BIOSORPTION ACTIVATED MEDIA (BAM) TO REDUCE NUTRIENTS IN STORMWATER

By Marty Wanielista
OVERVIEW

- ~ 15 years of lab and field data collection to validate removal and perfect designs and operations
- Biogeochemical assessment of pre/post data at areas using Biosorption Activated Media (BAM)
- Design and construction using BAM
- Quantitative analysis of N budget and flux beneath stormwater basins that use BAM
- Input – Output data on BMPs
PARTNERS in this work

- U.S. EPA, Edison NJ Stormwater Program
- Florida Department of Environmental Protection
- Marion County, Florida
- Florida Department of Transportation
- St. Johns River Water Management District
- Southwest Florida WMD
- Universities: UCF, USF, FSU and UF
- U.S. Geological Survey, Water Science Center
- Plastic Tubing Industries and
- Suntree Technologies

Special Thanks to many students and co-PIs on BAM, namely Drs. Ni-Bin Chang, UCF; & Andy O’Reilly, U of Mississippi

In addition to the speakers in this workshop.
BAM Media SELECTION
Ones for which we have effectiveness lab experiments

- Expanded Clay
- Peat
- Natural Sandy/Loamy/Clayey soils
- Sawdust (untreated)
- Paper/Newspaper
- Palm Tree Frauds
- Zeolite
- Tire Crumb
- Tire Chips
- Activated Carbon
- Limestone
- Crushed Shells
- Wood Fiber/Chips/
- Compost
- Coconut coir

Costly
Toxic Results
LABORATORY SOIL COLUMNS

- Test selected media mixtures to quantify their nutrient attenuation capabilities (removal)
- Life Expectancy

Trying to estimate
1. mg P/g media
2. Residence time
3. Environment,
   DO conditions
surface area of BAM identify using Scanning Electron Microscope

SEM of (a) concrete sand 1,000 x, (b) expanded clay 2,200 x, and (c) tire crumb 1,200 x magnification showing the surface structure and characteristics after residing in 24 days of column testing.
Roof and Lawn Gardens

vegetated areas with special media for water treatment and other benefits such as

• First used as a light weight media to “hold” N&P for plants
• Improving the “looks” of the area or property
• Reducing water pollution in runoff waters
• Replacing potable water used for irrigation
• Removing air pollutants and adding Oxygen
• Helping reduce heat island effects
• Reducing energy use within a building with greenroofs
• Providing for plant and animal diversity
Florida Greenroofs

• Scientific and engineering support introduced in Florida in 2003:
  – UCF Student Union, physical science and Stormwater Lab (3)
  – FSGE (Envirohome) (5) in Indialantic (2009 green roofs for healthy cities)
  – Bonita Bay (first one and has been modified for irrigation and media)
  – New American Home in Orlando
  – Charlotte County Stadium
  – UF Perry Construction Yard Building
  – Tecta-America Building in Sanford (tray vs. continuous)
  – Honda Headquarters in Clermont (greenroofs.com roof of the week)
  – Escambia County One Stop Permit Building (largest ~ 33,000 SF)
  – Residence on Casey Key
  – Orlando Fire Station #1
  – Environmental Center, Key West
  – Kimley-Horn Building in Vero Beach
  – First Green Bank with Tecta-America Southeast in Mount Dora
  – City of Sarasota Bay Front Park
  – Gulf Coast College, Panama City
  – Brickell City Center, Miami
  – WAWA gas station, Altamonte Springs
  – Starbucks, Walt Disney World
Depression or Lawn Garden Areas

Existing for 36 years, particulate fraction removal plus
Tree Box Filter Retention Design

Overflow storage
Overflow if not diverted
Flow to Tree Wells

Flow to Tree Well

Nitrogen and Phosphorus removal depends on media, (typical is > 70%)
Example Capture and Effectiveness with Retention BMPs
Pipe filter near an Estuary Area cannot infiltrate, thus filter
Bold & Gold Filter in a pipe

