Pathogen Removal Performance of Best Management Practices In Charlotte and Wilmington, North Carolina

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Abstract: *Pathogens are a target pollutant in many parts of North Carolina, particularly in areas that drain to shellfish waters. Single storm limits have been established for pathogen indicators in fresh water (200 cfu/ 100 ml for fecal coliform,* 126 col/100 ml for *E. coli, and 33 cfu/100 ml for enterrococcus) and marine waters (35 cfu/100 ml for enterrococcus) being used as full body recreational areas in an attempt to reduce public health risks. Runoff samples collected in coastal counties have often exceeded fecal counts of 20,000 cfu/ 100 ml (Bright 2007). The NCSU Biological and Agricultural Engineering Department monitored 14 total stormwater BMPs, 9 in Charlotte, NC, and 5 in Wilmington, NC, to evaluate their efficiency with respect to indicator bacteria removal. The study locations included 2 bioretention areas, 4 stormwater wetlands, 3 wet ponds, 2 dry detention, and 3 proprietary BMPs.*

Introduction

Pathogen pollution is a source of water quality degradation which impedes the initiative of the Clean Water Act "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." In the United States Environmental Protection Agency's (USEPA, 2002a) National Water Quality Inventory in 2000, 13% of the river and stream miles that were surveyed were impacted by bacteria (pathogens). Further, of the stream and river miles designated as impaired, either unable or partially unable to meet their designated use, more were impacted by pathogens than by any other pollutant or stressor (USEPA, 2002a). In light of the impact that pathogens and other pollutants have on surface waters in the United States, Total Maximum Daily Loads (TMDLs) are established to aid in reaching water quality goals in impaired water bodies.

Stormwater runoff is a transport mechanism for pathogens to surface and coastal waters. Pathogens come from both human and animal (domestic and wild) sources, and are transported through rainfall-runoff processes to nearby water bodies. A study by the Municipality of Anchorage Watershed Management Services (MOAWMS, 2003) stated that these transport mechanisms vary and are impacted based on land use, type of stormwater conveyance system, and the degree of stream modification. The study by MOAWMS indicated that fecal coliform loading is high in runoff that originates from landscaped areas associated with densely urbanized areas that are drained via curb and gutter conveyances. Schoonover and Lockacy (2006) found

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similar results in a study of 18 mixed land use watersheds in West Georgia, and determined that watersheds consisting of greater than 24% imperviousness exhibit higher fecal coliform concentrations than watersheds with impervious percentages less than 5% during both base flow and storm flow. Further, stormwater runoff from urbanized, coastal areas have often exceeded fecal counts of 20,000 cfu/ 100 ml (Bright 2007).

To test for the presence of harmful pathogens in surface waters, indicator species are used. Various indicator species have been used to assess water quality degradation due to pathogens including: total coliform, fecal coliform, *Escherichia coli* (*E. coli)*, and enterococci. In 1986, the EPA's Ambient Water Quality Criteria for Bacteria report (USEPA, 1986) discusses the merits of these various indicator species, and sets a criteria whereby *E. coli* and enterococci are used as indicators in freshwater environments and enterococci is suggested as an indicator in marine environments. This criteria states that for fresh waters designated for use as full body contact recreational waters, the geometric mean over a 30 day period should not exceed 126 col/100 ml for *E. coli* and should not exceed 33 col/100 ml for enterococci. For marine waters designated for use as full body contact recreational waters, the geometric mean over a 30 day period should not exceed 35 col/100 ml for enterococci.

Pathogens can be removed from surface waters and stormwater through a number of natural processes, such as ultraviolet light (from sunlight), sedimentation, filtration, and various environmental factors. These environmental factors can include temperature, moisture conditions, and salinity (USEPA, 2001; Schueler, 2000; Arnone, 2007; Davies-Colley et al., 1994). Urban stormwater is commonly treated by way of stormwater Best Management Practices (BMPs), each of which provides some combination of natural treatment mechanisms. These BMPs include wet ponds, dry detention basins, wetlands, bioretention areas, and proprietary devices.

Although BMPs have been studied in detail for many pollutants, little peer-reviewed literature is available which documents their ability to remove or inactivate pathogens. Nine sites in Charlotte, NC and 5 sites in Wilmington, NC were monitored to determine pathogen removal efficiency.

