Bacterra™ by Filterra® Advanced Bioretention System Discussion of the Benefits, Mechanisms and Efficiencies for Bacteria Removal

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Biographical Sketch

1) Mr. Larry Coffman has over 35 years of experience in stormwater management. He has authored numerous papers on stormwater management programs and pioneered the development of bioretention and is the principal author of Prince George's County's, Maryland national award winning "Low Impact Development Design Manual" an alternative technological approach to stormwater management. Mr. Coffman is considered one of the nation's leading experts on Low Impact Development technologies for water resources protection.

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Abstract

With the growing concern about bacterial impairment of recreational waters associated with stormwater runoff, extensive laboratory and field studies were conducted by Filterra®, division of Americast, Inc., to determine an optimum blend for bacteria removal. The Filterra® bioretention BMP blend is currently designed to utilize physical, chemical and biological pollutant mechanisms to remove typical stormwater pollutants such as TSS, phosphorus, nitrogen and heavy metals. Filterra® has developed a specialized treatment media to remove fecal coliform and other pathogens from urban stormwater runoff. This new media blend has been trade marked Bacterra.

Laboratory tests have shown bacteria removal rates between 77% and 99%, with preliminary field results showing removal between 94% and 99%. It is believed that the media goes through a maturation process where it develops a complex microbiological ecosystem that enhances predation, capture and destruction of fecal coliform. Physical, chemical and biological processes are all believed to contribute to the removal process, but sorption is believed to be the primary capturing mechanism.

This study showed that high bacteria removal rates of over 90% were achieved at extremely high flow rates at 100 inches per hour. This study does not support conventional thinking that slow flow rates and long contact times are needed to effectively remove bacteria from stormwater runoff using bioretention media. This paper summarizes the research effort and findings of Filterra® in the development of their Bacterra™ high flow bioretention media treatment technology.

Keywords: bioretention, bacteria removal, low impact development, stormwater management, stormwater treatment

1. Background

Numerous water bodies nationwide are impaired due to excessive levels of fecal bacteria from stormwater runoff. Fecal coliform exist in the digestive track of warm blooded animals. The major sources of fecal coliform in urban runoff are contributed by pet and wild animal, especially bird, feces. Previous studies by other researchers have shown that urban runoff can result in fecal coliform levels on average between 15,000 and 22,000 MPN/100mL (Center for Watershed Protection, 1999).

Fecal coliform was used as the indicator bacteria for this study, since this is considered a common means of studying removal, and is often used by regulatory agencies nationwide in monitoring drinking and recreational water quality. Other types of fecal indicator bacteria include Escherichia coli (E. coli) and Enterococci (Rusciano and Obropta, 2007). The Center for Watershed Protection states that over 90% of states still rely on fecal coliform as the primary indicator for recreational water quality standards (1999). Fecal coliform and E. coli are used to indicate water contamination by human or animal wastes. Bacteria from these wastes can cause severe gastrointestinal problems, headaches, and other symptoms (USEPA, 2006).

Bioretention media has been shown to remove bacteria based on media testing conducted by Rutgers State University of New Jersey. This Rutgers study found excellent fecal coliform removal around 95.9% and a range of 54.6 – 99.8%. The study presented showed similar removal at much higher flow rates than that of standard bioretention media. The Filterra® bioretention blend, manufactured by Americast in Ashland, VA, is currently designed to remove typical stormwater pollutants such as TSS, phosphorus, nitrogen and heavy metals. The new Bacterra™ blend was created to optimize bacteria removal.

Bacteria in stormwater is removed by bioretention media through a variety of physical, chemical and biological mechanisms. Sorption of bacteria to the organic material within the media is the primary mechanism for removal, and is enhanced by other removal mechanisms all at high flow rates.

2. Objective

With the growing concern about bacterial impairment of recreational waters associated with stormwater runoff, extensive laboratory studies were conducted to determine an optimum bioretention blend for bacteria removal. Four different column blends were tested on a weekly basis over a five month period between October 2006 and March 2007. Field testing was later conducted to validate laboratory data.

To study removal over different volumes, columns were tested at bypass or the maximum design flow rate for the first two to three months and then at non-bypass volumes during the remainder of the experiment. A total of sixteen tests were completed over a range of variables including volume, influent concentration, and time.

3. Hypothesis

It was hypothesized that smaller volumes would show better fecal coliform removal from spiked laboratory testing at high flow rates.