85% reduction of Nitrate, 76% reduction of TP

Credit Watermark Engineering
## Field SITE COMPARISONS

<table>
<thead>
<tr>
<th>Sandy Soil SW Basin</th>
<th>Parameter</th>
<th>BAM type Soil SW Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deeper</td>
<td>Water Table</td>
<td>Shallower</td>
</tr>
<tr>
<td>Less</td>
<td>Silty/Clayey Soils</td>
<td>More</td>
</tr>
<tr>
<td>Lower</td>
<td>Cation Exchange Capacity</td>
<td>Higher</td>
</tr>
<tr>
<td>Higher</td>
<td>Infiltration Rate</td>
<td>Lower</td>
</tr>
<tr>
<td>Higher</td>
<td>Dissolved Oxygen</td>
<td>Lower</td>
</tr>
<tr>
<td>Lower</td>
<td>Alkalinity</td>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
<td>Organic Carbon</td>
<td>Higher</td>
</tr>
<tr>
<td>Higher (median=2.2 mg/L)</td>
<td>Groundwater Nitrate</td>
<td>Lower (median=0.03 mg/L)</td>
</tr>
<tr>
<td>No</td>
<td>Nitrate Decline with Time</td>
<td>Yes</td>
</tr>
</tbody>
</table>
SOIL CHARACTERISTICS

- Textural differences contributed to large differences in the soil moisture retention curves.
TREATMENT with BAM

A retrofit to an existing area was completed based on the natural biogeochemical processes identified at an existing stormwater basins using naturally occurring BAM:

1. Excavation of native soil in the bottom of a portion of an area;
2. Emplacement of a 0.3 m thick amended soil layer ("Biosorption Activated Media" mix): 1.0:1.9:4.1 mixture (by volume) of tire crumb (to increase sorption capacity), silt+clay (to increase soil moisture retention), and sand (to promote sufficient infiltration); and
3. Construction of a berm forming separate nutrient reduction and flood control basins.
Marion County Basin—Uses BAM

- Reproduce soil conditions that exist at the SO basin by using an amended soil layer:
  - Increase soil moisture
  - Reduce oxygen transport
  - Increase sorption capacity
Basin with BAM – NITRATE

- 73% reduction for two feet deep B&G layer.

Basin with BAM – PHOSPHORUS

- > 80% reductions in total dissolved phosphorus (TDP) from pre-construction (2007–2009) to post-construction (2009–2010) median concentrations in soil water
Field measurements were obtained by continuous monitoring using time domain reflectometry and tensiometers.

Laboratory derived soil moisture retention curves were measured for the main drying curve on undisturbed soil cores using the pressure cell method.

Note: 1 meter head = 9.8 kPa
Field Capacity of soil = ~ 3.3 meters
SYSTEM DYNAMICS MODEL

- 1-D vertical, 4 layers
- Only water phase (gas and solid phases not modeled)
- Model layers approximate field conditions, e.g. BAM layer and locations of instrumentation
CONCEPTUAL MODEL

- Simulate advective inflow/outflow, fixation, ammonification, nitrification, denitrification, and plant uptake
CALIBRATION & VALIDATION

- Calibrate model for period 1–15 December 2009
- Validate model for period 2 March – 7 April 2010
Underground Systems in high water table areas
Up-Flow Filter at the Discharge
Sampling Results (estimated 70% of flow through filter)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus</th>
<th>Total Suspended Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Influent Concentration (mg/L)</td>
<td>1.87</td>
<td>0.281</td>
<td>105</td>
</tr>
<tr>
<td>Average Filter Removal (%)</td>
<td>45</td>
<td>58</td>
<td>40</td>
</tr>
<tr>
<td>Average System Removal (%)</td>
<td>67</td>
<td>79</td>
<td>81</td>
</tr>
<tr>
<td>Average Annual Removal (%)</td>
<td>54</td>
<td>67</td>
<td>70</td>
</tr>
</tbody>
</table>