Site Descriptions

The stormwater BMPs evaluated in this project were monitored as part of the Charlotte – Mecklenburg Stormwater Services (CMSS) Pilot BMP Program and the Burnt Mill Creek Watershed Restoration program in Wilmington, NC. As part of these studies, grab samples were taken and analyzed for both fecal coliform and *E. coli* from 9 stormwater BMPs in Charlotte, NC, and for *E. coli* and enterococcus at 5 stormwater BMPs in Wilmington, NC. In Charlotte, data was gathered from two dry detention basins, one wet pond, two stormwater wetlands, one bioretention area, and three proprietary BMPs. In Wilmington, data were gathered from two wet ponds, two stormwater wetlands, and one bioretention area. Although data collection has been completed in Charlotte, the study in Wilmington was ongoing at the time of this publication. The characteristics of the BMPs from each city are given in Table 1.

Table 1: BMP and Watershed Characteristics

Site (Charlotte)	Watershed Size (ha)	Description	Estimated Curve Number
Dry Detention 1	2.4	Office Park - Buildings and Parking	85
Dry Detention 2	1.5	Office Park - Buildings and Parking	94
Wet Pond	48.6	Residential	75
Wetland 1	21	Residential	80
Wetland 2	6.4	Residential and School	83
Bioretention	0.4	Municipal Parking Lot	98
Proprietary 1	0.3	Bus Maintenance Facility – Parking and Overhead Shelters	98
Proprietary 2	0.9	Bus Maintenance Facility – Parking and Overhead Shelters	98
Proprietary 3	0.9	Bus Maintenance Facility – Parking and Overhead Shelters	98
Site (Wilmington)	**Watershed Size (ha)**	**Description**	**Estimated Curve Number**
Bioretention	0.14	Parking Lot	98
Wetland 1	12.7	School Parking Lot and Fields	73
Wetland 2	2.2	Single Family Residential	80
Wet Pond 1	4.7	Commercial	81
Wet Pond 2	3.85	Multi Family Residential	75

Dry detention basins fill with runoff during storm events and provide temporary detention while slowly draining over a span of approximately 48 hours. The primary pollutant removal mechanism in these systems is sedimentation. Charlotte, dry detention 1 was an extended dry detention basin which received runoff from a 2.4 ha watershed comprised of an office park and its associated parking areas, landscape features and buildings. The dry detention facility was well vegetated with grass and had good sun exposure. There was some evidence of erosion and sedimentation within the facility. Charlotte dry detention 2 was sited in a similarly sized watershed, 1.5 ha, also comprised of an office park. Like dry detention 1, this facility had good sun exposure, was well vegetated with grass, and had evidence of some erosion and sedimentation. Both facilities appeared to be mowed frequently. CMSS staff noted the frequent presence of birds around the basins, with bird droppings noted on the boxes which housed flow and water quality sampling equipment.

Wet ponds work on the principle of plug flow whereby influent runoff enters the pond and theoretically replaces the runoff that has been stored since then last storm event. Sedimentation in the basin is the primary pollutant removal mechanism as the stormwater slows, but some treatment is also provided via other mechanisms such as plant uptake, oxidation-reduction reactions, and adsorption as contact is made between the soils and plants in the pond and the captured stormwater. The Charlotte wet pond was fed by a small, perennial stream and received stormwater runoff from a 48.6 ha watershed that was primarily residential. This pond was likely not originally created for stormwater management, and was constructed with no detention component. The estimated age of the pond was between 50 and 70 years old. Waterfowl were frequently observed at the pond during site visits. The pond was retrofit in the late 1990's to include a littoral shelf; however, the shelf was not planted and exhibited little vegetation during the study period. Despite the presence of trees around the BMP, there was good exposure on the pond. Wilmington wet pond 1 received runoff from a 4.7 ha commercial property, the bulk of the impervious area for this watershed was a 2 ha parking lot. Wilmington wet pond 2 drained a 3.85 ha multi family residential area. The soils beneath this pond were Seagate fine sand, causing captured runoff to infiltrate more rapidly than is typical for wet ponds.

