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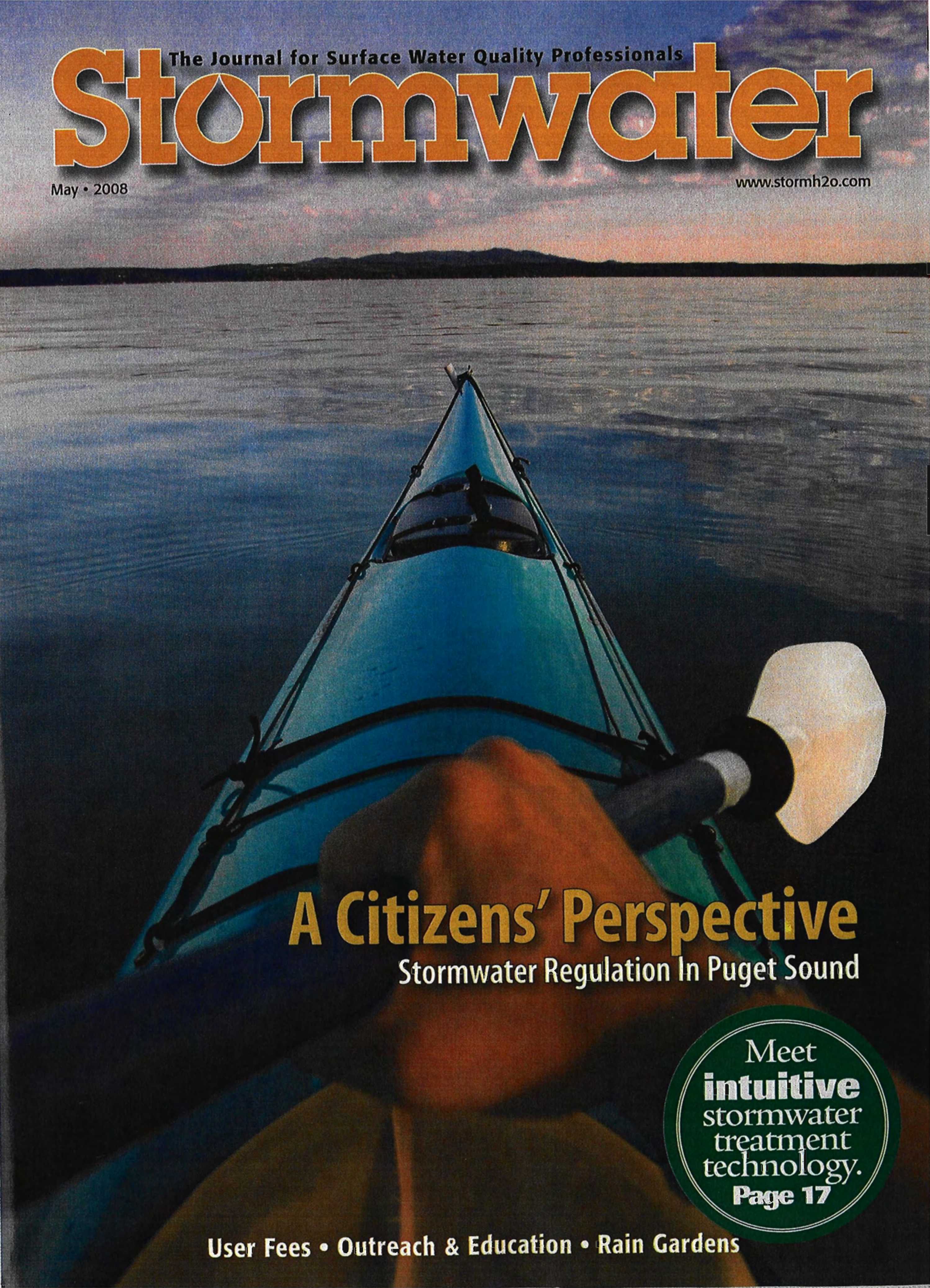

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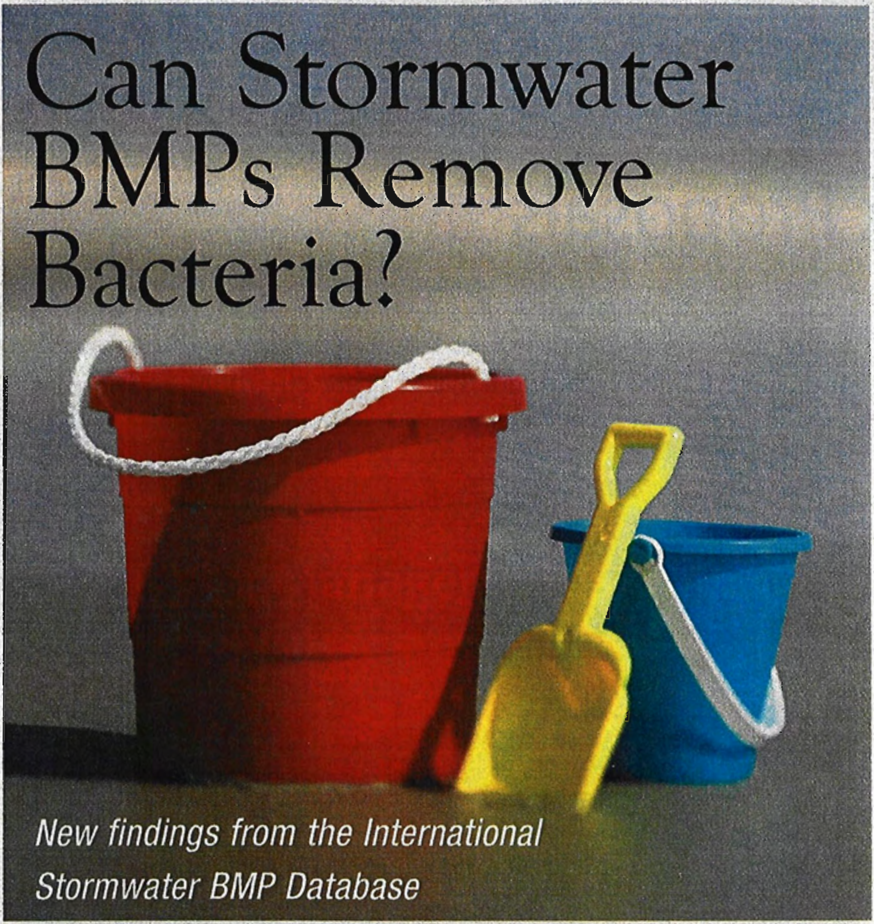


