Challenges in Attaining Recreational Stream Standards for Bacteria: Setting Realistic Expectations for Management Policies and BMPs

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ABSTRACT

Attainment of U.S. Environmental Protection Agency (EPA) recreational water quality criteria and state water quality standards for bacteria presents significant challenges to water resource managers in communities throughout the U.S. From a regulatory perspective, many communities 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 Stormwater (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. Many valid questions exist regarding how attainable current stream standards are and what measures are truly meaningful in reducing bacteria in streams and in development of meaningful TMDLs.

This paper provides a synopsis of Best Management Practice (BMP) performance data provided for bacteria in the International Stormwater BMP Database and discusses implications of these findings for stormwater managers. Findings from analysis of these data are used to provide some recommendations regarding the types of efforts that are expected to provide meaningful results in terms of water quality management policy and bacteria reduction in stormwater and receiving waters. Implications for development of TMDLs with the potential to provide real improvement of water quality is also discussed.

INTRODUCTION

Attainment of U.S. Environmental Protection Agency (EPA) recreational water quality criteria and state water quality standards for bacteria presents significant challenges to water resource managers in communities throughout the U.S. As one example, in some watersheds, largely uncontrollable natural sources of bacteria can cause or contribute to the exceedance of bacteria standards. When natural sources are comingled with controllable anthropogenic sources, it can be extremely difficult to establish realistic and meaningful strategies for attaining bacteria standards. As a result, draconian measures are sometimes implemented (e.g., prohibiting human use of recreational trails along waterways) or considered.

From a regulatory perspective, many communities 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 Stormwater (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. Many valid questions exist regarding how attainable current stream standards are and what measures are truly meaningful in reducing bacteria in streams and in development of meaningful TMDLs. The International Stormwater BMP Database provides data that can begin to help communities answer some of these questions. A summary of bacteria data in the BMP Database follows, along with findings and recommendations based on these data.

STORMWATER BMP MONITORING RESULTS FOR BACTERIA IN INTERNATIONAL STORMWATER BMP DATABASE

The International Stormwater BMP Database contains nearly 500 paired fecal coliform monitoring events at 61 sites (Table 1) and over 100 paired *E. coli* monitoring events at 12 sites (Table 2). The majority of the *E. coli* data sets are in Portland, Oregon and are from sites with Low Impact Development 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. A few caveats related to this data set include:

- Although a few event mean concentration (EMC) data sets for bacteria exist in the Database, the majority of samples are grab 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 timeframe. 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.
- 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 percent 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 (WQX) format developed by the U.S. Environmental Protection Agency (USEPA) is more intuitive and has been 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 strep.
- A complicating issue when evaluating *E. coli* data from multiple sources is that unlike most conventional chemical and physical parameters, bacteria has 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.

Table 1. Summary of Fecal Coliform Data for 485 Monitoring Events in the International Stormwater BMP Database 2009[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

Table 1. Summary of Fecal Coliform Data for 485 Monitoring Events in the International Stormwater BMP Database 2009[1]

BMP	City	State	# of Events	Geometric Mean Inflow (#/100 mL)	Geometric Mean Outflow (#/100 mL)
Media Filter					
BMP 57, Nannyhagen Road	Mt. 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 VVRS	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	Merrit 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 Manag. 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 less 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.

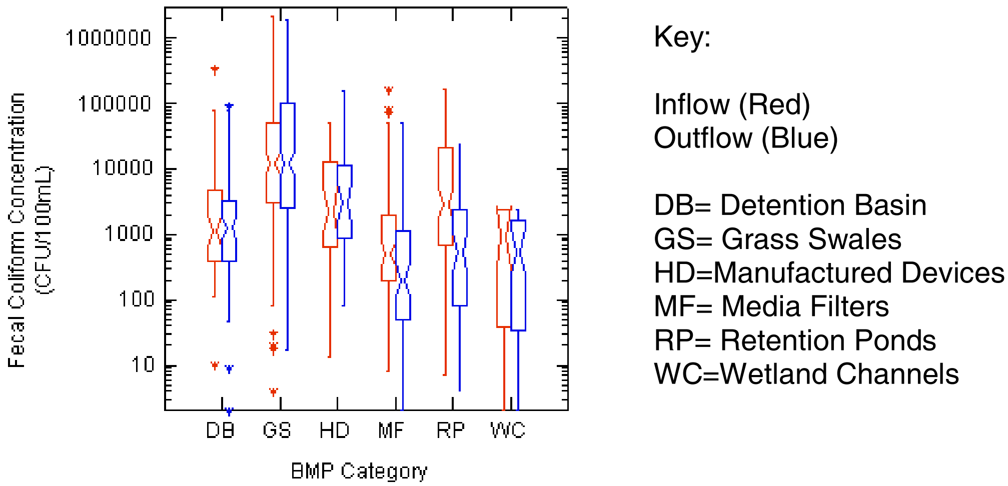
Table 2. Summary of *E. coli* Data for 114 Monitoring Events in the International Stormwater BMP Database 2009

