URBAN Waterways

Removal of Pathogens in Stormwater

Controlling pathogens in runoff presents a growing challenge for stormwater managers and designers. This fact sheet provides an overview of pathogens: what they are, how they affect people, and how they are regulated; describes their association with stormwater runoff; and investigates stormwater management practices that may limit pathogen presence in surface waters.

WHAT ARE PATHOGENS?

Microorganisms are common in the natural environment, often performing beneficial functions such as cycling nutrients, decomposing organic matter, and enhancing plant productivity through symbiotic relationships. The term *microorganism* generally refers to many different organisms including bacteria, protozoa, and fungi. Although often beneficial, some types of microorganisms can cause sickness when they enter the human body during consumption of contaminated shellfish, ingestion during water-related recreational activities, and even through skin contact with contaminated waters (USEPA 2001). Microorganisms (and viruses) that can cause illness are referred to as pathogens and are a major concern when they are present in streams, lakes, and marine waters. Common examples of Pathogens we presented in Figure and Table 1.

HOW DO WE KNOW IF A WATER BODY IS CONTAMINATED BY PATHOGENS?

Indicator species are used to test for the presence of harmful pathogens in surface waters. Although these species are normally not harmful to humans, their presence in surface waters can indicate contamination from the fecal matter of warm-blooded animals, a source of pathogens. 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 North Carolina, freshwater systems (class C, Table 2) are commonly evaluated using fecal coliform as an indicator. The geometric mean of at least five water quality samples (normally "grab" samples) taken over a month must not exceed 200 per 100 milliliters (400/100 ml should not be exceeded in more than 20 percent of these samples). Additionally, standards have been established for fecal coliform in waters designated for shellfish harvesting (SA waters), with the targeted geometric mean being no higher than 14 per 100 milliters (43/100 ml should not be exceeded in more than 10 percent of these samples). Enterococcus is commonly used in marine waters as an indicator in shellfish harvesting waters (SA), primary recre-

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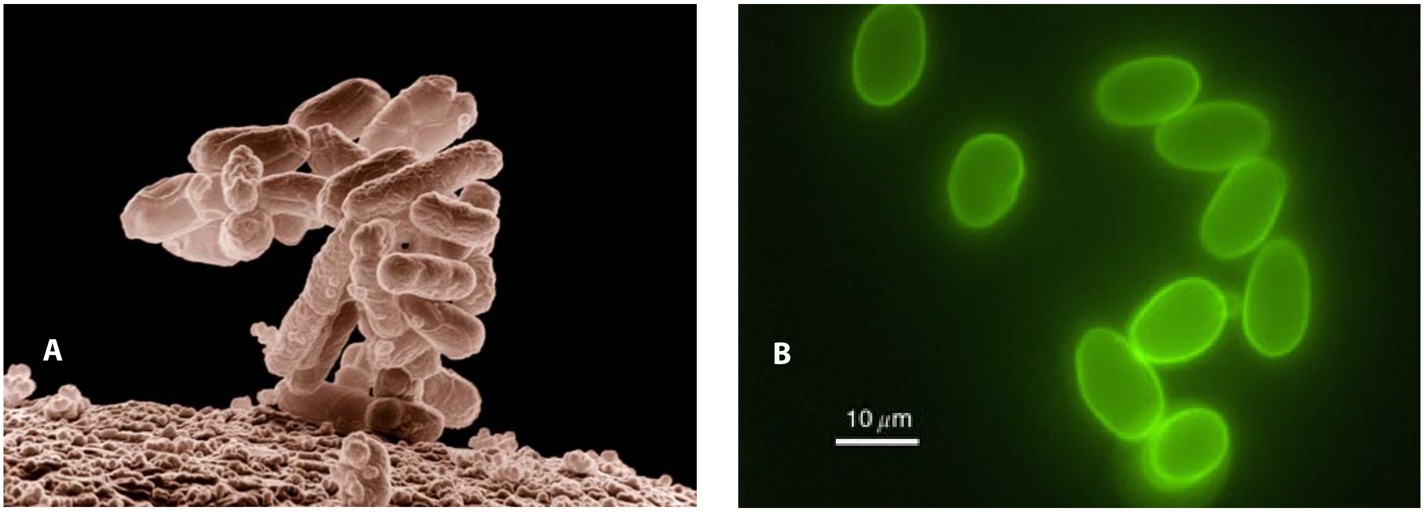

