FILTERRA® ADVANCED BIORETENTION SYSTEM  
PRODUCT OVERVIEW AND PERFORMANCE SUMMARY  

Application: Stand Alone Stormwater Treatment Best Management Practice  
Type of Treatment: High Flow Rate Media Filtration and Bioretention  
Manufactured by: Americast, Inc  
11352 Virginia Precast Road, Ashland VA 23005  
Toll Free (866) 349-3458  
www.filterra.com  
November 2010  

Filterra® Advanced Bioretention System  
Product Overview and Performance Summary  

Performance Summary for the following Pollutant Constituents:  
Total Suspended Solids  
Zinc  
Copper  
Phosphorus  
Nitrogen  
Oil and Grease  
Performance Over Time  
Flow Rate Performance  
Effluent Water Quality Performance  

Summary provided to ________________
PRODUCT DESCRIPTION

Filterra is an advanced high flow rate bioretention Best Management Practice (BMP) for treating urban stormwater runoff. Exceptional pollutant removal efficiencies are achieved by filtering runoff through a specially engineered plant / soil / microbe media that captures, removes, degrades and uptakes pollutants through a variety of physical, chemical, and biological processes.

Filterra is a self contained system that is delivered to a site completely assembled and ready for use. The system consists of a concrete box, three inches of mulch, two feet of filter media, plant (shrub or tree), observation / cleanout pipe and under-drain system.

Runoff drains directly from impervious surfaces through an inlet structure in the concrete box and flows through the mulch, plant, and soil filter media. Treated water flows out of the system via an under-drain connected to a storm drain pipe, receiving water body or other appropriate outfall.

The concrete container and treatment media are below grade with the only features visible being the concrete top slab, tree grate, plant, and inlet opening. Filterra® looks very similar to an ordinary tree box except that it is specially designed to treat runoff. This is the only commercially available BMP that can also help to enhance the aesthetic value of the urban setting since it uses typical landscaping plants.

The Filterra® engineered media is specifically designed to achieve relatively high flow-through rates, much greater than those found in typical bioretention or filtration practices. Based on available field and lab-scale test data and long-term continuous simulation modeling of the system’s hydraulic function, Filterra is designed to treat 90% or greater of the annual rainfall.

FILTERRA ADVANTAGES & BENEFITS

- Small, Shallow Footprint
- High Removal Rates & Effluent Quality
- High Treatment Volume
- Aesthetically Pleasing
- Low Maintenance
- Sustainable Design
- Well Engineered
- Simple to Design

BMP PERFORMANCE

The Filterra® media has been TAPE and TARP tested and approved.

TAPE
The Washington State Department of Ecology (DOE) has now approved the Filterra® Bioretention System for General Use Level Designation (GULD) for TSS, oil and grease, and enhanced dissolved metals. This new state approval recognizes Filterra as a proven, effective solution to mitigate unwanted pollutants from stormwater runoff.

Widely regarded as the industry’s most stringent testing standard, Filterra successfully completed the Technology Assessment Protocol for Ecology (TAPE) Process in Washington State. The program was accomplished by Filterra through third party support, verification and endorsement; a decision backed by extensive lab testing as well as years of tested site-based performance.

TARP
In addition to TAPE approval, the Filterra® Bioretention System has been approved for stand alone applications in Maryland and Virginia through University of Virginia laboratory and field third party monitoring under the Technology Acceptance and Reciprocity Partnership (TARP) protocol with results published in the Journal of Environmental Engineering and Management.

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866 349 3458
BMP PERFORMANCE COMPARISON

The performance data on Filterra® currently available indicates that the system is capable of providing effective treatment for TSS (solids), phosphorus, nitrogen, oil and grease, and metals. The table below compares the removal efficiency of Filterra with other BMP technologies. The table shows that Filterra performs as well or better than many other BMP technologies available.

<table>
<thead>
<tr>
<th>BMP TYPE</th>
<th>TSS</th>
<th>TP</th>
<th>TN</th>
<th>Heavy Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Filterra 3,4,5,6</td>
<td>85</td>
<td>60-70</td>
<td>43</td>
<td>58-82</td>
</tr>
<tr>
<td>Bioretention Systems 6</td>
<td>81</td>
<td>29</td>
<td>49</td>
<td>51-71</td>
</tr>
<tr>
<td>Sand Filters 7</td>
<td>81-90</td>
<td>39-44</td>
<td>36-53</td>
<td>50-92</td>
</tr>
<tr>
<td>Infiltration Systems 2</td>
<td>95</td>
<td>70</td>
<td>51</td>
<td>98</td>
</tr>
<tr>
<td>Proprietary Media Filters 7</td>
<td>40</td>
<td>17</td>
<td>13</td>
<td>53</td>
</tr>
<tr>
<td>Hydrodynamic Devices 7</td>
<td>0</td>
<td>15</td>
<td>5</td>
<td>8-17</td>
</tr>
</tbody>
</table>

* Average Efficiencies

CONCLUSION

The Filterra® Bioretention System has been developed over many years in order to provide a BMP technology that will reliably and effectively address your water quality requirements. Filterra has been designed with ease of maintenance in mind to ensure long term operation and effectiveness. Finally, we at Filterra are committed to providing you the highest quality performance and services available.

REFERENCES:


3. Yu, Shaw, 2001 Laboratory Testing of a Mix Media Filter System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.

4. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.


TOTAL SUSPENDED SOLIDS (TSS) - BACKGROUND

Total Suspended Solids (TSS) remains the basic standard parameter to measure BMP performance. Because many pollutants of concern (P / metals / organic toxins / etc) are attached to sediments in runoff (through weak electrostatic forces / adsorption / cation exchange / etc.), TSS is often used as a target pollutant and surrogate for many other pollutants. Generally, the smaller the sediment particles, the higher the surface area and the more reactive pollutants are to clinging onto small sediment particles. This means that finer sediments such as fine silts, clays, glacial tills and atmospheric deposits may carry with them higher concentrations of pollutants than sediment with larger particles. These fine particles are of greater concern than the coarse particles in that phosphorus, heavy metals and other toxins will readily attach to, and be transported with, fine particles.1

Therefore, in order to achieve better performance a BMP technology must be capable of removing finer sediment particles.2 For example, in areas where air deposition is one of the dominant sources of pollutant particulate matter, a BMP must be able to remove particle sizes ranging from about 10 microns to 60 microns. To evaluate TSS performance, it is important to understand not only the TSS removal efficiency but particle size distribution of the technology and sediment sources.3

LABORATORY STUDY RESULTS

Two laboratory studies have been conducted on lab-scale Filterra® system with specific particle size distributions. In 2006, GeoSyntec Consultants4 conducted a lab-scale particle size treatment analysis of the Filterra® system using Sil-Co-Sil 106 as the influent TSS (Table 1). This study was conducted in accordance with Washington’s Department of Ecology TAPE5 protocol. Over 15 rounds of tests, influent TSS concentrations ranged from 8.3 to 260 mg/L with a median of 75 mg/L. Effluent concentrations ranged from < 2.0 to 18.0 mg/L with a median of 7.8 mg/L. In 2009, an additional laboratory study was completed with third-party analysis and review6 to demonstrate pollutant removal at varying percentage flow rates of the design hydraulic loading rate at specified concentrations in accordance with Washington’s Department of Ecology TAPE5 guidance. Sil-Co-Sil 106 was used as the influent TSS constituent (Table 1). Over 30 simulations, influent TSS concentrations ranged from 41.6 to 252.5 mg/L while effluent concentrations ranged from 0.8 to 42.8 mg/L. In addition to varying influent concentrations, influent flow rates ranged from 50 to 150 % of the design hydraulic loading rate of the lab-scale Filterra® system. The range of individual event percent removals was 25.0 to 99.5 %, with an average removal of 90.6 % over the 30 simulations. The data also suggests flow rates exceeding design hydraulic loading rates were able to maintain successful TSS removal while producing effluent concentrations below 10 mg/L. Moreover, results indicate that the Filterra® media TSS performance is independent of both influent concentration (R^2 = 0.1894) and hydraulic loading (R^2 = 0.0043).

