
</tbody>
</table>

### MEDIA MIX 1

- Column 1: Initial: 0.382, Final: 0.626, Removal: -63.9%
- Column 3: Initial: 0.382, Final: 0.362, Removal: 5.2%
- Column 5: Initial: 0.382, Final: 0.141, Removal: 63.1%

### MEDIA MIX 2

- Column 1: Initial: 1.269, Final: 1.868, Removal: -47.3%
- Column 3: Initial: 1.269, Final: 0.921, Removal: 27.4%
- Column 5: Initial: 1.269, Final: 0.268, Removal: 78.9%

- Column 1: Initial: 2.529, Final: 2.526, Removal: 0.1%
- Column 3: Initial: 2.529, Final: 1.958, Removal: 22.6%
- Column 5: Initial: 2.529, Final: 0.798, Removal: 68.5%
# Saturated Nitrate Reduction:

DO concentrations at bottom of saturated columns 0.10-0.19 mg/L

<table>
<thead>
<tr>
<th>Control Column 2</th>
<th>Initial Concentration (mg/L NO3-N) Top Column 2</th>
<th>Final Concentration (mg/L NO3-N) Bottom Column 2</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average n=3</td>
<td>0.626</td>
<td>0.233</td>
<td>61.6</td>
</tr>
<tr>
<td>Average n=3</td>
<td>1.868</td>
<td>0.380</td>
<td>79.6</td>
</tr>
<tr>
<td>Average n=3</td>
<td>2.526</td>
<td>1.529</td>
<td>39.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Media Mix 1 Column 4</th>
<th>Initial Concentration (mg/L NO3-N) Top Column 4</th>
<th>Final Concentration (mg/L NO3-N) Bottom Column 4</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average n=3</td>
<td>0.362</td>
<td>0.022</td>
<td>93.9</td>
</tr>
<tr>
<td>Average n=3</td>
<td>0.921</td>
<td>0.023</td>
<td>97.4</td>
</tr>
<tr>
<td>Average n=3</td>
<td>1.958</td>
<td>0.021</td>
<td>98.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Media Mix 2 Column 6</th>
<th>Initial Concentration (mg/L NO3-N) Top Column 6</th>
<th>Final Concentration (mg/L NO3-N) Bottom Column 6</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average n=3</td>
<td>0.141</td>
<td>0.023</td>
<td>78.0</td>
</tr>
<tr>
<td>Average n=3</td>
<td>0.268</td>
<td>0.024</td>
<td>90.7</td>
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<tr>
<td>Average n=3</td>
<td>0.798</td>
<td>0.023</td>
<td>97.1</td>
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</table>
Overall Orthophosphate Reduction

<table>
<thead>
<tr>
<th>Control Column 1,2</th>
<th>Initial Concentration (mg/L PO4-P)</th>
<th>Final Concentration (mg/L PO4-P)</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Column 1</td>
<td>Average n=3 0.125</td>
<td>0.304</td>
<td>-143.1</td>
</tr>
<tr>
<td>Bottom Column 2</td>
<td>Average n=3 0.361</td>
<td>0.294</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>Average n=3 0.785</td>
<td>0.351</td>
<td>55.2</td>
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</table>

<table>
<thead>
<tr>
<th>Media Mix 1 Column 3,4</th>
<th>Initial Concentration (mg/L PO4-P)</th>
<th>Final Concentration (mg/L PO4-P)</th>
<th>Removal Efficiency (%)</th>
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<tbody>
<tr>
<td>Top Column 3</td>
<td>Average n=3 0.125</td>
<td>0.061</td>
<td>51.2</td>
</tr>
<tr>
<td>Bottom Column 4</td>
<td>Average n=3 0.361</td>
<td>0.050</td>
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<tr>
<td></td>
<td>Average n=3 0.785</td>
<td>0.068</td>
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<table>
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<th>Media Mix 2 Column 5,6</th>
<th>Initial Concentration (mg/L PO4-P)</th>
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<th>Removal Efficiency (%)</th>
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<td>Top Column 5</td>
<td>Average n=3 0.125</td>
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<tr>
<td>Bottom Column 6</td>
<td>Average n=3 0.361</td>
<td>0.058</td>
<td>83.9</td>
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<tr>
<td></td>
<td>Average n=3 0.785</td>
<td>0.106</td>
<td>86.5</td>
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</tbody>
</table>
Literature Review and Lab Summary

• Literature Review

• Lab Batch Test Experimentation

• Material Characterization

• Lab Column Test Experimentation
Laboratory Conclusions

- Media Mix 1 and Media Mix 2 are more effective than the control for nutrient reduction
- Wet conditions are necessary for denitrification
- Biosorption media mixes may be used to manage nutrients.
References


• Moberg, Mikhal, 2008. Effectiveness of Specifically Designed Filter Media. UCF Thesis, Orlando, Florida

References

BAM PART 1 Literature and Laboratory
Questions and Comments
Contact Marty Wanielista
martin.Wanielista@ucf.edu

Information abstracted from student theses, dissertations and refereed publications at UCF.