Figure 1: (A) Electron micrograph of *E. coli* cluster (U.S. Department of Agriculture – Agricultural Research Service) (B) Immunofluorescence image of *Giardia lamblia* cysts (H.D.A Lindquist, U.S. EPA)

Table 1: Pathogen types, descriptions, and example

Type	Brief Description	Example Pathogens (disease)
Bacteria	Single-celled organism with no nuclear membrane. Cell structure is simple, containing few organelles.	*Salmonella* (Salmonellosis), *Escherichia coli* 0157:H7 (Gastroenteritis), *Vibrio cholera* (Cholera), *Salmonella typhi* (Typhoid fever)
Protozoa	Single-celled organism, genetic material enclosed in nuclear membrane. Described as microfauna. Often feed on bacteria, algae, and other microorganisms.	*Giardia lamblia* (Giardiasis), *Cryptosporidium* (Cryptosporidiosis), *Entamoeba histolytica* (amoebic dysentery)
Virus	Infectious agent consisting (structurally) of either DNA or RNA covered in a protein coat.	Hepatitis A (infectious hepatitis), Rotavirus (Gastroenteritis), Adenovirus (respiratory disease, gastroenteritis)

Table 2: Description of various water classes in North Carolina (NCDWQ, *Surface Waters and Wetlands Standards,* 2007)

Class of Water	Description
C	Freshwater systems protected for secondary recreation (humans are only partially immersed in water, as when kayaking or rafting), fishing, and the propagation and survival of wildlife and aquatic life. All freshwater systems are classed at least as C to protect these minimum uses.
SA	Saltwater systems suitable for commercial fishing and all other tidal saltwater uses.
SB	Saltwater systems protected for primary recreation (humans are completely immersed in water, as when swimming and diving), fishing, and the propagation and survival of wildlife and aquatic life.
SC	Saltwater systems protected for fishing and the propagation and survival of wildlife and aquatic life. All saltwater systems are classed at least as SC to protect these minimum uses.

ation waters (SB), and in secondary recreation/aquatic propagation/aquatic protection waters (SC, Table 2). The standard for enterococcus in these waters is a geometric mean of 35 per 100 milliliters.

The U.S. Environmental Protection Agency (EPA) is currently promoting the use of either *E. coli* or enterococcus, rather than fecal coliform, as a bacterial indicator in fresh water because a stronger correlation between these two indicators and illness in recreational waters has been identified. The suggested target geometric mean in fresh waters is 126 per 100 milliliters for *E. coli* and 33 per 100 milliliters for enterococcus. Table 3 summarizes the current target pathogenic indicator bacteria concentrations for each class of water in North Carolina. For a further description of indicator bacteria, see EPA report number 841-R-00-002, "Protocol for Developing Pathogen TMDLs."

Table 3: Water quality standards for indicator bacteria in North Carolina (NCDWQ, *Surface Waters and Wetlands Standards*, 2007)

Class of Water	Indicator	Geometric Mean (per 100 ml)
C	Fecal coliform	200
SA	Fecal coliform	14
SA	Enterococcus	35
SB	Enterococcus	35
SC	Enterococcus	35

SIGNIFICANCE OF PATHOGENS AS POLLUTANTS

In 2000, the EPA's National Water Quality Inventory revealed that 13 percent of the surveyed river and stream miles were impaired by bacteria (pathogenic indicator bacteria) (USEPA 2002). Of the stream and river miles designated as impaired—either unable or partially unable to meet their designated use—more were affected by pathogenic indicator bacteria than by any other pollutant or stressor (USEPA 2002).

Although pathogens are often thought of as pollutants affecting water quality in coastal areas, numerous streams throughout North Carolina are on the 303(d) list, a list of impaired waters sent to the EPA by each state every two years, for fecal coliform. The North Carolina Division of Water Quality (NCDWQ) reported in 2007 that river basins primarily located in the mountains and piedmont (the Catawba, French Broad, and Yadkin-Pee) had a combined total of 231 stream miles impaired by fecal coliform. These studies illustrate the importance of understanding and treating pathogen pollution throughout North Carolina.

WHAT IS A GEOMETRIC MEAN?

