Impacts of Soil Texture, Structure, and Compaction on Biofiltration Device Performance: Results of Lab and Field Investigations

Redahegn Sileshi¹, Robert Pitt², and Shirley Clark³

¹Graduate Student, Dept. of Civil, Construction and Environmental Engineering, Univ. of Alabama, Tuscaloosa, AL 35487-0205; rksileshi@crimson.ua.edu

²Cudworth Professor of Urban Water Systems, Dept. of Civil, Construction and Environmental Engineering, Univ. of Alabama, Tuscaloosa, AL 35487-0205; rpitt@eng.ua.edu

³Associate Professor of Environmental Engineering, School of Science, Engineering and Technology, Penn State, Harrisburg, 777 W. Harrisburg Pike TL-105, Middletown, PA 17057; seclark@psu.edu

2011 Low Impact Development Symposium
Philadelphia, PA
Outline

- Introduction
- Literature review
- Field and laboratory studies
  - Turf-tec infiltration measurements
  - Infiltration measurements after rainfall events
  - Laboratory column infiltration measurements
- Results and Discussions
- Conclusions
- References
Introduction

- The performance of biofiltration and other infiltration devices can be affected by factors such as texture, structure and degree of compaction of the media and underlying soil during their construction (or improper use).

- Laboratory and field studies were conducted to provide insight on media characteristics of a poorly performing biofilter located in Tuscaloosa, AL.

- Double ring infiltrometer tests and soil compaction measurements were conducted along the biofilter to determine the *in-situ* characteristics of the media.
The rate of infiltration depends on a number of factors, including the condition of the soil surface and its vegetative cover, the properties of the soil, such as its porosity and hydraulic conductivity, and the moisture content of the soil (Chow, et al. 1988).

Infiltration practices have the greatest runoff reduction capability of any stormwater practice and are suitable for use in residential and other urban areas where measured soil infiltration rates exceed 1/2 inch per hour (VA DCR, 2010).

Pitt, et al. (2008) noted large detrimental effects of compaction on infiltration rates in both sandy and clayey soils. Infiltration rates were reduced to near zero in soils having even small amounts of clay, if compacted.
Field and laboratory studies

- Twelve double ring infiltrometer tests and soil compaction measurements were conducted in the existing biofilter.
- Infiltration measurements were also made during actual rain events.
- The effects of different compaction levels on the infiltration rates through the soil media were examined during laboratory column tests.
- Similar tests were also conducted examining compaction effects of the media after mixing with varying amounts of filter sand to investigate restoration options.
Location of study area

- The biofilter examined is located in Shelby Park, adjacent to the University of Alabama, Tuscaloosa, rental car parking lot (having about a 1.5 acre area), from which it receives flow.

- The biofilter is about 300 ft long and 30 ft wide (0.21 acres, or about 14% of the paved/roofed source area).

- The biofilter failed to work as expected soon after construction.
Field tests

- TURF-TEC Infiltrometers (Turf Tec 1989) were used to measure the infiltration rates at 12 test locations along the biofilter.
- The infiltrometers were gently driven into the surface of the biofilter media until the “saturn” ring was against the soil surface.
- Relatively flat areas were selected in the biofilter to install the Turf-Tec infiltrometers and small obstacles such as stones and twigs were removed.
- Each cluster of 3 infiltrometers were inserted within about a meter from each other to measure the variability of the infiltration rates of the media in close proximity.
- The tests were conducted for a period of 1 to 2.5 hours, until the infiltration rate become relatively constant.

Very little “bio” in this biofilter, indicating compacted media having adverse affects on plant growth.
Field tests cont’d

- *In-situ* soil density measurements were also made in the same locations of the infiltration measurements. A small hole 6 inch deep and 6 inch wide was hand dug very careful to avoid disturbance of the soil that would bound the hole.

- Sand was then poured into the hole from a graduated cylinder to measure the volume of the holes, up to the top of the soil that was removed from the biofilter.

- The excavated media was then transported to the university of Alabama geotechnical lab for moisture, mass, and texture analyses and the density calculations.
The particle distribution graph indicates that the material is relatively coarse but still subjected to severe compaction issues.
Infiltration after rainfall events

- Biofilter surface ponding was often observed following heavy rainfall events on the test site.
- Infiltration rate measurements were manually recorded from biofilter ponded areas after five rainfall events.
- Depth indicator rules were placed at 3 to 5 different locations along the biofilter at surface ponding areas.
- The decrease in the depth of water was measured every 30 min at the beginning of the observations for each event and less frequently as the test progressed, until the water completely infiltrated (or evaporated).
- These measurements were taken after the runoff ceased and the biofilter was fully saturated.
The ponded water measurements in the biofilter were obtained after complete saturation. Also, ponding was not consistent throughout the biofilter and preferentially pooled in areas having depressions with low infiltration rates. Silting likely occurred in the depressions decreasing the infiltration rates at these areas.