4. Lab Methods and Materials

4A. Column construction

Four 15.24 cm (6 inch) diameter clear columns were cut into 1.219 meter (4 foot) sections. The column apparatus was set up to mimic the same depth and configuration of the standard bioretention media blend including under drain, media and hardwood mulch. Screen was placed around the effluent side of the column to prevent media from exiting the columns. An end cap with a three inch drilled hole was placed over the mesh to allow for the collection of effluent samples.

A wooden table was constructed to support each column (Figure 1). Blends were thoroughly mixed by hand in plastic garbage bags. To replicate the 15.24 cm (6 inches) of head found in the standard bioretention system, a 15.24 cm mark was placed above the mulch on each column for determining the appropriate head for maximum design flow testing.

Figure 1: Photo of Column Setup

4B. Volume Calculations

Column tests were conducted at both 100% of the design flow rate capacity (bypass flows) and non-bypass volumes to observe removal over both small and large volumes. During bypass flow testing, 16.28 liters (4.3 gallons) was filtered through each column during a single test. This volume was determined based on the drainage area of a standard 1.829 meters x 1.829 meters (6 foot x 6 foot) bioretention unit. A 15.24 cm (6 inch) head remained constant above the mulch during testing to simulate the 15.24 cm ponding area within a full scale bioretention unit. During non-bypass testing, columns were tested at 500mL, 1000mL, and 2000mL volumes.

4C. Preparation of spiked influent mixture

Raw sewage obtained from the Ashland, VA Wastewater Treatment Plant was picked up every two to three weeks for spiking the influent for testing. Before this study began, dilutions were first run on a couple of raw samples and analysis performed to find out the range of fecal coliform levels to determine how much to dilute the samples for testing. Samples were diluted to achieve a fecal coliform concentration similar to that found in stormwater runoff. Raw sewage was mixed with a heavy duty laboratory mixer in a 113.6 liter (30 gallon) conical tank filled with well water for maximum design flow rate testing. Well water was used since it does not contain chlorine like tap water, which can kill the bacteria in the influent.

4D. Flushing

The mulch was washed using a screen before placement in the columns to reduce flushing times. All columns were flushed with well water prior to initial testing. A turbidity meter was used to analyze effluent over time until effluent levels dropped below 20 NTU. It is standard procedure to flush all media filters before testing to flush out the fines that could cause variability in results.

4E. Testing Procedure

1. Bypass flow rate

Columns were tested at bypass flow rate for three months. The bypass flow rate represents the maximum design flow rate of the media. The spiked influent was run through a series of hoses into each column with flow controlled by a valve for each hose. Columns were filled to the 6 inch bypass flow rate mark and constant at this mark throughout the test. Tests were conducted once a week to allow for a rest period between testing for the media to drain entirely.

Three influent samples were taken at the beginning, middle and end of each test to obtain a representative value over the entire testing period. Samples were collected after 3.785 liters (1 gallon) had first filtered through the column to ensure that residual water in the column from pervious tests was not included in the sample. A translucent, graduated effluent collection container was placed at the bottom of each column. The pH, temperature and turbidity for both influent and effluent samples were recorded during testing.

2. Non-bypass flow rate

During the last two months, columns were tested at smaller volumes including 500, 1000 and 2000mL. Influent samples were collected after 50mL had first discharged from the column. 100mL samples were collected during all tests, which is the required amount for analysis.

4F. Analysis

The samples were analyzed for fecal coliform MPN (Most Probable Number) according to the EPA approved HACH method 8368 using A-1 Medium Broth (Figure 2). Data were reported in MPN per 100mL.

Figure 2: Photograph of MPN Tubes Filled with Sample in A-1 Medium Broth

5. Field Methods and Materials

A field test site was installed in Southern California to validate laboratory findings (Figure 3). The project site is a popular harbor tourist area and local attraction suffering from a variety of high pollutant discharges from retail, commercial and residential activities.

Bacteria and other pathogen discharges significantly impaired the health of the aquatic environment and impacted the local economy. This area is also densely populated, offering limited space for large treatment and collection system runoff.

Filterra® was chosen with the Bacterra™ media blend to help meet bacteria TMDL requirements imposed by the Los Angeles Regional Water Quality Control Board. Los Angeles has been involved in monitoring the effectiveness of the Bacterra™ media blend in reducing bacteria discharges into adjacent waterways.

The 6.5' x 4' Bacterra™ media blend unit is an urban streetscape retrofit installed in December 2006 and activated in January 2007.

