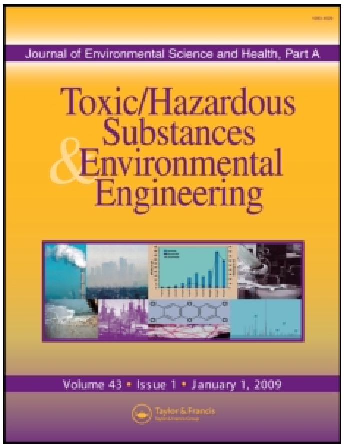

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Evaluation of Pathogenic Indicator Bacteria in Structural Best Management Practices

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This study evaluated the bacteria removal efficiency, re-suspension and survivability within two structural Best Management Practices (BMPs) called Vortechs installed at two different sites in Providence, Rhode Island. Twelve rain storms were sampled during years 2004 and 2005. Five pathogenic indicator bacteria, *E. coli*, *enterococci*, fecal *streptococci*, total coliform, fecal coliform, were analyzed. Results showed that Vortechs was effective in partial removal of pathogenic indicator bacteria (PIB, 39–86%), however, the PIB concentrations after Vortechs treatment were still significantly high, which could limit the use of receiving waters and raise concerns for public health. The indicator bacteria concentrations in the sump water were 1.2-2.6 times higher than that contributed by the incoming stormwater. This result suggests some bacteria were re-suspended from the sediments within the Vortechs. Low bacterial survivability of bacteria was found in the sump water at both sampling sites; however, much lower bacteria concentrations were detected at Site 2, suggesting a higher bacteria contamination from highway runoff.

Key Words: Best Management Practices (BMPs); Pathogenic indicator bacteria (PIB); Survivability; Re-suspension; Sump water.

INTRODUCTION

According to U.S. Environmental Protection Agency (USEPA)'s 1998 National Water Quality Inventory Report to Congress, about 40% of assessed US streams, lakes, and estuaries did not meet the criteria for locally designated uses such as fishing and swimming. High bacterial concentrations in stormwater runoff from agricultural and urban areas are a leading cause in the failures to meet designated use criteria.[1] Large concentrations of fecal coliform and pathogens such

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as *Pseudomonas aeruginosa* and *Staphylococcus aureus* in urban stormwater have been found.[2] Besides pathogenic organism, high concentrations of total suspended solids, organic pollutants, heavy metals are also commonly found in stormwater.[3]

Hydrodynamic separator units have been installed in many locations throughout the United States and abroad as structural Best Management Practices (BMPs). They are designed to treat stormwater runoff by capturing floatable debris, oil and grease and reducing Total Suspended Solids (TSS) concentrations.[4,5] However, fewer attempts have been made to study the fate and transport of bacteria within structural BMPs resulting in limited understanding of the treatment capacity of structural BMPs for bacterial removal. This paper evaluated the performance of one type of structural BMP, Vortechs, in bacterial removal as part of a large project to evaluate the performance of structural BMPs in stormwater management.

Indicator microorganisms are used to predict the presence of and/or minimize the potential risk associated with pathogenic microbes.[6] Indicator organisms are useful in that they circumvent the need to assay for every pathogen that may be present in water. Ideally, indicators are nonpathogenic, rapidly detected, easily enumerated, have survival characteristics that are similar to those of the pathogens of concern, and can be strongly associated with the presence of pathogenic microorganisms.[7]

Fecal coliform has commonly been used as an indicator organism in water quality examination.[6] Fecal coliform represents total pathogenic organisms present in various water. However, survival time for coliform bacteria is substantially less than that for many pathogens.[8] This complicates the efforts to correlate counts of fecal coliform bacteria with the densities of pathogens at any specific time. For these reasons, data on fecal coliform bacteria cannot in themselves be considered adequate for a thorough assessment of public health risks. Yet, fecal coliform bacteria continue to be used as an indicator because measurements of fecal coliform bacteria provide a basis for comparison with historical data.[8]

In 1986, EPA issued a revision to its bacteriological ambient water quality criteria recommendations to include new indicator bacteria, *E. coli* and *enterococci*, which provide better correlation with swimming-associated gastrointestinal illness than the previous criteria recommendations for fecal coliform bacteria.[9] *E. coli* is a member of fecal coliform group of bacteria. The presence of this organism in water indicates mammalian fecal contamination. It has good characteristics of fecal indicator, is normally nonpathogenic and is present at concentrations much higher than the pathogens it predicts.[10] *Enterococci* are a subgroup of fecal s*treptococci* indigenous to the intestines of warm blooded animals. Fecal *streptococci* can be used to indicate the contamination source from animals because animal feces contain higher levels of fecal *streptococci*.[11]

In this study, five indictor bacteria were monitored, including *E. coli, enterococci,* fecal *streptococci,* total coliform, and fecal coliform. The objectives of this study were to: (1) develop a "bacteria budget" to track influent and effluent bacteria concentrations as well as measuring the growth or reduction of bacteria within Vortechs; (2) determine the potential of bacteria re-suspension; and (3) determine the extent of bacteria survivability in Vortechs.