The geometric mean is similar to the average or arithmetic mean of a set of values; however, the geometric mean indicates the central tendency of the set, much as a median does. This is valuable when working with indicator bacteria because somewhat dramatic spikes and dips in bacteria measurements are not uncommon. Thus, using the geometric mean helps reduce the skew that such spikes can have on the calculated value for a given sample set and is considered a better metric for bacterial contamination.

Geometric mean $= (A_1 \times A_2 \times A_3 \ldots \times A_n)^{1/n}$
Where: A_1, A_2, etc. = a single sample in a given data set
n = number of samples in the data set

PATHOGEN SOURCES AND PRESENCE IN STORMWATER RUNOFF

Many pathogens are present in the fecal matter of both humans and animals (domestic and wild). These pathogens can enter surface waters in many ways, including through sewer pipe and septic tank leaks, by waterfowl and other animals defecating directly into water bodies, and through fecal matter that is transported via stormwater runoff (Figure 2). A study performed in North Carolina by Mallin, et al. (2000) indicated that as the amount of impervious area in a watershed increases, the amount of indicator bacteria monitored in nearby receiving waters seems to increase. Impervious areas indicate human activity and the associated presence of pet and vermin waste. Impervious areas also generate large amounts of runoff that is quickly transported to nearby surface waters, carrying pathogens with it.

Pathogen transport from urbanized areas to nearby surface waters presents a public health risk within both freshwater and marine environments. Extensive research has examined the impact of bacterial pollution on ocean and estuarine environments, where pathogens transported in stormwater and polluted streams can persist long enough to be consumed in contaminated shellfish or ingested by swimmers. Thus, there are economic and public safety concerns when pathogen pollution affects shellfish waters and recreational beaches (Figures 3a and 3b). For instance, according to the North Carolina Division of Marine Fisheries, over 33 million pounds of shellfish, valued at more than $32 million, were commercially fished from North Carolina in 2006. Likewise, water quality is important in maintaining recreational beaches: the North Carolina Department of Commerce estimated that 14 percent of visitor activities in 2006 were beach visits.

Figure 2: Waterfowl can produce substantial amounts of waste around urban ponds.

CAN WE TREAT PATHOGENS IN STORMWATER?

Pathogens can be removed from or inactivated in surface waters and stormwater through several treatment mechanisms, such as ultraviolet light (from sunlight), sedimentation, and filtration. Urban stormwater can be treated by implementing stormwater Best Management Practices (BMPs), each of which provides some combination of treatment mechanisms. Examples of stormwater BMPs are dry detention basins, wet ponds, wetlands, bioretention areas, and proprietary devices (Table 4). For more information on these BMPs, please see AG 588-1 Urban Stormwater Structural Best Management Practices.

Microbes require specific environmental conditions to thrive and survive. Intolerance to certain environmental conditions such as high or low temperature and pH, or predation from other microbes, can remove pathogens or cause die-off. BMPs commonly have moist soils and readily available nutrients, conditions that may be conducive to pathogen persistence. Additionally, there is concern that stormwater BMPs can be sources of pathogens. BMPs can attract wildlife including deer, waterfowl, rodents, and domestic animals. These animals defecate in and around the BMPs, resulting in direct pathogen inputs to the system. Ongoing research is being conducted at N.C. State University and elsewhere to determine if BMP designs can be manipulated to provide or enhance treatment mechanisms and environmental conditions that will stimulate pathogen inactivation and die-off.

Figure 3: (a) Closed shellfish waters in North Carolina (b) Posted warning sign at North Carolina beach.

Table 4: Description of various stormwater BMPs and theoretical pathogen removal mechanisms

BMP Type	Description	Treatment Mechanisms Relevant to Pathogen Removal
Dry detention basin	Fills during storm events, retains runoff for 1 to 2 days, and then slowly, but completely, drains. Remains dry between precipitation events. Primarily used for peak flow mitigation	Drying, sun exposure, sedimentation
Wet pond	Influent runoff theoretically replaces runoff captured from previous events (plug flow). Retains runoff for 1 or 2 days, and then slowly drains. Maintains water pool. Used for peak flow mitigation and some water quality improvement.	Sun exposure, sedimentation
Stormwater wetland	Fills during storm events, retains runoff for 1 or 2 days as it slowly drains. Maintains water pool. Has shallower water and more vegetation than wet pond. Normally used for water quality improvement, but can be used for peak flow mitigation.	Sun exposure, sedimentation, some drying
Sand filter	Runoff first enters a sedimentation chamber before flowing through a column of soil. Sand chamber is dry between events.	Drying, sedimentation, filtration
Bioretention	Similar to sand filter, runoff enters system and passes through a soil media, where it is filtered. May pond 6 to 12 inches. Primarily a water quality BMP. System is dry between events.	Drying, sun exposure, sedimentation, filtration
Grassed swales	Runoff flows through an engineered, grassed channel used to convey it from one location to another.	Sedimentation, sun exposure, drying
Proprietary devices	Use baffles, settling chambers, filtration, and other means to separate floatable solids and promote sedimentation. Primarily intended for water quality.	Varies based on manufacturer: normally sedimentation and sometimes filtration