Wetlands are commonly installed as water quality devices, whereby they are sized to treat small (2.5 cm) storm events. These BMPs promote sedimentation much like wet ponds, but provide more intense contact between the captured stormwater and wetland soils and plants in a shallow system. Charlotte wetland 1 received stormwater from approximately 21 ha of residential area. This wetland exhibited common wetland topography, and consisted predominantly of shallow water depths. During the course of the study, however, there was very little vegetation in the wetland, likely due to poor soil conditions, prolonged periods of high water levels due to slow drainage, and the impact of waterfowl grazing. This lack of vegetation resulted in a larger amount of full sun exposure to water in the wetland than would typically be expected. Waterfowl were commonly observed at this site. Charlotte wetland 2 was constructed with similar topography, but exhibited exceptional plant growth. Charlotte wetland 2 received stormwater from 6.4 ha of residential area and a school. This wetland had two inlets, thus, weighted average influent fecal coliform and *E. coli* concentrations were calculated by weighting the grab samples at each inlet based on the total flow they contributed to the system. Wildlife was observed at Charlotte wetland 2 during the study. Wilmington wetland 1 treated runoff from 12.7 ha of a school, which included parking lots and practice fields. Wilmington wetland 2 treated runoff from a 2.2 ha single family residential area. This watershed is known to have elevated bacteria levels. The wetland was design in a manner that would increase sunlight penetration in an effort to increase bacteria removal. Wilmington wetland 2 is located in a park where residents congregate to exercise their pets, therefore, it is expected that pet waste contributes to elevated pathogen levels in the overland flow entering the wetland.

Bioretention areas are filtration and infiltration BMPs. Stormwater enters the system and passes through a permeable soil media where pollutants are filtered, functioning similarly to sand filter systems. The BMP may pond water as much as 6 to 12 inches; however, it is drained within 12 to 24 hours. The system is intended to dry out in-between storm events. The Charlotte bioretention site received stormwater from a highly impervious 0.4 ha parking lot. This bioretention cell was studied and described in detail by Hunt et al. (2008). On at least one occasion, a diaper was observed in the parking lot, providing a potential source of bacteria to the BMP. Additionally, trees in the parking lot attract birds, and evidence of bird droppings have been observed by CMSS staff. Sun exposure in the BMP was fair, as it was limited by fairly dense vegetation. Wilmington bioretention area was a sodden bioretention that treated the runoff from a 0.14 ha parking lot at the headquarters of a coffee shop chain. A nearby dumpster contributes to the influent pathogen load. Sun exposure is good in this BMP.

All three proprietary systems were installed at the Charlotte Area Transit System Bus Operations Maintenance Facility. The watersheds were small (Table 1) but highly impervious, and consisted of bus parking areas, and some overhead metal shelters. These systems were underground and thus received no sunlight. Proprietary 1 works by passing influent runoff through a system where floatables and settleables are separated and captured. Proprietary 2 works by forcing influent flows into a swirl pattern where settleables and floatables are forced to the center and into a separation chamber. Proprietary 3 works by routing stormwater through a series of manholes where floatables are captured and sedimentation occurs. Flows are controlled to allow full treatment through all chambers during small storm events and to allow decreased treatment, treatment only in the main chamber, during extreme events.

With such highly variable uses, design specifications for the BMPs varied. Thus, there are some inherent differences in the function of the BMPs selected for this study with respect to both hydrology and water quality, making normalization problematic. However, these BMPs were selected because they are representative of the types of BMPs common to the City of Charlotte, NC, the City of Wilmington, NC, and elsewhere.

Monitoring Methods

Charlotte

As part of the Pilot BMP Program, grab samples were taken due to the small sample hold times required of bacteriological samples (USEPA, 2002b). Grab samples were tested for fecal coliform and *E. coli*. Samples were collected at the various sites in Charlotte between March 2004 and October 2006. The monitoring period and number of samples collected at each site varied (Table 2). *E. coli* was not initially tested for in the bacteria grab samples, but was later added as a parameter. This explains the lower number of *E. coli* samples compared to the number of fecal coliform samples at a number of the sites.

Wilmington

Grab samples were also collected at each Wilmington, NC, site beginning in August of 2007. The samples from Wilmington were analyzed for enterococci and E. coli. Enterococci has proven to be a more reliable indicator species in environments with higher salinity (USEPA, 1986). Table 3 shows the number of samples collected at each site. Because of the abnormally low rain fall in 2007 and the beginning of 2008 few samples were collected and therefore, no analysis was possible.