In both the 2006 and 2009 lab-scale study results are summarized in Table 2.

In 2006, GeoSyntec Consultants4 conducted a lab-scale particle size treatment analysis of the Filterra® system using Sil-Co-Sil 106 as the influent TSS (Table 1). This study was conducted in accordance with Washington’s Department of Ecology TAPE5 protocol. Over 15 rounds of tests, influent TSS concentrations ranged from 8.3 to 260 mg/L with a median of 75 mg/L. Effluent concentrations ranged from < 2.0 to 18.0 mg/L with a median of 7.8 mg/L. Over 15 rounds of tests, individual percent removals ranged from 70.1 to 95.5 % with a median of 90.7 %. The study showed that the lab-scale Filterra® system could remove an average of 87 % of a Sil-Co-Sil 106 mix with a mean influent particle size of 19 microns with 80 % of the particles below 50 microns (see Table 1). This result is of particular relevance when runoff sediments are dominated by small particles.

In 2009, an additional laboratory study was completed with third-party analysis and review7 to demonstrate pollutant removal at varying percentage flow rates of the design hydraulic loading rate at specified concentrations in accordance with Washington’s Department of Ecology TAPE5 guidance. Sil-Co-Sil 106 was used as the influent TSS constituent (Table 1). Over 30 simulations, influent TSS concentrations ranged from 41.6 to 252.5 mg/L while effluent concentrations ranged from 0.8 to 42.8 mg/L. In addition to varying influent concentrations, influent flow rates ranged from 50 to 150 % of the design hydraulic loading rate of the lab-scale Filterra® system. The range of individual event percent removals was 25.0 to 99.5 %, with an average removal of 90.6 % over the 30 simulations. The data also suggests flow rates exceeding design hydraulic loading rates were able to maintain successful TSS removal while producing effluent concentrations below 10 mg/L. Moreover, results indicate that the Filterra® media TSS performance is independent of both influent concentration (R^2 = 0.1894) and hydraulic loading (R^2 = 0.0043).

Both the 2006 and 2009 lab-scale study results are summarized in Table 2.
FIELD MONITORING & STUDY RESULTS

Industrial Port Monitoring
Extensive third-party TSS sampling was conducted over a 14 month period at an industrial port under the Washington Department of Ecology (WADOE) Technology Assessment Protocol for Ecology (TAPE) protocol. Automated sampling was conducted for 27 storm events for TSS. Across 22 qualifying sampled storms events, the influent TSS concentrations ranged from 20 to 40 mg/L, with a median value of 28 mg/L. Effluent TSS concentrations across these same storm events ranged from 2.0 to 7.8 mg/L, with a median value of 4.2 mg/L. TSS removal efficiency estimates from these 22 storm events ranged from 79 to 90 percent, with a median value of 86 %. Mean TSS data from the TAPE industrial port monitoring is displayed in Table 3.

It is important to note that the irreducible TSS concentration was established as 20 to 40 mg/L by Schueler in 1996. All 22 of the qualifying influent concentrations sampled at the industrial port are within or below this irreducible concentration range. The sampling conducted at the industrial port demonstrated that TSS reduction beyond this threshold is possible with a maximum effluent concentration of 7.8 mg/L. Thus, the Filterra® system challenges typical stormwater effluent irreducible concentrations and raises the bar for stormwater treatment performance.

Field Studies
In addition to the extensive TAPE field monitoring at the industrial port, several third-party studies have been performed in the field. Table 3 below shows the findings of the University of Virginia (UVA) TARP field study9, 10 and an additional simulated stormwater TARP field study10. TSS field data was analyzed using EPA Method 160.2 using a 0.45 micron pore size with a practical range of the method of 4 mg/L to 20,000 mg/L.

Table 3. Summary of Third-Party TSS Field Data

<table>
<thead>
<tr>
<th>Site / Study</th>
<th>Influent Concentration Range (mg/L)</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Effluent Concentration Range (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVA TARP Field Study9</td>
<td>10 – 110</td>
<td>28.8</td>
<td>2.3 – 26</td>
<td>5.2</td>
<td>87.5 *</td>
</tr>
<tr>
<td>Additional TARP Field Study9</td>
<td>42.3 – 87.7</td>
<td>66.3</td>
<td>4.8 – 18.9</td>
<td>11.1</td>
<td>83.3 *</td>
</tr>
<tr>
<td>TAPE Industrial Port Monitoring</td>
<td>20 – 40</td>
<td>29</td>
<td>2.0 – 7.8</td>
<td>4.3</td>
<td>85</td>
</tr>
<tr>
<td>Typical Concentration11</td>
<td>180 - 548</td>
<td>141</td>
<td>3.0 – 17.6</td>
<td>6.9</td>
<td>85.2</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>24.1 – 79.2 **</td>
<td>41.4</td>
<td>3.0 – 17.6</td>
<td>6.9</td>
<td>85.2</td>
</tr>
</tbody>
</table>

* Efficiency ratio – Preferred efficiency evaluation method of TARP12
** Does not include NURP11 data in average

PERFORMANCE OVER TIME

Older Filterra® systems are being sampled to determine if pollutant removal fluctuates over time. TSS is being monitored at both a 4.5 year old Filterra system treating an oil service station commercial parking lot and a 2.5 year old Filterra® system treating a restaurant commercial parking lot.

Nine duplicated samples were collected over a period of 2.5 years with an influent range of 13 to 180 mg/L. Third-party monitoring verifies an average removal of >76.9 % at the oil service station commercial parking lot. Similarly, twelve storm events were sampled during a 1.75 year period with an influent range of 2.2 to 326 mg/L. Third-party monitoring demonstrated an average percent removal of 83.4 % at the restaurant commercial parking lot.

CONCLUSION

Based on these findings, Filterra® has demonstrated a TSS percent removal of approximately 85 % for typical urban runoff sediments. Performance over time monitoring demonstrates that the Filterra® system continues to meet pollutant removal claims over time.
REFERENCES:

1. URS Greiner Woodward Clyde, 1999. USEPA Issue Paper, Measurement of TSS in Runoff, l:\89FR977001.00\TO ZUss-final.doc, San Diego, CA.

2. California Department of Transportation, Division of Environmental Analysis, 2004, BMP Pilot Retrofit Program, REPORT ID CTSW - RT - 01 – 050, Sacramento, CA 95814


8. Yu, Shaw, et al., 2006. Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA. Table ES-1


HEAVY METALS - BACKGROUND

The major anthropogenic sources of heavy metals come from intensive automobile use, weathering of building materials, and atmospheric deposition which contribute lead, copper, zinc, and other heavy metals to urban and roadway runoff. Metals may be found in natural waters in particulate form by the formation of precipitates, such as hydroxides, sulfides, and carbonates, or by adsorption to clay, silica, or organic particulate matter.

 Metals have been found to be one of the leading pollutants of lakes, reservoirs, estuaries and ponds in the U.S. Metals accumulate in the environment in sediments and find their way into the food chain. Metals bio-accumulate in living organisms and may become toxic. Human health can be affected if metals enter the drinking water supply or if consumed by eating contaminated fish and shellfish.

