Field Evaluation of Indicator Bacteria Removal by Stormwater BMPs in North Carolina

J.M. Hathaway[1*,] W. F. Hunt[2], J.D. Wright[3] and S.J. Jadlocki[4]

[1] Graduate Research Assistant, [2] Assistant Professor and Extension Specialist, and [3] Extension Associate, Department of Biological and Agricultural Engineering, North Carolina State University, Campus Box 7625, Raleigh, NC 27695; email: jon_hathaway@ncsu.edu
[4]Charlotte-Mecklenburg Storm Water Services, Charlotte, N.C., USA

Abstract: In the United States Environmental Protection Agency's National Water Quality Inventory in 2000, 13% of the river and stream miles that were surveyed were impaired by pathogen indicator bacteria (USEPA 2002). Stormwater runoff is a transport mechanism for indicator bacteria to receiving waters, resulting in an increased risk to public health through consumption of contaminated shellfish or ingestion by swimmers. Urban stormwater is commonly treated by stormwater Best Management Practices (BMPs), each of which provides some combination of natural treatment mechanisms and fosters certain environmental conditions. Although BMPs have been studied in detail for many pollutants, little peer-reviewed literature is available which documents their ability to remove or inactivate indicator bacteria. The North Carolina State University Department of Biological and Agricultural Engineering evaluated 10 stormwater BMPs in Charlotte and Wilmington, NC, to evaluate their efficiency with respect to indicator bacteria removal. The study practices included two bioretention cells, four stormwater wetlands, two wet ponds, and two dry detention areas. Data collected from these studies indicates that positive removal of indicator bacteria is possible in many types of BMPs; however, removal can be highly variable from practice to practice. Further, stormwater BMPs may foster environments where indicator bacteria can persist, becoming sources of indicator bacteria. Finally, even if positive reductions in indicator bacteria are noted, research indicates that achieving effluent concentrations of indicator bacteria consistent with USEPA standards may be difficult with many types of BMPs.

Introduction

In the United States Environmental Protection Agency's (USEPA 2008) National Water Quality Inventory in 2006, approximately 12% of the river and stream miles that were surveyed were impaired by indicator bacteria. Of the stream and river miles designated as impaired, either unable or partially unable to meet their designated use, more were impacted by this pollutant than by any other. Indicator bacteria were also the number one source of impairment in bays and estuaries, the number two source of impairment in oceans and near coastal areas, and the number three source of impairment along coastal shorelines (USEPA 2008). In light of the negative impact that indicator bacteria have on surface waters in the United States (indicating the possible presence of pathogens), TMDLs have been established for impaired water bodies. Municipalities across the country are exploring options to reduce indicator bacteria inputs from point and non-point sources.

Numerous studies have indicated that development in watersheds leads to increased export of indicator bacteria. In a study of 18 mixed land use watersheds in West Georgia, Schoonover and Lockacy (2006) indicated that watersheds consisting of greater than 24% imperviousness exhibit higher fecal coliform concentrations than watersheds with impervious percentages less than 5% during both base and storm flow. Studies by Line et al. (2008) and Mallin et al. (2000) conclude similarly that urbanization in watersheds leads to increases in indicator bacteria export.

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) discussed the merits of these various indicator species, and set a criteria whereby *E. coli* and enterococci are suggested 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. The recommendation for fecal coliform, set in 1976 by the USEPA, is that the log mean over a 30-day period should not exceed 200 CFU/100ml (colony forming units per 100 ml) and no more than 10 percent of the samples should exceed 400 CFU/100ml (USEPA 1976).