Can Stormwater BMPs Remove Bacteria?

New findings from the International Stormwater BMP Database

By Jane Clary, Jonathan Jones, Ben Urbonas, Marcus Quigley, Eric Strecker, and Todd Wagner

Many communities throughout the United States are faced with total maximum daily loads (TMDLs) for bacteria, typically for either *E. coli* or fecal coliform. For local governments responsible for National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) permits, this issue can be particularly challenging, and many questions arise with regard to whether stormwater best management practices (BMPs) can reduce bacteria in stormwater runoff.

For over a decade, the International Stormwater BMP Database project has been steadily collecting performance data for a broad array of BMPs, with more than 340 BMPs now included in the database. Although not all BMP studies in the database are monitored for bacteria, a data set now exists with approximately 600 pairs of influent and effluent bacteria data. This article provides a brief background regarding bacteria in urban runoff, summarizes the bacteria data available in the BMP database, provides analysis results, and suggests how these findings may affect the selection and design of BMPs to assist in meeting TMDL goals. The underlying data set used in this analysis can be downloaded from the BMP database Web site at **www.bmpdatabase.org**.

Background

Elevated bacteria in stormwater runoff and during wet-weather flow conditions in urban streams is well documented by many researchers (Pitt 2004, Schueler and Holland 2000, Bossong et al. 2005, as a few examples). Recent findings from monitoring programs around the United States show that bacteria concentrations in stormwater runoff are typically elevated well above primary contact recreation standards, regardless of the type of land use in the watershed (e.g., open space, residential, commercial, industrial, or highway).

Many communities, researchers, industries, and others have made efforts to identify the sources of bacteria in urban runoff, and many others are beginning this process. In some cases, human-induced problems exist as a result of illicit connections of sanitary sewers to storm sewers, sanitary sewer overflows, improper disposal of pet waste, and leaking sanitary sewers, as a few examples. Correction of these problems is of unquestionable benefit to the environment and human health. In other cases, nonanthropogenic sources of bacteria are suspected. Regardless of the sources, MS4 permit holders can find themselves with a wasteload allocation for indicator bacteria and be required to make measurable progress in reducing it under TMDLs.

Obvious first steps in controlling bacteria discharges from storm sewers include dry-weather screening of stormwater outfalls to remove blatant sources of bacteria associated with illicit connections and leaking sanitary sewers, but what next? If an MS4 permit holder is subject to TMDL requirements, use of BMPs may be the next step. Intuitively, nonstructural BMPs that include educating citizens about proper disposal of pet waste and increasing containers for disposal of this waste may serve as one of the source control BMPs. The question remains whether traditional structural and low-impact development (LID)–oriented stormwater BMPs, such as detention basins, retention ponds, sand filters, porous landscape detention (bioretention cells), grass swales, and other practices, can also help and to what degree. This is where the International Stormwater BMP Database provides some initial answers.

Data Summary and Analysis

The International Stormwater BMP Database contains more than 100 **paired *E. coli* monitoring events at 12 sites (Table 1)** and **nearly 500 paired fecal coliform monitoring events at 61 sites (Table 2)**. The majority of the *E. coli* data sets are in Portland, OR, and are from sites with LID BMPs, such as bioswales and green roofs. The fecal coliform data set is more geographically diverse with studies in California, Florida, Virginia, Ontario, New York, Texas, Georgia, North Carolina, and Oregon. Also available, but not discussed in this article, are fecal *Streptococcus* data for 33 events at two locations. A few caveats prior to analyzing the data set are appropriate:

•Although a few event mean concentration data sets for bacteria exist in the database, the majority of samples are grab

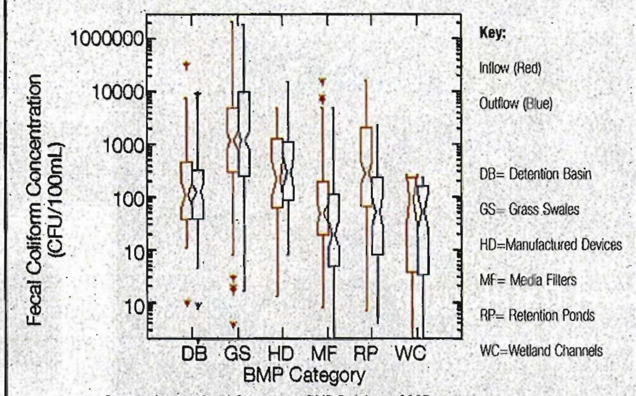
Table 1. Summary of *E. coli* Data for 114 Monitoring Events in the International Stormwater BMP Database 2007