Long-term and continuous monitoring in a biofilter during rains is the best indication of performance, and these spot checks likely indicate the lowest values likely to occur.

These rates were similar to the lowest infiltration rates observed with the infiltrometers and also corresponded to the compacted media column tests.

Most of the infiltration in biofilters likely occurs with saturated conditions and the lowest rates observed may be most representative of actual conditions during rains.
Laboratory column tests

- The effects of different compaction levels on the infiltration rates through the biofilter media (extracted from the biofilter) when mixed with varying amounts of filter sand was also examined.
- Four-inch (100 mm) diameter PVC pipes (Charlotte Pipe TrueFit 4 in. PVC Schedule 40 Foam-Core Pipe) 3 ft (0.9 m) long, were used for these test.
- The bottom of the columns had a fiberglass window screen secured to contain the media and were placed in funnels.
- The columns were first filled with about 2 inches of pea gravel.
- To separate the gravel layer from the media layer, a permeable fiberglass screen was placed over the gravel layer.
- The columns were then filled with the biofilter media that obtained by excavating it from the biofilter.
Laboratory column tests, cont’d.

- The columns had various mixtures of media and filter sand that has a median particle size ($D_{50}$) of about 700 μm and a uniformity coefficient ($C_u$) of 3.3.
- The media layer was about 1.5 ft (0.5 m) thick.
- Each filter media was filled in roughly 3 inch lifts for the modified proctor compaction, 6 inch lifts for the standard proctor compaction, and about 18 inch for hand compaction, and suitably compacted after each lift.
- The infiltration rates were measured in each column using clean tap water.
- The surface ponding depths in the columns ranged between 11 in. (28 cm) and 14 in. (36 cm) to correspond to the approximate maximum ponding depth at the site biofilter.
- Infiltration rates in the media mixtures were determined until apparent steady state rates were observed.

<table>
<thead>
<tr>
<th>Column No.</th>
<th>Compaction Method</th>
<th>Dry Density (g/cc)</th>
<th>Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hand</td>
<td>1.54</td>
<td>Only biofilter media</td>
</tr>
<tr>
<td>2</td>
<td>Standard</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Modified</td>
<td>1.94</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hand</td>
<td>1.63</td>
<td>50% biofilter media and</td>
</tr>
<tr>
<td>5</td>
<td>Standard</td>
<td>1.7</td>
<td>50% filter sand</td>
</tr>
<tr>
<td>6</td>
<td>Modified</td>
<td>1.77</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Hand</td>
<td>1.52</td>
<td>75% biofilter media and</td>
</tr>
<tr>
<td>8</td>
<td>Standard</td>
<td>1.71</td>
<td>25% filter sand</td>
</tr>
<tr>
<td>9</td>
<td>Modified</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Hand</td>
<td>N/A</td>
<td>90% biofilter media and</td>
</tr>
<tr>
<td>11</td>
<td>Standard</td>
<td></td>
<td>10% filter sand</td>
</tr>
<tr>
<td>12</td>
<td>Modified</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**In-situ** biofilter infiltration results:

- The average initial infiltration rate during the TURF-TEC field tests was about 11 in/hr (280 mm/hr), and ranged from 3 to 28 in/hr (76 to 710 mm/hr).

- The final rates had an average value of about 4.6 in/hr (115 mm/hr), and ranged from 1.5 to 10.5 in/hr (38 to 270 mm/hr).

- Variations of infiltration rates (about a factor of 2) were also observed along the biofilter.

**Horton's parameters**

<table>
<thead>
<tr>
<th>Test site location</th>
<th>( f_a (\text{in/hr}) )</th>
<th>( f_c (\text{in/hr}) )</th>
<th>( k (1/\text{min}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>range</td>
<td>mean</td>
</tr>
<tr>
<td>1</td>
<td>6.5</td>
<td>(4.5-9.0)</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>16.6</td>
<td>(2.9-27.8)</td>
<td>6.0</td>
</tr>
<tr>
<td>3</td>
<td>12.5</td>
<td>(8.1-14.8)</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>9.0</td>
<td>(7.4-11.0)</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Turf-Tec infiltration measurements taken at location #1 in the biofilter

Field Infiltration Tests

Field infiltration measurements fitted to Horton equation.
Laboratory infiltration measurements fitted to Horton equation. The media from the biofilter was mixed with filter sand to show how the infiltration rates could be improved (and to protect it from severe compaction). Similar tests were conducted using different portions of added sand.
Infiltration measurements taken at ponded locations

- The actual rain event ponded infiltration rates were about ten times less than the TURF-TEC values, being somewhat less than the lowest infiltrometer measurements observed, indicating fully saturated conditions.

