Assessing Performance of Bioretention Boxes in Hot and Semi-arid Regions: A Highway Application Pilot Study

Ming-Han Li, Ph.D., RLA, PE
Chan Yong Sung, Ph.D.
Myunghee Kim
Kung-Hui Chu, Ph.D.

January 25, 2011
Credit

• Texas Department of Transportation
  – Research Project 0-5949 Bioretention for Stormwater Quality Improvement in Texas
• Ret. Steve Ligon (past project director)
• Jon Geiselbrecht (present project director)
**Bioretention**

- Terrestrial-based, **stormwater** quality and quantity BMP
- Using **chemical**, **biological** and **physical** mechanisms, and microbes for removal of pollutants from stormwater runoff
- On-site source control
- **No** permanent water pool (drains in 24 hours)

Potential Applications

- Residential areas (also called rain gardens, bioswale, biofiltration, bioinfiltration)
- Commercial / institutional areas
- Highway corridors


http://www.ence.umd.edu

Prince George’s County, 2002.
The Project

TxDOT 0-5949

Bioretention for Stormwater Quality Improvement in Texas
Purpose

• Investigate the applicability and identify benefits and drawbacks of bioretention BMPs in Texas (hot & semi-arid), specifically for highway-related or large-scale applications
Facilities

- Hydraulic, Sedimentation and Erosion Control Laboratory, TTI
- Environmental engineering labs, Texas A&M University
Pilot Box Experiments
Lab Pilot Experiment (Box Test)

- Focus on TSS and metal removal → no need of denitrification → no saturation zone
- Five bioretention cells of 6' (1.8m) long, 6' wide, and 4' (1.2m) deep
- Column test was conducted to determine sand-compost ratio prior to box test
Column Test

2’ (60 cm)

Sand : Compost ratio

<table>
<thead>
<tr>
<th></th>
<th>5 : 5</th>
<th>6 : 4</th>
<th>7 : 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration rate (in/hr)</td>
<td>12.0</td>
<td>10.5</td>
<td>9.75</td>
</tr>
<tr>
<td></td>
<td>[ 30</td>
<td>27</td>
<td>25 ] (cm/hr)</td>
</tr>
</tbody>
</table>
Box Transformation
Pilot Bioretention Schematics

Prescribed Inflow

Ponding

Mulch

70% Sand, 30% Compost

3/8” Pea Gravel

1~2” Gravel

Underdrain pipe
Installation by Layer

4" (10 cm) Perforated pipe
Installation by Layer

1 1/2" Gravel (7" deep)
Installation by Layer

3/8" Pea gravel (3" deep)
Installation by Layer

7:3 Sand/compost mix (24" deep)
Tested Vegetation

Box 1: Control
Box 2: Bermudagrass
Box 3: Native grasses
Box 4: TxDOT Bryan District standard seed mix (sand)
Box 5: Shrubs
  • Wax Myrtle
  • Dwarf Yaupon Holly
  • Texas Sage (Cenizo)
Runoff Test Schematics

- Synthetic runoff
- Bioretention
- Flow meter
- Outflow sampler

Mixing tank

18
### Synthetic Runoff

**Date:** 02/29~03/19/2009

**Pollutant Concentrations**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Conc. (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>98.16</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>0.770</td>
</tr>
<tr>
<td>NO₂-N</td>
<td>0.148</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>0.148</td>
</tr>
<tr>
<td>TP</td>
<td>0.173</td>
</tr>
<tr>
<td>Cu</td>
<td>0.020</td>
</tr>
<tr>
<td>Pb</td>
<td>0.008</td>
</tr>
<tr>
<td>Zn</td>
<td>0.132</td>
</tr>
</tbody>
</table>

**Flow rates**

- **Mean 3hr storm (Brazos CO.)**
- **SCS Type III**
- **Drainage basin: 3,600 ft²**
  - (100 X of bioretention area)
• Use “Centroid Concept”

\[ Q = T_{MO} - T_{MI} \]

\[ = \frac{\sum (\text{Outflow flow rate}_i \times \text{time}_i)}{\sum (\text{Inflow flow rate}_i \times \text{time}_i)} \]

• Detention time of stormwater runoff

\[ = \frac{\sum (\text{Outflow flow rate}_i \times \text{time}_i)}{\sum (\text{Outflow flow rate}_i)} \]
\[ - \frac{\sum (\text{Inflow flow rate}_i \times \text{time}_i)}{\sum (\text{Inflow flow rate}_i)} \]
Removal Efficiency

\[ 1 - \left[ \sum_{\forall \, t} C_{out, \, t} \times Effluent_{t} \times \Delta t \Bigg/ \sum_{\forall \, t} C_{in, \, avg} \times Influent_{t} \times \Delta t \right] \]

where,

- $C_{out, \, t}$ is effluent concentration measured at the closest to time $t$ in mg/L;
- $C_{in, \, avg}$ is average concentration of all influent samples of the tested box in mg/L;
- $Effluent_{t}$ and $Influent_{t}$ are the flow rates of effluent and influent at time $t$; and
- $\Delta t$ is time interval of flow data, i.e., one minute.
Results
Hydraulic Performance

- a. Shrubs
  - D: 26 min
  - R: 28%

- b. TXDOT seedmix
  - D: 24 min
  - R: 32%

- c. Native seedmix
  - D: 18 min
  - R: 19%

- d. Bermudagrass
  - D: 15 min
  - R: 14%

- e. Control
  - D: 118 min
  - R: 75%
Removal Efficiency (%)
Vegetation Succession

05/10/2008 (Day 1)
Vegetation Succession

06/07/2008 (1 month later)
Vegetation Succession

02/02/2009 (9 MONTH LATER - dormant)
Vegetation Succession

08/20/2009 (14 month later – 2nd growing season)
# Vegetation (14 months later)

<table>
<thead>
<tr>
<th>Shrub</th>
<th>%</th>
<th>TxDOT</th>
<th>%</th>
<th>Native</th>
<th>%</th>
<th>Bermuda grass</th>
<th>%</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenizo</td>
<td>75</td>
<td>Giant Ragweed</td>
<td>70</td>
<td>Giant Ragweed</td>
<td>50</td>
<td>Johnson Grass</td>
<td>70</td>
<td>Unvegetated</td>
</tr>
<tr>
<td>Nutsedge</td>
<td>15</td>
<td>Bermuda Grass</td>
<td>25</td>
<td>Illinois Bundle Flower</td>
<td>15</td>
<td>Giant Ragweed</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Prostrate Spurge</td>
<td>5</td>
<td>Johnson Grass</td>
<td>5</td>
<td>Johnson Grass</td>
<td>35</td>
<td>Bermuda Grass</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Pigweed</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wax Myrtle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Species marked in red are in the original seedmixes*
Discussion

- Plant roots increase infiltration → poor TSS removal
- However, plants improve TN removal
- Compost leached NO$_3$-N, TN & TP → use compost wisely
- Fire ants → saturation zone
- Saturation zone → improve TN removal
Challenges

- Drought
- Fire ant infestation
- Weed