Investigations by the University of Maryland have shown that bioretention facilities are quite effective in removing metals such as lead, copper, and zinc from stormwater runoff. Removal rates of these metals were excellent.

FILTERRA REMOVAL PROCESSES

Filterra uses several mechanisms to remove heavy metals.

First, metals strongly attached to TSS particulate matter are removed through sedimentation and filtration. Filterra has been shown to have a TSS removal efficiency of 85%.

Second, dissolved metals react with the organic matter (i.e., carboxyl ions) to form organic complexes. Metals tightly bind to the mulch and other organic particles in the engineered media. In a 2001 bioretention lab study performed by Davis et al., the surface mulch layer exhibited a high capacity for metal removal with sorption capabilities two to three times greater than the soil used.

Third, metal removal occurs by the microbes and plant uptake. As the organic matter decays metals are released and available for up-take by the plants. Filterra bio-accumulates metals within the plant and captures metals in the media. As the plant grows so does Filterra’s capacity to store more metals.

STUDY RESULTS

Industrial Port Monitoring
Extensive third-party heavy metals sampling was conducted over a 14 month period at an industrial port under the Washington Department of Ecology (WADOE) Technology Assessment Protocol for Ecology (TAPE) protocol. Automated sampling was conducted for 23 storm events for zinc. Across these 23 sampled storm events, the influent dissolved zinc concentrations ranged from 0.101 to 0.549 mg/L, with a median value of 0.194 mg/L. Effluent dissolved zinc concentrations ranged from 0.014 to 0.291 mg/L, with a median value of 0.082 mg/L. Across these 23 storms, dissolved zinc removal efficiency estimates ranged from 42 to 94 percent, with a median value of 54 percent. Table 1 displays the mean dissolved zinc data from the industrial port monitoring.

<table>
<thead>
<tr>
<th>Dissolved Zinc</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.266</td>
<td>0.115</td>
<td>58</td>
</tr>
</tbody>
</table>

Other Studies
In addition to results from the TAPE port monitoring, a third-party field study has been completed with an independent evaluation by GeoSyntec of monitoring data gathered by the University of Virginia in 2006 according to the 2003 Technology Acceptance Reciprocity Partnership (TARP).
The UVA field monitoring samples were analyzed for total zinc, among other constituents. This data is summarized in Table 2 along with additional third-party field monitoring data for total zinc.

<table>
<thead>
<tr>
<th>Site</th>
<th>Influent Concentration Range (mg/L)</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Effluent Concentration Range (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Parking Lot (TARP)</td>
<td>0.023 – 0.21</td>
<td>0.066</td>
<td>&lt; 0.02 – 0.069</td>
<td>&lt; 0.024</td>
<td>&gt; 64</td>
</tr>
<tr>
<td>Industrial Port</td>
<td>0.123 – 0.580</td>
<td>0.299</td>
<td>0.016 – 0.291</td>
<td>0.123</td>
<td>60</td>
</tr>
<tr>
<td>Commercial Oil Service Station Parking Lot</td>
<td>0.081 – 0.76</td>
<td>0.268</td>
<td>0.022 – 0.160</td>
<td>0.068</td>
<td>71</td>
</tr>
<tr>
<td>Commercial Gas Station Parking Lot</td>
<td>0.037 – 0.717</td>
<td>0.282</td>
<td>0.02 – 0.167</td>
<td>0.055</td>
<td>68</td>
</tr>
<tr>
<td>Typical Concentration</td>
<td>0.202 – 0.633</td>
<td>0.229</td>
<td>&lt; 0.019 – 0.172</td>
<td>&lt; 0.068</td>
<td>&gt; 66</td>
</tr>
</tbody>
</table>

*A Does not include NURP data in average

Even at atypically low total zinc influent concentrations in the GeoSyntec Evaluation Study, the Filterra systems performed very well. The performance was comparable to performance with typical influent concentrations from the industrial port and commercial parking lots.

PERFORMANCE OVER TIME

Older Filterra systems are being sampled to determine if pollutant removal fluctuates over time. Heavy metals, including total zinc, are being monitored at both a 4.5 year old Filterra system treating an oil service station commercial parking lot and a 4 year old Filterra system gas station commercial parking lot.

Over nine duplicated samples collected over a period of 2.5 years, with an influent range of 0.081 to 0.76 mg/L, third-party monitoring verifies an average removal of 71% at the oil service station commercial parking lot.

Similarly, over nine storm events during a 2 year period, third-party monitoring demonstrated an influent range of 0.037 to 0.717 mg/L at the gas station commercial parking lot with an average percent removal of 68%.

These data may provide evidence that systems receiving regular maintenance will perform as well or better over time. These total zinc removal efficiencies are consistent with Filterra's performance claim of approximately 66% removal of zinc.

REFERENCES:

2. Davis, A., M., Shokouhian, et., al. 1998 Optimization of Bioretention Design for water Quality and Hydrologic Characteristics, Department of Civil Engineering, University of Maryland, College park, MD
5. GeoSyntec Consultants, Inc. 2006 Filterra® Bioretention Treatment System Technical Evaluation Report, Acton, MA. Appendix E Table 1
HEAVY METALS - BACKGROUND

The major anthropogenic sources of heavy metals come from intensive automobile use, weathering of building materials, and atmospheric deposition which contribute lead, copper, zinc, and other heavy metals to urban and roadway runoff. Metals may be found in natural waters in particulate form by the formation of precipitates, such as hydroxides, sulfides, and carbonates, or by adsorption to clay, silica, or organic particulate matter 1.

Metals have been found to be one of the leading pollutants of lakes, reservoirs, estuaries and ponds in the U.S. Metals accumulate in the environment in sediments and find their way into the food chain. Metals bio-accumulate in living organisms and may become toxic. Human health can be affected if metals enter the drinking water supply or if consumed by eating contaminated fish and shellfish.

Investigations by the University of Maryland have shown that bioretention facilities are quite effective in removing metals such as lead, copper, and zinc from stormwater runoff. Removal rates of these metals were excellent 2.

FILTERRA REMOVAL PROCESSES

Filterra uses several mechanisms to remove heavy metals.

First, metals strongly attached to TSS particulate matter are removed through sedimentation and filtration. Filterra has been shown to have a TSS removal efficiency of 85%.

Second, dissolved metals react with the organic matter (i.e., carboxyl ions) to form organic complexes. Metals tightly bind to the mulch and other organic particles in the engineered media. In a 2001 bioretention lab study performed by Davis et al., the surface mulch layer exhibited a high capacity for metal removal with sorption capabilities two to three times greater than the soil used 3.

Third, metal removal occurs by the microbes and plant uptake. As the organic matter decays metals are released and available for uptake by the plants. Filterra bio-accumulates metals within the plant and captures metals in the media. As the plant grows so does Filterra’s capacity to store more metals.

STUDY RESULTS

Industrial Port Monitoring

Extensive third-party heavy metals sampling was conducted over a 14 month period at an industrial port under the Washington Department of Ecology (WADOE) Technology Assessment Protocol for Ecology (TAPE) protocol4. Automated sampling was conducted for 23 storm events for copper. Across these 23 sampled storms events, the influent dissolved copper concentrations ranged from 0.0029 to 0.0174 mg/L, with a median value of 0.0056 mg/L. Effluent dissolved copper concentrations across these same storm events ranged from 0.0015 to 0.0099 mg/L, with a median value of 0.0033 mg/L. Dissolved copper removal efficiency estimates from these 23 storm events ranged from 24 to 74 percent, with a median value of 44 percent. Table 1 displays the mean dissolved copper data from the industrial port monitoring.