BMP Name	City	State	# of Events	Geometric Mean Inflow (#/100 mL)	Geometric Mean Outflow (#/100 mL)
Bioswale					
Bureau of Environmental Services (BES) Bioswale Native[1] East	Portland	OR	6	1,079	3,035
BES Bioswale Non-Native West	Portland	OR	6	1,079	2,529
Russell Pond Bioswale	Portland	OR	7	780	575
WPCL Bioswale East	Portland	OR	10	2,121	3,789
WPCL Bioswale West	Portland	OR	10	2,121	3,286
Bioretention					
Hal Marshall Bioretention Cell	Charlotte	NC	13	275	17
BES Water Garden	Portland	OR	6	5,024	184
Green Roof					
Hamilton Ecoroof East Roof 2001 & 2002	Portland	OR	8	NA	27
Hamilton Ecoroof West Roof 2001 & 2002	Portland	OR	8	NA	25
Ponds and Sand Filters					
Heritage Estates Stormwater Management Pond	Richmond Hill	ON	25	1,271	109
Lexington Hills: Detention Pond	Portland	OR	10	399	272
Parkrose Sand Filter	Portland	OR	5	2,099	79

[1] Refers to vegetation types planted in bioswales.

samples, typically because a six-hour maximum holding time is specified for bacterial analysis, making it inconvenient and difficult to collect samples for a representative hydrograph using automated samplers and to deliver the samples to the laboratory within this time frame. Thus, the limitations of grab samples, which are well documented in the technical literature, apply. Additionally, some monitored storm events in the database are based on a single pair of grab samples of the influent and effluent, whereas others are based on arithmetic averages of several grab samples, and some are flow-weighted averages.

Fugure 1. Notched Box and Whisker Plots Summarizing Paired Fecal Coliform BMP Monitoring Results



Source: International Stormwater BMP Database 2007

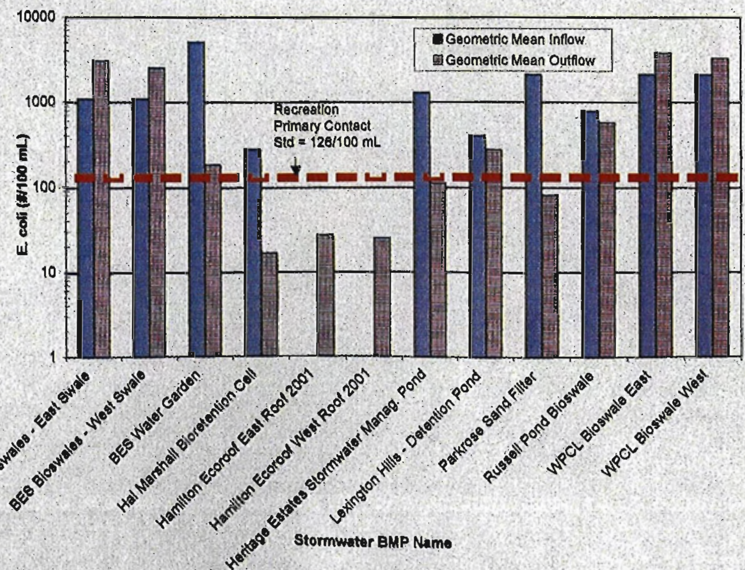
•The number of events sampled for studies presented in Tables 1 and 2 varies. For the *E. coli* data set, an average of 10 storms per BMP was monitored. For fecal coliform, an average of eight storms per BMP was monitored; however, six of the studies (10% of the studies) had fewer than three sampling events, resulting in their exclusion from subsequent analysis.

•Prior to 2008, the water-quality data entered into the database were based on "Legacy STORET" nomenclature, which many people found confusing. (The new Water Quality Exchange, or WQX, format developed by the USEPA is more intuitive and was adopted in 2007 updates to the database.) The authors have assumed that the reported data with various STORET codes fall into these three categories: fecal coliform, *E. coli*, and fecal *Streptococcus*.

•A complicating issue when evaluating *E. coli* data from multiple sources is that, unlike most conventional chemical and physical parameters, bacteria have an upper quantitation limit that can vary by orders of magnitude between studies or sometimes even within studies. The upper quantitation limit is influenced by the dilution of the sample during analysis. As a result, statistical analysis of lumped data sets can be problematic, and it may be necessary to examine the performance of each BMP individually.

In addition to review of the tabulated data, graphical presentation of the data is useful in identifying potential trends. The International Stormwater BMP Database analysis protocols (Geosyntec and WWE 2007) used for conventional water chemistry analysis focus on the effluent concentrations achieved by various BMPs (e.g., is the BMP helping protect receiving-water quality?) and whether there is a statistically significant reduction between influent and effluent concentrations (e.g., is the reduction in reported means real?), along with several other factors, including changes in runoff volumes. In keeping with this approach, Figure 1 provides

Figure 2. Comparison of Geometric Mean *E. coli* Data for Stormwater BMPs in International Stormwater BMP Database



notched box and whisker plots of the fecal coliform data according to BMP type for several categories of BMPs. Figure 1 indicates that swales (GS) and detention basins (DB) do not appear to effectively reduce bacteria in effluent concentrations and may possibly increase bacteria concentrations. Although the effluent values are still above primary contact recreation standards, media filters and retention ponds show potential promise in reducing bacteria counts, based on statistically significant differences between the influent and effluent medians (i.e., the 95th percentile confidence limits for the medians of the influent and effluent data sets do not overlap). Data sets for wetlands and manufactured devices are not of adequate size to draw meaningful conclusions.

