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Conference Topic: Watershed Management Technology

High Performance Bio-Filtration Media For Bacteria, Heavy Metal And Other Pollutant Removal From Stormwater Runoff

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Abstract

Bioretention systems use an aerobic plant / soil / microbe filter media complex to remove a wide range pollutants from urban runoff. This complex media uses a variety of physical, chemical and biological processes to capture, degrade and sequester pollutants such as bacteria, heavy metals, suspended solids and nutrients. Bioretention was commercialized in 2000 in the US under the name of Filterra http://www.filterra.com/ . To make this technology economically practical for use in high density urban settings extensive laboratory and field studies have been conducted over the last ten years. The focus of the research was to increase media flow rate to optimize the annual runoff volume treated; reduce the footprint required for high density urban applications; customize the media blend to optimize removal of target pollutants; and decrease maintenance burdens by reducing clogging potential. These studies have resulted in a very high performance treatment system that can achieve long term sustainable flow rates of 140 inches/ hour and higher with pollutant removal rates of 85% TSS; 57 % TP; 43% TN; 57 % heavy metal; 96% oil / grease; and 99% for fecal bacteria. Of particular importance is the high flow characteristic of the media which allows for a very compact small surface area system that saves space and dramatically reduces costs for urban retrofit and redevelopment applications. The advanced high flow media can reduce the size of a typical bioretention system by a factor of over 50. This paper summarizes the findings of several studies that support the efficacy of high performance / high flow bioretention systems.

Background

Bioretention is defined as “filtering stormwater through an upland terrestrial aerobic plant / soil / microbe complex to remove pollutants through a variety of physical, chemical and biological treatment processes”. The system consists of an upper layer of 2 inches of mulch, 1.5 to 3.0 feet of an engineered soil media, plants and an under drain system. The word “bioretention” was derived from the fact that the biomass of the system (plants, bacteria, fungus, protozoa, worms, insects, etc.) eventually retains many of the pollutants of concern through biological degradation and uptake. Many of the pollutants of concern (nitrogen, phosphorus, heavy metals and organic compounds) are

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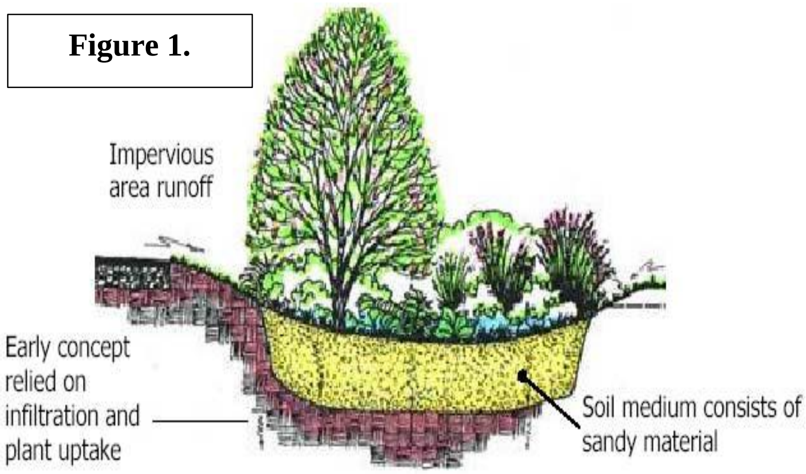
nutrients that support the soil organisms and plant growth. Essentially bioretention involves engineering a complex soil ecosystem that uses natural processes to capture, recycle and sequester pollutants.

Bioretention was first described 1993 in a design manual entitled "Design Manual for the Use of Bioretention in Stormwater Management", Prince George's County, Maryland. Figure 1 below shows the original configuration and components taken from the 1993 design manual. The practice is widely used today for stormwater treatment throughout the US and in many countries. In the past it was assumed that slower flowing (1 to 2 inches/ hour) media was most appropriate as it allowed more residence time for pollutant capture. However, over the last 18 years, experience has shown slow flow rate media often makes bioretention use in high density applications both physical and economically impractical. Some of the problems experienced with slow flow media are listed below.

