Colorado *E. coli* Toolbox: A Practical Guide for Colorado MS4s

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The intent of this Toolbox is to provide a concise, easy-to-read reference for use in urban areas in Colorado. Thus, more detailed technical analysis supporting the condensed discussion in this Toolbox can be obtained from the following sources for more detailed discussions, which provide the technical underpinnings of this Toolbox.

Urban Water Resources Research Council of the Environmental and Water Resources Institute of the American Society of Civil Engineers. (2014). *Pathogens in Urban Stormwater Systems*. Eds. J. Clary, B. Steets, and R. Pitt. Prepared with support from the Urban Drainage and Flood Control District and the Urban Watersheds Research Institute. August.

Center for Watershed Protection and R. Pitt. (2004). *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments*. Center for Watershed Protection, Ellicott City, MD, and University of Alabama, Tuscaloosa, AL. http://www.cwp.org/online-watershed-library/cat_view/64-manuals-and-plans/79-illicit-discharge-detection-and-elimination

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International Stormwater BMP Database, including various statistical summaries such as Wright Water Engineers and Geosyntec. (2010). *International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Fecal Indicator Bacteria*, and 2014 statistical appendices. Project sponsors include: Water Environment Research Foundation, Federal Highway Administration, American Society of Civil Engineers Environmental and Water Resources Institute, U.S. Environmental Protection Agency and American Public Works Association. Accessible at: www.bmpdatabase.org

U.S. Environmental Protection Agency. (2012). *Recreational Water Quality Criteria*. Office of Water 820-F-12-058. http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/

Acronyms and Abbreviations

BMP	best management practice (also known as stormwater control practice)
CCTV	closed circuit television
CDC	Centers for Disease Control
CDPS	Colorado Discharge Permit System
cfu	colony forming units
CSO	combined sewer overflow
CWQCC	Colorado Water Quality Control Commission
CWQCD	Colorado Water Quality Control Division
DSV	discharger specific variance
EPA	U.S. Environmental Protection Agency
FIB	fecal indicator bacteria
GIS	geographic information system
IDDE	illicit discharge detection and elimination
LA	load allocation
M&E	monitoring and evaluation
MEP	maximum extent practicable
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
MST	microbial source tracking
NEEAR	National Epidemiological and Environmental Assessment of Recreational Water
NPDES	National Pollutant Discharge Elimination System
NSE	natural source exclusion
NSQD	National Stormwater Quality Database
PCA	principal component analysis
PCR	polymerase chain reaction
QMRA	quantitative microbial risk assessment
WWTP	wastewater treatment plant
qPCR	quantitative polymerase chain reaction
RWQC	Recreational Water Quality Criteria
SCCWRP	Southern California Coastal Water Research Project
SOP	standard operating procedure
SSM	single sample maximum
SSO	sanitary sewer overflow
STV	statistical threshold value
TIL	tolerable illness level
TMDL	total maximum daily load
UAA	use attainability analysis
UDFCD	Urban Drainage and Flood Control District
USDCM	Urban Storm Drainage and Flood Control Manual
UV	ultraviolet
WHO	World Health Organization
WLA	wasteload allocation

TABLE OF CONTENTS

Tables

Figures

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EXECUTIVE SUMMARY

The purpose of this Colorado *E. coli* Toolbox is to provide a consolidated resource to support local governments with Municipal Separate Storm Sewer System (MS4) permits working to reduce *E. coli* loading to impaired waterbodies in Colorado. As of 2016, approximately 70 stream segments in Colorado are identified as impaired or in need of additional monitoring and evaluation due to elevated *E. coli* concentrations relative to recreational water quality standards. This Toolbox provides a concise overview of regulations driving Total Maximum Daily Loads (TMDLs) and MS4 permit conditions and focuses on approaches to understanding sources of *E. coli*, potential non-structural and structural best management practices (BMPs) to reduce *E. coli* loading, and regulatory alternatives.

Pathogens (disease-causing organisms) are impractical to monitor directly, so fecal indicator bacteria (FIB) are used as a surrogate to indicate risk of gastrointestinal illness in place of direct measurement of pathogens. Although there are a number of limitations with use of *E. coli* for this purpose, the U.S. Environmental Protection Agency (EPA 2012) concluded that *E. coli* (or enterococcus) were the best currently available indicators appropriate for use in nationally-applicable recreational criteria. When communicating with the public, it is often important to clarify that the fecal indicator bacteria called *E. coli* are not equivalent to the pathogenic strain of *E. coli* (O157:H7) that the public may be familiar with due to highly publicized foodborne illness outbreaks.

Most streams in Colorado's urban areas are assigned "existing primary contact" recreation standards. Primary contact recreation is defined as "recreational activities where the ingestion of small quantities of water is likely to occur. Such activities include but are not limited to swimming, rafting, kayaking, tubing, windsurfing, water-skiing, and frequent water play by children" (WQCC 2012). Colorado's primary contact standard of 126 colony forming units per 100 milliliters (cfu/100 mL) for *E. coli* is expressed as a not-to-be-exceeded geometric mean value, which is consistent with EPA's 2012 Recreational Water Quality Criteria and corresponds to an allowable swimmer illness rate of 36 illnesses per 1,000 exposures. Although a wide range of trends can occur for *E. coli*, a common trend in warm-water Colorado streams is elevated *E. coli* during the summer and/or early fall months and attainment of the standard during the winter.

As of early 2016, the Water Quality Control Division (Division) has finalized three *E. coli* TMDLs in Colorado, including Segment 14 of the South Platte River, Boulder Creek Segment 2b, and Segment 15 of the South Platte River. Each of these TMDLs includes unique aspects, although basic requirements for EPA-approvable TMDLs are included in each. The Division has prioritized completion of additional *E. coli* TMDLs as a high priority on its near-term planning horizon.

Sources of pathogens and FIB in MS4s and receiving waters vary widely, originating from both non-human and human sources. Representative sources of FIB in urbanized areas in Colorado may include SSOs (sanitary sewer overflows), wet weather (stormwater) discharges from MS4s (which mobilize and convey sources deposited on land surfaces), sewer leaks into and illicit connections to storm sewer systems (e.g., sanitary sewer connections to the storm sewer), illicit discharges to storm sewer systems (e.g., recreational vehicle dumping), failing or improperly located onsite wastewater treatment systems (septic systems), wastewater treatment plants (if not meeting discharge permit limits), urban wildlife, domestic pets, agriculture, and other sources. Allowed discharges to MS4s such as irrigation runoff and uncontaminated groundwater discharges may also transport FIB originating from other sources. It is beneficial for MS4 permittees to have a broad understanding of the diverse sources of *E. coli* that may contribute to waterbody impairments; however, MS4 permittees are only responsible for controlling sources contributed through their MS4. In addition to fecal sources, non-fecal sources or reservoirs of FIB exist. These include sediments in receiving waters, biofilms in storm sewers and waterbody substrate/sediments, and naturalized FIB associated within plants and soil. Although agricultural sources are not the focus of this Toolbox, both livestock and manure management can be sources of FIB in watersheds where MS4 permittees are working toward watershed-scale solutions.