Indicator bacteria 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 indicator bacteria. Six sites in Charlotte, NC, and 4 sites in Wilmington, NC, were monitored to determine indicator bacteria 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 6 stormwater BMPs in Charlotte, NC, and 4 stormwater BMPs in Wilmington, NC. In Charlotte, data were gathered from two dry detention basins, one wet pond, two stormwater wetlands, and one bioretention area. In Wilmington, data were gathered from one wet pond, 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
Site (Wilmington)	**Watershed Size (ha)**	**Description**	**Estimated Curve Number**
Bioretention 2	0.14	Parking Lot	98
Wetland 3	12.7	School Parking Lot and Fields	73
Wetland 4	2	Mulit-Family Residential	80
Wet Pond 2	4.7	Commercial	81

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. Wet pond 2 in Wilmington, NC, received runoff from a 4.7 ha commercial property which included a highly impervious 2 ha parking lot.

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 shallow a 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 3 treated runoff from 12.7 ha of a school, which included parking lots and practice fields. Wilmington wetland 4 is located in a multi-family residential complex. This wetland exhibits high amounts of infiltration in between storm events resulting in a normal pool where water is held mostly inside the deep pools.

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 2 was a sodded bioretention that treated the runoff from a 0.14 ha parking lot at the headquarters of a coffee shop chain. The Wilmington bioretention area is broken into two paired cells, one with a 30 cm (1-foot) soil depth and one with a 60 cm (2-foot) soil depth. Observations have been made that the 30 cm deep cell receives more stormwater due to parking lot grading. This cell characteristically appears to stay more moist, likely due to the shallow soil depth and greater watershed area. Detailed surveys of the watershed area for the Wilmington bioretention area are planned to determine the exact sub-watersheds for each cell. Sun exposure at the Wilmington bioretention area is high.

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, 2002). 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).

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.

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

Table 3 Number of samples taken at each Wilmington Study Site

Site (Wilmington)	Number of enterococci	Number of *E. coli* Samples
Bioretention 2	9	9
Wetland 3	9	8

Wetland 4	8	8
Wet Pond 2	8	8

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 determined by calculating the geometric mean of the influent and effluent indicator bacteria concentrations and using them in equation 1 below:

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

Lastly, the geometric mean 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 indicator bacteria removal for each system, but also the practicality of using stormwater BMPs to improve runoff from urban watersheds to indicator bacteria concentrations equal to or below targeted concentrations.

Results and Discussion

Table 3 presents the results for fecal coliform and Table 4 presents the results for E. coli for the BMPs studied in Charlotte, NC. Table 4 presents the results for *E. coli* and table 5 presents the results for enterococcus for the BMPs studied in Wilmington, NC. It should be noted that not all BMPs exhibit similar performance for both indicator bacteria for which they were tested. This indicates that BMP removal percentages generated for one indicator bacteria may not be applicable to other types of indicator bacteria data.

For the Charlotte BMPs, the wet pond, wetland 1, wetland 2, and bioretention area, exhibited greater than 50% removal of fecal coliform. 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) and Davies and Bavor (2000). 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. Wetland 1 had good sun exposure, likely leading to higher die off rates. Stormwater wetlands and bioretention areas also facilitate sediment removal through sedimentation and, in the case of bioretention, filtration and drying. All of these factors likely have some impact on indicator bacteria removal in stormwater BMPs. The poorest performing BMPs were the two dry detention basins. These systems 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 indicator bacteria could persist for an extended period of time. Bird droppings were also noted by staff, likely leading to additional bacteria inputs to the BMP.

Table 3: Fecal Concentration Efficiency for BMPs in Charlotte, NC.

BMP Type	Fecal Coliform Concentrations (col/100ml)		
	Geometric Mean Influent	Geometric Mean Effluent	Concentration Reduction[1]
Dry Detention 1	1985	2873	-0.45
Dry Detention 2	1327	1590	-0.20
Wet Pond	9033	2703	0.70
Wetland 1	9560	184	0.98
Wetland 2	8724	3874	0.56
Bioretention	2420	258	0.89

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

Table 4: *E. coli* Concentration Efficiency for BMPs in Charlotte, NC.

