Optimization of Bioretention Soil Mix for Nutrient Removal
LID Research and Innovation Symposium

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Department of Civil Engineering
University of New Hampshire
Special Thanks

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Robert Roseen – Geosyntec
Robin Stone – UNHSC
Funders:
Stantec
EPA Region 1
Part of the Problem – Point Source Pollution
Impact of Impervious Cover

Stream Quality

- Good
- Fair
- Poor

Watershed Impervious Cover

- Sensitive
- Impacted
- Non-Supporting
- Urban Drainage

Adapted from Schueler
LID in 2013
TSS Removal Efficiencies

The graph shows the TSS removal efficiencies for various systems and methods:

- **Stone Swale**: Approximately 50% removal
- **Veg Swale**: Approximately 60% removal
- **Berm Swale**: Approximately 40% removal
- **Retention Pond**: Approximately 30% removal
- **HDS Systems**: Approximately 90% removal
- **Pipe Infiltration**: Approximately 80% removal
- **Infiltration Chamber**: Approximately 70% removal
- **MTD Filter**: Approximately 60% removal
- **Bioretention (4)**: Approximately 50% removal
- **Tree Filter (2)**: Approximately 40% removal
- **Gravel Wetland**: Approximately 30% removal
- **Porous Asphalt**: Approximately 20% removal
Unit Operations & Processes (UOPs) in the Gravel Wetland

- Physical Operations
- Biological Processes
- Chemical Processes
- Hydrologic Operations
What we know

• Nitrogen is controlled through vegetative uptake and anaerobically through microbial denitrification

• Phosphorus is controlled through veg uptake and sorbed to electrostatically charged soil particles (clay/humus/organic matter)
Mass loading for DRO, Zn, NO₃, TSS as a function of normalized storm volume for two storms: (a) a large 2.3 in rainfall over 1685 minutes; (b) a smaller 0.6 in storm depth over 490 minute. DRO=diesel range organics, Zn= zinc, NO₃= nitrate, TSS= total suspended solids.
Experimental Design

Phase 1: Test Drain time and ISR:WQV Ratio

Phase 2: Test bioretention soil mix and four different soil amendments

Phase 3: optimize the ratio of loam to sand for P removal, as well as to further optimize the soil to soil amendment ratio for top mixes (\( \text{Fe}_2 \) and \( \text{WTR} \))
# Phase 1

<table>
<thead>
<tr>
<th>Column #</th>
<th>Soil Mix and saturation zone size</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1-N0</td>
<td>UNHSC BSM with no saturation zone (control)</td>
<td>- Drainage to filter ratio 80:1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Soil depth in columns: 24”</td>
</tr>
<tr>
<td>T1-N1</td>
<td>UNHSC BSM with 25% WQV</td>
<td>- 12 hour drain time</td>
</tr>
<tr>
<td>T1-N2</td>
<td>UNHSC BSM with 50% WQV</td>
<td>- Soil tested: UNHSC mix</td>
</tr>
<tr>
<td>T1-N3</td>
<td>UNHSC BSM with 75% WQV</td>
<td></td>
</tr>
<tr>
<td>T1-N4</td>
<td>UNHSC BSM with 100% WQV</td>
<td></td>
</tr>
<tr>
<td>T1-N5</td>
<td>UNHSC BSM with 25% WQV</td>
<td>- Drainage to filter ratio 80:1</td>
</tr>
<tr>
<td>T1-N6</td>
<td>UNHSC BSM with 50% WQV</td>
<td>- Soil depth in columns: 24”</td>
</tr>
<tr>
<td>T1-N7</td>
<td>UNHSC BSM with 75% WQV</td>
<td>- 30 hour drain time</td>
</tr>
<tr>
<td>T1-N8</td>
<td>UNHSC BSM with 100% WQV</td>
<td>- Soil tested: UNHSC mix</td>
</tr>
</tbody>
</table>
Nitrogen Results