It is also worthwhile to evaluate the performance of individual BMPs. Bar charts presenting the geometric mean concentrations for the influent and effluent for each study are presented in Figures 2 through 6. The geometric mean was used because attainment of stream standards is based on the geometric mean of the bacteria data. The USEPA-promulgated instream standard for primary contact recreation is currently 126/100 milliliters for *E. coli* and was 200/100 milliliters for fecal coliform prior to the USEPA's adoption of *E. coli* as a pathogen indicator.

Figure 3. Retention Pond Fecal Coliform Data (8 studies)

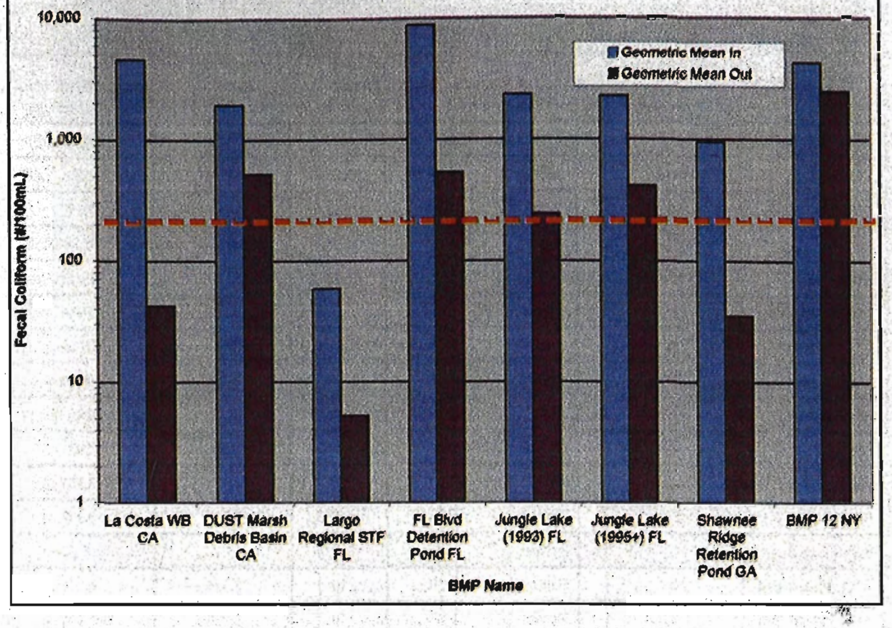


Figure 2 provides the geometric mean influent and effluent concentrations for *E. coli* studies in the database. The best-performing BMPs are the Hal Marshall Bioretention Cell in North Carolina (data provided by William Hunt, North Carolina State University); the Portland Bureau of Environmental Services (BES) Water

