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Report Follows

EFFICIENCY OF BIORETENTION SYSTEMS TO REDUCE FECAL COLIFORM COUNTS IN STORMWATER

Gregory M. Rusciano and Christopher C. Obropta
Graduate Assistant, Department of Environmental Sciences
Assistant Professor, Department of Environmental Sciences

Rutgers, The State University of New Jersey
Cook College
14 College Farm Road
New Brunswick, NJ 08901

ABSTRACT
Currently, 7,742 water bodies in the nation are impaired for pathogenic bacteria, viruses and/or parasites (14.4% of all reported water bodies), more than for any other impairment (USEPA, 2003). Impairments result in large part from nonpoint sources of pollution carried by urban and agricultural stormwater runoff. Fecal coliform (FC) counts are commonly used as an indicator of pathogens and are used by governmental agencies to help manage drinking water quality and recreational activities such as swimming, boating and fishing. The study seeks to evaluate the ability of bioretention systems to effectively reduce fecal coliform colony counts. Bioretention systems were modeled in the laboratory with columns with representative depths of gravel, sand and soil. *Panicum virgatum*, typically used in bioretention systems, was integrated into the columns. Typical rainfall conditions for New Jersey will be mimicked in the laboratory with regard to rainfall intensity and frequency and stormwater composition (bacterial colony counts). The drainage area received by a typical bioretention system was estimated to determine the appropriate flow rate of water input into the system. maximum percolation rate was observed to be approximately 37 mL/minute. Ponding occurred in the top of the column during every simulated storm event, although its maximum height never surpassed 12 inches. TSS removal was generally high with an average ratio of 92.3% and range of 82.5-99.4%. FC count reductions were generally high, with an average ratio of 87.8% and a range of 54.7-99.7%. The turbidity was observed to be significantly lower in leachate samples (see Figure 4). On average, the pH and temperature of the influent was 7.14 and 25.4 ^{o}C, respectively. The pH and temperature of the leachate was 4.71 and 22.9 ^{o}C, respectively. In addition to filtration and adsorption mechanisms, other mechanisms are responsible for acting directly on the bacteria regardless of their association with particulates. The primary mechanism is the pH. It is also likely that predation of FC bacteria by other microorganisms was a factor. Since bioretention is increasingly being implemented as a primary watershed management tool across the United States, this research will provide data to help optimize its effectiveness in the field and improve regulatory guidance for the future.

INTRODUCTION

Currently, 7,742 water bodies in the nation are impaired for pathogenic bacteria, viruses and/or parasites (14.4% of all reported water bodies), more than for any other impairment (USEPA, 2003). Impairments result in large part from nonpoint sources of pollution carried by urban and agricultural stormwater runoff. Runoff also contributes many other pollutants to receiving water bodies including suspended solids and heavy metals (Barrett *et al.*, 1998; Wu *et al.*, 1998; and Sansalone and Buchberger, 1997). Recent water quality studies investigating pathogens found high concentrations of fecal-indicator bacteria in water bodies receiving stormwater runoff from mixed land uses (Tufford and Marshall, 2002). Other sources of contamination include combined sewer over flows (CSOs), sewer leakages, septic fields, and publicly owned treatment works (POTWs) discharges (Marsalek and Rochfort, 2004). Burnes (2003) determined that the sources of fecal contamination originate from both humans and animals, including cattle, domestic, and wild species.

Fecal coliform (FC) counts are commonly used as an indicator of pathogens and are used by governmental agencies to help manage drinking water quality and recreational activities such as swimming, boating and fishing. While coliform bacteria themselves do not cause illness, they originate from the digestive tracts of warm-blooded animals and their presence suggests the occurrence of harmful pathogens from the same origin. Other fecal-indicator organisms include enterococci, total coliforms, and *Escherichia coli*. Haile *et al.* (1999) reported epidemiological evidence that shows an increased risk of adverse health associated with swimming in recreational waters that are contaminated with untreated urban stormwater. The Beaches Environmental Assessment and Coastal Health Act (BEACH Act) was signed into law on October 10, 2000, and amends the Clean Water Act (CWA), incorporating provisions to reduce the risk of illness to users of the Nation's recreational waters. Total Daily Maximum Loads (TMDLs) for FC are developed to identify all point and nonpoint sources in impaired water bodies. Currently, five FC TMDLs have been established for water bodies in New Jersey, which may require the development of watershed management plans for the reduction of nonpoint sources of FC (NJDEP, 2004a).