MATERIALS AND METHODS

Sampling Sites

Vortechs is a type of BMP structure. It has three major components: grit chamber, oil chamber and flow control chamber. This design ensures proper physical separation and capture of sediments and oil.[16] Two existing Vortechs Stormwater Treatment Units (Fig. 1) installed at two different sites in Providence, RI were selected for this study. They were selected based on their close proximity to one another (approximately a 5-mile radius) in order to maintain comparable rainfall and antecedent conditions. The model and configurations of each unit are shown in Table 1. Prior to the start of the study, these units were thoroughly cleaned on May 20, 2004 to ensure they were free of sediment, standing water and debris.

Rain Events Monitoring

Each rain event was monitored by a rain gauge (American Sigma Model 2459) located on the rooftop of the Department of Transportation in Providence, Rhode Island, which is 3 miles from the sampling sites. The rain gauge records the precipitation amounts in inches and the duration of each storm. It is connected to a computer to allow the rainfall data to be downloaded.

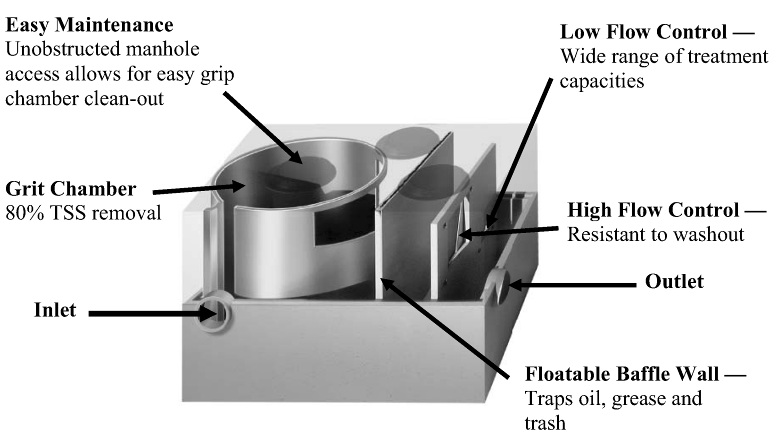

Figure 1: Vortechs stormwater treatment system (Stormwater 360, formerly Vortechnics, Inc.).

Table 1: Sampling sites.

	Site 2 (Fig. 2)	Site 1 (Fig. 3)
Location	Garfield Ave. In a parking lot in front of a restaurant	Charles Street next to Route 146 North Ramp
Model	11,000	7,000
Peak flow rate	17.5 cfs	11 cfs
Dimensions	16 ft × 10 ft	14 ft × 8 ft
Effluent is discharged to	Spectacle pond	A central piping system

Sampling

Studies were performed on 12 rain events (indicated by R1, R2, etc.) that had rainfall depths of at least 0.1 inch or greater. A grab sample of sump water and stream was taken from the second manhole above the Vortechs treatment unit (see Fig. 2) from Site 2 on May 6, May 13, and May 21, 2005 during dry weather conditions to establish background information on pathogenic indicator bacteria in the sump water and Spectacle Pond (i.e., stream). A grab sample of influent, effluent, sump water, and stream was taken within the first couple of hours of rain events R1, R11, and R12 to perform bacterial removal efficiency analysis. A grab sample of sump water was taken from the second manhole at 1 day, 3 days, and 5 days after the cessation of rainfall for the first ten rain events to compare bacterial survivability and concentrations at two sampling sites (see Figs. 2 and 3). For rain events 3 and 7, samples were also taken on the day that the rain occurred. Samples collected on the days it rained showed identical

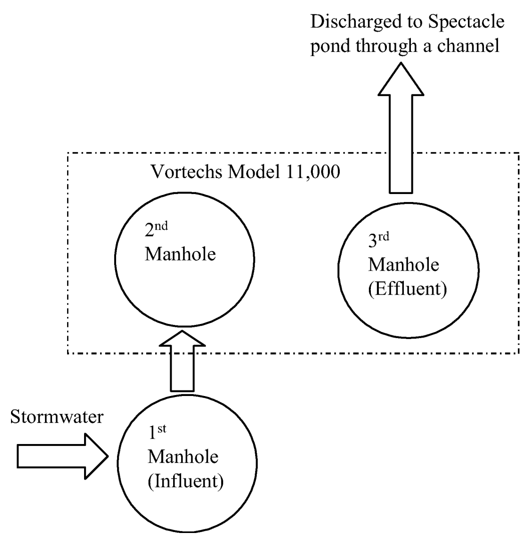

Figure 2: Location and schematics of sampling Site 2.