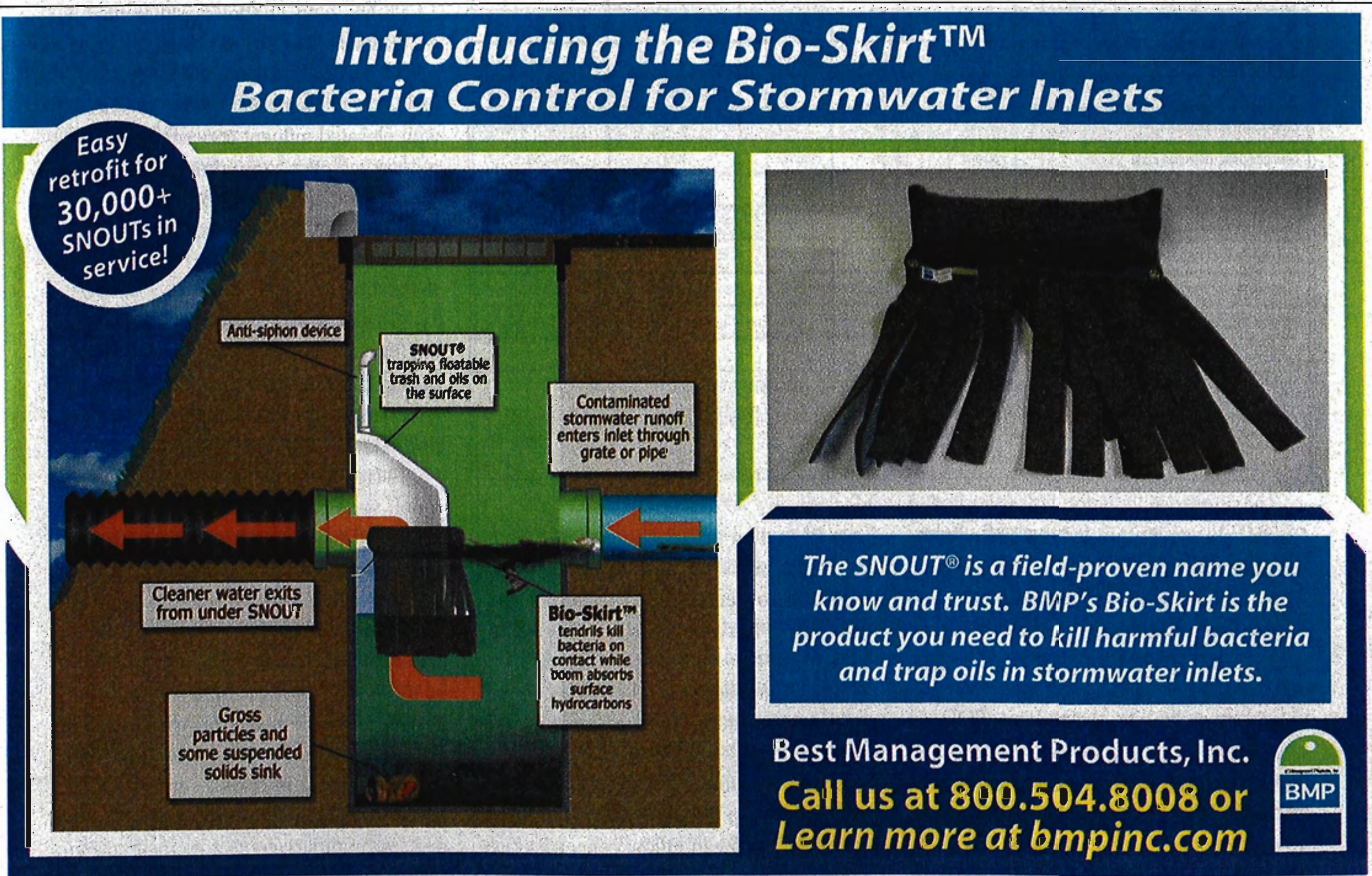


Table 2. Summary of Fecal Coliform Data for 485 Monitoring Events in the International Stormwater BMP Database 2007[1]

BMP	City	State	# of Events	Geometric Mean Inflow (#/100 mL)	Geometric Mean Outflow (#/100 mL)
Bioswales					
Altadena (strip)	Altadena	CA	3	386	459
Carlsbad Biofiltration Strip[2]	Carlsbad	CA	2	84,853	47
I-605/SR-91 Strip[2]	Cerritos	CA	2	490	1,122
US 183 at MoPac Grass Filter Strip	Austin	TX	10	59,606	37,321
Cerritos MS[2]	Cerritos	CA	2	20,199	2,915
I-605/SR-91 Swale[2]	Cerritos	CA	1	5,000	900
I-5/I-605 Swale[2]	Downey	CA	2	65	105
I-605/Del Amo	Lakewood	CA	4	9,460	9,168
SR-78/Melrose Dr.	Vista	CA	3	1,366	239
Key Colony Swale	Key Colony Beach	FL	6	355	380
BES Bioswales: East Swale	Portland	OR	6	1,116	3,176
BES Bioswales: West Swale	Portland	OR	6	1,116	2,852
Russell Pond Bioswale	Portland	OR	4	677	795
WPCL Bioswale East	Portland	OR	10	2,924	4,724
WPCL Bioswale West	Portland	OR	10	2,924	4,134
Alta Vista PUD w/ Swales	Austin	TX	19	36,193	25,428
Monticello High School Bioretention Area	Charlottesville	VA	3	5	1
Dayton Biofilter: Grass Swale	Seattle	WA	5	2,628	7,336
Detention Basins					
I-605/SR-91 EDB	Cerritos	CA	7	654	813
I-5/Manchester (east)	Encinitas	CA	4	978	6,708
I-15/SR-78 EDB	Escondido	CA	9	438	766
I-5/SR-56	San Diego	CA	9	NA	1,103
The Reserve at DeBary	DeBary	FL	48	682	45
Key Colony Detention Pond	Key Colony Beach	FL	10	95	68
Mountain Park	Lilburn	GA	9	168	1,839
BMP 13, West Lake Drive	Valhalla	NY	13	14,184	5,454
Lexington Hills: Detention Pond	Portland	OR	7	529	289
I-5/I-605 EDB	Downey	CA	5	2,237	325
Green Roof					
Hamilton Ecoroof East Roof 2001	Portland	OR	4	NA	34
Hamilton Ecoroof East Roof 2002	Portland	OR	3	NA	11
Hamilton Ecoroof West Roof 2001	Portland	OR	4	NA	13
Hamilton Ecoroof West Roof 2002	Portland	OR	3	NA	28

[1] Two porous pavement studies and one vegetated buffer strip were excluded from the analysis due to data limitations.

[2] BMPs with fewer than three studies have been excluded from subsequent analysis due to small sample size but have been retained in this table for general information. The geometric mean is not a meaningful statistic for these studies.

NA = not available

Garden and the Parkrose Sand Filter (both data sets provided by Tom Liptan, Portland BES); and the Heritage Estates Stormwater Management Pond (data provided by Ontario Ministry of Environment and Energy). Green roofs had effluent concentrations below stream standards. There could be several explanations for green roof performance, including the filtering action of the roof media, residence time within the media, the fact that the rainwater falling on the roofs does not have significant bacterial concentrations, and the fact that bird droppings (if any) on the roof were insignificant. Several bioswales showed higher bacteria in effluent concentrations. These findings related to *E. coli* are consistent with the fecal coliform data presented in Figure 1.

Key observations based on plots of geometric mean data for fecal coliform include the following:

•Figure 3 summarizes the results for eight retention ponds, where seven studies had geometric mean inflow concentrations above in-stream standards. All eight studies showed reductions in fecal coliform concentrations, with some being significant; however, only two of the studies with elevated influent concentrations reduced effluent concentrations below stream standards.

•Figure 4 summarizes the results for 10 detention basins, where seven studies had geometric mean influent concentrations above in-stream standards (one study didn't report influent data). Only two of the studies, both located in Florida, showed effluent concentrations below the stream standard, whereas four studies showed increases in effluent concentrations. It is also noteworthy that about half of the data set is associated with highway runoff in California.

•Figure 5 summarizes the results for 13 vegetated swales, with 12 of the studies showing influent concentrations above stream standards. Nine of the studies had effluent values greater than or comparable to the influent values, with only four showing some reduction in fecal coliform. None of the studies with elevated influent concentrations was able to reduce effluent values below stream standards.