Although some FIB sources can be controlled to an appreciable extent (e.g., wastewater discharges, sanitary sewer leaks, illicit connections), other sources are much more difficult to control. These diffuse, ubiquitous, and often mobile sources include anthropogenic (e.g., homeless populations) as well as non-anthropogenic sources such as wildlife (e.g., raccoons, beavers, and birds). Furthermore, not all sources present the same public health threat; human fecal sources present a much higher illness risk than non-human and non-fecal sources. Properly accounting for and identifying potential sources in a particular area is the first step in working toward minimizing FIB contributions from controllable sources and protecting public health.

Monitoring strategies to characterize local sources of FIB can range from simple and relatively inexpensive sample collection and analysis of FIB and basic water quality parameters to higher cost microbial source tracking (MST) approaches relying on advanced molecular methods. It is recommended that entities with wasteload allocations in *E. coli* TMDLs begin with simple methods to identify and prioritize anthropogenic FIB sources in their drainage areas and collection systems and then target source control strategies to address these. Monitoring and source tracking techniques selected may be limited by budget constraints, regulatory drivers, and available technical expertise. Although monitoring and investigation can be costly, these costs are typically much less than the cost of structural BMP implementation. It is typically worthwhile to invest in a well-designed monitoring program that enables well-supported identification of sources to determine source controls and, where necessary, structural BMPs that effectively target highest priority (or highest risk) sources. This approach is expected to provide the greatest likelihood of achieving meaningful contributions to public health protection and recreational beneficial use restoration.

The foundation of *E. coli* load reduction plans is source controls, which are non-structural measures (behaviors) that help to reduce the *E. coli* sources and/or flow sources that are transporting *E. coli* to the storm drainage systems. Effective implementation of source control practices typically involves coordination with multiple local government departments, including sanitary sewer collection system owners/operators. Interdepartmental and interjurisdictional coordination and collaboration are essential to achieving meaningful pathogen and FIB reduction.

Structural stormwater control practices, referred to as permanent post-construction BMPs, are key tools to help reduce *E. coli* loading in urban runoff. Options include flow-through and volume reduction-based treatment controls. Existing performance data indicate that passive (i.e., non-disinfection) flow-through BMPs are unlikely to consistently achieve primary contact limits in treated effluent; therefore, volume reduction-based BMPs are the primary structural control strategy for achieving bacteria load reductions. Green infrastructure approaches should be considered because they encourage infiltration of stormwater and reduce dry weather flows. Flow-through treatment BMP types with performance data indicating the potential ability to reduce *E. coli* concentrations include retention (wet) ponds, media filters, bioretention facilities and subsurface flow wetlands. Site-specific constraints, cost and sustainability (ability to maintain performance over time) will also affect selection of BMPs that are suitable for any particular site. Active treatment, such as ultraviolet disinfection, and diversion of dry-weather low flows to the sanitary sewer system are generally a last resort for controlling *E. coli* discharges to receiving waters, due to their high cost.

In some urban areas across the United States, multi-million or billion dollar MS4 implementation plans have been developed to address FIB TMDLs; thus, substantial benefits may be gained by well-developed and clearly targeted special studies. For example, USEPA's 2012 Recreational Water Quality Criteria recognize the need for and allow the development of site-specific standards based on demonstration that local illness risks are low (due to the predominance of non-human sources). Meanwhile, MST techniques have become better validated, standardized, commercialized, and familiar/acceptable to state and federal water quality regulators over the past few years. Therefore, states are becoming more accustomed and open to using MST and other tools like Quantitative Microbial Risk Assessment (QMRA) to modify TMDLs and water quality standards (or discharger-specific permit variances) after human sources are demonstrated to be absent or mostly absent.

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1 INTRODUCTION

1.1 PURPOSE OF THIS TOOLBOX

As of 2016, approximately 70 stream segments in Colorado are identified as impaired or in need of additional monitoring and evaluation due to elevated *E. coli* concentrations relative to recreational water quality standards. For streams identified as impaired on Colorado's "303(d) List," typically the next step is development of a total maximum daily load (TMDL), which determines the load reductions needed to attain recreational water quality standards. In urban areas, municipal separate storm sewer systems (MS4s) subject to Colorado Discharge Permit System (CDPS) permits may have additional permit requirements to reduce *E. coli* loading as a result of these TMDLs.

The purpose of this Toolbox is to provide a consolidated resource to support local governments with MS4s working to reduce *E. coli* loading to impaired waterbodies. Although the issue of *E. coli* impairment in urban areas is complex, this Toolbox has been kept as simple as possible with the intention of providing readers with a broad range of backgrounds a resource to develop a general understanding of the issues and to provide tools that may be useful for reducing *E. coli* loads from urban areas. This Toolbox is organized into six chapters including:

- Introduction: this chapter provides a basic overview of recreational water quality criteria and use impairment, Colorado's approach to bacteria TMDLs, and suggestions for entities who should be at the table to work collaboratively towards solutions.

- Finding the Sources: the key to success in reducing *E. coli* loading to streams is understanding and identifying the sources of bacteria loading. This chapter provides an overview of source identification techniques that a local government may want to consider to develop a better understanding of sources.

- Developing a Control Strategy: controlling bacteria loads in urban areas can be both complex and expensive. This chapter provides general guidance on how to develop a control strategy progressing from control of dry weather sources then wet weather sources, focusing first on human-related sources of bacteria loading.

- Source Control Practices: source control practices are the foundation of *E. coli* load reduction strategies. This chapter provides a description of source control practices that communities should consider for reducing *E. coli* loading.

- Structural Control Practices: structural control practices can reduce dry weather and wet weather loading to streams. Ideally, for dry weather discharges from MS4s, source controls are the primary solution; however, some structural controls can be used for dry weather flows, typically as a last resort. For wet weather flows, Urban Drainage and Flood Control District's (UDFCD) *Urban Storm Drainage Criteria Manual (Volume 3)* is a key source of design information for structural best management practices (BMPs) suitable for use in Colorado's urban areas. This chapter provides additional information on performance expectations for stormwater BMPs and techniques that help to enhance their performance.