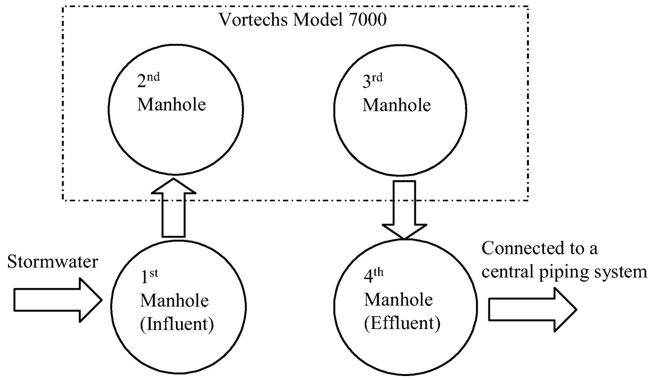

Figure 3: Location and schematics of sampling Site 1.

patterns to the samples collected one day after the rain ceased; therefore, the data points collected on the days it rained were lumped together with the data points collected one day after the cessation of rain for statistical analysis. The sump water was taken within 1 ft of the water surface using a swing sampler (RABCO, Inc.).

USEPA microbiology methods manual[12] was followed as a standard sampling procedure. Samples were collected in HDPE bottles, properly labeled, tagged, and stored in insulated ice containers at a temperature of 1–4°C and transited to the environmental laboratory at the University of Massachusetts, Lowell for immediate analyses.

Pathogenic Indicator Bacteria Analyses

Five pathogenic indicator bacteria (PIB) were analyzed in this study; *E. coli* (EPA Membrane filtration method 1603[14]), *enterococci* (EPA Method 1600, 1997), fecal *streptococci* (Membrane Filtration Method 9230A[11]), total coliform (MPN Method 9221B[11]), and fecal coliform (MPN Method 9221E[11]). For the membrane filtration methods, 10 mL of a diluted sample was passed through a membrane filter using magnetic filter funnel assembly (Gelman Sciences). For the MPN method, 1 mL of diluted sample was added into a culture tube filled with 9 mL media and an inverted Durham's tube.

Bacteria analyses were performed on all samples collected (influent, effluent, stream, and sump water). All bacterial analyses were initiated immediately after the samples arrived the lab, and finished within 8 hours after collection of the samples as required by the USEPA.[13] See Figure 4 for the experimental setup. Phosphate-buffered dilution water was used for serial dilutions. Throughout the study, all glassware, media, filtration units, and phosphate buffered dilution water were either sterilized by autoclaving or UV sterilization. Duplicates were run for each sample.

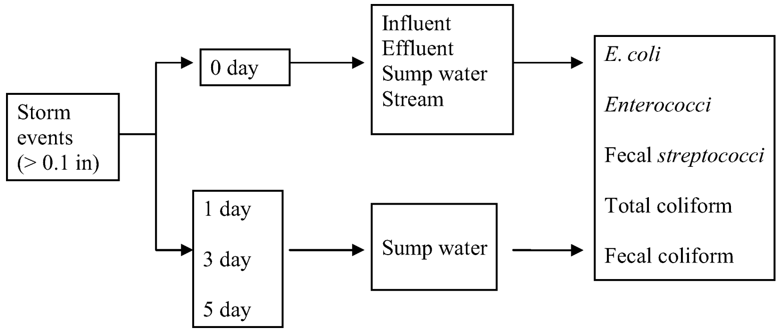

Figure 4: Experimental setup.

RESULTS AND DISCUSSION

Rainfall Record

Twelve rain events with each rainfall precipitations greater than 0.1 inch were sampled for the whole study. Ten events during the period of July 13, 2004 and December 17, 2004 were sampled to conduct bacteria survivability study. The average rainfall precipitation was 0.78 inches (ranging from 0.15 to 1.63 inches) and the average rainfall duration was 10.5 hours (ranging from 3.25 to 26 hours). Rain events 11 and 12 were sampled in 2005 and used together with the data from R1 to evaluate the bacterial removal efficiency by Vortechs. The average rainfall precipitation was 0.48 inches (ranging from 0.41

Table 2: Rainfall information.