Figure 1.



- Systems are extremely large in order to store treatment volumes for 72 hour draw down time required. The large surface areas make the system impractical for high density urban setting where space is limited.

- Slow flow rate media is prone to rapid clogging requiring frequent and extensive maintenance.

- The large surface area requires using large volumes of media resulting in very high excavation and materials costs.

- Long periods of ponded water (over 6 hours) causes soil saturation and anaerobic conditions which can result in loss of heavy metals and P from the media as well as inhibit plant growth. Under anaerobic conditions the system is much less efficient.

- Lack of uniform media standards and quality control has led to inconsistent results. This has led to frequent failures and expensive replacement costs for defective soils and dead plants.

- Increased amounts of clay, silts and organic materials in the media to achieve slow flow rates causes extreme variation in the media performance and longevity with inconsistent results.

Figure 2 shows the difference in the surface area required for a slow flow system compared to high flow system. The City of Portland, OR slow flow system requires a surface area that takes up an entire block. The Ocean City, MD high flow system only requires two 36 square foot tree boxes.

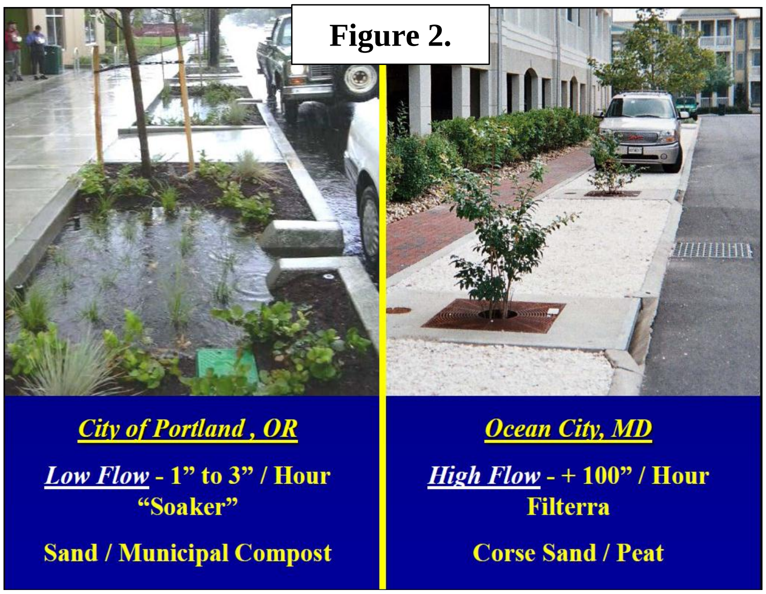


Figure 2.

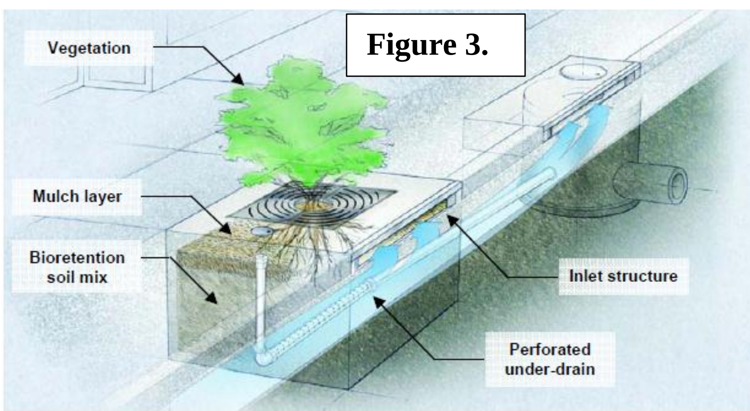


Figure 3.

In 1997 work began on the Filterra high flow bioretention system to address the problems with slow flow media. This led to a patent on high flow bioretention system issued in 2000. Over the last twelve years numerous laboratory and field tests have been conducted to optimize the design with over 4500 systems installed throughout the US. This has provided extensive documentation on the performance of the system such as flow rate longevity and removal efficiencies for bacteria, TSS, N, P and oil / grease. The high flow rate media used in Filterra eliminates many of the problems with slow flow media. Figure 3 shows a typical cross section of a Filterra system.