<table>
<thead>
<tr>
<th>Table 1. TAPE Mean Dissolved Copper Concentrations at Port</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Dissolved Copper</td>
</tr>
</tbody>
</table>

Other Studies

In addition to results from the TAPE port monitoring, third-party laboratory and field studies have been completed including a 2001 University of Virginia Laboratory Study for Cu and a 2006 field monitoring study also conducted by the University of Virginia according to the 2003 Technology Acceptance Reciprocity Partnership (TARP). Table 2 summarizes the UVA laboratory study total copper results.
Table 2. Summary of Third Party Laboratory Data for Total Copper

<table>
<thead>
<tr>
<th>Study</th>
<th>Influent Concentration Range (mg/L)</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Effluent Concentration Range (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 UVA³</td>
<td>0.92 – 2.17</td>
<td>1.505</td>
<td>0.09 – 0.465</td>
<td>0.244</td>
<td>82</td>
</tr>
</tbody>
</table>

The UVA field monitoring samples were analyzed for total copper, among other constituents⁶. This data is summarized in Table 3 along with additional third-party field monitoring data for total copper.

Table 3. Summary of Third Party Field Monitoring Data for Total Copper

<table>
<thead>
<tr>
<th>Site</th>
<th>Influent Concentration Range (mg/L)</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Effluent Concentration Range (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Parking Lot (TARP)</td>
<td>0.0051 – 0.026</td>
<td>0.016</td>
<td>0.002 – 0.010</td>
<td>&lt; 0.008</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>TAPE Industrial Port</td>
<td>0.0043 – 0.0218</td>
<td>0.0098</td>
<td>0.0021 – 0.0113</td>
<td>0.0043</td>
<td>54</td>
</tr>
<tr>
<td>Commercial Oil Service Station Parking Lot</td>
<td>0.028 – 0.25</td>
<td>0.09</td>
<td>0.006 – 0.067</td>
<td>0.02</td>
<td>74</td>
</tr>
<tr>
<td>Commercial Gas Station Parking Lot</td>
<td>0.004 – 0.276</td>
<td>0.074</td>
<td>0.001 – 0.081</td>
<td>0.03</td>
<td>55</td>
</tr>
<tr>
<td>Typical Concentration¹</td>
<td>0.043 – 0.118</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td>0.0104 – 0.1435 *</td>
<td>0.0475</td>
<td>0.0051 – 0.0423</td>
<td>&lt; 0.0156</td>
<td>&gt; 58</td>
</tr>
</tbody>
</table>

* Does not include NURP⁷ data in average

PERFORMANCE OVER TIME

Older Filterra systems are being sampled to determine if pollutant removal fluctuates over time. Heavy metals, including total copper, are being monitored at both a 4.5 year old Filterra system treating an oil service station commercial parking lot and a 4 year old Filterra system gas station commercial parking lot.

Over nine duplicated samples collected over a period of 2.5 years, with an influent range of 0.028 to 0.25 mg/L, third-party monitoring verifies a mean removal of 74% at the oil service station commercial parking lot.

Similarly, over nine storm events during a 2 year period, third-party monitoring demonstrated an influent range of 0.004 to 0.276 mg/L at the gas station commercial parking lot with a mean percent removal of 55%.

These data may provide evidence that systems receiving regular maintenance will perform as well or better over time. These total copper removal efficiencies are consistent with Filterra’s performance claim of approximately 58% removal of copper.

REFERENCES:

2. Davis, A., M., Shokouhian, et., al. 1998 Optimization of Bioretention Design for water Quality and Hydrologic Characteristics, Department of Civil Engineering, University of Maryland, College Park, MD
5. Yu, Shaw, 2001 Laboratory Testing of a Mix Media Filter System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.
6. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.
TOTAL PHOSPHORUS - BACKGROUND

Phosphorus is often identified as a pollutant of concern where runoff discharges to fresh or brackish lakes and bays. In these aquatic ecosystems too much phosphorus can contribute to eutrophication and algae blooms that can cause harm to fisheries and restrict recreational uses. When phosphorus enters a lake or a bay it generally accumulates in the bottom sediments and cycles seasonally between organic and inorganic forms making phosphorus readily available for plant and algae uptake.

Urban runoff can contain levels of P that are many (three to five) times higher than a natural stream or river. To minimize phosphorus buildup and its adverse environmental impacts it is necessary to prevent it entering urban runoff by reducing non-point inputs such as controlling the use of fertilizers or capturing phosphorus in treatment technologies before it enters the aquatic system.

Filterra works differently from most BMPs in how it removes phosphorus from runoff. Filterra works in two stages. In the first stage phosphorus is captured by the filter media. Organic phosphorus (i.e., part of the plants, animal tissues and their waste) is removed by filtration and sedimentation. Inorganic phosphorus (i.e. from fertilizers) and soluble ortho-phosphorus (from decaying matter) chemically react with Fe, Ca and Al silicates in the media’s sand components to create phosphate compounds.

The second stage of removal is unique to bioretention technology and Filterra. The soluble ortho-phosphorus from runoff is created by decomposition of organic matter and is up-taken and retained by both the media micro-organisms and plant – hence the term “Bioretention”. Filterra not only captures phosphorus, but consumes it. As Filterra’s plant grows so does Filterra’s capacity to transform and retain phosphorus. Filterra is capable of regeneration of its pollutant removal capacity as long as the plant continues to grow.

STUDY RESULTS

The total phosphorus performance summary data table below shows the findings of the University of Virginia field monitoring program and additional spiked field testing. The studies were performed according to the procedures set forth in the Technical Acceptance Reciprocity Protocol (“TARP”: Final Protocol 8/01; Updated 7/03). Additional spiked tests at the same study site were performed using synthetic runoff that contained a wider range of influent concentrations than the original field study. The average percent removals for each study are presented below.

Total Phosphorus was determined in the influent and effluent samples by Standard Method 184500 P B+E (colorimetric determination of dissolved orthophosphate; persulfate digestion, ascorbic acid determination).

<table>
<thead>
<tr>
<th>Study</th>
<th>Average Influent (mg/L)</th>
<th>Average Effluent (mg/L)</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVA Field TARP Study</td>
<td>0.23</td>
<td>0.09</td>
<td>60%</td>
</tr>
<tr>
<td>Spiked Field TARP Study</td>
<td>0.59</td>
<td>0.18</td>
<td>70%</td>
</tr>
</tbody>
</table>

EFFLUENT QUALITY

The Filterra system produced an average effluent Total Phosphorus concentration of 0.09 to 0.18 mg/L; the mean irreducible concentration for filtering systems is 0.14 mg/L with a lower confidence limit concentration of 0.01 mg/L. This shows that Filterra performs as well as or better than other media filters.

<table>
<thead>
<tr>
<th>Influent</th>
<th>TSS 141 - 224</th>
<th>Total P 0.37 - 0.47</th>
<th>Total Kjeldahl N 1.68 - 2.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filterra</td>
<td>&lt;4.95 - 11</td>
<td>0.09 - 0.18</td>
<td>1.1</td>
</tr>
<tr>
<td>All Other Filter Systems</td>
<td>20 - 40</td>
<td>0.15 - 0.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Concentrations in mg/L.
REFERENCES:

1. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.