- Regulatory Alternatives: Colorado's Basic Standards and Methodologies for Surface Water (Regulation 31) define how water quality standards are adopted in Colorado, allowing development of site-specific standards and discharger specific variances under certain conditions. Additionally, in its 2012 Recreational Water Quality Criteria update, the U.S. Environmental Protection Agency (EPA) outlined three options for alternative or site-specific standards for recreational water quality. Communities where these alternatives may be most viable are those where human sources of bacteria have been mostly controlled.

1.2 COLORADO RECREATIONAL WATER QUALITY CRITERIA AND RECREATIONAL USE IMPAIRMENT

The Colorado Water Quality Control Commission (WQCC) establishes water quality standards to protect designated uses for streams and lakes in Colorado. These standards are reviewed every five years and modified based on changes in federal and state regulations and other factors. Colorado streams are classified according to whether primary contact is present, potentially present, not present or undetermined.

Determination of impairment of a waterbody for recreational use depends on the recreational use classification assigned to a waterbody and assessment of available *E. coli* data following the most current version of Colorado's 303(d) Listing Methodology, which is updated biennially. Consistent with EPA's 2012 Recreational Water Quality Criteria (EPA 2012), Colorado uses *Escherichia coli* (*E. coli*) as the indicator of potential fecal contamination of waterbodies. Pathogens (disease-causing organisms) are impractical to monitor directly, so fecal indicator bacteria (FIB) are used as a surrogate to indicate risk of gastrointestinal illness in place of direct measurement of pathogens. Although there are a number of limitations with use of *E. coli* for this purpose, EPA (2012) concluded that *E. coli* (or enterococcus) were the best currently available indicators appropriate for use in nationally-applicable recreation criteria.[1] When communicating with the public, it is often important to clarify that the fecal indicator bacteria called *E. coli* are not equivalent to the pathogenic strain of *E. coli* (O157:H7) that the public may be familiar with due to highly publicized foodborne illness outbreaks.

Difference between Fecal Indicator Bacteria (FIB) and Pathogens

Fecal matter often contains pathogens, which are disease-causing organisms. Because of impracticality of testing for many pathogens associated with fecal waste, fecal indicator bacteria or "FIB" are used as indicators of fecal contamination. The FIB currently recommended by EPA include *Escherichia coli* (*E. coli*) and/or enterococcus. Historically, fecal coliform bacteria were also recommended indicators. FIB are not necessarily disease-causing and may be present due to non-fecal sources such as decaying plant matter and other environmental sources.

Water quality standards are expressed in term of 1) magnitude (numeric value), 2) duration over which the standard is assessed, and 3) frequency of allowed exceedances. In Colorado, the numeric values for *E. coli* allowed in a waterbody depend on the assigned use, which includes existing (E) primary contact recreation, potential (P) primary contact recreation (within the next 20 years), not (N) primary contact, and unclassified (U) recreational use. Most streams in urban areas are assigned existing primary contact recreation standards. Primary contact recreation is defined as "recreational activities where the ingestion of small quantities of water is likely to occur. Such activities include but are not limited to swimming, rafting, kayaking, tubing, windsurfing, water-skiing, and frequent water play by children"

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[1] The 2012 Recreational Water Quality Criteria include some new provisions that allow for use of alternative indicators, provided that equivalent protection of human health is provided. From a practical perspective, significant epidemiological and/or risk-based verification of alternative indicators typically would be required for such a standard to be adopted. See Section 7 for additional discussion and nuances.

(WQCC 2012). Many urban streams in Colorado have limited flows that preclude swimming and boating; however, if the public can access the stream for activities such as wading and water play by children, then a primary contact recreational use is typically assigned. Table 1 summarizes the numeric values associated with Colorado's currently applicable recreational water quality criteria. These standards are assessed using static bimonthly intervals set at January-February, March-April, May-June, July-August, September-October, and November-December.

Table 1. Recreational Water Quality Criteria for Colorado[2]

Use Classification	Description	Standard for *E. coli*[1] (cfu/100 mL)
Class E - Existing Primary Contact	These surface waters are used for primary contact recreation or have been used for such activities since November 28, 1975.	126
Class P - Potential Primary Contact	These surface waters have the potential to be used for primary contact recreation. This classification is assigned to water segments for which no use attainability analysis has been performed demonstrating that a recreation class N classification is appropriate, if a reasonable level of inquiry has failed to identify any existing primary contact uses of the water segment, or where the conclusion of a use attainability analysis is that primary contact uses may potentially occur in the segment, but there are no existing primary contact uses.	205
Class N - Not Primary Contact	These surface waters are not suitable or intended to become suitable for primary contact recreation uses. This classification is applied only where a use attainability analysis demonstrates that there is not a reasonable likelihood that primary contact uses will occur in the water segment(s) in question within the next 20-year period.	630
Class U - Undetermined	These are surface waters whose quality is to be protected at the same level as existing primary contact use waters, but for which there has not been a reasonable level of inquiry about existing recreational uses and no recreation use attainability analysis has been completed. This is the default classification until inquiry or analysis demonstrates that another classification is appropriate.	126

[1]Expressed as a two-month geometric mean.

If the geometric mean *E. coli* value exceeds the relevant numeric criteria during any bimonthly assessment period, then the stream is considered to be impaired for recreational use. When calculating the geometric mean, values lower than the detection limit are replaced with 1 and values above the

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[2] Colorado's primary contact standard of 126 cfu/100 mL expressed as a not to be exceeded geometric mean value is consistent with EPA's 2012 Recreational Water Quality Criteria and corresponds to an allowable swimmer illness rate of 36 illnesses per 1,000 exposures. EPA's updated criteria also recommend some additional provisions such as a 30-day assessment period (Colorado uses a 60-day period) and adoption of an additional Statistical Threshold Value (STV) not to be exceeded in more than 10 percent of samples. For *E. coli*, the STV value would be 410 cfu/100 mL if adopted in the future in Colorado. Potential changes to Colorado's standards as a result of the 2012 Recreational Water Quality Criteria are not expected prior to the Colorado Basic Standards Rulemaking Hearing in 2021; therefore, the currently applicable Colorado standards are used in this Toolbox.

upper quantification limit (e.g., 2,419.6 MPN/100 mL) are replaced with the upper quantification limits. A sample size of five or more is required for assessment of the two-month intervals. Data are assessed for each year if adequate data from each two-month interval for any given year are available. If adequate data are not available to make an attainment decision using annual data, then the Division will assess *E. coli* data for that two-month interval over the entire period of record (Division 2015a). As a practical matter, many voluntary monitoring programs conduct monthly sampling, so it is common for the latter procedure to be used for assessment purposes.