DIN (mg/l)
Nitrogen Results
# Phase 2: Phosphorus

<table>
<thead>
<tr>
<th>Column #</th>
<th>Soil Mix</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2-P0</td>
<td>UNHSC BSM (control)</td>
<td></td>
</tr>
<tr>
<td>T2-P1</td>
<td>UNHSC 95% BSM + 5% WTR</td>
<td>• Drainage to filter ratio 80:1</td>
</tr>
<tr>
<td>T2-P2</td>
<td>UNHSC 90% BSM + 10% WTR</td>
<td>• Soil depth in columns: 24”</td>
</tr>
<tr>
<td>T2-P3</td>
<td>UNHSC 97% BSM+3% Fe₂</td>
<td>• 24 hour drain time</td>
</tr>
<tr>
<td>T2-P4</td>
<td>UNHSC 94% BSM+6% Fe₂</td>
<td>• Soil tested: UNHSC mix</td>
</tr>
<tr>
<td>T2-P5</td>
<td>UNHSC 97% BSM+3% Slag</td>
<td></td>
</tr>
<tr>
<td>T2-P6</td>
<td>UNHSC 95% BSM+5% Slag</td>
<td></td>
</tr>
<tr>
<td>T2-P7</td>
<td>UNHSC 95% BSM +5% Limestone</td>
<td></td>
</tr>
<tr>
<td>T2-P8</td>
<td>UNHSC 90% BSM +10% Limestone</td>
<td></td>
</tr>
</tbody>
</table>
Phosphorus Results

Phase 2 - Phosphorus as PO4-P

PO4 (ug/l)

Control 5% WTR 10% WTR 3% Fe 6% Fe 3% Slag 5% Slag 5% Limestone 10% Limestone Influent
Phase 2 - PO4-P

Orthophosphate-P (μg P/L)

Storm number

T2_P0
T2_P5
T2_P6
T2_P7
T2_P8
T2_P1
T2_P2
T2_P3
T2_P4
# Phase 3: Phosphorus Optimization

<table>
<thead>
<tr>
<th>Column #</th>
<th>Soil Mix</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4-P1</td>
<td>90% Stantec loam + 10% sand</td>
<td>• Drainage to filter ratio 25:1</td>
</tr>
<tr>
<td>T4-P2</td>
<td>75% Stantec loam + 25% sand</td>
<td>• Soil depth: 12”</td>
</tr>
<tr>
<td>T4-P3</td>
<td>60% Stantec loam + 40% sand</td>
<td>• Percentage of amending materials was based on test results from Phases 2 and 3</td>
</tr>
<tr>
<td>T4-P4</td>
<td>45% Stantec loam + 55% sand</td>
<td></td>
</tr>
<tr>
<td>T4-P5</td>
<td>30% Stantec loam + 70% sand</td>
<td></td>
</tr>
<tr>
<td>T4-P6</td>
<td>15% Stantec loam + 85% sand</td>
<td></td>
</tr>
<tr>
<td>T4-P7</td>
<td>100% sand</td>
<td></td>
</tr>
<tr>
<td>T4-P8</td>
<td>0.5% Fe2 + 99.5% UNHSC mix</td>
<td></td>
</tr>
<tr>
<td>T4-P9</td>
<td>2% WTR + 98% UNHSC mix</td>
<td></td>
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</tbody>
</table>
Optimization Results

![Box plot showing the distribution of PO4 (ug/l) for different treatments. The x-axis represents various soil and water treatments, including loam, sand, Fe2, and UNHSC in different percentages. The y-axis represents the concentration of PO4 in micrograms per liter. The box plots indicate the median, quartiles, and outliers for each treatment, allowing for a visual comparison of the effectiveness of different treatments in reducing PO4 concentrations.](image-url)
Conclusions - the obvious!

- Compost leaches nutrients
- Filters are superior at sediment removal
- Hydraulic loading ratio and retention time have a large influence on performance
Conclusions – the promising...

• Modified bio systems show remarkable improvements to DIN and Ortho-P removals in the lab and in the field: ~ 60 - >90%
• Nitrogen removal is less media dependent and improves with ISR and with longer retention
• Loam has an excellent P-sorp capacity and should be incorporated in higher proportions in BSM
Conclusions – the curious...

• Details regarding BSM components are vague at best
• If optimal RE are to be achieved designs should be fine tuned and systems maintained
Questions?