BMP Type	*E. Coli* Concentrations (MPN/100ml)		
	Geometric Mean Influent	Geometric Mean Effluent	Concentration Reduction
Dry Detention 1	915	1121	-0.22
Dry Detention 2	655	658	0.00
Wet Pond	2122	1153	0.46
Wetland 1	2400	106	0.96
Wetland 2	1295	864	0.33
Bioretention	241	20	0.92

For the Wilmington BMPs, the deep Bioretention cell 2, Wet Pond 2, and Wetland 4 all showed a fair ability to remove both types of indicator bacteria. The best performing of the BMPs was the Wet Pond 2, which removed a high percentage of *E. coli* and enterococcus. Further investigation is planned to determine factors which may lead to the high concentration reduction noted for this site. There is good sun exposure to the Wet Pond, potentially aiding bacteria removal. Studies by Mallin et al. (2002) and Davies and Bavor (2000) showed variable performance by Wet Ponds; however, two of the wet ponds evaluated in Wilmington, NC, by Mallin et al (2002) did show concentration reductions of greater than 50%.

Wetland 4 showed good performance for both indicator bacteria while Wetland 3 only removed enterococcus. However, influent *E. coli* concentrations to Wetland 3 were low, having a geometric mean of 255 MPN / 100 ml. It is possible that some natural background concentration of indicator bacteria is present and low influent concentrations of indicator bacteria result in poor performance when the data is evaluated using percent removal metrics.

Perhaps the most interesting relationship in the Wilmington data is the performance of the deep Bioretention 2 compared to the shallow Bioretention 2. The shallow cell showed poor performance for both *E. coli* and enterococci, and essentially acted as a source of bacteria. Further investigation of this cell has revealed that the shallow cell is potentially more moist due to a larger drainage area and shallow soil. This would provide a more favorable environment for indicator bacteria persistence and is concerning considering the potential for indicator bacteria removal that is seen in Bioretention 1 in Charlotte, NC, and in bioretention soil column studies performed by Rusciano and Obropta (2007).

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

BMP Type	*E. Coli* Concentrations (MPN/100ml)		
	Geometric Mean Influent	Geometric Mean Effluent	Concentration Reduction
Bioretention 2 (shallow cell)	111	792	-6.11
Bioretention 2 (deep cell)	111	44	0.60
Wetland 3	255	293	-0.15
Wetland 4	1315	720	0.45
Wet Pond 2	1621	83	0.95

Table 6: Enterococci Concentration Efficiency for BMPs in Wilmington, NC.

BMP Type	Enterococci Concentrations (MPN/100ml)		
	Geometric Mean Influent	Geometric Mean Effluent	Concentration Reduction
Bioretention 2 (shallow cell)	248	576	-1.32
Bioretention 2 (deep cell)	248	35	0.86
Wetland 3	1617	827	0.49
Wetland 4	2198	861	0.61
Wet Pond 2	497	52	0.89

Analysis of the geometric mean effluent concentrations from all BMPs reveals that not every BMP was able to reach EPA target concentrations for surface waters. The bioretention areas showed good performance for indicator bacteria. Other than the shallow bioretention cell, target concentrations were approached for fecal coliform, *E. coli*, and enterococcus via the bioretention cell in Charlotte, NC, and the deep bioretention cell in Wilmington, NC. Wetland 1 was also able to reach target concentrations for fecal coliform and *E. coli*, and Wet Pond 2 was able to reach or approach target concentrations for *E. coli* and enterococcus.

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. Stormwater BMPs in both Charlotte, NC, and Wilmington, NC, were able to reduce indicator bacteria concentrations by over 50%. Bioretention cells in Charlotte, NC, and Wilmington, NC, performed well; however, the shallow bioretention cell in Wilmington, NC, indicates that some design features may impact the ability of a bioretention area to remove indicator bacteria. The Charlotte Wetland 1, which performed well for both fecal coliform and enterococcus, 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 may have led to increased indicator bacteria inactivation and removal by way of exposure to ultraviolet light. The substantial indicator bacteria removal in Wilmington Wet Pond 2 must be further explored to determine factors leading to its performance.