BAM (B&G) Filter

Water Quality Lab data by ERD, Orlando Florida
There was ~30% overflow (by-pass) of the up-flow filter during high flow per year
Improved Treatment Using Up-flow Filters with Wet Pond

**Filters Work to remove more**

- Filters can be designed to remove nitrogen without media replacement
- For phosphorus, media replacement time is specified
- Can be used in BMP & LID Treatment Train Applications with other treatment
Up-Flow Input from Wet Detention to Filter

- **Performance**
  - Concentration
  - Averages based on field data
  - Average yearly based on 1.0 inch design for filter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TN</th>
<th>TP</th>
<th>TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Influent Concentration (mg/L)</td>
<td>1.83</td>
<td>0.73</td>
<td>42.7</td>
</tr>
<tr>
<td>Expected Average Pond Removal (%)</td>
<td>38</td>
<td>63</td>
<td>79</td>
</tr>
<tr>
<td>Average Pond + Filter Removal (%)</td>
<td>70</td>
<td>72</td>
<td>91</td>
</tr>
<tr>
<td>Average Annual System Performance</td>
<td>67</td>
<td>70</td>
<td>89</td>
</tr>
</tbody>
</table>
This program is compiled from stormwater management publications and deliberations during a two year review of the stormwater rule in the State of Florida. Input from the members of the Florida Department of Environmental Protection Stormwater Review Technical Advisory Committee and the staff and consultants from the State Water Management Districts is appreciated.

The State Department of Transportation provided guidance and resources to compile this program. The Stormwater Management Academy is responsible for the content of this program.

### Stormwater BMP Options

BAM can be used with many BMPs

<table>
<thead>
<tr>
<th>RETENTION BASIN</th>
<th>WET DETENTION</th>
<th>EXFiltration Trench</th>
<th>RAIN (BIO) GARDEN</th>
<th>SWALE</th>
<th>USER DEFINED BMP</th>
</tr>
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<tbody>
<tr>
<td>PERVIOUS PAVEMENT</td>
<td>STORMWATER HARVESTING</td>
<td>FILTRATION including BIOFILTRATION</td>
<td>LINED REUSE POND &amp; UNDERDRAIN INPUT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GREENROOF</td>
<td>RAINWATER HARVESTING</td>
<td>FLOATING ISLANDS WITH WET DETENTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VEGETATED NATURAL BUFFER</td>
<td>VEGETATED FILTER STRIP</td>
<td>VEGETATED AREA Example tree well</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE !!!:** All individual systems must be sized prior to being analyzed in conjunction with other systems. Please read instructions in the MULTIPLE WATERSHEDS AND TREATMENT SYSTEMS ANALYSIS tab for more information.
In-Line or Off-Line Up-flow Filters

<table>
<thead>
<tr>
<th>RETENTION BASIN</th>
<th>WET DETENTION</th>
<th>EXFILTRATION TRENCH</th>
<th>RAIN (BIO) GARDEN</th>
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Example tree well

USER DEFINED BMP

CATCHMENT AND TREATMENT SUMMARY RESULTS

NOTE !!!: All individual system must be sized prior to being analyzed in conjunction with other systems. Please read instructions in the CATCHMENT AND TREATMENT SUMMARY RESULTS tab for more information.