If adequate data from two-month intervals for the period of record are not available to make an attainment decision, then assessment of the data is conducted on a seasonal basis. Because recreation typically occurs in the summer, the season of May through October is used unless there is evidence that a different season is more appropriate. Data sets comprised of two to four samples that indicate impairment of the *E. coli* standard are placed on Colorado's Monitoring and Evaluation (M&E) List. Segments with *E. coli* data sets comprised of five to ten samples where there is overwhelming evidence of non-attainment are placed on the 303(d) List. Data sets of more than ten samples indicating any degree of nonattainment also result in inclusion on the 303(d) List (Division 2015a).

Although some states (particularly "Beach Act" states) also incorporate a "single sample maximum" standard, Colorado standards are only based on the geometric mean. However, Colorado has a "Natural Swimming Area" regulation (5 CCR 1003-5) that requires a swim beach to be closed and a public health notice posted if a single *E. coli* sample exceeds 235 cfu/100 mL. The swimming area must remain closed until sample results indicate that *E. coli* levels have returned below 235 cfu/100 mL. A natural swimming area is defined as a designated portion of a natural or impounded body of water in which the designated portion is devoted to swimming, recreative bathing, or wading and for which an individual is charged a fee for the use of such area for such purposes (Division 2015b).

1.3 COLORADO'S APPROACH TO *E. COLI* TMDLS

As of early 2016, the Water Quality Control Division (Division) has finalized three *E. coli* TMDLs in Colorado, including Segments 14 and 15 of the South Platte River and Boulder Creek Segment 2b. Each of these TMDLs includes unique aspects, although basic requirements for EPA-approvable TMDLs are included in each. To understand Colorado's approach to TMDLs, it is important to be aware of Colorado's TMDL prioritization process, the basic components of a TMDL, integration of TMDL-related requirements into MS4 permits and alternatives to TMDLs, as briefly described further below.

1.3.1 TMDL Prioritization Process

As of 2016, the Division has been working to implement EPA's "National Long-Term Vision for the Clean Water Act Section 303(d) Program" (EPA 2013). EPA's goals include prioritization, engagement, integration, protection, alternative approaches and assessment. For Colorado, a key step in this process has been developing a TMDL Prioritization Strategy to prioritize TMDL targets for federal fiscal years 2016-2022 (see https://www.colorado.gov/pacific/cdphe/tmdl-prioritization). As part of "Phase 1" screening, *E. coli* impairments have been identified as high priority for TMDL development by the Division. A second level screening is under development by the Division to further prioritize the high priority TMDLs, incorporating a variety of criteria and considering use of EPA's Recovery Potential Screening Tool (RPST) to help further prioritize TMDL priorities based on relative restorability of water quality. Beginning in 2018, the prioritization strategy and 2022 TMDL development targets will be revisited as part of the biennial 303(d) listing methodology process.

1.3.2 Basic Components of a TMDL

A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. TMDLs consider both volume of discharge and pollutant concentration to calculate pollutant loads. The basic components of a TMDL include: wasteload allocations (WLAs) for point sources, load allocations (LAs) for non-point sources, and a margin of safety (MOS). A Reserve allocation may also be allocated to allow capacity for addition of new discharges. Wastewater treatment plant (WWTP) discharges and MS4s are considered point source discharges, with TMDL-related wasteload reductions enforceable under CDPS permit requirements. For non-point sources, load allocations are implemented on a voluntary basis. The basic formula for a TMDL is expressed as:

$$\text{TMDL} = \Sigma\text{WLA} + \Sigma\text{LA} + \text{MOS}$$

Where:

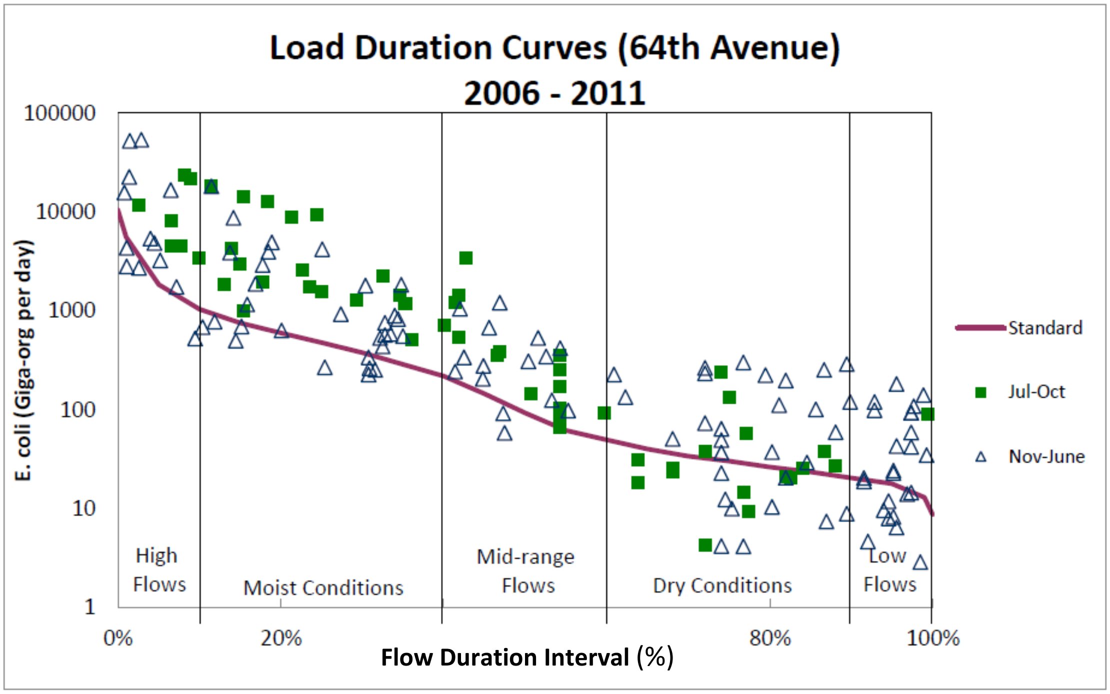
WLA = the sum of wasteload allocations (point sources such as permitted wastewater and stormwater discharges)

LA= the sum of load allocations (nonpoint sources and background)

MOS= the margin of safety

Colorado allows a variety of approaches for development of TMDLs. The most common basic approach is the use of Load Duration Curves (Figure 1), which can be completed using a spreadsheet. For guidance on Load Duration Curves, see *An Approach for the Development of TMDLs Using Load Duration Curves* (EPA 2007). Colorado State University's "eRAMS" flow analysis tools also allow simple development of load duration curves (see https://erams.com/documentation/flow-analysis/). The Division's current practice also includes identifying which bimonthly assessment periods require load reductions, when sufficient data are available to conduct this level of analysis. For example, it may be that load reductions are only needed on a stream during the July-August assessment period, or perhaps the three bimonthly summer assessment periods, with no reductions needed during winter months. Examples of TMDLs completed for *E. coli* in Colorado can be accessed at: https://www.colorado.gov/pacific/cdphe/total-maximum-daily-loads-tmdls. Also see *Protocol for Developing Pathogen TMDLs* (EPA 2001) for more information on the TMDL process applicable to *E. coli* TMDLs.