Testing began in the spring of 2007. A third party lab was used to take sample, and samples were analyzed using standard method 9221E. Only eight events have been sampled to date due to drought conditions in 2007.

The sample procedure included taking two separate grab samples. One sample was taken at the beginning of the storm event to capture the first flush and one thirty minutes to an hour afterwards.

Figure 3: Photograph of Southern California Bacterra™ Media Blend Test Site

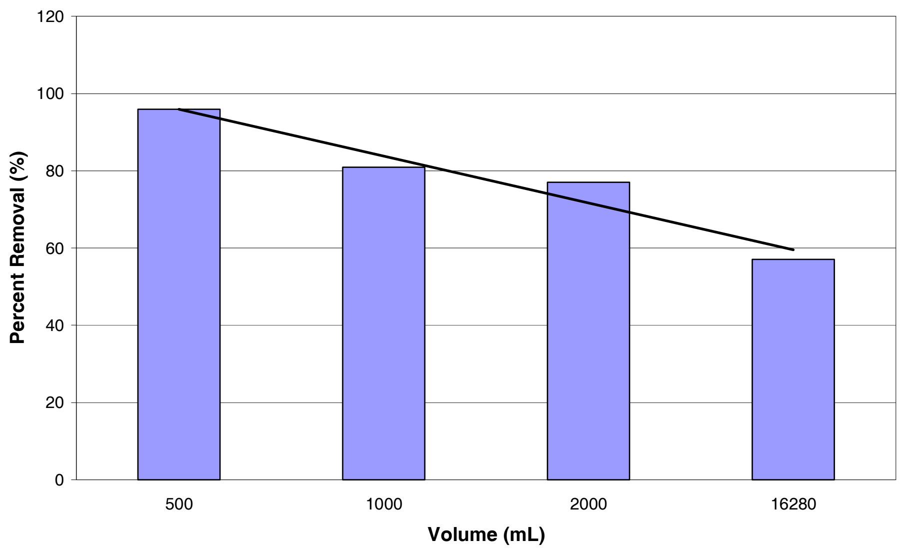
Lab Results

Percent Removal vs. Volume

Figure 4 below represents the effect of volume on the percent bacteria removal by the bacteria blend. Tests were conducted under different volumes to represent real-world storm events. The smaller volumes represent low intensity storms, and this is where the bacteria blend would be expected to perform under standard design criteria. The maximum design flow is approximately equivalent to a ten year storm event with some breakthrough expected.

The trendline shows that smaller volumes produced higher removal efficiencies. Small volumes produced removal efficiencies between 77% and 99%. The average maximum volume (bypass flow) was 57%.

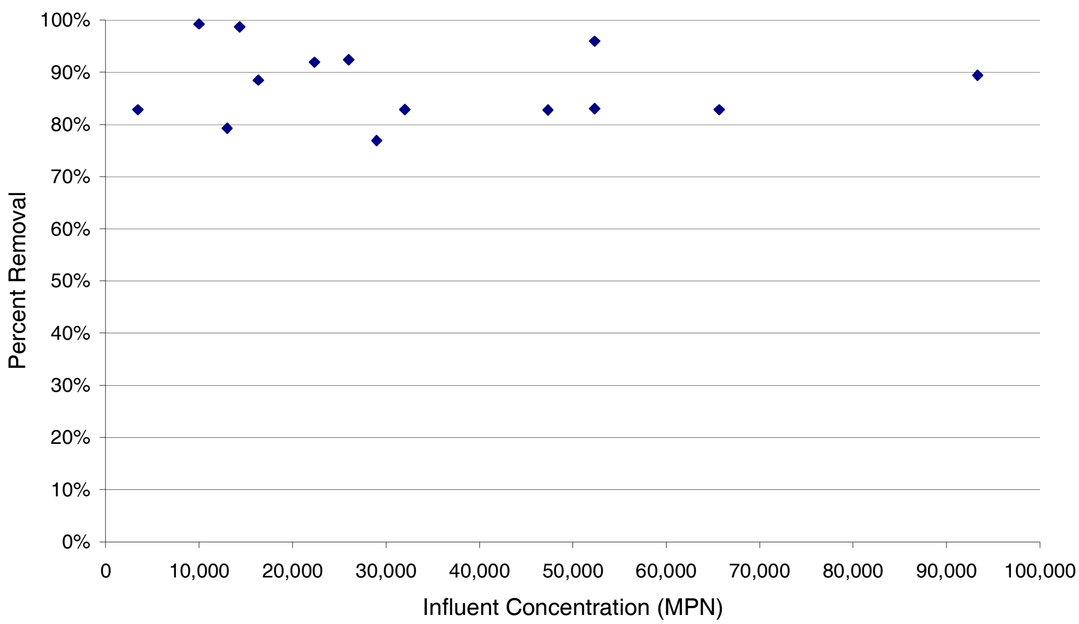
Figure 4: The Effect of Volume on Percent Bacteria Removal by the Bacteria Blend