NITROGEN REMOVAL - BACKGROUND

Total Kjeldahl nitrogen (TKN) is a parameter that is sometimes used as an indicator of pollution. TKN includes nitrogen from ammonia, amino acids, polypeptides, proteins or other organic sources. TKN is a measure of the concentration of reduced forms of nitrogen in surface water, principally, ammonium and amino forms of organic nitrogen. TKN plus NO₂ and NO₃ is generally used to derive total nitrogen TN. TKN and TN are not synonymous as they include different forms of nitrogen. However, TKN and TN are often used interchangeably as TKN usually comprises the major source of nitrogen in urban runoff. Because nitrogen is so readily converted from one form to another depending on environmental conditions, identifying sources of nitrogen from analyses of different forms at a single monitoring station is difficult. Filterra's field testing focused on TKN which means the TN would have been slightly higher by adding nitrate and nitrite components.

Filterra was designed to support a complete soil ecosystem and thus Filterra cycles nitrogen. As organic nitrogen (detritus material) and ammonia enter the media, it is biologically transformed by bacteria into nitrates and then nitrites. Nitrate is the form of nitrogen that plants can up-take and transform in tissue. Nitrogen from fertilizer contains inorganic forms of nitrate that is readily available for plant up-take. So whether nitrogen enters the Filterra ecosystem in an organic or inorganic form, nitrogenous compounds are eventually transformed into nitrates ready for plant uptake. Essentially any form of nitrogen pollution becomes plant food. The result is the plant grows more vigorously. Just as with most of the pollutants of concern the plant performs a vital role of retaining nitrogen by up-take into its tissue – i.e. bioretention.

A major benefit of Filterra and bioretention technology is the ability of the system to capture and hold pollutants such as N, P and metals as long as the plant is alive and thriving. Vigorous plant growth is the indicator that nature is transforming pollutants in the runoff into plant food.

STUDY RESULTS

TKN was determined in the influent and effluent samples by U.S. EPA Method 351.3 (Colorimetric; Titrimetric; Potentiometric). Total Kjeldahl nitrogen is defined as the sum of free-ammonia and organic nitrogen compounds which are converted to ammonium sulfate when the sample is heated in the presence of concentrated sulfuric acid, potassium sulfate and mercuric sulfate. The ammonia is distilled and determined by titration if the concentration of nitrogen is above 1 mg/L, by colorimetric procedures if the nitrogen concentration is below 1 mg/L, or by a potentiometric procedure for nitrogen concentrations between 0.05 and 1,400 mg/L.

The results shown below are the findings from all Filterra studies.

<table>
<thead>
<tr>
<th>Summary of Filterra TN (TKN) % Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study</td>
</tr>
<tr>
<td>UVA Lab</td>
</tr>
<tr>
<td>UVA Field Monitoring</td>
</tr>
<tr>
<td>GeoSyntec Evaluation Study</td>
</tr>
<tr>
<td>Average % Removal</td>
</tr>
</tbody>
</table>

For ordering and technical information call: 866 349 3458
REFERENCES:

1. Yu, Shaw,  2001 Laboratory Testing of a Mix Media Filter System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.

2. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA. Table 23


4. Richard, Larson et.al., 2002, Nitrate Management Using Terrestrial and Aquatic Plant Species, 12th annual IGC Conference Ground Water Consortium Proceedings, University of Illinois at Urbana-Champaign
OIL AND GREASE - BACKGROUND

High concentrations of oil and grease (O&G) can cause toxicity in receiving waters. Thus, many jurisdictions are requiring that O&G discharge be reduced or eliminated in stormwater discharges. Sources of O&G in stormwater are primarily from the operation, use, and handling of oil associated with automobile operation and maintenance. O&G can also be found in higher concentrations depending on the land use and types of activities. Generally, O&G concentrations are higher in industrial and commercial land uses and highways and lower in residential uses. Of course, O&G can be discharged through accidental spills or illegal dumping from restaurants, individuals, and maintenance facilities.

Once O&G finds its way into stormwater runoff, it can become emulsified with water to form little droplets, float on the surface of the water, or attach to the surface of trash debris or sediments through absorption or adsorption. O&G that becomes attached to trash, debris and sediment can be removed by any number of processes commonly used by most BMP technologies. The portion of the O&G difficult to remove is the part that is free flowing on the surface or emulsified within the water column.

FILTERRA’S REMOVAL PROCESSES

Filtterra very efficiently captures the portion of the O&G attached to trash, debris and sediments through the simple filtration process. Essentially, all of the trash and debris is captured on the surface of the filter media. O&G attached to sediment are also trapped within the filter media. Studies show that Filtterra will capture about 85% of all sediments.

The emulsified and free floating portion of the O&G is captured, absorbed, or soaked up by the organic material in the Filtterra system, i.e. 3” of mulch on the surface of the media and the organics within the media. Once the emulsified and free floating O&G have been captured, it is then degraded and transformed by bacteria to smaller, less harmful compounds that can be volatilized or completely consumed to CO₂ and water. This biological degradation of O&G occurs over the course of 3 to 10 days with 92% efficiency ¹.

In 2003, the University of Maryland (UM) conducted a series of tests to demonstrate the effectiveness of mulch in capturing and removing O&G from runoff ². The UM study showed about 90% of the O&G is captured through sorption by mulch. Within 3 to 10 days, 92% of the captured O&G has been degraded through microbiological processes. Additional findings and recommendations from the 2003 UM report the importance of mulch in bioretention systems are provided below:

“Overall, it can be concluded that there are several advantages to placing a surface mulch layer on a bioretention system for O&G removal.

- **First**, it appears that high contaminant removal efficiency can be achieved by the placement of a thin (~3 cm) layer of mulch to treat both dissolved and particulate-associated hydrocarbon contaminants.

- **Second**, because it only takes a relatively short time (3 to 4 days with single contaminants, and a maximum 10 days with the higher contamination of oil) to degrade the trapped contaminants after the storm event, no accumulation of hydrocarbons occurs, demonstrating that this is a sustainable process.

- **Third**, there is no need to inoculate the mulch with specific microorganisms to degrade the O&G contaminants because the native microbial population in the mulch tested has been found to have an appropriate biodegradation capacity. In addition, after exposure of the mulch microorganisms to the contaminants, an increased population of contaminant-degrading microbes is available for biodegradation during a subsequent re-exposure.

- **Fourth**, the moisture content of the mulch layer did not decrease drastically after the storm event under an air stream, which will be beneficial for microorganisms in the mulch as well as in the soil below.

- **Fifth**, the mulch layer has high permeability; therefore, it should not cause significant head build-up on the surface of bioretention systems during the storm event, so that the runoff can readily infiltrate to the soil.”

FILTERRA THIRD PARTY FIELD MONITORING RESULTS

Extensive O&G sampling was conducted over a 14 month period at a commercial port under the Washington Department of Ecology (WADOE) Technology Assessment Protocol for Ecology (TAPE) protocol ³. Grab samples were conducted for 27 storm events, 12 of which exhibited influent O&G concentrations greater than 10 mg/L. The influent O&G concentrations for these 12 storm events at the port ranged from 11 to 120 mg/L, with a median value of 43 mg/L. Across the same storm events, effluent TPH concentrations ranged from

---

¹ Recommendations from the 2003 UM report for placing mulch in bioretention systems are provided below:

- **Overall, it can be concluded that there are several advantages to placing a surface mulch layer on a bioretention system for O&G removal.

- **First**, it appears that high contaminant removal efficiency can be achieved by the placement of a thin (~3 cm) layer of mulch to treat both dissolved and particulate-associated hydrocarbon contaminants.

- **Second**, because it only takes a relatively short time (3 to 4 days with single contaminants, and a maximum 10 days with the higher contamination of oil) to degrade the trapped contaminants after the storm event, no accumulation of hydrocarbons occurs, demonstrating that this is a sustainable process.