Figure 1. Example Load Duration Curve from South Platte River Segment 15 TMDL



Description: The red line represents the allowable load (flow x concentration). Instream loads above that line exceed the allowable load. In this case, both seasons of data plotted exceed the allowable load. Exceedances occur during both high flow and low flow conditions.

It is generally in the best interest of a community or MS4 permittee potentially subject to a TMDL to develop a robust data set that can be used to refine the understanding of the source(s) of bacteria and conditions under which elevated bacteria occur. Collection of *E. coli* samples is relatively low cost and can be used to bracket reaches of stream where additional source characterization is needed or to limit the portion of the segment included in the TMDL. Within the past few years, use of commercial and other laboratories to conduct microbial source identification using molecular methods allowing enumeration of fecal source-specific DNA has become more reliable and accessible to more communities (i.e., does not require a research laboratory). Although such molecular analyses are relatively expensive (e.g., several hundred dollars per test per sample versus less than ten dollars per sample for in-house *E. coli* analysis), quantitative information related to fecal sources can be useful for crafting more equitable TMDLs and for identifying potential solutions for controlling high priority fecal waste sources. (Note: the highest priority sources for protection of human health may not necessarily coincide with the highest *E. coli* concentrations.) As a medium-cost approach, *E. coli* analyses can be combined with other “flow fingerprinting” techniques to determine sources of flows associated with elevated *E. coli* (CWP and Pitt 2004).

Regardless of the approach selected within the monitoring constraints of a local government, it is well worth the upfront effort to obtain robust monitoring data prior to planning capital improvements or intensive maintenance programs and implementing other programs to reduce *E. coli*. Monitoring programs are typically in terms of thousands of dollars, whereas capital investments and source control programs are often in terms of millions of dollars. For example, urban case studies in various parts of the country indicate that implementation of *E. coli* TMDL implementation plans or load reduction plans may have costs on the order of $1 to 9 million per square mile of tributary urban area (UWRRC 2014).

1.3.3 Integration of Wasteload Allocations into Stormwater Permits

If the approved TMDL includes a wasteload allocation and associated wasteload reduction for an MS4, the MS4 permit requirements (Division 2016) may be affected in several ways:

- Continued implementation of existing permit conditions without additional requirements. This would occur if the Division determines that existing permit requirements are adequate to ensure compliance with the WLA. For example, Phase 2 permittees are already required to implement the "six minimum control measures" which include a variety of measures that can help to reduce *E. coli*. The six minimum measures include: Public Education and Outreach, Public Involvement/Participation, Illicit Discharge Detection and Elimination, Construction Site Stormwater Runoff Control, Post-Construction Management, and Pollution Prevention/Good Housekeeping. The Division will amend the permittee's certification if necessary to address additional reporting or documentation requirements to demonstrate compliance with the WLA.

- Implementation of additional BMP-based requirements to reduce bacteria loading. If the Division determines that the conditions of the permit are not adequate to bring about compliance with the WLA, the Division may modify the permit or require the permittee to apply for and obtain an individual or alternate general CDPS or NPDES permit. A compliance schedule and additional reporting requirements are also typically required if additional BMPs are warranted. Permits are scheduled for review on a five-year cycle, with requirements subject to change when the permit is reviewed.

- Implementation of numeric effluent limits at end of pipe. To date, this approach has not been implemented in Colorado and is not required by EPA. (A shortcoming of this approach is that some of the most effective strategies for reducing *E. coli* loads include volume reduction, which are not necessarily reflected on a concentration basis.)

- Monitoring may also be required on a case-by-case basis if a stormwater-based TMDL and WLA have been put into place for any waterbody into which the permittee discharges.

Example CDPS Stormwater Permit Requirements:
City of Boulder and Boulder County MS4s Boulder Creek for Boulder Creek TMDL
(Source: Division 2016, paraphrased)

1. Monitoring: Conduct monitoring as needed to identify progress towards meeting the TMDL's WLA.
2. Annual Report: Prepare an annual report that includes:
   a) A description of all control measures planned by the permittee to reduce the discharge of *E. coli*, including specific target dates for implementation.
   b) A description of all control measures implemented to reduce the discharge of *E. coli*.
   c) An identification of all illicit discharges identified by the permittee determined or suspected by the permittee to contribute to discharges from the MS4 > 126 cfu/100 mL.
   d) An indication of if the illicit discharges have been eliminated. If the discharge has not been eliminated, a description of any planned control measure that the permittee intends to take to address the discharge must be included.
   e) A description of monitoring activities conducted, or planned, to meet requirements of #1.

1.3.4 Alternatives to TMDLs

With support from EPA Region 8, Colorado is also exploring alternatives to TMDL development. In these cases, development of a TMDL is foregone (at least for a designated time period)[3] and a "straight to implementation" approach is used. In these cases, the stream segment remains identified as impaired on the 303(d) List while actions are taken to reduce *E. coli* loading over a specified time period. If the standard is still exceeded at the end of the time period, then a TMDL may still be pursued for the impaired segment. The primary benefit of this approach is that it allows resources to be applied directly to reducing loading, rather than for development of the TMDL, which can be a time-consuming, lengthy and expensive process. For MS4 permitees, an added benefit is that the actions implemented are not integrated into MS4 permit requirements while the alternative approach is being implemented. Good candidates for this alternative approach are watersheds where a local government or watershed organization has the ability to implement actions needed to reduce *E. coli* loading and where there is a reasonable expectation that the stream standard could be achieved within the designated timeframe. Guidance for this alternative "straight to implementation" approach are being further developed by the Division and EPA.