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 Manag. 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.

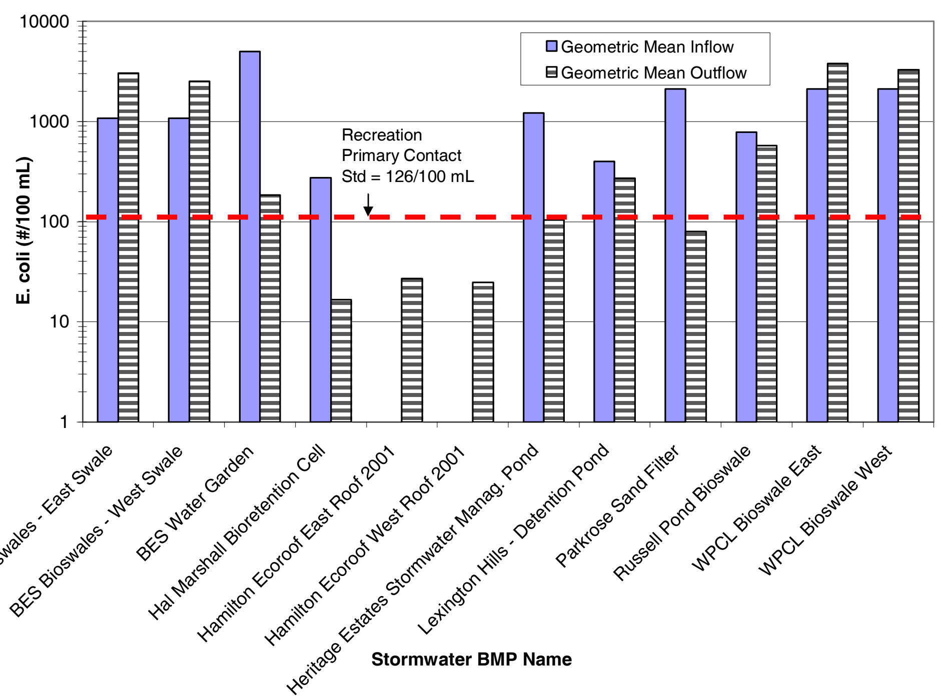
In addition to review of the tabulated data, graphical presentation of the data is useful in identifying potential trends. The International Stormwater BMP Database analysis protocols (Geosyntec and WWE 2007) used for conventional water chemistry analysis focus on the effluent concentrations achieved by various BMPs (e.g., is the BMP helping to 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?). Several other factors such as changes in runoff volumes are also considered. In keeping with this approach, Figure 1 provides notched box and whisker plots of the fecal coliform data according to BMP type for several categories of BMPs. The geometric mean is used as a benchmark in these plots 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 mL for *E. coli* and was 200/100 mL for fecal coliform prior to USEPA's adoption of *E. coli* as a pathogen indicator. 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.

Figure 1. Notched Box and Whisker Plots Summarizing Paired Fecal Coliform BMP Monitoring Results (Source: International Stormwater BMP Database 2007)



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 were prepared. Figure 2 provides the geometric mean influent and effluent concentrations for *E. coli* studies in the database. A series of similar plots for fecal coliform were also prepared according to BMP type (Clary et al. 2008) based on the data summarized in Table 1, but are not reproduced in this paper due to space limitations.