If the proper environment exists, it may be possible for stormwater BMPs to be sources of indicator bacteria. This may be due to both animal activity and to indicator bacteria persistence within BMPs. This was potentially the case for the two dry detention basins in Charlotte and the shallow Bioretention 2 studied in Wilmington, NC. This emphasizes the need for further study as to which environmental factors impact indicator bacteria sequestration, inactivation, and persistence in stormwater BMPs.

Acknowledgements

The authors would like to thank Charlotte – Mecklenburg County Stormwater Services for funding the research in Charlotte, NC, and collecting the data discussed herein. In particular, the authors thank Ron Eubanks, John Beller, and Jeff Price for their sample collection and analysis. The authors also would like to thank the Cape Fear River watch for their support with samples collection in Wilmington, NC. In particular, the authors wish to thank Joe Abbate.

References

Arnone, R.D. and J.P. Walling. (2007). “Waterborne Pathogens in Urban Watersheds.” *Journal of Water and Health*. 5(1): 149-162.

Davies, C.M. and H.J. Bavor. (2000). “The fate of stormwater-associated bacteria in constructed wetland and water pollution control pond systems.” *Journal of Applied Microbiology*, 89, 349-360.

Davies-Colley, R.J., R.G. Bell, and A.M. Donnison.(1994). “Sunlight Inactivation of Enterococci and Fecal Coliforms in Sewage Effluent Diluted in Seawater.” *Applied and Environmental Microbiology*. 60(6): 2049-2058.

Hunt, W.F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, and P.R. Eubanks. (2008). "Pollutant Removal and Peak Flow Mitigation by a Bioretention Cell in Urban Charlotte, NC." *Journal of Environmental Engineering*. 134(5): 403-408.

Line, D.E., J. Wu, J.A. Arnold, G.D. Jennings, and A.R. Rubin. (1997). "Water quality of first flush runoff from twenty industrial sites." *Water Environment Research*, 69(3), 305 – 310.

Mallin, M.A., K.E. Williams, E.C. Esham, and R.P. Lowe. (2000). "Effect of human development on bacteriological water quality in coastal watersheds." *Ecological Applications*, 10(4), 1047-1056.

Mallin, M.A., S.H. Ensign, T.L. Wheeler, and D.B. Mayes. (2002). "Pollutant removal efficacy of three wet detention ponds." *Journal of Environmental Quality*, 31, 654-660.

Rusciano, G.M. and C.C. Obropta. (2007). "Bioretention column ctudy: fecal coliform and total suspended solids reductions." *Transactions of the ASABE*, 50(4), 1261-1269.

Schoonover, J.E. and B.G. Lockacy. (2006). "Land Cover Impacts on Stream Nutrients and Fecal Coliform in the Lower Piedmont of West Georgia." *Journal of Hydrology*. 331:371-382.

Schueler, T. (2000). "Microbes and Urban Watersheds: Ways to Kill 'Em." Technical Note 67. Watershed Protection Techniques. 3(1):566-574.

USEPA. (1976). "Quality criteria for water." EPA-440/9-76-023, Office of Water, Washington, DC.

USEPA. (1986). "Ambient Water Quality Criteria for Bacteria – 1986." EPA 440/5-84-002. Office of Water, Washington, DC.

USEPA. (2001). "Protocol for developing Pathogen TMDLs." EPA-841-R-00-002. Office of Water, Washington, DC.

USEPA and American Society of Civil Engineers. (2002). "Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater Database Requirements." U.S. EPA. EPA-821-B-02-001. Washington, DC.

USEPA. (2008). "Water quality assessment and total maximum daily loads information (ATTAINS)." < http://www.epa.gov/waters/ir/index.html> (November 29, 2008)