•Figure 6 summarizes the media filter studies reporting fecal coliform data for 13 studies, with 11 showing influent concentrations above stream standards. The majority of the studies are located along highways in California. Of the 10 studies with elevated influent concentrations, five reduced effluent concentrations below stream standards, and two studies had both influent and effluent concentrations below stream standards.

Findings and Implications

Findings and implications for stormwater managers based on a review of the bacteria data in the International Stormwater BMP Database include the following:

•Bacteria concentrations in untreated runoff were consistently high for the majority of the BMP study sites, with the influent concentrations varying substantially. The variation may be a result of both site-specific conditions and the upper quantitation limit reported in the study.

•The ability of structural BMPs to reduce bacteria counts varies widely within BMP categories. No single BMP type appears to be able to consistently reduce bacteria in surface effluent to levels below in-stream primary contact recreation standards. As a result, stormwater managers, permit writers, and TMDL participants

Table 2 (continued)

BMP	City	State	# of Events	Geometric Mean Inflow (#/100 mL)	Geometric Mean Outflow (#/100 mL)
Media Filter					
BMP 57, Nannyhagen Road	Mount Pleasant	NY	6	NA	765
Kearny Mesa MS	San Diego	CA	7	200	170
Clear Lake Packed Bed Filter	Orlando	FL	11	2,653	1,012
Lake Olive WRS	Orlando	FL	5	4,710	859
Hal Marshall Bioretention Cell	Charlotte	NC	14	1,278	172
Lakewood P&R	Downey	CA	6	122	175
Via Verde P&R	San Dimas	CA	6	393	232
La Costa P&R	Carlsbad	CA	7	538	33
Escondido MS	Escondido	CA	8	377	182
Foothill MS (Sand Filter)	Monrovia	CA	4	8,284	1,531
I-5/SR-78 P&R	Vista	CA	7	510	1,254
Eastern Regional MS SF	Whittier	CA	6	627	200
Parkrose Sand Filter	Portland	OR	4	1,602	83
Manufactured Device					
I-210/Filmore Street	Lake View Terrace	CA	18	1,972	2,676
I-210/Orcas Ave	Lake View Terrace	CA	13	2,681	4,187
Retention Pond					
I-5/La Costa (east)	Encinitas	CA	6	4,619	42
DUST Marsh Debris Basin	Fremont	CA	9	1,929	515
Indialantic Project H Pond[2]	Indialantic	FL	2	387	77
Largo Regional STF	Largo	FL	24	58	5
FL Blvd Detention Pond	Merritt Island	FL	5	8,746	530
Jungle Lake (1993)	St. Petersburg	FL	4	2,320	241
Jungle Lake (1995+)	St. Petersburg	FL	7	2,247	411
Shawnee Ridge Retention Pond	Suwanee	GA	5	946	35
BMP 12, Malcolm Brook	Valhalla	NY	16	4,231	2,475
Heritage Estates Stormwater Management Pond	Richmond Hill	ON	22	1,446	133
Wetland					
BES Water Garden	Portland	OR	5	7,087	108
DUST Marsh System A	Fremont	CA	8	455	223
DUST Marsh System B	Fremont	CA	8	566	291
DUST Marsh System C	Fremont	CA	9	280	405

[1] Two porous pavement studies and one vegetated buffer strip were excluded from the analysis due to data limitations.

[2] BMPs with fewer than three studies have been excluded from subsequent analysis due to small sample size but have been retained in this table for general information. The geometric mean is not a meaningful statistic for these studies.

NA = not available

should not assume that structural BMPs can meet numeric effluent limits for bacteria for all storms and under all conditions. This is consistent with 2006 findings from *Storm Water Panel Recommendations to the California State Water Resources Control Board* (CSWRCB) regarding the feasibility of numeric effluent limits for stormwater in general (CSWRCB 2006).

•Computer modeling of bacteria in stormwater should incorporate significant variability in both untreated runoff (influent) and BMP effluent and should be undertaken with caution. Feedback from some environmental engineers and consultants who apply common models to pathogen and fecal indicator transport suggests that the models provide highly uncertain predictions for pathogen and indicator concentrations and fluxes (USEPA 2007, based on input from Ali Boehm, Stanford University). Models should be kept simple, with results not reported in unrealistically precise terms. TMDLs should acknowledge this variability and incorporate terms of compliance based on real-world monitoring data.

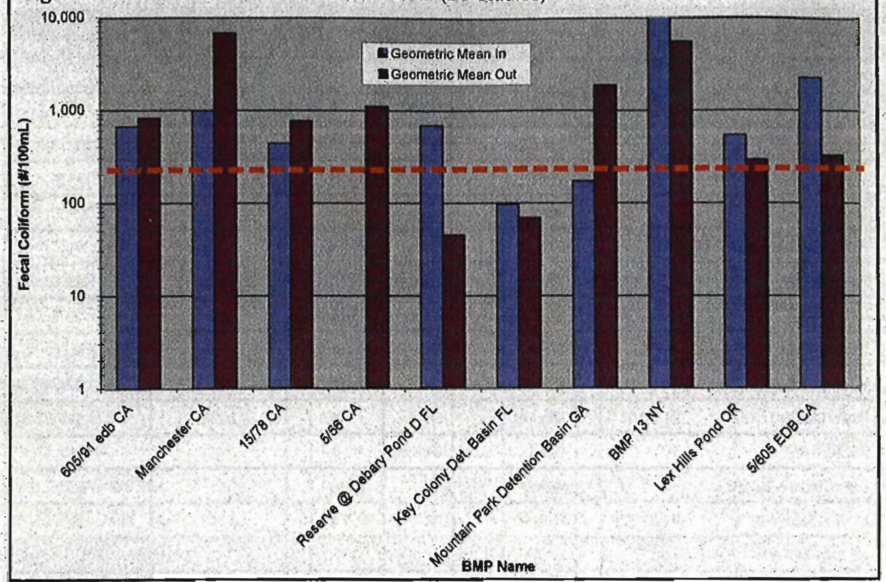
•BMP categories that appear to have potential for bacteria reduction in effluent include retention ponds and media filters (inclusive of bioretention cells). Considerations related to these two BMP categories include the following:

> Retention ponds may be well suited for development with significant land area and adequate water rights (typically a challenge in semiarid and arid states, such as Colorado) or abundant rainfall. In ultra-urban areas, infill development, and arid/semiarid climates, retention ponds are often impractical. Another potential disadvantage with retention ponds is that they can attract waterfowl and wildlife, which can increase bacterial levels.
>
> Media filters and bioretention cells show promise in removing bacteria at the site level. For new developments based on LID techniques, the use of bioretention cells or rain gardens is becoming more common in some parts of United States. The key unit treatment process (filtration) associated with media filters is well proven in the drinking-water arena, so it is not surprising that these BMPs would reduce bacteria, provided that the facilities are properly maintained. For existing developments, some targeted retrofitting in bacteria "hot spot" areas could be possible, but costs of watershed-wide retrofits with many media filters will likely be cost prohibitive. One of the important aspects of long-term functioning of distributed controls, such as bioretention cells, is ensuring that these facilities are maintained and continue to function as designed in perpetuity. In many cases, local governments are already stretched to ensure maintenance of regional stormwater facilities, so although these practices may hold promise, "ensuring" their continued function may be administratively challenging.

•Swale and detention pond BMPs appear to have low effectiveness in reducing bacteria and in some cases have the potential for exporting bacteria. The authors hypothesize that potential causes could include the fact that these types of BMPs tend to attract ducks, geese, other wildlife, and domestic pets, which may contribute to bacteria loading. Regardless, these BMPs can still be effective at reducing pollutant concentrations such as total suspended solids (TSS), total metals, and other constituents, as demonstrated in the 2007 analysis of the International Stormwater BMP Database (Geosyntec and WWE 2007), and are valuable components of stormwater management programs.

•Several BMP categories have data sets

Figure 4. Detention Basin Fecal Coliform Data (10 studies)



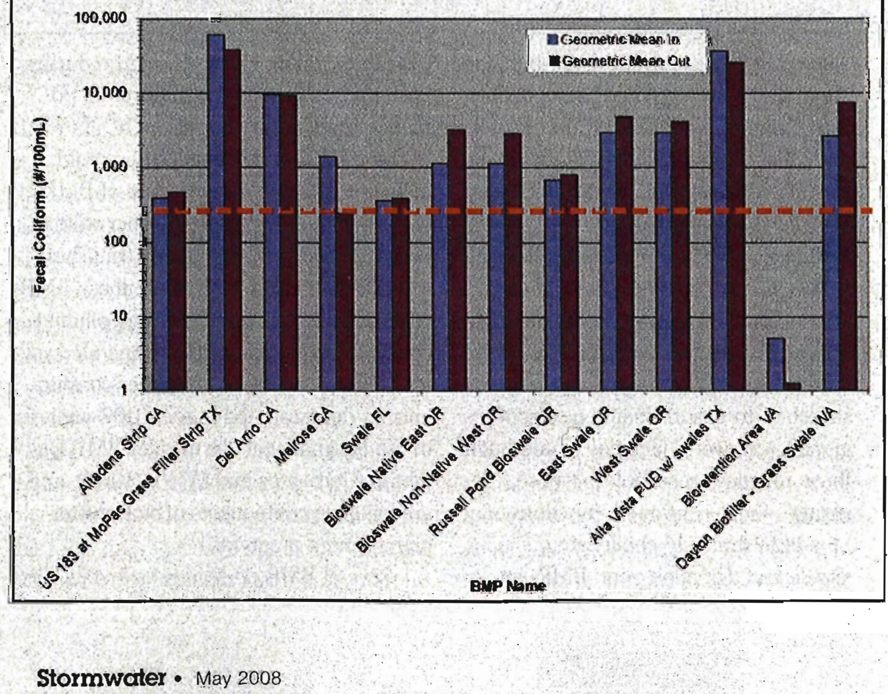
too small to warrant interpretation; these include the wetland, porous pavement, and manufactured device categories. However, one could anticipate how some of these BMPs may perform by evaluating BMPs with similar unit processes. For example, properly designed porous pavements, such as those with a sand layer above the subsurface underdrains, as recommended by some local criteria (UDFCD 1999), should perform similarly to media filters.

- In addition to the ability of a BMP to reduce concentrations of bacteria, it is also important to consider whether the BMP reduces the volume of stormwater runoff and the frequency of discharges. Such BMPs as bioretention, vegetated biofilters, and, in some cases, dry extended detention basins have shown the ability to reduce runoff volumes via infiltration and/or evapotranspiration losses. These factors should also be considered in BMP selection.