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



FINDINGS AND IMPLICATIONS FOR STORMWATER MANAGERS

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

- 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 due to both site-specific conditions as well as the upper quantitation limit for the study.
- The ability of structural BMPs to reduce bacteria varies widely within BMP categories. No single BMP type appears to be able to consistently reduce bacteria in surface effluent to levels below instream primary contact recreation standards. As a result, stormwater managers, permit writers and TMDL participants 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 a Storm Water Panel Recommendations to the California State Water Resources Control Board 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). Additionally, modeling assumptions related to microbe association with particles are typically not well developed (Characklis and Camper 2009). 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 and bioretention practices, with these considerations:
    - Retention ponds may be well suited for development with significant land area and adequate water rights (typically a challenge in semi-arid and arid states such as Colorado) or abundant rainfall. In ultra-urban areas, infill development, and arid/semi-arid climates, retention ponds are often impractical. Another potential disadvantage with retention ponds if bacteria removal is an objective is that they can attract waterfowl and wildlife, which can increase bacterial levels. Research related to unit treatment processes that are potentially effective for retention ponds is needed. For example, Characklis and Camper (2009) are conducting ongoing research related to microbe association with particles. This is important because the degree to which microbes in the water column associate with settleable particles has important implications for microbial removal via sedimentation-based BMPs.
    - Media filters and bioretention cells show promise in removing bacteria at the site-level. These findings are consistent with recent research by Hathaway and Hunt (2008) in North Carolina. For new developments based on Low Impact Development techniques, the use of bioretention cells or rain gardens is becoming more common in some part 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 extended detention (dry) 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 that fact that these types of BMPs tend to attract geese, 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 Wright Water Engineers 2007), and are valuable components of stormwater management programs. Some infiltration may also occur in these facilities, as well.
- Several BMP categories have data sets 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 sub-surface underdrains, could potentially 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. BMPs such 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 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:

- *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).
- *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 ADDITIONAL RESEARCH

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 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 other pollutants such as TSS and total metals and may help to reduce runoff volumes and frequencies (thereby reducing bacteria loading). The bacteria-related findings reinforce earlier research by investigators such as Pitt (2004) and Schueler and Holland (2000). Recommendations for additional research include:

- Analysis of site specific conditions at BMP studies may help to identify factors such as exposure to sunlight, meteorological conditions, natural (non-human) 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. It is essential that evaluation of BMP performance related to bacteria include geometric mean effluent concentrations due to the fact that even when large percentage removals are present (and the BMP appears to be "doing something"), the effluent concentrations still typically exceed primary contact stream standards. This is critical for realistic expectations in BMP-based stormwater permits.
- Continued national data-based dialogue and research regarding bacteria levels in stormwater runoff relative to instream recreational water quality criteria is needed, in keeping with USEPA's expert workshop and critical path science plan for 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 issues such as the significance of natural versus human-induced sources of bacteria, determination of acceptable risk levels, and other factors. This is critically important research to ensure that time and effort expended by regulators and MS4 permit holders is meaningful in terms of protection of human health. As an example, recent microbial risk assessment conducted for the Chicago Waterways Project (Petropolou et al. 2008) showed relatively low risk to human health due to secondary contact recreation in waters, despite elevated bacteria concentrations. Ideally, EPA would also support bacteria-related monitoring for BMPs so that a national baseline

expectation regarding the ability of structural BMPs to effectively treat bacteria could be developed.

- From a practical standpoint, state and federal regulators should carefully consider whether appropriate recreational use classifications are assigned to streams. Assigning primary contact recreation standards to streams that are not truly used for primary contact recreation can result in unnecessary 303(d) listing of streams and costly TMDL efforts that may result in BMP-based requirement to treat bacteria in MS4 permits. These situations do not provide meaningful increases in protection of human health and can be costly, diverting resources away from other real water quality issues. Aside from source control BMPs such as pet waste ordinances and illicit discharge detection and removal, MS4 permit holders may find themselves with unachievable permit requirements. This situation can also result in dilemmas for state regulators who may ultimately find themselves unable to issue a permit that contributes to an exceedance of a water quality standard. Some states (e.g., Kansas and Texas) have recently worked to develop more detailed recreational use standards that focus on streams where true primary contact recreation is occurring.
- 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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