Percent Removal vs. Influent Concentrations

Figure 5 represents the effect of influent concentration on the percent bacteria removal by the bacteria blend. Influent concentrations ranged from 3,433 to 93,333 MPN during testing with an average of approximately 36,300 MPN. The trendline shows that the bacteria blend showed high removal even at higher influent concentrations.

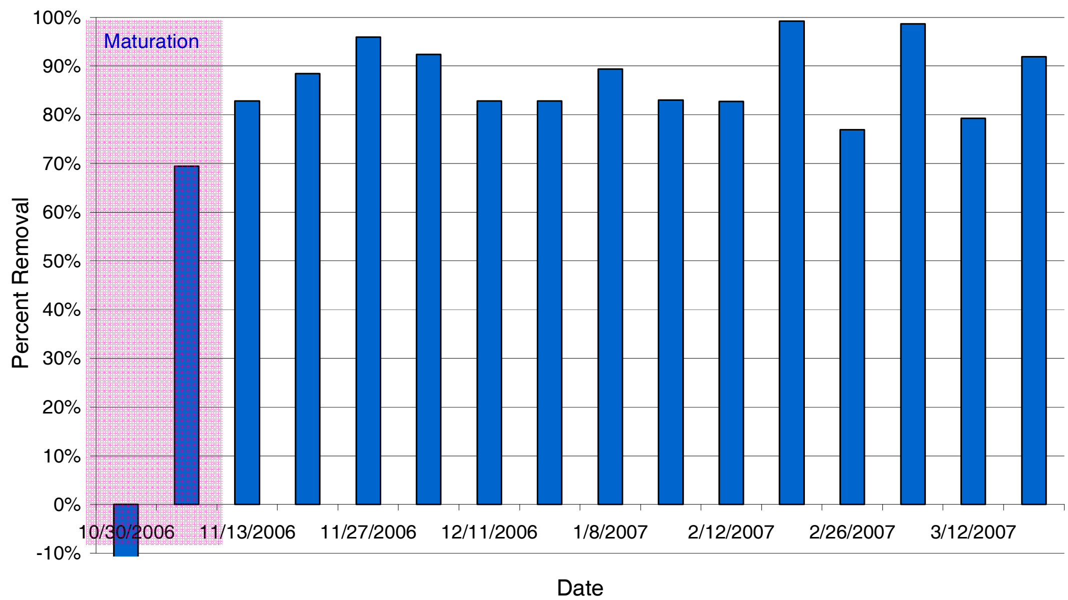
Figure 5: The Effect of Influent Concentration on the Percent Bacteria Removal by the Bacteria Blend



Percent Removal vs. Time

Figure 6 represents the effect of time on the percent bacteria removal by the bacteria blend. The trendline shows that removal efficiencies increased over the study period with higher removal efficiencies (77% - 99%) after the maturation period.

Figure 6: The Effect of Time on the Percent Bacteria Removal by the Bacteria Blend