Research to optimize the media focused on increasing flow rates without sacrificing pollutant removal performance. To optimize the media it is essential to have an understanding of the pollutant capturing mechanisms involved in this complex system. The media must be designed to effectively capture most pollutants during the storm event. Once pollutants are retained biological processes are involved in the long term sequestration of pollutants. These biological processes will develop naturally in the system provided the proper environmental conditions are created in the media, e.g. a media that supports healthy growth of plants, fungus and microbes. Figure 4 lists examples of important pollutant / sequestration processes at work in a well-designed bioretention system.

Figure 4. Pollutant Removal and Transformation Processes

Event Unit Processes	* Rate Generalized	Description
Important Particle Capturing Mechanisms		
Sedimentation	Fast	Particles settle on surface of media by gravity.
Physical straining (filtering)	Fast	Larger particles cannot pass the media pores.
Inertial Impaction	Fast	Particles adhere to filter media as they collide.
Interception	Fast	Particles in close proximity attach to one another.
adsorption	Fast	Accumulation of material onto filter media surface.
absorption		Incorporation of material into the filter media.
Bacterial adsorption	Fast	Particles stick or adhere to bacteria cell wall slime.
Plant adsorption	Fast	Particles adhere on plant roots.
Chemical Biological Capturing Mechanisms Important in P, N and heavy metal removal		
Precipitation	Fast – Medium	For example P may react with AL or Fe to form insoluble compounds.
Cation & Anion Exchange		Compounds with exchangeable positive and negative ions are bond soil particles and organic material in the media
Plant & Microbe ion exchange	Fast – medium	Plant roots, mycelium hairs and microbe cell walls all have the ability to actively exchange ions with nutrients such as P, N and heavy metals
Physical Adsorption	Fast	Electrostatic forces, electrokinetic forces and Vander Waals forces
Volatilization	Medium	Volatile compounds are removed from the media through evaporation or actively removed through transpiration.
Plant / Microbial Sequestration / transformation / growth	Slow	Mediated decay of organic material, uptake of nutrients and transformations of complex compounds for growth and energy.

* Fast occurs instantaneously or in seconds; Medium occurs in minutes or hours; Slow occurs in hours or days.

Evaluation of Hydrologic Performance

In a 2008 Geosyntec Consultants, Inc. conducted a study to review the third party / state approved field monitoring data of Filterra to determine the optimum design flow rate. The data set was found to be adequate and representative. These data was evaluated using a SWMM model to obtain representative performance over a 58 year rainfall data base from Washington National Airport. Selected sizing results for 6’x8’ Filterra units with both 6-inch and 9-inch ponding depths, and 0.04 ft/ft catchment slope were determined. The analysis performed on data from two field studies found that a design flow rate of 140 inches / hour was justified and optimal. Figure 5 shows the summary of the field data.

Figure 5.