Successfully meeting recent TMDL requirements will require some degree of on-site stormwater treatment (USEPA, 2001). A variety of structural best management practices (BMPs) are available to treat stormwater including extended detention basins, wet ponds, stormwater wetlands, bioretention systems, enhanced swales, prefabricated treatment devices, and riparian forest buffers. The selection of the most appropriate BMP depends on: (1) estimated pollutant removal capabilities of the BMP; (2) most appropriate land use conditions; and (3) treatment suitability of the stormwater (NJDEP, 2004b).

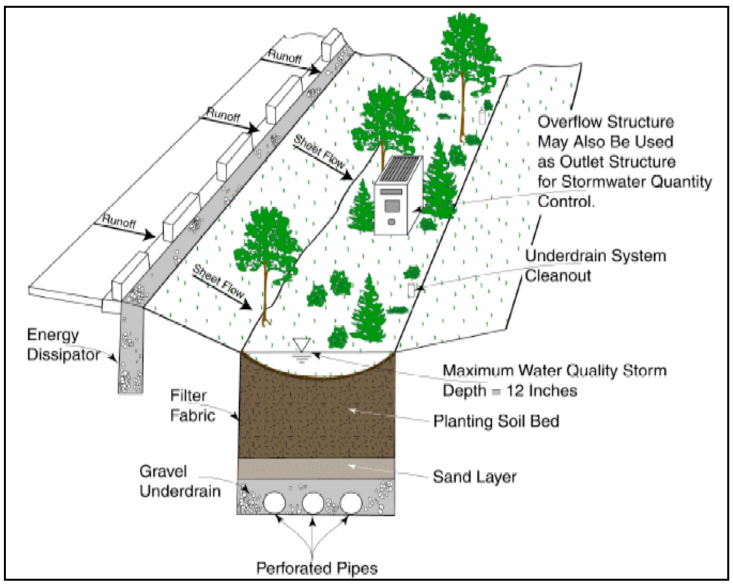


Figure 1: Conceptual Bioretention System (NJDEP, 2004b)

The bioretention system is a structural stormwater BMP that is commonly used in suburban settings, especially for the treatment of parking lot runoff. The typical design for a bioretention system includes a sloped grass buffer strip, a ponding area with native vegetation (provides settling of suspended solids), a three-foot deep soil planting layer, and a one-foot deep sand layer. Some systems are equipped with gravel and under-drain piping where soils are not appropriate for groundwater recharge. The soil planting layer: (1) acts as a primary filter with attenuation of pollutants to soil particles, (2) provides rapid infiltration of stormwater runoff (complete infiltration within 72 hours to avoid mosquito breeding), and (3) sustains healthy vegetation at the surface. The soil planting bed consists of a high sand content to achieve infiltration requirements. The sand layer acts as a secondary filter and transition between the soil planting bed and the under-drain system or underlying soil. A thin mulch layer can be applied to the top of the soil planting bed to retain moisture and attenuate pollutants. Water collected in the under drain can be retrofitted to a stormwater sewer system, which eventually discharges into surface waters. Systems without an under drain system are used to recharge groundwater through infiltration.

Plants in a bioretention system consist of native grasses, shrubs and trees that are intended to adapt well to the soil and climate of the region in which they are implemented. They must also tolerate pollutants and varied depths of water. The plants are intended to uptake water contaminated with excess nutrients and pollutants, however, plant roots may also provide pore spaces which will provide a habitat for microorganisms, thus promoting biological degradation of some pollutants and predation of other bacteria (Davis et al., 2001). Bioretention systems are intended to remove suspended solids, nutrients, metals, hydrocarbons, and bacteria (NJDEP, 2004a); however they have not been investigated thoroughly for FC in the United States.