EPA's Expectations for Elements in Alternative Restoration Approach Plans

(Source: EPA 2015, Best-Wong Memorandum to EPA Regions)

- Identification of specific impaired water segments or waters addressed by the alternative restoration approach, and identification of all sources contributing to the impairment.
- Analysis to support the implementation of the alternative restoration approach is expected to achieve Water Quality Standards (WQS).
- An Action Plan or Implementation Plan to document: a) the actions to address all sources—both point and nonpoint sources, as appropriate—necessary to achieve WQS (this may include e.g., commitments to adjust permit limits when permits are re-issued or a list of nonpoint source conservation practices or BMPs to be implemented, as part of the alternative restoration approach); and, b) a schedule of actions designed to meet WQS with clear milestones and dates, which includes interim milestones and target dates with clear deliverables.
- Identification of available funding opportunities to implement the alternative restoration plan.
- Identification of all parties committed, and/or additional parties needed, to take actions that are expected to meet WQS.
- An estimate or projection of the time when WQS will be met.
- Plans for effectiveness monitoring to: demonstrate progress made toward achieving WQS following implementation; identify needed improvement for adaptive management as the project progresses; and evaluate the success of actions and outcome.
- Commitment to periodically evaluate the alternative restoration approach to determine if it is on track to be more immediately beneficial or practicable in achieving WQS than pursuing the TMDL approach in the near-term, and if the impaired water should be assigned a higher priority for TMDL development.

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[3] At the time that this Toolbox was completed, the timeframe was considered to be the 2016-2022 TMDL planning horizon.

1.4 STAKEHOLDER ENGAGEMENT

One of the most important aspects of formulating and implementing an effective plan to reduce *E. coli* loading is to get the right people to the table. This includes individuals who have knowledge of watershed conditions, those who are already implementing controls that may help to reduce *E. coli*, and those who are affected by the *E. coli* impairment, as a few examples. Figure 2 summarizes potential partners who may be able to support TMDL development and implementation.

Figure 2. Partners for Development of Effective *E. coli* Load Reduction Strategies

Local Goverment
- Wastewater/Utilities
- Water Providers
- Stormwater/MS4
- Parks and Open Space
- Social/Community Services
- Police

State/Federal Government
- Water Quality Control Division
- Parks and Wildlife
- U.S. EPA Region 8

Non-Governmental Organizations/Non-profits
- Watershed Groups
- Environmental Organizations
- Coalitions for Homeless

Community: Businesses & Residents
- Restaurants
- Private Garbage Collection Services
- Recreators (e.g., kayakers)
- Homeowners/ Residents

2 FINDING THE SOURCE(S) OF *E. COLI*

The starting point for effective *E. coli* load reduction is developing a reasonable understanding of the sources of *E. coli* in the watershed, as well as understanding sources of flows transporting *E. coli* to receiving waters. This chapter provides a summary of common sources in urban areas, followed by guidance on source identification approaches. It can be challenging to identify sources and the actual risk to human health associated with the elevated *E. coli*. As one example, a stream segment could be impaired due to a persistent year-round source of *E. coli* associated with leaking sanitary sewer infrastructure or illegal sanitary-storm drain connections, posing a clear human health risk. As another example, a stream could attain the standard for five of the six bimonthly assessment periods, then slightly exceed the standard in July-August due to birds nesting on bridges (Sejkora et al. 2011; Pendergrass et al. 2013, 2015). The human health risk from scenarios such as these would be expected to differ (Schoen and Ashbolt 2010, Soller et al. 2010b), reinforcing the importance of understanding FIB sources.

2.1 COMMON SOURCES IN URBAN AREAS

In order to develop an effective plan for managing and reducing FIB in urbanized areas, it is first necessary to identify the likely sources and associated transport pathways to receiving waters. Effectively targeting source controls requires substantial information about the land uses and activities within the watershed. Sources of pathogens and FIB in MS4s and receiving waters vary widely, originating from both non-human and human sources. Representative sources of FIB in urbanized areas in Colorado may include SSOs (sanitary sewer overflows), wet weather (stormwater) discharges from MS4s, illicit connections to storm drain systems (e.g., sanitary sewer connections to the storm drain), illicit discharges to storm drain systems (e.g., power washing), failing or improperly located onsite wastewater treatment systems (septic systems), wastewater treatment plants (if not meeting discharge permit limits), urban wildlife, domestic pets, agriculture, and other sources. Allowed discharges to MS4s such as irrigation runoff and uncontaminated groundwater discharges may also transport FIB originating from other sources. From a regulatory perspective, MS4 permittees are not required to address all of these sources (e.g., non-point sources); however, it is beneficial for MS4 permittees to have a broad understanding of the diverse sources of FIB that may be present in impaired waterbodies that receive discharges from the MS4. Table 2 provides a summary of potential FIB sources that communities should consider, depending on the conditions potentially present in a watershed.

Although agricultural sources are not the focus of this Toolbox, both livestock and manure management can be agricultural sources of FIB in watersheds where MS4 permittees are working toward watershed-scale solutions. Secondary sources of persistent FIB include sediments in receiving waters, biofilms in storm drains and waterbody substrate/sediments, and naturalized FIB associated with plants and soil (Francy et al. 2003, Ran et al. 2013, Byapanahalli et al. 2012, McCarthy 2009, Ellis et al. 1998, Ishii and Sadowsky 2008, among others).

Although some of these sources can be controlled to an appreciable extent (e.g., wastewater discharges, sanitary sewer leaks, illicit connections), other sources are much more difficult to control. These diffuse and often mobile sources include wildlife such as raccoons, beavers, birds, etc., as well as environmental sources, such as the biofilms and sediments which provide a stable habitat for these organisms to reproduce. Properly accounting for and identifying potential sources in a particular area is the first step in working toward minimizing FIB contributions from controllable sources.