- **Third**, there is no need to inoculate the mulch with specific microorganisms to degrade the O&G contaminants because the native microbial population in the mulch tested has been found to have an appropriate biodegradation capacity. In addition, after exposure of the mulch microorganisms to the contaminants, an increased population of contaminant-degrading microbes is available for biodegradation during a subsequent re-exposure.

- **Fourth**, the moisture content of the mulch layer did not decrease drastically after the storm event under an air stream, which will be beneficial for microorganisms in the mulch as well as in the soil below.

- **Fifth**, the mulch layer has high permeability; therefore, it should not cause significant head build-up on the surface of bioretention systems during the storm event, so that the runoff can readily infiltrate to the soil.”

---

² First tests conducted to demonstrate the effectiveness of mulch in capturing and removing O&G from runoff.

³ Technology Assessment Protocol for Ecology (TAPE) protocol.
0.018 to 13 mg/L, with a median value of 1.2 mg/L. Across all 12 sampled storm events, O&G removal efficiency estimates ranged from 70 to 99 percent, with a median value of 97 percent. Table 1 displays the range of influent concentrations, effluent concentrations, and associated percent removals for each storm event.

Table 1. TAPE Oil & Grease Concentrations at Port

<table>
<thead>
<tr>
<th>Event No.</th>
<th>Influent Concentration (mg/L)</th>
<th>Effluent Concentration (mg/L)</th>
<th>Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>14.3</td>
<td>2.11</td>
<td>85</td>
</tr>
<tr>
<td>8</td>
<td>11.4</td>
<td>3.38</td>
<td>70</td>
</tr>
<tr>
<td>12</td>
<td>16.1</td>
<td>1.29</td>
<td>92</td>
</tr>
<tr>
<td>15</td>
<td>120</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>16</td>
<td>62.3</td>
<td>1.1</td>
<td>98</td>
</tr>
<tr>
<td>17</td>
<td>48.2</td>
<td>0.85</td>
<td>98</td>
</tr>
<tr>
<td>18</td>
<td>81.2</td>
<td>0.99</td>
<td>99</td>
</tr>
<tr>
<td>21</td>
<td>38.6</td>
<td>1.42</td>
<td>96</td>
</tr>
<tr>
<td>22</td>
<td>79.1</td>
<td>12.9</td>
<td>84</td>
</tr>
<tr>
<td>23</td>
<td>117</td>
<td>0.82</td>
<td>99</td>
</tr>
<tr>
<td>24</td>
<td>14.7</td>
<td>1.27</td>
<td>91</td>
</tr>
<tr>
<td>26</td>
<td>25.1*</td>
<td>0.18*</td>
<td>99</td>
</tr>
<tr>
<td>MEAN</td>
<td>52</td>
<td>2.3</td>
<td>93</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>43</td>
<td>1.2</td>
<td>97</td>
</tr>
<tr>
<td>MINIMUM</td>
<td>11</td>
<td>0.18</td>
<td>70</td>
</tr>
<tr>
<td>MAXIMUM</td>
<td>120</td>
<td>13</td>
<td>99</td>
</tr>
</tbody>
</table>

* estimated values based on the data quality assurance review

In addition to the TAPE port O&G sampling, third party O&G grab sampling has been conducted since March 2008 on a 4 year old Filterra system treating an oil service vehicle shop parking lot, and will continue to be monitored. Two grab samples were taken per storm event at 45 minute intervals for a total of ten samples over five storm events. Effluent levels at the monitoring site were near or below the levels of detection, and included variation in storm intensities and durations. Table 2 shows that even at low influent concentrations, Filterra is still capable of removing O&G near or below detection limits. Since Filterra is a bioretention system with a 3 inch layer of mulch it is not surprising that Filterra performs with similar efficiency as tests show in the UM study.

Table 2. Oil & Grease Influent and Effluent Concentrations at Oil Service Vehicle Shop

<table>
<thead>
<tr>
<th>Date</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/7/2008</td>
<td>6.4</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>3/7/2008</td>
<td>5.6</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>3/27/2008</td>
<td>16</td>
<td>5.2</td>
</tr>
<tr>
<td>3/27/2008</td>
<td>11</td>
<td>5.7</td>
</tr>
<tr>
<td>7/13/2008</td>
<td>4.4</td>
<td>6.9</td>
</tr>
<tr>
<td>7/13/2008</td>
<td>&lt;5.0</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>9/5/2008</td>
<td>8.2</td>
<td>7</td>
</tr>
<tr>
<td>9/5/2008</td>
<td>370</td>
<td>7.3</td>
</tr>
<tr>
<td>9/9/2008</td>
<td>11</td>
<td>5.6</td>
</tr>
<tr>
<td>9/9/2008</td>
<td>7.2</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>11/13/2008</td>
<td>3.5</td>
<td>2.6</td>
</tr>
<tr>
<td>11/13/2008</td>
<td>&lt;5.0</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>12/10/2008</td>
<td>6.8</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>12/10/2008</td>
<td>6.0</td>
<td>5.3</td>
</tr>
</tbody>
</table>

AVERAGE EFFLUENT <5.0

REFERENCES:

1. Hong, Eunyoung, 2002, Sustainable Oil and Grease Removal from Stormwater Runoff Hotspots using Bioretention, "MS Dissertation, Department of Civil and Environmental Engineering, A.J. Clark School of Engineering, University of Maryland, College Park, Maryland, 167 pages.


**PERFORMANCE OVER TIME – BACKGROUND**

Performance over time is a major area of interest in stormwater best management practice (BMP) research. Because of this, older Filterra® systems are continually being monitored to determine if pollutant removal fluctuates over time. Filterra® system performance is being evaluated for a range of constituents at three study sites in Maryland and Virginia. These study sites, listed below, contain both differently sized and aged systems. Field sampling and laboratory analyses are being conducted by third-party laboratories. Based on results to-date, the Filterra® system continues to meet pollutant removal performance claims as the systems age and receive regular maintenance.

**Study Test Sites:**
- **Site A**: Restaurant Commercial Parking Lot
  - 3.08 years old; 6’x4’ Filterra®
- **Site B**: Oil Service Station Commercial Parking Lot
  - 4.92 years old; 6’x6’ Filterra®
- **Site C**: Gas Station Retail Area
  - 5.00 years old; 6’x8’ Filterra®

**TOTAL SUSPENDED SOLIDS**

Study Sites A & B are being monitored for TSS. At Study Site A and over fourteen storm events during a two year period, third-party monitoring demonstrated a TSS influent concentration range of 2.2 to 326 mg/L and an effluent range of < 1 to 21 mg/L. Similarly, over ten duplicated samples collected over a period of 2.8 years, third-party monitoring verifies an influent range of 13 to 190 mg/L and effluent range of 3.2 to 69 mg/L at Study Site B. For some time, the laboratory monitoring Study Site B set reporting limits at 10 mg/L and 5 mg/L. These higher reporting limits help to explain the lower removal efficiency. The laboratory has lowered the effluent reporting limit to 1.0 mg/L in order to provide more accurate removal efficiencies. This TSS data is summarized in Table 1 below and supports Filterra’s claim of approximately 85% removal of TSS.

**TOTAL & DISSOLVED PHOSPHORUS**

Total and dissolved phosphorus removal is being monitored at Study Site A. Current results at Study Site A indicate an average total phosphorus removal of >65% for all influent between 0.1 and 0.5 mg/L (Table 2). This range for total phosphorus was established by the Washington’s Department of Ecology TAPE guidance2. Effluent total phosphorus concentrations range from <0.02 to 0.15 mg/L for this dataset. These results support Filterra’s claim of 60 to 70% phosphorus removal.

