“Swirling Currents of Water Quality Regulations”

Performance of a Bio-Retention System
Or How Come My Bio-Retention System Works?
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Purpose of Presentation

• Provide data on the water quality and infiltration performance of two retention basins
  – What Site Characteristics are indicators of nutrient removal?
• Detail a Design of a Retention Basin “BAM” filter
  – BAM Basin Performance
  – Relate to other retention systems
PARTNERS

- Marion County
- Florida Department of Environmental Protection
- Southwest Florida WMD
- St. Johns River WMD
- University of Central Florida
- U.S. Geological Survey
- U.F. Soil and Water Science Department

Special recognition to Dr. Andy O’Reilly USGS
STUDY AREA

- 2 stormwater basins studied near Silver Springs (Q = 22 m$^3$/s).
- Increasing nitrate in Silver Springs.

Source: Phelps (2004)
NITRATES IN GROUND WATER

- Elevated nitrate concentrations common.
- Historical data 1990-2006, 569 wells.
APPROACH

1. LABORATORY – Document the fate of nitrogen.

2. ANALYSIS/DESIGN – Compare pre- and post-bio-sorption activated media (BAM) amendment for attenuation efficiencies. Investigate nitrogen cycling. Identify alternative design criteria for infiltration BMPs.

3. FIELD – Monitor basins before and after incorporating BAM as a soil amendment.
HUNTER TRACE DRAINAGE BASIN LAND USE

2004

Legend
- Surface water collection basins
- Longleaf pine
- Residential, low density
- Residential, medium density

Land Use Data Source: SJRWMD
Hunters Trace (HT) Basin

- 0.7 ac basin,
- 10 ft deep, 51’ bottom ~61-62’ at the top
- 56 ac drainage basin, only 4.2 ac EIA
- Water table ~10 ft below basin bottom
  - Well sampling location
SOUTH OAK DRAINAGE BASIN LAND USE

2004

Legend
- Residential, low density
- Residential, medium density

Land Use Data Source: SJRWMD
South Oak (SO) Basin

- 0.4 ac basin,
- 5 ft deep
- 72 ac drainage basin only ~ 3.6 ac EIA
- Water table normally at basin bottom
  - Well sampling location
WATER QUALITY MONITORING

- Major elements
- Nutrients (nitrogen and phosphorus)
- Organic carbon
- Trace metals
- Dissolved and soil gases
- Stable oxygen and hydrogen isotopes of water; and oxygen and nitrogen isotopes of nitrate and nitrogen gas
- Soil mineralogy and chemistry
- Nitrite reductase gene density by real-time polymerase chain reaction (RT-PCR)
FIELD INSTRUMENTATION

- Ground-water level
- Basin water stage
- Rainfall

**Hunters Trace basin**

<table>
<thead>
<tr>
<th>Julian day</th>
<th>Ground water level, in feet above NAVD88</th>
</tr>
</thead>
<tbody>
<tr>
<td>290</td>
<td>40</td>
</tr>
<tr>
<td>295</td>
<td>41</td>
</tr>
<tr>
<td>300</td>
<td>42</td>
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<tr>
<td>305</td>
<td>43</td>
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<tr>
<td>310</td>
<td>44</td>
</tr>
<tr>
<td>315</td>
<td>45</td>
</tr>
</tbody>
</table>

- GW affected by basin water
- 15-ft deep well
- Pond
- 30-ft deep well

**Basin stage, in feet above land surface**
Nitrate concentrations (mg/L) higher at Hunters Trace than South Oak.
SOIL CHARACTERISTICS

- Textural differences contributed to large differences in the soil moisture retention curves.
- Soil moisture is important because $O_2$ diffusion through water is 10,000 times less than through air.

Sample depth = 0.3 m
Particle-Size Distribution (PSD) Results

- South Oak soils
  - Uniformly graded
  - Classified Sand on textural triangle
  - 8.5-12.5% silt/clay (USDA)
- Hunter’s Trace soils
  - Uniformly graded
  - Classified Sand on textural triangle
  - 1-3.2% silt/clay (USDA)
Soil Moisture Conditions

- Soil moisture data indicate soil stays wetter longer at the SO site compared to the HT site.
- A substantial gas phase fraction is more conducive to $O_2$ diffusion and aerobic groundwater.
- Oxygen availability has important implications for denitrification and other biogeochemical processes.
NITRATE TRANSPORT & FATE

At the SO basin, evidence of denitrification is supported by

- Excess N$_2$ concentrations as high as 3 mg/L; and
- Isotopically heavy $^{15}$N and $^{18}$O of nitrate (up to 25 and 15‰, respectively).