Rain event	Rainfall date	Precipitation amount, in	Duration, h	Intensity, in/h
R1	7/13/2004	0.41	12.75	0.03
R2	7/18/2004, 7/19/2004	0.69	12	0.06
R3	7/24/2004	0.15	3.25	0.05
R4	8/15/2004	1.63	8.25	0.20
R5	8/31/2004	0.47	5.25	0.09
R6	10/16/2004	1.05	11.5	0.09
R7	10/19/2004	0.32	11.45	0.03
R8	11/4/2004	1.12	6.5	0.17
R9	12/1/2004	1.23	7.25	0.17
R10	12/10/2004	0.70	26.5	0.026
Summary of R1 through R10		0.78 ± 0.47*	10.47 ± 6.47	0.09 ± 0.06
R1	7/13/2004	0.41	12.75	0.03
R11	5/25/2005	0.46	18	0.026
R12	7/8/2005	0.57	20.5	0.03
Summary of R1, R11, R12		0.48 ± 0.08	12.42 ± 3.95	0.03 ± 0.00

*One standard deviations are shown in all tables.

Table 3: Background bacteria concentrations during dry weather.

Pathogenic indicator bacteria (CFU/100 ml or MPN/100 mL)	Sump water	Stream	Bacterial standards for recreational water use in Rhode Island[17]
E. coli	155 ± 169	183 ± 267	126
Enterococci	122 ± 79	110 ± 57	33
Fecal *streptococci*	227 ± 206	188 ± 227	
Fecal coliform	557 ± 648	550 ± 212	200
Total coliform			1,000

to 0.57 inches) and the average rainfall duration was 12.4 hours (ranging from 12.75 to 20.5 hours). See Table 2 for detailed rainfall information related to each rain event.

Concentrations of PIB During Dry Weather

Samples collected during dry weather conditions from Site 2 were analyzed to establish background information on pathogenic indicator bacteria in the sump water and Spectacle Pond (i.e., stream). As can be seen from Table 3, the concentrations of PIB in the sump water and stream were higher than the bacterial standards for recreational water use in Rhode Island. This background information forms the baseline of this research.

Removal Efficiency of PIB

Between 39–86% of all indicator bacteria were removed by Vortechs from both sampling sites, leaving another 14–61% of all bacteria in the sump water and/or sediments (Table 4). This indicates that Vortechs can only partially remove pathogenic indicator bacteria.

The indicator bacteria concentrations were 2–25 times higher in the effluent discharged from the Vortechs than that in the receiving water during dry weather condition at Site 2 (see Table 5). This finding shows that bacteria concentrations after Vortechs treatment were still significantly high and this could significantly limit the use of receiving waters and raise concerns for public health.

Table 4: Bacteria removal efficiency.

Pathogenic indicator bacteria removal	Site 1 (%)	Site 2 (%)
E. coli	41.7 ± 34.1	66.8 ± 10.8
Enterococci	71.4 ± 40.4	62.7 ± 8.4
Fecal *streptococci*	55.6 ± 8.8	53.3 ± 35.7
Total coliform	86.1 ± 17.3	67.1 ± 17.7
Fecal coliform	73.0 ± 3.4	39.2 ± 29.1

Table 5: High PIB discharge at Site 2.

Pathogenic indicator bacteria	Bacteria discharged from Vortechs were # times higher than that in the receiving water during dry weather condition
E. coli	9 ± 8
Enterococci	2
Fecal *streptococci*	25 ± 6
Total coliform	14 ± 6
Fecal coliform	—

Table 6: Re-suspension potential at Site 2.

Pathogenic indicator bacteria	Ratio of bacteria in the sump water to the bacteria in the influent
E. coli	2.6 ± 1.1
Enterococci	0.11
Fecal *streptococci*	0.6 ± 0.3
Total coliform	1.8
Fecal coliform	1.2 ± 0.2

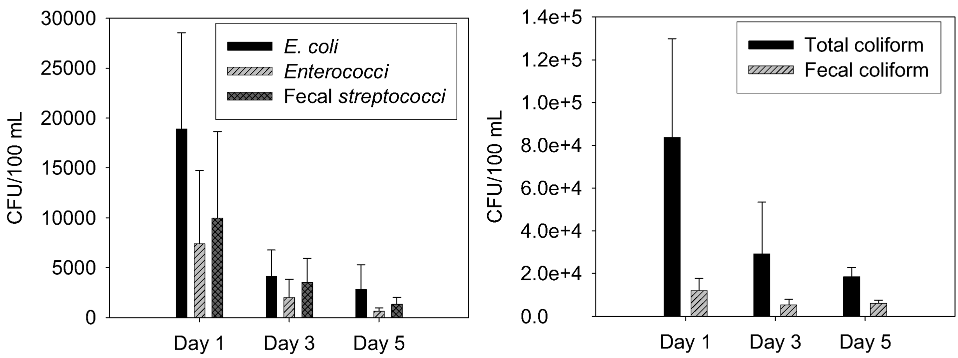

Figure 5: Survivability of pathogenic indicator bacteria in the sump water* (Site 1). (*error bars indicate 95% Confidence Interval in all figures).