HOW EFFECTIVE ARE STORMWATER BMPS IN REMOVING PATHOGENS?

Although BMPs have been studied in detail for many pollutants, only a few peer-reviewed studies, mostly of stormwater wetlands and wet ponds, have documented their ability to remove or inactivate pathogens. Studies performed on stormwater wetlands in Australia by Birch, et al. (2004) and Davies and Bavor (2000) showed mean fecal coliform of 76 percent and 79 percent, respectively. The average fecal coliform outflow concentration for each of the wetlands was higher than the EPA target value of 200 per 100 milliliters. Davies and Bavor (2000) also studied a wet pond receiving residential stormwater runoff. There was a 2.5 percent mean addition of fecal coliform based on weekly samples taken from the site. Davies and Bavor (2000) associated the poor performance of the wet pond, relative to the wetland, to its poor removal of fine clay particles to which the bacteria were "predominately absorbed." The mean effluent concentration of fecal coliform was 8100 per 100 milliliters.

Research was also conducted at three wet ponds in Wilmington, North Carolina, by Mallin, et al. (2002). The ponds were sampled monthly, regardless of whether the pond discharge was base flow or storm flow. The authors did not report the percentage of samples associated with wet weather. The average fecal coliform removal in the three ponds was 56 percent, 86 percent, and 13 percent, and a correlation was observed between fecal coliform concentrations and rainfall occurring within 24 hours of sampling. The average effluent fecal coliform concentrations for the three wet ponds was 70, 43, and 85 per 100 milliliters, respectively; however, only one of the wet ponds had an average influent fecal coliform concentration higher than the EPA targeted value of 200 per 100 milliliters (488 per 100 milliliters). These effluent concentrations also include samples taken during base flow. These studies suggest some variability in wet pond performance with regard to pathogen removal.

Most of the BMP data associated with pathogen removal is available in a database format through the International Stormwater BMP database (www.bmpdatabase.org). Analyses of this database by Clary, et al. (2008) and by the Center for Watershed Protection (2007) show the potential that BMPs offer for bacteria removal, but results vary among the different BMP types. Results also vary among BMPs in the same category. Due to the limited amount of literature pertaining to pathogen removal by stormwater BMPs, more research is needed to help communities throughout the United States reach their pathogen reduction goals.

RECENT RESEARCH AT N.C. STATE

Charlotte-Mecklenburg Stormwater Services conducted a study with the N.C. State University Biological and Agricultural Engineering department to assess the treatment capabilities of various types of stormwater BMPs in Charlotte, NC. Two stormwater wetlands, two wet ponds, two dry detention basins, a bioretention area, and four proprietary BMPs were monitored as part of this study. Enough bacteria data—no fewer than six samples—were collected from nine of these BMPs to begin to evaluate their performance for both *E. coli* and fecal coliform. Some of the results of this study are presented in Table 5.

These data indicate that some types of stormwater BMPs may effectively reduce indicator bacteria, and thus potentially pathogens, in stormwater. Specifically, the wet pond, two wetlands, bioretention area, and one of the proprietary systems showed positive fecal coliform removal (results vary to some degree for *E. coli*). Only the two wetlands and the bioretention area had statistically significant reductions. Despite these observed reductions in indicator bacteria concentration, reducing urban runoff to concentrations below North Carolina standards may be difficult using stormwater BMPs. For example, the data collected from the BMPs in Charlotte, NC, showed only one BMP produced effluent concentrations of fecal coliform below a geometric mean of 200 per 100 milliliters. This BMP was a stormwater wetland with poor vegetative growth, which possibly increased the exposure of indicator bacteria to UV radiation. The lack of vegetation is not an ideal characteristic for stormwater wetlands, as the vegetation provides aesthetic appeal, cools the outflow, uptakes nutrients, and aids in oxidation-reduction reactions (Figure 4). Research is ongoing elsewhere in North Carolina, with a number of stormwater BMPs being evaluated for pathogenic indicator bacteria removal.