In addition, dissolved phosphorus is being monitored at Study Site A. Influent dissolved phosphorus concentrations ranged from 0.03 to 0.26 mg/L while effluent concentrations ranged from <0.02 to 0.10 mg/L. This data provided an average of >40% removal and is summarized in Table 3.

---

**Table 1. Summary of Third-Party TSS Field Data Over Time**

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>62.9</td>
<td>&lt; 4.0</td>
<td>&gt; 85.2 %</td>
</tr>
<tr>
<td>Site B</td>
<td>62.7</td>
<td>&lt; 14.1</td>
<td>&gt; 75.6 %</td>
</tr>
<tr>
<td><strong>Typical Concentration</strong></td>
<td><strong>180 - 548</strong></td>
<td><strong>&lt; 10 - 69</strong></td>
<td><strong>&gt; 80.4 %</strong></td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>62.8</strong></td>
<td><strong>&lt; 9.1</strong></td>
<td><strong>&gt; 80.4 %</strong></td>
</tr>
</tbody>
</table>

* Does not include NURP* data in average

**Table 2. Summary of Third-Party Total Phosphorus Field Data Over Time**

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Mean Influent Concentration* (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>0.21</td>
<td>&lt; 0.07</td>
<td>&gt; 65 %</td>
</tr>
<tr>
<td>Typical Concentration</td>
<td>0.42 - 0.88</td>
<td>&lt; 0.07</td>
<td>&gt; 65 %</td>
</tr>
</tbody>
</table>

* Influent concentration range: 0.1 to 0.5 mg/L as established by WADOE TAPE guidance2

**Table 3. Summary of Third-Party Dissolved Phosphorus Field Data Over Time**

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>&lt; 0.07</td>
<td>&lt; 0.04</td>
<td>&gt; 40 %</td>
</tr>
</tbody>
</table>

---

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HEAVY METALS

Heavy metals are being monitored at both Study Sites B and C. Total zinc and copper have been monitored over ten duplicated samples collected over a 2.8 year period at Site B. Similarly, total zinc, copper, and lead have been monitored at Study Site C for eleven storm events over 2.58 years. Mean influent concentrations, mean effluent concentrations, and mean percent removals for each study site and heavy metal constituent are summarized in Table 5 below. By Study Site, mean percent removal efficiencies range from 68 to > 74 %, > 57 to > 68 % for total zinc and copper, respectively. With low influent concentrations, the mean percent removal for Study Site C is > 41 % for total lead. These heavy metal removal efficiencies are consistent with Filterra’s performance claim of 66 % removal for zinc and 58 % removal for copper.

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site B</td>
<td>0.26</td>
<td>&lt; 0.06</td>
<td>&gt; 74 %</td>
<td>0.09</td>
<td>&lt; 0.03</td>
<td>&gt; 68 %</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Site C</td>
<td>0.34</td>
<td>0.07</td>
<td>68 %</td>
<td>0.07</td>
<td>&lt; 0.02</td>
<td>&gt; 57 %</td>
<td>0.016</td>
<td>&lt; 0.010</td>
<td>&gt; 41 %</td>
</tr>
<tr>
<td>Typical Concentration</td>
<td>0.202 - 0.633</td>
<td>0.043 - 0.118</td>
<td>63 %</td>
<td>0.08 *</td>
<td>&lt; 0.03</td>
<td>&gt; 61 %</td>
<td>0.016 *</td>
<td>&lt; 0.010</td>
<td>&gt; 41 %</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>0.30 *</td>
<td>&lt; 0.07</td>
<td>&gt; 71 %</td>
<td>0.08 *</td>
<td>&lt; 0.03</td>
<td>&gt; 63 %</td>
<td>0.016 *</td>
<td>&lt; 0.010</td>
<td>&gt; 41 %</td>
</tr>
</tbody>
</table>

OIL & GREASE

Table 6 presents mean oil and grease data for Study Site B. The average effluent concentration at this monitoring site is near or below levels of detection at 5.0 mg/L. Over ten duplicated samples collected over a 2.8 year period, influent oil and grease concentrations ranged from 3.4 mg/L to 370 mg/L. Effluent concentrations ranged from < 5.0 mg/L (detection limit) to 7.3 mg/L. At both low influent concentrations and much higher influent concentrations, the Filterra® system is capable of removing oil and grease to near or below detection limits. Moreover, these effluent concentrations meet typical effluent discharge standards.

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Mean Influent Concentration (mg/L)</th>
<th>Mean Effluent Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site B</td>
<td>29.7</td>
<td>&lt; 5.5</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Based on current data, the Filterra® system continues to meet pollutant removal performance claims over time.

REFERENCES:


HIGH FLOW RATE

One of the most innovative and advanced features of Filterra is its high design flow rate. It was the design objective to engineer a media that had the highest flow rates possible to treat large volumes yet still retain pollutant removal capabilities to meet water quality standards. Current conventional thinking supports the theory that slow flow rate bioretention media is capable of superior stormwater pollutant removal to high flow rate bioretention media. However, water quality data collected from high flow rate systems and knowledge of the pollutant removal mechanisms of bioretention systems demonstrate that this is not the case.

The principal treatment processes of bioretention systems, inert and reactive filtration, primarily occur during storm events. The scientific principles behind these treatment mechanisms suggest that slow flow rate media will not necessarily achieve significantly higher removal of dissolved and particulate-bound constituents than high flow rate bioretention media. In fact, processes occurring between storm events are critical for the retention of captured pollutants and provide media sustainability. Inter-storm processes do not vary significantly between high flow rate and slow flow rate bioretention systems. Through the incorporation of mulch, specialized media, and biologically active components, the Filterra® Bioretention System is designed to promote intra- and inter-storm treatment processes characteristic of bioretention systems. Because of these scientific principles, the high flow rate Filterra® Bioretention System is expected to be capable of achieving pollutant removal efficiencies similar to conventional slow flow rate bioretention systems.

A whitepaper on Filterra's® high flow rate treatment illustrates the intra- and inter-storm pollutant removal mechanisms of bioretention systems, pollutant removal efficiencies of slow flow rate bioretention media, third-party analyses of high flow rate Filterra® system pollutant removal efficiencies, and a comparison of these efficiencies to other stormwater filtration best management practices.7

Generally, media filters (sand / bioretention) operate in the flow range of 0.25 inches/hour to 4.0 inches/hour1. Filterra operates at a conservative design flow rate of 140 inches/hour4,5. The 140 inches/hour design flow rate has been reviewed and approved by local and state jurisdictions. Americast, Inc. spent over two years developing the current Filterra media formula through their work with the Civil Engineering Department at the University of Virginia2. Filterra's high flow rate is orders of magnitude higher than conventional practices. High flows are key to Filterra's ability to treat high volumes of runoff with a small filter surface area. Generally, Filterra is designed to treat >90% of the total annual rainfall events using a filter surface area/drainage area (FSA/DA) ratio of 0.03. Higher volume treatment is possible by increasing the FSA/DA ratio.