Table 2. Potential Sources of FIB in Urbanized Areas and Adjoining Watersheds

General Category	Source/Activity
Municipal Sanitary Infrastructure (piped)	Sanitary sewer overflows (SSOs)
	Leaky sewer pipes (Exfiltration) (see Sercu et al. 2011)
	Illicit Sanitary Connections to MS4
	WWTPs (if inadequate treatment or upsets)
Other Human Sanitary Sources (some also attract urban wildlife)	Leaky or failing septic systems
	Homeless encampments
	Porta-Potties
	Dumpsters (e.g., diapers, pet waste, urban wildlife)
	Swimmers/bathers, boaters, trail users (e.g., hikers, runners)
	RVs (mobile)
	Trash cans
	Garbage trucks
Domestic Pets	Dogs, cats, etc.
Urban Wildlife (naturally-occurring and human attracted)	Rodents/vectors (rats, raccoons, squirrels, opossums)
	Birds (gulls, geese, ducks, pigeons, swallows, etc.)
	Open space (coyotes, foxes, beavers, feral cats, etc.)
Other Urban Sources (including areas that attract vectors)	Landfills
	Food processing facilities
	Outdoor dining
	Restaurant grease bins
	Bars/stairwells (washdown areas)
	Green waste, compost/mulch
	Animal-related facilities (e.g., pet boarding, zoos, off-leash parks)
Urban Non-stormwater Discharges (Potentially mobilizing surface-deposited FIB)	Power washing
	Excessive irrigation/overspray
	Car washing
	Pools/hot tubs
	Reclaimed water/graywater (if not properly managed)
MS4 Infrastructure	Illegal dumping
	Illicit sanitary connections to MS4 (*also listed above*)
	Leaky sewer pipes (exfiltration) (*also listed above*)
	Biofilms/regrowth
	Decaying plant matter, litter and sediment in the storm drain system
Agricultural Sources (potentially including ranchettes within MS4 boundaries or areas in urban growth boundaries)	Livestock, manure storage
	Livestock, pasture
	Livestock, corrals
	Livestock, confined animal feeding operations (CAFO) (NPDES-regulated)
	Manure spreading, pastures/crops
	Municipal biosolids re-use
	Reclaimed water (if not properly managed)
	Irrigation tailwater
	Slaughterhouses (NPDES-regulated)
Natural Open Space/Forested Areas	Wildlife populations
	Grazing
	Natural area parks, off-leash areas
Other Naturalized Sources	Decaying plants/algae, sand, soil (naturalized FIB)

Note: this table is a Colorado adaptation of work by San Diego County (Armand Ruby Consulting 2011).

2.2 PRIORITIZING SOURCES FOR INVESTIGATION

2.2.1 General Considerations

Given the many sources of FIB in urban areas and some of the challenges associated with definitively determining sources, it is helpful to develop a source prioritization process. Such processes should consider factors such as:

- Human health risk
- Magnitude of loading
- Geographical distribution relative to recreational use locations
- Controllability/Ability to Implement/Ability to Leverage Other Planned Projects
- Frequency of standards exceedances[4]

When source identification is prioritized with these considerations in mind, then resources for source identification can be allocated to identify sources with high risk to human health, higher loads, close proximity to actively used recreation areas, sources that could reasonably be controlled if identified, and sources that cause frequent exceedances of standards. It may be beneficial for MS4 managers to explore how other ongoing programs or projects may be leveraged. For example, communities may be required to survey storm drain outfalls to meet Community Rating System requirements for flood control and outfall reconnaissance for illicit discharges could be conducted at the same time. Similarly, local governments may also have capital improvement projects planned that allow opportunistic integration of stormwater quality features (e.g., inlet retrofits, implementation of curb-side bioretention in conjunction with road repaving or bike lane work). An example source prioritization process used in San Diego follows.

2.2.2 San Diego County Example

San Diego County developed a consensus-based source prioritization process that leverages local knowledge and provides a framework potentially adaptable to other communities. The process was developed by a work group of San Diego County MS4 co-permittees and their consultants in 2011-2012 (Armand Ruby Consulting 2011) and used to target source control efforts in multiple watersheds across the county. The source prioritization process evolved from work group meetings that initially focused on developing conceptual models for bacteria sources, fate and transport, along with a literature review. Based on the conceptual models and the literature review results, the work group focused on developing a process for prioritizing bacteria sources within watersheds. As a starting point, the conceptual models recognized two overarching, categorical distinctions:

- Wet weather vs. dry weather conditions
- Watersheds (including MS4s, creek and river systems) vs. lagoons (including beaches)

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[4] List adopted from the Source Prioritization Process prepared by Armand Ruby Consulting (2011) for the San Diego County MS4 co-permittees.

Second, the work group recognized that bacteria sources should be identified by their relationship to human activity and established the following broad categories for bacteria sources:

- Human origin (i.e., from the human body)
- Anthropogenic, non-human origin (resulting from human activities, but not the human body)
- Non-anthropogenic origin (independent of human activity)

Building on these initial frameworks, the work group developed a rating system using a spreadsheet tool to prioritize efforts. In its initial meetings, the work group produced a lengthy list of potential bacteria sources, which was used to inform construction of the conceptual model diagrams. The source list was sub-divided into the three main source type categories (human, anthropogenic non-human, non-anthropogenic). Only sources with a potential pathway into an MS4 or a receiving water (e.g., creek, river, lagoon, or ocean) were included on the list. The potential sources were further aggregated according to common characteristics. The draft lists of sources were then incorporated into the conceptual model diagrams. To support the goal of reducing discharges of pollutants in urban runoff to the maximum extent practicable (MEP), the work group agreed it was important to prioritize sources for further investigation regarding possible application of BMPs (either source controls or local/regional treatment controls).

The work group agreed that prioritization criteria ought to include additional factors other than simply magnitude alone. Temporal variation (dry vs. wet weather) was identified as a top-level consideration and led to a decision that the prioritization process would be performed separately for dry weather and wet weather sources. Table 3 lists factors considered in the source prioritization process, aggregated under the following general themes described in Section 2.2.1 (Human Health Risk, Magnitude, Geographical Distribution, Controllability/Ability to Implement, Frequency of Exceedances).

From this exercise, a quantitative ranking scheme was developed for the relative scoring and ranking of sources within a given watershed. The five themes listed above were identified as the factors that would be used in the scoring matrix that was developed into a spreadsheet tool, with example output provided in Table 4. Human health risk and magnitude were identified as the most important of the five thematic factors for bacteria source prioritization. Within the scoring scheme, these two factors were given the highest weight, with possible score ranges of 1-10. The other three factors (geographical distribution, controllability, and frequency) were allocated possible score ranges of 1-5. Because of the primary importance of the source type (human, anthropogenic non-human, non-anthropogenic), this factor was given the role of then providing an overall weighting for the source score. The weighting factors for this tool were:

- x 5 for human sources (bacteria derived from the human body)
- x 3 for anthropogenic (resulting from human activity), non-human sources
- x 1 for non-anthropogenic (natural) sources
- x 0 for sources with no apparent transport mechanism from source to MS4 or receiving waters

Table 3. Factors Considered in a Source Prioritization Process

(Adapted from San Diego Co-permittees, as summarized by Armand Ruby Consulting 2011)