Research on stormwater-associated bacteria has been conducted for similar structural stormwater BMPs such as constructed wetlands and wet ponds. Birch *et al.* (2004) found a 76% removal of FC colony counts from constructed wetlands that received contaminated stormwater from four high-flow rainfall events. Kadlec and Knight (1996) reported an average 90% removal of coliform bacteria for constructed wetlands. Davies and Bavor (2000) reported constructed wetland removal efficiencies of 79% and 85% for thermotolerant coliforms and enterococci, respectively; and removal efficiencies of -2.5% and 23% for wet ponds. Bacterial removal was significantly less effective in the wet pond because of its inability to retain fine clay particles (<2 µm) to which bacteria were predominantly adsorbed (Davies and Bavor, 2000; Baudart *et al.*, 2000). Davies and Bavor (2000) correlate increased vegetation with increased removal efficiency.

Since bioretention systems remove about 80% of the total suspended solids (TSS; NJDEP, 2004a), FC bacteria attached to sediments should be held up in the system. Simultaneous analysis of TSS and FC will be performed to test this hypothesis. We also hypothesize that as the system cycles through periods of wetness and dryness, aerobic and anaerobic microniches are formed. These conditions could support predatory bacteria. Thus, in addition to sediment entrapment and sorption as methods of removal, predation might also be important. Bioretention systems are an ideal candidate for managing pathogens in stormwater due to their manageable size, potential to remove sediments and their potential to induce predation. Bioretention systems can also be *engineered* for removal of pollutants through the choice of planting bed media. Thus, two different types of such media will be investigated. Three different concentrations of manure slurry will also be investigated to account for a possible variability in pollutant removal efficiency. Since bioretention is increasingly being implemented as a primary watershed management tool across the United States, this research will provide data to help optimize its effectiveness in the field and improve regulatory guidance for the future.

METHODS

Column construction

Pilot bioretention systems were constructed in the laboratory using six-inch diameter, clear PVC pipe cut into five-foot lengths (Harvel Plastics, Inc.). One end of the pipe was wrapped in perforated filter fabric and fitted with a six-inch to four-inch PVC reducer coupling (see Figure 2). The reducer coupling was filled with pea gravel (AASHTO M-43) and capped with a four-inch PVC cap which was drilled with a half-inch diameter hole for collecting leachate. The bottom twelve inches of the column was packed with clean medium aggregate concrete sand (ASTM C-33) at a bulk density of approximately 1.8 grams/cc. The next thirty-six inches of the column were packed with the soil planting bed media at a bulk density of approximately 1.3 grams/cc. The transparency of the clear PVC made packing easier. However, the

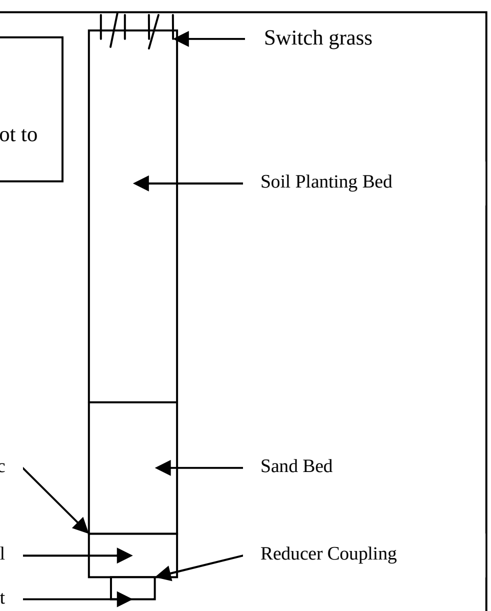


Figure 2: Bioretention column schematic (not to scale).

columns were wrapped in an opaque covering after packing to prevent algal growth. The soil planting bed consisted of three equal parts (by volume) of sphagnum peat, triple-shredded hardwood mulch and medium aggregate concrete sand. The mixture was blended homogeneously by hand before packing. An additional soil planting bed consisting of compost, top soil and medium aggregate sand will be investigated subsequently. A control column will be used and consists of soil-core samples of material taken from a New Jersey suburb. Five to seven two-inch plugs of switchgrass (*Panicum virgatum*) were planted at the top of the soil-planting bed. The switchgrass was watered regularly and permitted to grow for several months before experimentation. All stages of the experiment took place in a temperature-controlled greenhouse (21-27^{o} C). Three columns were constructed identically and housed in a heavy-duty wooden workbench (see Figure 3).