Field Results

Percent Removal vs. Influent Concentrations

Figure 7 below represents the effect of influent concentration on the percent bacteria removal by the bacteria blend. Influent concentrations ranged from 1,100 to 160,000 MPN. The trendline shows that the bacteria blend showed high removal even at higher influent concentrations.
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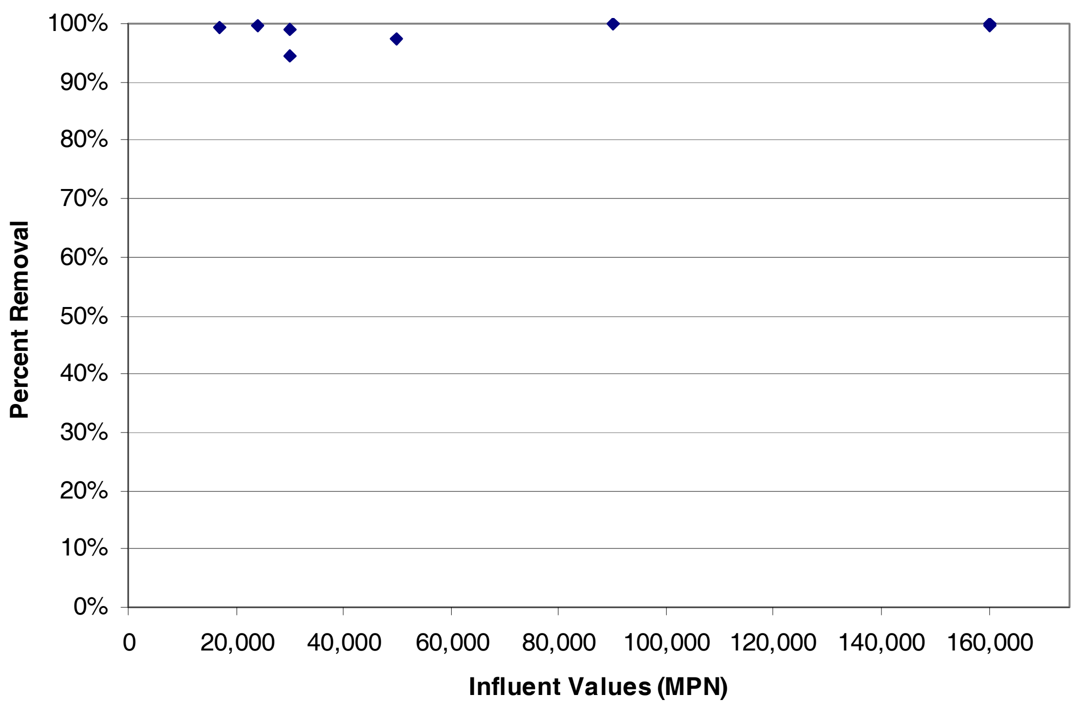
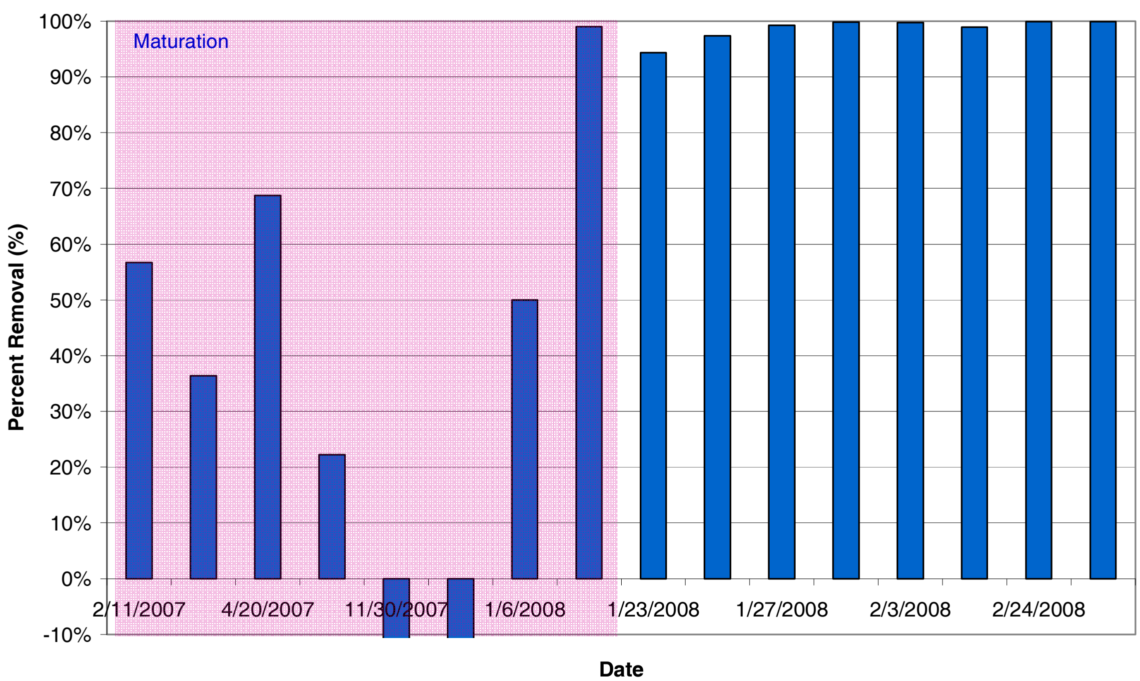
Figure 7: The Effect of Influent Concentration on Bacteria Removal by the Bacteria Blend



Percent Removal vs. Time

Figure 8 below represents the effect of time on percent bacteria removal by the bacteria blend. The graph shows that as time passed, the removal efficiency increased. Note that rainfall did not occur between April 2007 and November 2007 due to drought conditions which reinitiated the maturation period. Missing graph bars represent export. After the maturation period, the removal efficiencies range from 94% to 99%.