As part of the data analysis, the authors also compared the conclusions based on the International Stormwater BMP Database to previous findings reported by others, such as Pitt (2004) and Schueler and Holland (2000). A few representative excerpts from previous findings include the following:

- *A natural outcome of discussions after examining microorganism levels in urban waters focuses on their potential control. Unfortunately, there does not appear to be an easy (inexpensive) solution to reduce the often-times very high indicator bacteria levels found in stormwater. … The most basic control program would incorporate the required inappropriate discharge detection and elimination program … included in the NPDES stormwater permit program, and dog feces controls. These can be highly effective and of low to moderate (or higher) cost. … Dog feces control programs are a basic public health and aesthetic benefit and should also be implemented (including enforcement) … the remaining indicator bacteria, although possibly still quite high in comparison to the current criteria, would indicate minimal risks, as they should mostly originate from urban wildlife. … In order to reduce the bacteria levels to criteria levels, much more costly control programs will be needed. These should only be implemented after a local risk-assessment is conducted and actual human health impairments are identified* (Pitt 2004).

Figure 5. Bioswale (Grass Strips/Swales) Fecal Coliform Data (13 studies)

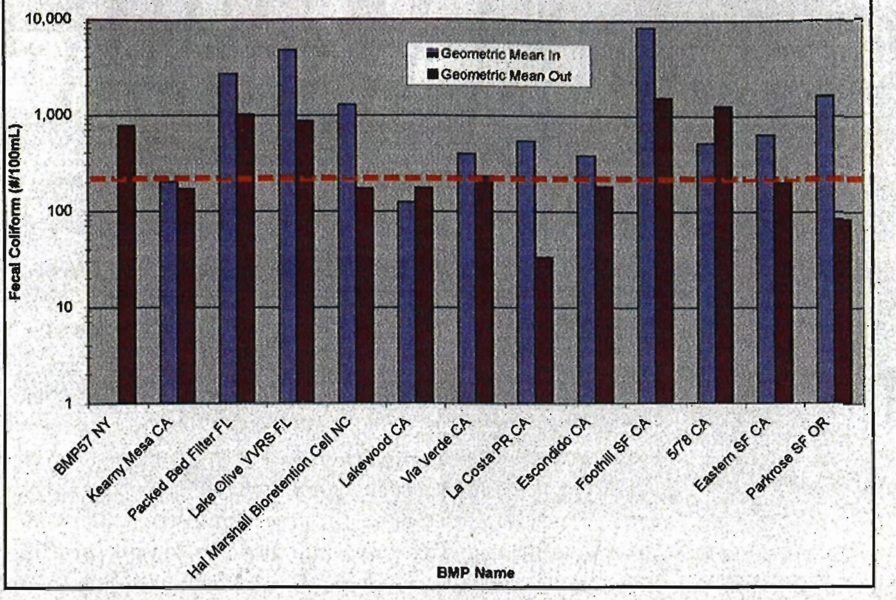


- *Typical concentrations of bacteria (whether measured as* E. coli *or fecal coliform) in urban stormwater are often two orders of magnitude greater than instream primary contact recreational standards. Even when urban stormwater concentrations are significantly reduced through treatment by BMPs, the concentrations in effluent typically remain an order of magnitude greater than the instream standard during wet weather conditions* (Schueler and Holland 2000).
- *Concentrations of bacteria in urban stormwater are notoriously variable on a site-specific basis, even for similar land use types and even at the same sampling location. Due to the wide variability of bacterial data, it is difficult to make accurate estimates of expected pollutant loading and pollutant removal that are transferable from site-to-site with any degree of confidence. Even with the significant variability, all of the databases and literature sources agree that bacteria concentrations in untreated urban stormwater are very high (estimates range from 15,000/100 mL to over 50,000/100 mL for fecal coliform) and difficult to reduce to instream standards* (Schueler and Holland 2000).

Conclusions and Recommendations for Future Work

The International Stormwater BMP Database provides a relatively large and growing bacterial data set that is useful in evaluating the effectiveness of various structural BMPs with regard to bacteria removal. Media filters and retention ponds were most effective based on the current data set; however, effluent concentrations

Figure 6. Media Filter Fecal Coliform Data (13 studies)



for these BMPs remained above primary contact recreation standards in many cases. Although several BMP types, such as extended detention basins and grass swales, did not appear to be effective at reducing bacteria concentrations, these BMPs can be effective at removing such other pollutants as TSS and total metals and may help reduce runoff volumes and frequencies (thereby reducing bacteria loading). The bacteria-related findings reinforce earlier research by such investigators as Pitt (2004) and Schueler and Holland (2000).

Recommendations for additional research include the following:

•Analysis of site-specific conditions at BMP studies may help identify such factors as exposure to sunlight, meteorological conditions, natural (nonhuman) contributions of bacteria associated with the BMP, and other factors that help to explain why some BMPs perform better than others. A more refined level of statistical analysis may also be valuable (e.g., hypothesis testing to determine statistically significant differences between influent and effluent concentrations, along with other techniques).

•Continued submittal of bacteria monitoring data for BMPs to the International Stormwater BMP Database is needed to continue to refine these findings and enable more statistically robust conclusions. Even though the overall number of paired storm events is fairly large, the number of studies per BMP category remains relatively small, as does the number of storm events monitored for some BMP studies.

•Continued national data-based dialogue regarding bacteria levels in stormwater runoff relative to in-stream recreational water-quality criteria is needed, in keeping with the USEPA's Pellston-style workshop on revising recreational water-quality criteria (USEPA 2007) that acknowledges that many unanswered questions exist regarding recreational standards for bacteria. Near-term "critical path" research identified as part of the USEPA (2007) workshop includes addressing such issues as the significance of natural versus human-induced sources of bacteria, determination of acceptable risk levels, and other factors.

•Development of cost-benefit data for stormwater BMPs relative to bacteria reduction for municipal stormwater managers is important. Most local governments need this type of information for decision making when determining how to best allocate limited resources.

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