<u>*Preparation of manure slurry*</u>

Fresh horse manure (from animals not treated with antibiotics) was collected on experimentation days. A 200 gram equal-parts-by-volume manure mixture (from three different horses) was added to 1800 mL of phosphate buffered dilution water (AWWA, 2001) in a 6000 ml Erlenmeyer flask. The mixture was then placed on a gyratory shaker for at least thirty minutes at 200 RPM. One liter of the supernatant was decanted and added to nine liters of dilution water. The total dilution was 100-fold. Ten- and thirty-fold dilutions will also be used to determine the differences in removal efficiencies of bioretention systems receiving different concentrations of pollutants (ASCE, 1999). All glassware was sterilized in a steam autoclave prior to use.

Figure 3: Photo of bioretention columns.

<u>*Experimental methods*</u>

Manure slurry was applied to the top of the column at a rate of 77 mL/minute for two hours using a peristaltic pump. This rate was based upon a 1.25-inch rainfall event over two hours, the storm event considered to be ideal for water quality research by the NJDEP. A rational method runoff coefficient of 0.8 was assumed, and the bioretention area was assumed to be 5% of the drainage area (Davis *et al.*, 2001). Approximately fifteen simulated storm events will be conducted on each column by the end of the study. Each column will receive differently-diluted manure slurry, as discussed earlier. Simulated storm events were conducted at least one week after each other to allow for complete drainage and drying (Davis *et al.*, 2001).

The manure slurry was sampled before it was applied to the column. To determine a "background die-off rate" of FC bacteria, two identical samples of the influent slurry were collected. One was left open to the atmosphere for a known time period while the other was plated and incubated immediately. Leachate samples were collected from the bottom spout at approximately one-hour intervals from the time of first appearance; leachate flow rate was also determined. The pH and temperature of all samples was measured using pH/temperature meter at the time of collection. Samples were stored in an ice-filled cooler during transport to the laboratory. Samples for TSS analysis were collected in 500 mL high-density polyethylene jars. Samples for FC analysis were collected in sterile 15 mL glass culture tubes with sterile high-density polyethylene screw caps.

Samples were analyzed for FC using the delayed incubation method from *Standard Methods* (AWWA, 2001). Samples were filtered onto sterile 0.45 µm, 0.47 mm diameter gridded membranes by vacuum filtration. Membranes were plated into sterile 0.5 mm Petri dishes with adsorbent pads soaked with 2 mL of sterile FC broth (with rosolic acid). All instruments were steam-sterilized prior to use. Petri dishes were incubated for 24 hours in a 44.5^{o} C water bath. All samples were plated in triplicate. Influent samples of the 100-fold dilution manure slurry were filtered in 0.1 and 1 mL volumes. Leachate samples were filtered in 1 and 10 mL volumes. All samples were simultaneously analyzed for TSS using *Standard Methods* (AWWA, 2001).

When all storm events are completed, the material from the columns will be sampled at different depths and analyzed for FC bacteria. A slurry will be prepared using each of these samples. The slurries will then be analyzed for FC using the delayed incubation method. This analysis will be compared with background data obtained on the soil before experimentation.

RESULTS

Results at the time of this conference paper are preliminary. To date, five simulated storm events were conducted using the 100-fold dilution manure slurry. A removal efficiency ratio was calculated for each simulated storm event by subtracting the influent concentration from the average leachate event mean concentration (EMC). The EMC is defined as: $EMC = \frac{\sum_{i=1}^{n} V_i C_i}{\sum_{i=1}^{n} V_i}$, where V_i = the volume of flow during period i, C_i=the concentration associated with period i, and n = the total number of measurements taken during an event. V_i was estimated using observed flow rate values (ASCE, 1999). TSS removal was generally high with an average ratio of 92.3% and range of 82.5-99.4%. FC count reductions were generally high, with an average ratio of 87.8% and a range of 54.7-99.7%. The turbidity was observed to be significantly lower in leachate samples (see Figure 4). On average, the pH and temperature of the influent was 7.14 and 25.4 ^{o}C, respectively. The pH and temperature of the leachate was 4.71 and 22.9 ^{o}C, respectively.