Figure 8: The Effect of Time on the Percent Bacteria Removal by the Bacteria Blend



Bacteria concentrations

Table 1 below shows results for fecal coliform and E. coli removal for the eight monitored storm events. Both fecal coliform and E. coli show averages of 98.6% removal after the maturation period (January 6th, 2008). The maturation period is highlighted in pink with concentrations below commonly used recreational use water quality standards highlighted in yellow.

Table 1: Bacterra™ Media Blend Influent and Effluent Bacteria Levels and Associated Percent Removal Values for Individual Samples

	Fecal Coliform (MPN)			E. coli. (MPN)		
Sample Date	Influent	Effluent	% Removal	Influent	Effluent	% Removal
2/11/2007	3,000	1,300	56.7%	2,046	201	90.2%
2/11/2007	1,100	700	36.4%	563	216	61.6%
4/20/2007	160,000	50,000	68.8%	19,863	17,329	12.8%
4/20/2007	90,000	70,000	22.2%	17,329	12,033	30.6%
11/30/2007	1,700	30,000	-1664.7%	1,674	1,470	12.2%
11/30/2007	1,300	3,000	-130.8%	1,043	2,481	-137.9%
1/6/2008	400	200	50.0%	341	160	53.1%
1/6/2008	>160,000	130	>99%	>24,196	31	>99%
1/23/2008	30,000	1,700	94.3%	19,863	488	97.5%
1/23/2008	50,000	1,300	97.4%	>24,196	1,145	>95.3%
1/27/2008	17,000	130	99.2%	17,329	175	99.0%
1/27/2008	24,000	40	99.8%	>24,196	156	>99.4%
2/3/2008	160,000	500	99.7%	>24,196	318	>98.7%
2/3/2008	30,000	340	98.9%	>24,196	275	>98.9%
2/24/2008	>160,000	80	>99.9%	>24,196	20	>99.9%
2/24/2008	90,000	40	99.9%	>24,196	10	>99.9%

Discussion and Conclusions

The laboratory study clearly demonstrates that high flow rates can produce fecal coliform removal rates between 77% and 99%. Based on current field data, the field findings support the laboratory data showing high removal at both low and high influent concentrations and increased removal after the maturation period of the bacteria blend (94% to 99%). The study clearly demonstrates that the bacteria blend will reduce fecal coliform levels to receiving waters. It is assumed that other types of bacteria (such as Enterococci) and pathogens are also reduced since the capture / removal mechanisms are the same.

It was observed in both lab and field data that as time passes, the bacteria removal efficiency increases. The lab and field data show that the media goes through a maturation process where it develops a complex microbiological ecosystem that enhances predation, capture and destruction of fecal coliform. This period is equivalent to about several weeks or 4 to 5 storm events.

In the Rusciano and Obropta study (2007) previously mentioned, it is believed that adsorption and filtration are the primary mechanisms for removal. The study mentions other possibilities including organic matter, the development of biofilms, temperature, pH and flow rate. Dr. Allen Davis from University of Maryland speculated predators as a possible means for removal at the 2007 LID Conference Proceedings (Davis 2007).

Other media filters have been studied for bacteria removal. A study on the bacteria performance of the Austin Sand Filter has shown a removal efficiency of 76% (City of Austin, Texas 1988). A peat sand filter studied by Galli in 1990 showed 90% bacterial removal. There are a few laboratory studies that have looked at bioretention media for bacteria removal including a study performed by Davis in 1998 showing a removal efficiency of 90%. Also the Rusciano and Obropta study showed a removal efficiency of 88%. A study conducted by Hunt in 2006 looked at bioretention cells in the field and observed removal efficiencies at 71% for bacteria. Based on these studies, the bacteria blend in this study is just as effective, if not more effective, in removing bacteria from stormwater runoff.

The field data show that Bacterra is capable of meeting discharge water quality standards for fecal coliform and E. coli. After maturation, 60% of the discharge concentrations were below the commonly used recreational uses water quality standards of 200 MPN for fecal coliform.

This study demonstrates that extremely high flow rates (100+ inches/hr) can achieve high bacteria removal efficiencies. Further monitoring is planned at Bacterra™ sites across the country and results will continue to be reported.

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