Table 2: Monitoring Period and Number of Samples Taken at Each Study Location

Site	**Start**	**End**	**Number of Sample Tested For Fecal Coliform**	**Number of Samples Tested For *E. coli***
Dry Detention 1	Feb-05	Jul-06	9	9
Dry Detention 2	Jan-05	Dec-05	12	12
Wet Pond	Aug-04	Apr-06	14	10
Wetland 1	Mar-04	Jun-05	9	6
Wetland 2	Sep-04	Dec-05	15	10
Bioretention	Aug-04	Mar-06	19	14
Proprietary 1	Oct-05	Oct-06	7	7
Proprietary 2	Oct-05	Oct-06	6	6
Proprietary 3	Oct-05	Oct-06	6	6

Table 3 Number of samples taken at each Wilmington Study Site

Site (Wilmington)	**Number of *E. coli***	**Number of enterococcus**
Bioretention	1	1
Wetland 1	1	1
Wetland 2	2	2
Wet Pond 1	1	1
Wet Pond 2	1	1

Data Analysis

To adequately describe the bacteria sequestration and removal performance of each BMP, various analyses were performed. This included a calculation of concentration reduction efficiency and an analysis of effluent concentrations. The concentration reduction efficiency (CR) was calculated by averaging the concentration of the influent samples and the effluent samples that were collected and using them in equation 1 below:

Equation 1: CR = 1 – (average outlet concentration / average inlet concentration)

Statistical analysis was performed only on the Charlotte data due to the small sample set available for the Wilmington study at the time of this document. Data were transformed into the correct distribution and were tested for significant differences between the influent and effluent bacteria concentrations using a non-parametric Wilcoxon signed rank test. Lastly, the median effluent concentrations of fecal coliform and *E. coli* leaving each site were compared to the maximum 30-day geometric mean for each indicator as established by the USEPA for full body contact (EPA, 1986; EPA 1976). This will aid in evaluating not only the efficiency of pathogen removal for each system, but also the practicality of using stormwater BMPs to improve runoff from urban watersheds to pathogen concentrations equal to or below targeted concentrations.

Results and Discussion

Charlotte

Table 4 presents the results for fecal coliform and table 5 presents the results for E. coli for the BMPs studied in Charlotte, NC.

Any pathogen increase is likely due to either animal activity or from bacteria reproducing within the BMPs. For the majority of BMPs, a similar reduction (or addition) in concentration was noted for both fecal coliform and *E. coli*; however, some BMPs exhibited dramatically different concentration reductions for these two indicators. This was possibly due, in part, to the difference in the number of samples taken for each pathogen at a given site; however, even for sites with the same number of fecal coliform and *E. coli* samples, variations in the CR calculated for each pathogen existed (such as proprietary 1). This indicates that data generated for BMP removal of fecal coliform may not be applied to BMP removal of *E. coli*.

Table 4: Fecal Concentration Reduction Efficiency for BMPs in Charlotte, NC.

BMP Type	Median Influent (col/100ml)	Median Effluent (col/100ml)	Efficiency Fecal Coliform (%)	% of effluent samples under 200 col/100 ml
Dry Detention 1	2100	2100	-3%[1]	0
Dry Detention 2	1095	1345	-21%[1]	0
Wet Pond	7450	4500	57%	7
Wetland 1	6900	180	99%[2]	56
Wetland 2	7270	4600	70%[2]	13
Bioretention	2700	100	69%[2]	74
Proprietary 1	200	200	77%	43
Proprietary 2	225	26	-169%[1]	50
Proprietary 3	1750	2750	-381%[1]	0

1: Negative values indicate an increase in concentration
2: Significant reduction between the influent and the effluent

Table 5: *E. coli* Concentration Reduction Efficiency for BMPs in Charlotte, NC.

BMP Type	Median Influent (MPN/100ml)	Median Effluent (MPN/100ml)	Efficiency *E. coli* (%)	% of effluent samples under 126 MPN/100 ml
Dry Detention 1	2400	1700	5%	0
Dry Detention 2	1350	680	14%	8
Wet Pond	2400	2200	18%	10
Wetland 1	2400	145	92%[2]	50
Wetland 2	2117	1900	22%	10
Bioretention	515	19	71%[2]	86
Proprietary 1	21	33	-13%[1]	71
Proprietary 2	2	21	-186%[1]	83
Proprietary 3	186	173	-96%[1]	50

1: Negative values indicate an increase in concentration
2: Significant reduction between the influent and the effluent

For fecal coliform, the wet pond, wetland 1, wetland 2, bioretention area, and proprietary 1 exhibited greater than 50% removal. The high fecal coliform removal determined for wetland 1 and wetland 2, 99% and 70%, is similar to that found by Birch et al. (2004). Conversely, only one of the three wet ponds studied by Mallin et al. (2002) showed fecal coliform removal equal to or greater than 70%. For *E. coli*, only wetland 1 and the bioretention area provided high (> 50%) concentration reductions.