HIGH FLOW VERIFICATION

The high flow rate has been verified with laboratory column tests, simulated field flow tests, and actual storm event testing. The results of these tests are discussed below. A detailed description of Filterra’s hydraulic and water quality performance studies can be found in Filterra's high flow rate treatment whitepaper.7

LABORATORY TESTS

The independent soils testing firm GeoTesting Express, Inc. in Acton, MA3, performed the laboratory tests. Testing was performed under constant head conditions using ASTM D 2434 protocol. One set of tests was conducted using a highly compacted sample and one with low compaction resulting in an average flow rate of 173 inches/hour. These evaluations were performed to test the extremes in flows. The heavily compacted sample was prepared using extreme force (e.g. compacted as hard as possible by hand). It would not be possible to compact the media this hard under normal construction and operation conditions; the Filterra media is protected within a concrete container. The lightly compacted sample was gently shaken to settle the material then tested. These tests also confirm Filterra's very high flow rate.
LONG TERM SIMULATED FIELD FLOW TESTS

Each media batch is quality assured and quality controlled to ensure consistency. In addition, periodic simulated field flow tests are performed on in-service systems (see figure below). Filterra systems are flow tested in various land uses, at various times since activation, and at various phases in the Filterra maintenance cycle. These tests are intended to provide support for development of design flow rates, and to evaluate the impact of age, maintenance, and sediment accumulation on media flow rates. In 2008, comprehensive statistical analysis of 10 field flow tests was performed by Geosyntec Consultants to provide a design flow rate incorporating factors of safety. This analysis resulted in a conservative design flow rate of 140 inches/hour. In 2009, 15 field sites were flow tested in the same manner, and no statistical difference was found between the 2008 and 2009 data sets. Therefore, the Filterra design media flow rate of 140 in/hr remains supported from 2008 to 2009.

STORM EVENT FIELD MONITORING

A total of sixteen precipitation events were monitored from October 2004 through November 2005 following the TARP protocol. The population of storms that were monitored includes a range of precipitation average intensities from a maximum of 1.07 inches/hour (June 29, 2005) to 0.01 inches/hour (November 28, 2005). During the study period, only three storm events may have caused the unit to over flow. During these overflow events the measured effluent of the unit was at or above 116 inches/hour (i.e. at the measurement capacity of the weir used for the effluent from the unit). The total rainfall that fell during the events monitored was measured at 15 inches. The amount measured through the study Filterra unit was between 93% and 97% of the total rainfall, providing further confirmation of the 90% treatment performance goals, even before allowing for a reduction in observed runoff versus rainfall. The 90% treatment goal was further supported during the 27 precipitation events monitored from May 2008 to April 2009 following the TAPE protocol in Washington. Infiltration rates upwards of 160 inches/hr were observed during the study period, with 99% total annual volume treated.

REFERENCES

2. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA.

Manufactured by: Americast, Inc
11352 Virginia Precast Road, Ashland VA 23005
Toll Free (866) 349-3458
www.filterra.com

For ordering and technical information call:
866 349 3458


EFFLUENT WATER QUALITY COMPARISON

Each BMP technology has a practical limit to the quality of effluent it can achieve. Effluent quality is a function of various design parameters, influent concentration and the nature of the pollutant removal mechanism(s) used for a given technology.6

For example, Filterra has been designed to optimize the pollutant removal mechanisms incorporating an array of physical (i.e., filtration / sedimentation) chemical (i.e., cation exchange / adsorption) and biological (i.e., degradation / uptake) pollutant removal processes found in nature’s plant / soil / microbe complex.

Hydrodynamic devices and dry detention basins rely primarily on physical sedimentation processes.

Generally, the more pollutant removal mechanisms, the higher the treatment levels tend to be. This is the theory behind treatment trains where several different technologies are placed in a series to improve water quality. Filterra is designed as a self contained treatment train containing all treatment mechanisms possible in one system.

For media filters in general, any device capable of high removal efficiency with high pollutant influent concentration may show low removal efficiency with low influent concentrations.

Decreased efficiency of media and other BMPs receiving low influent concentration has been demonstrated and it has been shown that in some cases there is an ‘irreducible’ concentration achievable. The following extract discusses this fact: 1,2

“As treatment occurs and pollutants in stormwater become less concentrated, they become increasingly hard to remove. There appears to be a practical limit to the effluent quality that any BMP can be observed to achieve for the stormwater it treats. This limit is dictated by the chemical and physical nature of the pollutant of concern, the treatment mechanisms and processes within the BMP, and the sensitivity of laboratory analysis techniques to measure the pollutant. This concept of “irreducible concentration” has significant implications for how BMP efficiency estimates are interpreted.”

Therefore, in order to understand how to evaluate the relative performance of BMPs by percent removal alone, even where the results are statistically significant, often does not provide a useful method to compare BMP performance.4

<table>
<thead>
<tr>
<th>Table 1. Relative Effluent Concentration Comparison for BMPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent</td>
</tr>
<tr>
<td>Filterra 7,8,10</td>
</tr>
<tr>
<td>Sand Filters 9</td>
</tr>
<tr>
<td>Proprietary Media Filters 9</td>
</tr>
<tr>
<td>Hydrodynamic Systems 9</td>
</tr>
<tr>
<td>Concentrations in mg/L.</td>
</tr>
</tbody>
</table>

It can be seen from Table 1 that based on the best available information on the expected effluent quality that Filterra effluent water quality is as good as or better than sand filters, proprietary media filters and hydrodynamic systems.

Filterra’s effluent water quality as measured by TSS, Total P and heavy metals (Table 2 below) has been shown to be as good or better than other media filters based on data from the International Stormwater BMP Database. This is of particular interest when considering BMP choice to achieve TMDL targets.
### Table 2. Effluent Water Quality Comparison

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Units</th>
<th>Biofilter</th>
<th>Media Filter</th>
<th>Filterra® System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Influent</td>
<td>Effluent</td>
<td>Influent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>&lt; Influent?</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>mg/L</td>
<td>41-63</td>
<td>15-33</td>
<td>27-60</td>
</tr>
<tr>
<td>Total Suspended</td>
<td>mg/L</td>
<td>0.22-0.28</td>
<td>0.26-0.41</td>
<td>0.15-0.26</td>
</tr>
<tr>
<td>Solids</td>
<td>µg/L</td>
<td>25-39</td>
<td>7.7-14</td>
<td>11-18</td>
</tr>
<tr>
<td>Total Copper</td>
<td>µg/L</td>
<td>10-18</td>
<td>5.7-12</td>
<td>4.6-11</td>
</tr>
<tr>
<td>Dissolved Copper</td>
<td>µg/L</td>
<td>128-225</td>
<td>28-52</td>
<td>52-132</td>
</tr>
<tr>
<td>Total Zinc</td>
<td>µg/L</td>
<td>33-79</td>
<td>19-32</td>
<td>38-101</td>
</tr>
<tr>
<td>Dissolved Zinc</td>
<td>µg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- mg/L: milligrams per liter
- µg/L: micrograms per liter

Influent and effluent ranges are calculated based on the 95 percent confidence intervals about the median for the ISBMPD (GeoSyntec and WWE 2008a) and five Filterra® field studies (Yu and Stanford 2006; ATR Associates 2009; Americast, Inc. 2009b; Herrera 2009; M. Ruby personal communication, June 8, 2010).

a Based on a non-parametric analysis of the difference in median values of site averages (GeoSyntec and WWE 2008b).

b Based on a Wilcoxon signed-rank (1-tailed) test with a significance level at p<0.05.

## REFERENCES:

7. Yu, Shaw, et.al., 2006 Field Evaluation of Filterra® Stormwater Bioretention Filtration System, Department of Civil Engineering, University of Virginia, Charlottesville, VA. Table 4, 5, 6

9. California Department of Transportation, Division of Environmental Analysis, 2004, BMP Pilot Retrofit Program, REPORT ID CTSW - RT - 01 – 050, Sacramento, CA 95814