Table 5: Fecal concentration reduction efficiency for BMPs in Charlotte, NC.

BMP Type	Geometric Mean Influent (per 100ml)	Geometric Mean Effluent (per 100ml)	Efficiency Fecal Coliform (%)	% of effluent samples under 200 (per 100 ml)
Dry Detention 1	1985	2873	-3[1]	0
Dry Detention 2	1327	1590	-21[1]	0
Wet Pond	9033	2703	57	7
Wetland 1	9560	184	99[2]	56
Wetland 2	8724	3874	70[2]	13
Bioretention	2420	258	69[2]	74
Proprietary 1	667	277	77	43
Proprietary 2	235	368	-169[1]	50
Proprietary 3	1472	2379	-381[1]	0

1: Negative values indicate an increase in concentration

2: Significant reduction between the influent and the effluent

Table 6: Relative pathogen removal capabilities of various stormwater BMPs

BMP	Proposed Fecal Coliform Removal Ability
Dry extended detention basin	Medium
Wet detention basin (wet pond)	Medium
Stormwater wetlands	Medium
Sand filter	High
Bioretention	High
Grassed swale	Low
Proprietary devices[1]	Likely varies based on design

(NCDENR – *Stormwater Best Management Practices Manual*, 2007)

[1] Category added to the table by authors

Figure 4: Substantial sun exposure at Wetland 1 in Charlotte, NC, possibly leading to low effluent concentrations of pathogen indicator species.

WHAT'S THE VERDICT?

Pathogen removal appears to vary not only by BMP type, but also among similar BMP types at various locations. The variations in bacteria removal efficiency within BMPs are not well understood; however, some performance assumptions can be inferred based on a scientific understanding of how microorganisms are sequestered and killed in the natural environment. The North Carolina Division of Water Quality's *2007 Stormwater BMP Manual* presented estimates of fecal coliform removal by BMP type. These estimates are a good starting point and are presented for a selected group of BMPs in Table 6. A more extensive list can be found in the *2007 Stormwater BMP Manual*.

Bioretention and sand filters are rated as "high" (Table 6). These systems have little input from animals due to their lack of exposed standing water, eliminating a common attraction for waterfowl. Sediment-bound pathogens are filtered in these systems during storms, and some sun exposure is provided in bioretention areas. These systems are designed to dry out between storms, potentially drying out pathogens at the same time.

Conversely, swales are rated as "low" (Table 6). Swales are attractive to animals such as dogs and are not necessarily intended to completely dry between storms, potentially providing an environment where pathogens can persist. Sediment (and the associated sediment-bound pathogens) may fall out of the runoff as it passes through the swale, but little permanent sediment sequestration occurs. Ongoing research in North Carolina and elsewhere in the United States seeks to not only determine how effective current stormwater BMP designs are for pathogen removal, but also what design features can be manipulated to enhance pathogen removal and decrease pathogen persistence in stormwater BMPs.

RESOURCES

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N.C. COOPERATIVE EXTENSION BULLETINS

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Hunt, W.F., and L.L. Szpir. 2006. Permeable Pavements, Green Roofs, and Cisterns: Stormwater Treatment Practices for Low-Impact Development. N.C. Cooperative Extension Urban Waterways Series, AG-588-06. http:// www.bae.ncsu.edu/stormwater/Publication Files/BMPs4LID.pdf

RELATED WEBSITES

www.bae.ncsu.edu/stormwater.NCSU BAE Stormwater Group Web site highlighting stormwater research projects and extension programs across N.C.

www.ncstormwater.org. State of North Carolina Stormwater Web site.

http://www.deh.enr.state.nc.us/shellfish/index.htm. NCDENR Shellfish Sanitation and Recreational Water Quality Section.

http://csi.northcarolina.edu/index.htm. University of North Carolina Coastal Studies Institute.

http://www.epa.gov/nerlcwww/index.html. United States Environmental Protection Agency Microbiology home page.

www.sph.unc.edu. University of North carolina at Chapel Hill-School of Global Public Health.

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