Overall, wetland 1 and the bioretention proved most proficient at reducing influent concentrations of both kinds of bacteria. Each practice had a substantial amount of sun exposure, likely leading to higher die off rates. Additionally, stormwater wetlands and bioretention areas facilitate sediment removal through sedimentation and, in the case of bioretention, filtration and drying.

The poorest performing BMPs were the two dry detention basins and proprietary devices 2 and 3. The two dry detention basins had good sun exposure but remained moist for a substantial period of time after each rain event (per CMSS staff observation). It is possible that the wet soil provided an environment where the pathogens could survive for an extended period of time. It should be noted that the proprietary devices, particularly proprietary 1 and 2, had low influent concentrations of both fecal coliform and *E. coli* relative to the other BMPs, potentially contributing to the low CRs for these systems.

Wilmington

E. coli and enterococcus data is presented in table 6 for the BMPs studied in Wilmington, NC. No statistical analysis was preformed on the Wilmington data due to the limited number of samples collected. Limited data also make trends in data difficult to observe. Additional data collection will potentially result in a better understanding of the effectiveness of the Wilmington BMPs in regard to pathogen removal.

Table 6: *E. coli* and Enterococcus Concentrations for BMPs in Wilmington, NC.

		E. Coli		**Enterococcus**	
BMP Type	**Date**	**Influent (CFU/100mL)**	**Effluent (CFU/100mL)**	**Influent (c/100m)**	**Effluent (c/100m)**
Bioretention	27-Aug-07	15,600	12,400	2,420	1,554
Wetland 1	27-Aug-07	25,600	108,800	2,420	2,420
Wetland 2	20-Oct-07	66,000	41,000	2,420	2,420
Wetland 2	20-Oct-07	28,600	9050	2,420	1,414
Wet Pond 1	20-Oct-07	57,000	6,400	2,420	687
Wet Pond 2	20-Oct-07	23,500	0	2,420	0

Conclusions

The results of this study support the literature that urban watersheds are a non-point source of bacterial pollution in surface waters. Even in watersheds consisting primarily of parking lots, concentrations of indicator bacteria entering BMPs can be higher than government assigned maximum values. Unfortunately, there are limited data regarding bacteria removal in the stormwater BMPs commonly used to treat runoff from these urban watersheds.

This study suggests that some stormwater BMPs may effectively sequester and remove bacteria. In particular, bioretention areas and wetlands showed promise in Charlotte, NC. The Charlotte bioretention area significantly ($P<0.05$) reduced both fecal coliform and *E. coli* concentrations from the inlet to the outlet with a concentration reduction efficiency of 69% and 71%, respectively. The Charlotte wetland 1, which performed better of the two wetlands monitored in Charlotte, was atypical due to its lack of vegetated growth. The shallow water depths present in wetland 1 (15 – 45 cm) and minimal vegetative coverage led to more sun exposure than would normally be expected in a stormwater wetland. This high sun exposure likely led to increased pathogen inactivation and removal by way of treatment by ultraviolet light. If the proper environment exists, it is also possible that stormwater BMPs can be sources of pathogens. This is due to both animal activity and to pathogen persistence and regeneration within BMPs. This was potentially the case for the two dry detention basins in Charlotte.

In the Charlotte study, positive concentration reductions were achieved by BMPs for both fecal coliform (5 of 9 BMPs) and *E. coli* (6 of 9 BMPs). However, only the bioretention area provided a positive concentration reduction and a median effluent concentration lower than USEPA targeted concentration for both fecal coliform and *E. coli*. Wetland 1 had an effluent concentration below the targeted value for fecal coliform, but not for *E. coli*. It should be noted that median influent indicator bacteria concentrations were higher for wetland 1 than for the bioretention. Therefore, some bias might be present based on the bioretention area receiving runoff with lower influent concentrations than either of the wetlands or the wet pond. Further study is necessary to determine if the effluent of various stormwater BMPs can reach USEPA targeted values. Additional study is also recommended for proprietary systems with higher influent concentrations of fecal coliform and *E. coli* over a larger number of events.

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