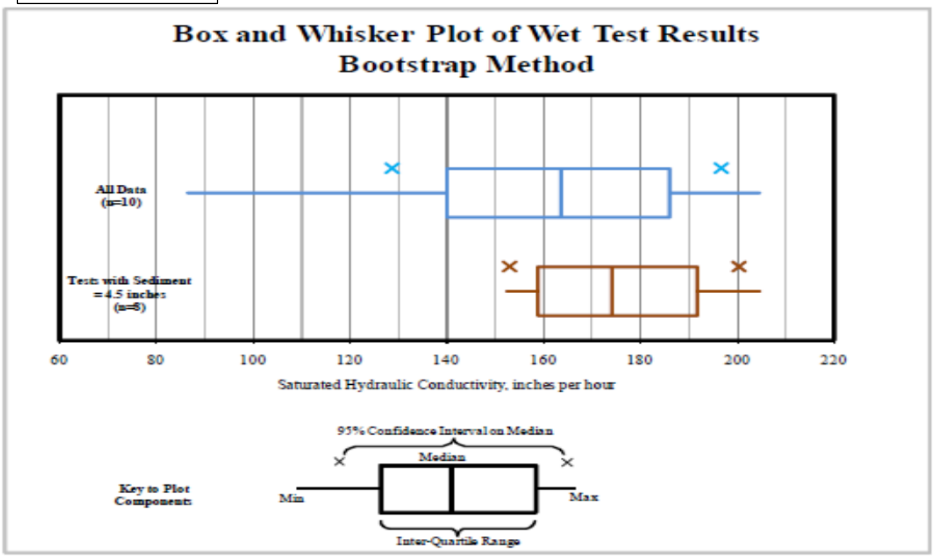


Figure 6 below summarizes various flow rates and ponding depths assuming capture of the 90th percentile of annual rain fall.

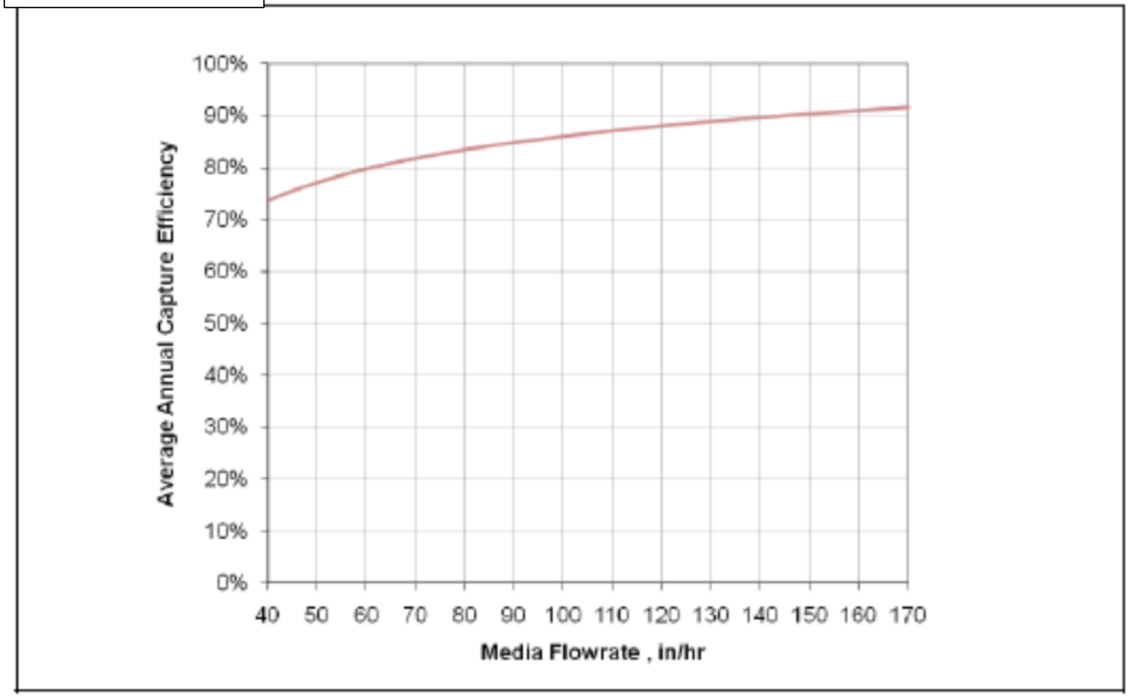
Figure 6.

Design Media Flowrate, in/hr	Required Capture Efficiency (Tc ≈ 5 minutes)	Allowable Tributary Area, ac	
		6-inch Ponding Depth	9-inch Ponding Depth
80	90%	0.135	0.15
101	90%	0.165	0.18
120	90%	0.195	0.21
140	90%	0.225	0.24
160	90%	0.25	0.27

Based on 6'x8' Filterra unit in Fairfax County, VA.