- The average initial and final infiltration rates from the ponded locations did not vary greatly and were about 0.5 in/hr (12mm/hr) and 0.55 in/hr (14 mm/hr) respectively.

- These very low values were about equal to the observed laboratory tests conducted under the most severe compaction conditions (the modified Proctor compaction tests).

Ponded infiltration measurements fitted to Horton equation.
Laboratory column infiltration rate results:

- For the laboratory tests, the mean final infiltration rates through the media with increasing degrees of compaction were 4.1, 0.8, and 0.3 in/hr using hand compaction, standard proctor compaction and modified proctor compaction methods, respectively.

- The average final infiltration rates of the hand compacted mixture were reduced by 80 and 93 percent using the standard proctor compaction and modified proctor compaction methods, respectively.

<table>
<thead>
<tr>
<th>Compaction</th>
<th>Day</th>
<th>fo (in/hr)</th>
<th>fc (in/hr)</th>
<th>K (1/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>modified proctor density 1.94g/cc</td>
<td>1</td>
<td>0.54</td>
<td>0.34</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.44</td>
<td>0.33</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.19</td>
<td>0.12</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>0.39</td>
<td>0.26</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>range</td>
<td>(0.19-0.54)</td>
<td>(0.12-0.34)</td>
<td>(0.001-0.002)</td>
</tr>
<tr>
<td>standard proctor density 1.66g/cc</td>
<td>Day</td>
<td>fo (in/hr)</td>
<td>fc (in/hr)</td>
<td>K (1/min)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.13</td>
<td>0.97</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.05</td>
<td>0.94</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.79</td>
<td>0.50</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>0.99</td>
<td>0.81</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>range</td>
<td>(0.79-1.13)</td>
<td>(0.5-0.97)</td>
<td></td>
</tr>
<tr>
<td>hand density 1.54g/cc</td>
<td>Day</td>
<td>fo (in/hr)</td>
<td>fc (in/hr)</td>
<td>K (1/min)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5.00</td>
<td>3.14</td>
<td>0.0250</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.91</td>
<td>3.19</td>
<td>0.0390</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9.69</td>
<td>5.95</td>
<td>0.0450</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>6.20</td>
<td>4.09</td>
<td>0.0363</td>
</tr>
<tr>
<td></td>
<td>range</td>
<td>(3.9 - 9.7)</td>
<td>(3.1 - 6.0)</td>
<td>(0.025 - 0.05)</td>
</tr>
</tbody>
</table>
Laboratory infiltration measurements plots

Laboratory infiltration measurements of the biofilter media fitted to the Horton equation.
Summary of field and laboratory infiltration measurements fitted with Horton equations.

Field infiltration tests

Biofilter infiltration tests after rainfall event

Laboratory infiltration tests using biofilter media only

50% biofilter media and 50% filter sand
Conclusions

- Mixing the biofilter media with filter sand improved the infiltration rates of the media and also reduced the impact of compaction on the infiltration rates.

- The mixture containing 50% biofilter media and 50% filter sand exhibited the highest infiltration rates, although lesser amounts of added sand also indicated significant improvements in the infiltration rates.

- The laboratory test results demonstrate that soil compaction has dramatic effects on the infiltration rates; therefore care needs to be taken during stormwater treatment facilities construction to reduce detrimental compaction effects.

- The infiltration values from the ponded locations are very small compared to the laboratory and field test infiltration values indicating fully saturated conditions and severely compacted conditions. Rebuilding the biofilter using the same media, but with 10 to 50% added filter sand and with minimal compaction, is expected to enable satisfactory biofilter operation.
References

Acknowledgments

- This research was supported by the Dept. of Civil, Construction and Environmental Engineering, Univ. of Alabama, Tuscaloosa, as a cooperative project assisting the City of Tuscaloosa in restoring the biofilter.

- The authors would like to thank Ryan Bean, a UA graduate student in environmental and water resources engineering for his assistance in the construction of the laboratory columns.
Questions

???