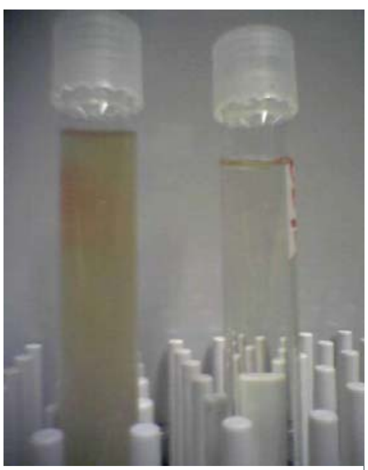


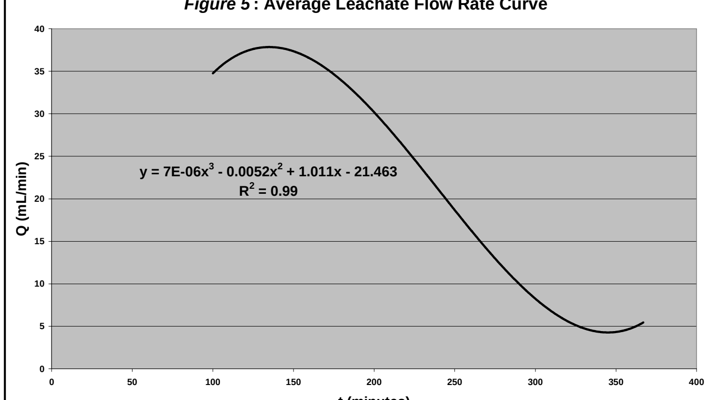
Figure 4: Photo of an influent sample (left) and a leachate sample (right).

In general, it took one hour before leachate water was observed in the bottom spout. A curve was fitted to all leachate flow rate data versus time (Figure 5), and the maximum percolation rate was observed to be approximately 37 mL/minute. Ponding occurred in the top of the column during every simulated storm event, although its maximum height never surpassed 12 inches. NJDEP specifications require no more than 12 inches of ponded water for bioretention systems.

DISCUSSION

Currently the data is preliminary but looks consistent with regard to bioretention removal efficiency. Both FC and TSS were reduced by the bioretention column. This supports the idea that FC bacteria are associated with particles greater than or equal to 2μm in diameter. It is likely that a combination of filtration and adsorption is primarily responsible for FC and

Figure 5 : Average Leachate Flow Rate Curve



TSS retention within the system. Bouwer (1984) reported that filtration generally occurs when the diameter of suspended particles is larger than 0.2 times the diameter of particles constituting the porous media. It is also likely that filtration is more effective during unsaturated conditions when transport takes preferential flow paths through the smallest pores (Stevik *et al.*, 2004). The presence of macropores or channeling in the media will have reduced the filtration capacity of the bioretention column. Water that flows along the sides of the bioretention column is also less effectively filtered. Macropores surrounding the mulch were observed through the clear PVC. In areas of the media where pore spaces are large, adsorption is the dominant physical mechanism for retaining FC and TSS (Sharma *et al.*, 1985). Adsorption of bacteria is influenced by physical, chemical and microbiological factors including the size and texture of porous media, presence of organic matter and biofilm, temperature, flow rate, ionic strength, pH, hydrophobicity, chemotaxis and electrostatic charge (Stevik *et al.*, 2004).

In addition to filtration and adsorption mechanisms, other mechanisms are responsible for acting directly on the bacteria regardless of their association with particulates. The primary mechanism is the pH. Bacterial survival decreases with non-neutral pH values (Sjogren, 1994). Sjogren (1994) reported negative survival of *E. coli* bacteria in more acidic soils. Considering the average observed pH value of the leachate was 4.71, a portion of FC bacteria did not survive the bioretention column. The peat portion of the bioretention soil planting bed media likely contributed to the acidity of the system. Increased temperature relates to a decrease in bacterial survival. Differences between observed influent and leachate temperature (i.e., 25.4 ^{o}C and 22.9 ^{o}C respectively) show that temperature was probably not a factor in reducing FC bacteria survival. It is also likely that predation of FC bacteria by other microorganisms was a factor. Protozoa are the main predators of bacteria (Acea and Alexander, 1988). FC bacteria may have also been negatively affected by competition for nutrients and inhibitory secretions from other microorganisms (Stevik *et al.*, 2003).

Clogging of the system with the accumulation of stable solids and bacterial biofilm build-up is likely to occur over time. This should enhance the filtration and adsorption capacity of the system by limiting pore space size (Stevik *et al.*, 2004). However, the benefits will later be surpassed by the system's inability to meet required percolation rate specifications.

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