Underground locations, thus do not take land
Removal and mixes

<table>
<thead>
<tr>
<th>Media and Typical Location in BMP Treatment Train</th>
<th>MATERIAL</th>
<th>TSS REMOVAL EFFICIENCY</th>
<th>TN REMOVAL EFFICIENCY</th>
<th>TP REMOVAL EFFICIENCY</th>
<th>TYPICAL LIMITING FILTRATION RATE (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B&amp;G ECT (ref A) A first BMP, ex. Up-Flow Filter in Baffle box and a constructed wetland (USER DEFINED BMP)</td>
<td>Expanded Clay, Tire Chips</td>
<td>70%</td>
<td>55%</td>
<td>65%</td>
<td>96 in/hr</td>
</tr>
<tr>
<td>B&amp;G OTE (ref A,B) Up-flow Filter at Wet Pond &amp; Dry Basin Outflow (FILTRATION)</td>
<td>Organics, Tire Chips, Expanded Clay</td>
<td>60%</td>
<td>45%</td>
<td>45%</td>
<td>96 in/hr</td>
</tr>
<tr>
<td>B&amp;G ECT3 (ref C) Inter-event flow using Up-flow Filter at wet pond and Dow n-Flow Filter at Dry Basin (FILTRATION)</td>
<td>Expanded Clay, Tire Chip</td>
<td>60%</td>
<td>25%</td>
<td>25%</td>
<td>96 in/hr</td>
</tr>
<tr>
<td>SAT (ref D) A first BMP, as a Dow n-flow Filter (FILTRATION)</td>
<td>Sand</td>
<td>85%</td>
<td>30%</td>
<td>60%</td>
<td>1.75 in/hr</td>
</tr>
<tr>
<td>B&amp;G CTS (ref E,F) Dow n-Flow Filters 12&quot; depth*** at wet pond or dry basin pervious pave, tree well, rain garden, swale, and strips</td>
<td>Clay, Tire Crumb, Sand, Topsoil</td>
<td>90%</td>
<td>60%</td>
<td>90%</td>
<td>0.25 in/hr</td>
</tr>
</tbody>
</table>

Note: Other filter media being tested
Notes and References

1. Tire Chip 3/8” and no measurable metal content (approximate dry density = 730 lbs/CY)
2. Expanded Clay 5/8 and 3/8 blend (approximate dry density = 950 lbs/CY)
3. Sand ASTM C-33 with no more than 3% passing # 200 sieve (approximate dry density = 2200 lbs/CY)
4. Expanded Clay 3/8 in blend (approximate density = 950 lbs/CY)
5. Tire Crumb 1-5 mm and no measurable metal content (approximate density = 730 lbs/CY)
6. Medium Plasticity typically light colored Clay (approximate density = 2500 lbs/CY)
7. Sand with less than 5% passing #200 sieve (approximate density = 2200 lbs/CY)
8. Organic Compost (approximate density of 700 lbs/CY) Class 1A Compost or Mix of yard waste
9. Local top soil is used over CTS media in dry basins, gardens, swales and strips, is free of roots & debris but is not used in other BMPs.

D - City of Austin Environmental Criteria Manual, Section 1.6.5, Texas, 2012
F - Improving Nitrogen Efficiencies in Dry Ponds, Williams and Wanielista, Florida Stormwater Association, June 18 2015
Additional Support References

• Alternative Stormwater Sorption Media for the Control of Nutrients,

• Improving Nitrogen Treatment Efficiency in Dry Retention Ponds

• Soil Property Control of Biogeochemical Processes beneath Two Subtropical Stormwater Infiltration Basins

• Nutrient removal using biosorption activated media: Preliminary biogeochemical assessment of an innovative stormwater infiltration basin


CONCLUSIONS

1. Over 15 years of experience measuring BAM (Bold & Gold) to remove nutrients from stormwater.

2. Sorption media controls surface/subsurface oxygen exchange by maintaining elevated moisture content, thereby controlling biogeochemical processes and N and C cycling.

3. Retrofitting infiltration areas using BAM resulted in decreased nitrate concentrations, which is partly due to intermittent denitrification, and decreased phosphorus, which is likely due to sorption.

4. About 60-90% reduction in nitrate, and about 80-90% reduction in phosphorus are achievable and typical removal ranges.

5. System dynamics modeling can provide quantitative estimates of N budget and fluxes, which indicated that in stormwater BMPs with BAM, there is nitrogen removal and it was occurring predominantly in the BAM layer.

6. Most WMDs giving credit.
COMMENTS AND DISCUSSION (BAM) TO REDUCE NUTRIENTS IN STORMWATER

By Marty Wanielista