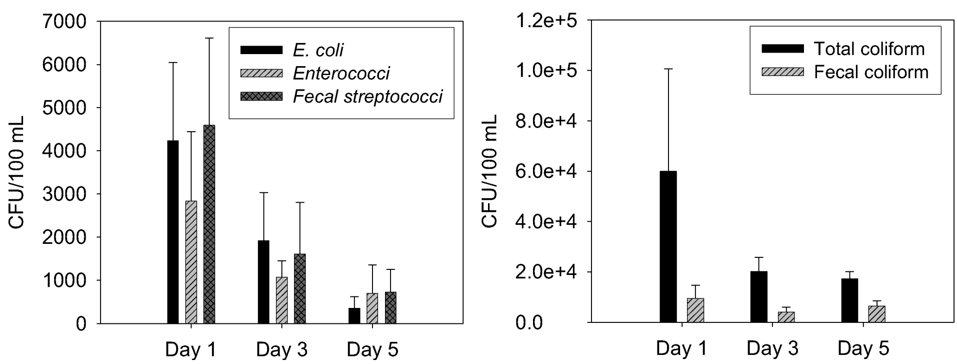

Figure 6: Survivability of pathogenic indicator bacteria in the sump water (Site 2).

Bacteria Re-suspension Potential

Three out of five indicator bacteria concentrations in the sump water were 1.2–2.6 times higher than that found in the incoming stormwater (Table 6). Zhang and Lulla[15] reported higher PIB concentrations in the sediments than that in the sump water, which suggests some PIB could be re-suspended from the sediments within Vortechs when a rainfall occurs. Re-suspension of bacteria adds extra loading to the hydrodynamic separator units and may reduce the treatment efficiency of the units. Therefore, maintenance strategies such as regular cleaning and routine checking may be necessary to enhance the units' treatment efficiency.

The Survivability of PIB in the Sump Water

In Figures 5 and 6, mean bacterial concentration and 95% Confidence Interval are presented for each indicator bacteria several days after the rainfall ceased. At both sampling sites, we found there was a surge of all indicator bacteria one day after the cessation of each rain event for the first 10 rain events (see Figs. 5 and 6). The surge of all indicator bacteria may be due to first-flush phenomenon, where the initial storms usually have higher pollutant concentrations.[16] However, all indicator bacteria concentrations decreased sharply over the 5-day dry period following rain. Therefore, the survivability of all pathogenic indicator bacteria in the sump water of Vortechs was low. In both influent and sump water, low biological oxygen demand (BOD) (less than 10 mg/L, data not shown) was found on the day it rained and several days later following rain. This preliminary result indicates an oligotrophic environment (i.e., lack of nutrients) within Vortechs which will not support bacteria re-growth.

Comparatively, lower bacteria concentrations were detected at Site 2 than that at Site 1, suggesting a higher bacterial contamination from street and highway runoff (Site 2 is located on a parking lot in the back of an inner street).

CONCLUSIONS

This study evaluated the bacteria removal efficiency, bacteria re-suspension potential, and survivability within two Vortechs located at two different locations. The following conclusions can be made: (1) Vortechs was effective in partial removal of pathogenic indicator bacteria (39–86%), however, the bacteria concentrations after BMP treatment were still significantly high which could limit the use of receiving waters and raise concerns for public health; (2) the indicator bacteria concentrations in the sump water were 1.2–2.6 times higher than that contributed by the incoming stormwater. This result suggests some bacteria were re-suspended from the sediments within the Vortechs; (3) the survivability of pathogenic indicator bacteria was low in the sump water. No re-growth was observed. The sump water at Site 2 had much lower bacteria concentration than that at Site 1 suggesting higher bacteria contamination from highway runoff.

Based on the research results presented, it seems much improvement is needed to enhance the performance of Vortechs to effectively remove pathogenic indicator bacteria from stormwater. Sediments in the Vortechs should be cleaned out more frequently to help prevent bacteria re-suspension and incubation.

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