One of the interesting findings of the Geosyntec study was that a reduction in the media flow rate only had a minor effect in reducing the system's ability to capture the annual pollutant load. This is due to the higher initial flow rate of the media and the fact that the bulk of the annual pollutant load comes from smaller storm events which the system still completely treats even at drastically reduced flow rates. This means that even if flow rates drop from 140 inches / hour to 70 inches / hour the pollutant removal capacity only falls by 10%. Figure 7 shows the relationship between flow reduction and annual volume treated.

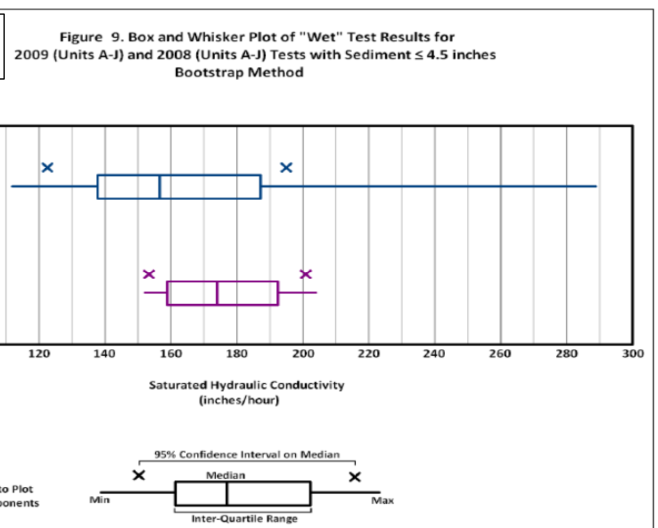
Figure 7.



Field Verification of Flow Rates and Media Longevity

In 2008 and 2009 a series of field flow tests were randomly conducted on 15 units that had been in use from one to four years. The units had been maintained at different intervals from a routine interval of one year to no maintenance over a 3 ½ year period. During this extensive field flow testing conducted in 2008 / 2009, it can be concluded that the fifteen units tested exhibited a median average flow rate of 184 inches / hour during repeated "dry" tests where the media had several days to dry out. A median average flow rate of 157 inches / hour was observed during the "wet" tests where the media was saturated and in by-pass conditions. The evaluation clearly shows that over several years the design flow of 140 inches/ hour was maintained and even increased, see Figure 8. The increase in flow rates may be due

Figure 8.



to the positive effect of the root system which is constantly swelling shrinking and growing working the media to help to create pathways for water to move through the media. The plants make bioretention and living dynamic systems that allows it to adapt to varying conditions and promotes longevity.

Hydraulic Loading and Pollutant Removal

In 2010 Herrera Environmental Consultants prepared a white paper reviewing the data for all field and laboratory monitoring. They concluded: "Third-party analyses of the Filterra® system have demonstrated sustained high media flow rates and treatment performance. Laboratory scale testing results support media filtration rates of greater than 100 inches per hour. Results from field scale testing of hydraulic function of systems of a variety of ages support the current design flow rate recommendation of 100 to 140 inches per hour." Their study further concludes: "Results from five field studies were fairly consistent for total suspended solids (TSS) with efficiency ratios ranging from 83 to 88 percent. The efficiency ratio for total phosphorus had a much wider range from 9 to 70 percent, across five studies; the low end of this range was due to low total phosphorus concentrations and high fractions of soluble reactive phosphorus measured during one study. Total Kjeldahl nitrogen (TKN) had an efficiency ratio of 40 percent in one study. The efficiency ratio for total copper ranged from 33 to 77 percent in three studies, while dissolved copper had an efficiency ratio of 48 percent in one study. The efficiency ratio for total zinc removal ranged from 48 to 79 percent in three studies, while dissolved zinc had an efficiency ratio of 55 percent in one study… total petroleum hydrocarbon (TPH) efficiency ratio was 96 percent."