At the HT basin, no excess N$_2$ and no isotopic enrichment thus minimum denitrification.
Denitrifying Organisms Present

- At the SO basin, evidence of denitrification is supported by real-time PCR (DNA) results indicating elevated nitrite reductase gene densities at depths above 1.4 m.

![Nitrite reductase graph]

Nitrate Present in This volume of soil
Aerobic conditions (dissolved oxygen 5-8 mg/L) persisted beneath the HT basin, resulting in depletion of dissolved organic carbon (DOC) and NO$_3^-$ leaching.

Aerobic conditions precluded the reduction of other electron acceptors.
GROUNDWATER QUALITY
South Oak basin

- N primarily in organic form when $O_2$ low and $NO_3^-$ form when aerobic
- Typically low $O_2$ or anoxic
- GW DOC $\sim \frac{1}{2}$ of SW DOC
- Cl and $NO_3^-$ variations dissimilar ($r^2 = 0.21$ for well PW) suggests reaction-dominated N fate
GROUNDWATER QUALITY
Hunter’s Trace Basin

- N nearly exclusively in NO$_3^-$ form
- Aerobic, DO 5–8 mg/L
- Low DOC 0.5–1.0 mg/l
- Cl and NO$_3^-$ variations very similar ($r^2 = 0.64$ for M-0506) suggests *advection*-dominated N fate
SOIL ANALYSIS – Chemistry

- CEC higher at South Oak
- Higher CEC than typical Florida soils, likely due to prevalence of clay mineral smectite
# Site Comparisons

<table>
<thead>
<tr>
<th>Hunters Trace (HT)</th>
<th>Parameter</th>
<th>South Oak (SO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Water Table</td>
<td>Higher</td>
</tr>
<tr>
<td>Higher</td>
<td>Infiltration Rate</td>
<td>Lower</td>
</tr>
<tr>
<td>Lower</td>
<td>Clay soils</td>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
<td>CEC</td>
<td>Higher</td>
</tr>
<tr>
<td>Higher</td>
<td>DO</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</td>
<td>Nitrate</td>
<td>Lower</td>
</tr>
<tr>
<td>No</td>
<td>Nitrate Decline with Time</td>
<td>Yes</td>
</tr>
</tbody>
</table>
DENITRIFICATION SUMMARY

The four conditions required for denitrification are:
(1) Nitrate present (electron acceptor);
(2) Oxygen very low or absent;
(3) Electron donor present (typically an organic carbon compound); and
(4) Denitrifying bacteria present.

- Conditions 2, 3, and 4 exist at the SO basin, therefore when nitrate is present denitrification occurs rapidly.
- At the HT basin, data indicate condition 2 is the critical missing condition.
- Differing oxygen levels between the two basins likely are due to soil textural characteristics. The fine-textured soil at the SO basin retains moisture, thereby substantially reducing oxygen transport into the subsurface.
Soil Texture and Bio Chemical Properties

- Can we replicate the conditions at the SO basin at the HT basin?
  - Soil Moisture is the primary goal.
  - Reproduce the soil conditions found at SO at HT
  - Soil amendment that is economical.

Sample depth = 0.3 m
SOIL AMENDMENT SELECTION
Some Promising Recycle and Natural Options

- Florida Peat
- Sandy/Loamy/Clayey soils
- Sawdust (untreated wood)
- Paper/Newspaper
- Palm Tree Frauds
- Tire Crumb
- Limestone
- Crushed Shells
- Wood Fiber/Chips/
- Compost
LABORATORY SOIL COLUMNS

- Test selected media mixtures to quantify their nutrient attenuation capabilities
- More closely resemble natural conditions than batch tests
Amended Soils Basin Installation

BAM was developed based on and to “mimic” the natural biogeochemical processes identified at SO Basin:

1. Excavation of native soil in the bottom of a portion of the HT existing basin.

2. Re-placement of a 1 foot (0.3 m) thick amended BAM soil layer: 1.0:1.9:4.1 mixture (by volume) of tire crumb (for sorption capacity), to clayey sand (for soil moisture retention); and sand (for infiltration rate).