They further concluded that the most important factor that determines efficiency is the influent concentration. In all cases of low efficiency influent concentrations were

Figure 9

		Biofilter			Media Filter			Filterra® System		
Pollutant	Units	Influent Range	Effluent Range	Effluent < Influent?[a]	Influent Range	Effluent Range	Effluent < Influent?[a]	Influent Range	Effluent Range	Effluent < Influent?[b]
Total Suspended Solids	mg/L	41-63	15-33	Yes	27-60	9.7-22	Yes	31-41	3.5-5.0	Yes
Total Phosphorus	mg/L	0.22-0.28	0.26-0.41	No	0.15-0.26	0.11-0.16	Yes	0.16-0.25	0.08-0.14	Yes
Total Copper	µg/L	25-39	7.7-14	Yes	11-18	8.2-12	Yes	9.3-26	4.3-10	Yes
Dissolved Copper	µg/L	10-18	5.7-12	Yes	4.6-11	7.3-11	No	4.5-7.0	2.6-3.9	Yes
Total Zinc	µg/L	128-225	28-52	Yes	52-132	17-59	Yes	158-290	41-80	Yes
Dissolved Zinc	µg/L	33-79	19-32	Yes	38-101	29-74	Yes	177-322	75-110	Yes

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 $p<0.05$.

at or near detection limits of the testing protocols used. They found that the effluent concentrations achieved in the field monitoring studies were generally equal to or lower than median effluent concentrations for the biofilter and media filter classes of best management practices (BMPs) reported in the International Stormwater BMP Database, Figure 9.

Finally, Herrera concluded that the high flow media performance " makes the Filterra system a well-suited BMP, designed based on low impact development (LID) principles, for a wide variety of conditions, allowing pollutant loads to be addressed close to their source even on space-constrained sites where the use of traditional slow flow rate systems would be problematic or infeasible."

Bacteria Removal


Figure 10

A special media blend for bacteria capture and deactivation has been developed called Bacterra. A full scale Bacterra unit was installed in Marina Del Rey, CA and has been in operation and receiving regular maintenance since January 2007. Pictured in Figure 10, this retrofit site is in a high density urban setting in a densely populated area of Los Angeles County, CA. The purpose for retrofitting this site was to reduce fecal bacteria levels in the runoff draining to a marina. This full scale monitoring over several years showed greater than 95% removal of all key bacterial pathogen indicators analyzed, including fecal coliforms, E. coli and Enterococcus spp.

Figure 11 shows the bacteria removal by storm event. This data shows that it takes several weeks for the media to mature before it reaches full performance. This maturation period is believed necessary for the organisms that prey on the bacteria, e.g. protozoa to fully develop. Predation is

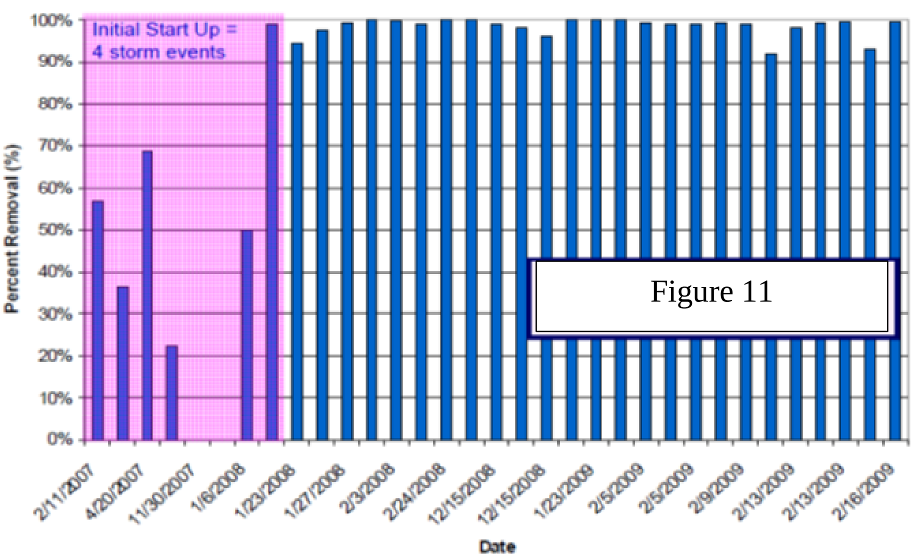


Figure 11

believed to be the primary mechanism for deactivation of the fecal coliform.

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