3. Construction of a berm forming separate pollution (nutrient) control and flood control basins.

4. Cost was $6/SF of nutrient control area (not including permit and other related fees).
HUNTER’S TRACE – NEW BMP

• Reproduce soil conditions that exist at the SO basin by using an amended soil layer (BAM):
  – Increase soil moisture thus
    • Reduce oxygen transport
    • Increase sorption capacity
    • encourage denitrifier growth
HUNTERS TRACE – NEW BMP

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

![Diagram of soil layers](image)

**Section A-A’**

- Flood Control Basin
- Pollution Control Basin

Native soil berm
- Native soil backfill
- Amended media
- Coarse sand filter

**Amended bottom area**
Before and After BAM at HT

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.
HUNTERS TRACE – NEW BMP

Nutrient Control Basin

Berm

Flood Control Basin

Nutrient Control Basin
HUNTERS TRACE – Design Model Testing

Simulate August 2008 Tropical Storm Fay event.

The EIA was 1.67 ha (~20% larger than the DCIA)

<table>
<thead>
<tr>
<th>Rainfall (inches)</th>
<th>7.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration rate (ft/hr)</td>
<td>0.029</td>
</tr>
<tr>
<td>Early infiltration (ft/hr)</td>
<td>0.120</td>
</tr>
</tbody>
</table>

- Runoff/water-balance model:
  \( R \times EIA - \text{Infil.} = \Delta \text{Storage} \)

Good match to field data using realistic model parameters indicates model is suitable for design purposes.
HUNTERS TRACE – Design Simulation
Modified Basin

• Simulate 100-yr (11-inch) 24-hr storm event (type 2)
• Peak stage = 56.2 ft
• Basin capacity was not exceeded up to a 26 inch 24-hr storm.

![Graph showing stage vs. time for different sections of the basin.]
Operating Photo
After placement of erosion control blanket on berm and 3.7 inch storm...
Limiting Infiltration Rates
Double Ring and Operational

- **SO Double Ring**
  0.3 ft/hr (7.2 ft/day)
- **SO Operational**
  0.05 ft/day

- **HT Double Ring**
  1.1 ft/hr (26.4 ft/day)
- **HT Operational**
  0.03 ft/hr
  or 0.35 in/hr
  or 0.72 ft/day

- **After BAM Operational**
  0.26-0.44 in/hr
  (0.52 – 0.88 ft/day)
Nitrate Present in This volume of soil
After BAM – Nitrate


- Nitrate decreases most likely due to dilution, sorption, reduced nitrification, denitrification, or some combination of these processes.
After BAM – NO$_3^-$/Cl$^-$ Ratios

- Compare NO$_3^-$ and Cl$^-$ to determine dilution effects.
- A zero NO$_3^-$/Cl$^-$ slope indicates NO$_3^-$ and Cl$^-$ are changing at the same rate due to dilution.
- Positive slope (pre BAM) indicates NO$_3^-$ production (no denitrification).
- Negative slope (post BAM indicates NO$_3^-$ reduction (possibly denitrification).
After BAM– Phosphorus

- No change in TDP at water table.
- TDP decreases may be due to dilution, sorption, precipitation, microbial assimilation, or some combination of these processes
- ortho-P > 80% TDP, total P (unfiltered) is ~1–10x TDP
CONCLUSIONS

- Fine-textured soil controls surface/subsurface oxygen exchange by maintaining elevated moisture content, thereby controlling biogeochemical processes.

- Implementation of a modified infiltration basin using BAM resulted in decreased nitrate concentrations and is expected to be a viable alternative for improving and protecting groundwater quality.

- Examination of major elements, isotopes, dissolved gas, soil chemistry, real-time PCR, and soil gas sampling results provide greater insight into the biogeochemical processes controlling nitrate fate and the environmental and cost effectiveness of the new basin with BAM.
Recommendations in general or for other retention sites

• For infiltration basins or areas, use soil media mixes that can remove nutrients in areas where the parent soils are not capable of doing so.

• The soil mix should include materials to insure high moisture content. Or how come my system works? It has BAM in it.
Thanks for the Opportunity
~ Questions ~
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Thank You and Discussion
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