SOURCE CATEGORIES
TEMPORAL/FLOW CONDITION
Temporal Distribution of sources: wet weather vs. dry weather
PRIORITIZATION CRITERIA HUMAN HEALTH RISK
Potential for human pathogens to be present
Potential for human exposure
Dose
MAGNITUDE
Concentration and/or loading
Frequency of occurrence
Variability
GEOGRAPHICAL
Spatial distribution of sources; discrete locations (can map location) or spread out or distributed (e.g., pet waste, soil)
Proximity to Primary Contact Recreational Uses
Proximity to MS4 impermeable surfaces
Land uses, hydrology, soil types, population (design parameters)
Redevelopment opportunities
Ease of transport pathway to receiving waters
CONTROLLABILITY/IMPLEMENTABILITY
Cost, social impact, technological barriers, organizational barriers
Challenge of changing behavior/culturally
How many application sites for BMPs
Repetitive nature of behavioral changes
POTENTIAL BENEFITS
Ability to maximize human health improvement
Potential for multiple (secondary/additional) benefits
Other water quality issues
Other benefits (e.g., flood control)
Ability to target underlying water quality issues
Consideration of the benefits of source activities (e.g., flood control)
TECHNICAL/DESIGN
Structural: siting, costs, maintenance
Site-specific flow conditions
WWTP capacity for low-flow dry weather diversions
ORGANIZATIONAL
Regulatory imperative
Code barriers, conflicts w/state-federal regulations
Political opposition/pushback; public support/lack
Organizational ease of implementation
Benefit to public (per cost)
FREQUENCY of EXCEEDANCES

Table 4. Example Ranking of Weighted Scores for FIB Sources under Dry Weather Conditions Using San Diego Spreadsheet Tool as Applied to the San Diego River

(Source: San Diego Co-permittees, as summarized by Armand Ruby Consulting 2011)

Rank	Human Waste	Dry Score
1	Sanitary sewer overflows (SSOs)	105
2	Homeless Encampments	105
3	Leaky Sewer Pipes (Exfiltration)	100
4	Bathers	95
5	Boaters	95
6	RVs (mobile)	85
7	Porta-Potties	80
8	Dumpsters	64
9	Trash cans	64
10	Garbage trucks	60
11	Illegal Dumping	56
12	Leaky or Failing Septic Systems	55
13	Illicit Connections	55
14	Illegal Discharges	40
15	Gray Water Discharges	40
16	Pools	36
17	Hot Tubs	36
18	Biosolids Re-use	0
19	Landfills	0
	Anthropogenic Non-human	
1	Pets	72
2	Rodents (Mice, Rats), Rabbits, etc.	54
3	Birds (Gulls, Pigeons, etc.)	54
4	Garbage Trucks	42
5	Dumpsters	36
6	Trash Cans	36
7	Manure/Compost	33
8	Vectors	33
9	Washwater	33
Rank	**Anthropogenic Non-human *(continued)***	**Dry Score**
10	MS4s Infrastructure - Biofilm/Regrowth	33
11	Reclaimed Water	30
12	Green Waste	27
13	Litter	27
14	Outdoor Dining/ Fast Food	27
15	Grease Bins	24
16	Soil	18
17	Livestock	0
18	Manure Re-use Non-Ag	0
19	Landfills	0
20	Livestock	0
21	Manure Re-use	0
22	Irrigation Tailwater	0
23	Soil and Decaying Plant Matter	0
24	Food Processing	0
25	Bio-Tech Manure Management	0
	Non-anthropogenic	
1	Wildlife (Birds and Others)	18
2	Wrackline (Flies, Decaying Plants)	18
3	Plants	16
4	Algae	16
5	Soil	9

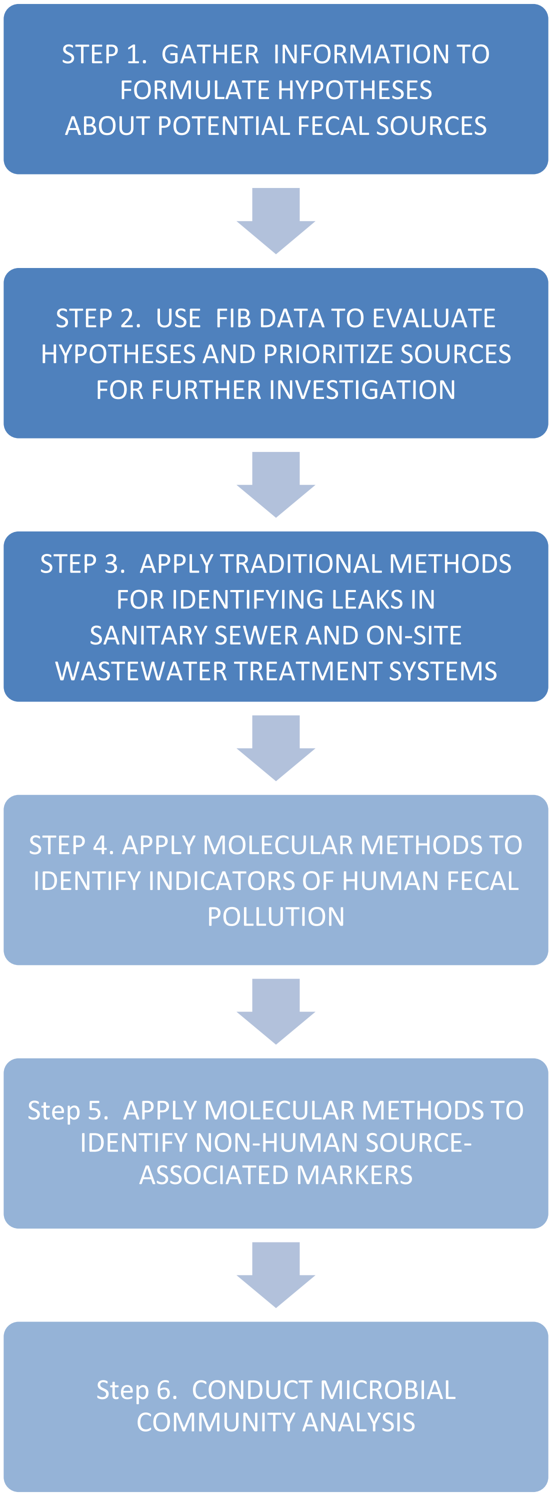
2.3 SOURCE IDENTIFICATION METHODS

Monitoring strategies to develop an understanding of the sources of FIB can range from simple and relatively inexpensive sample collection and analysis of FIB and basic water quality parameters to more complex microbial source tracking (MST) approaches relying on advanced molecular methods. It is recommended that entities facing *E. coli* TMDLs begin with simple methods to identify and prioritize reaches of the receiving water of concern and then evaluate prioritized reaches based on local infrastructure conditions. If sources cannot be identified through these inexpensive measures, then the use of advanced methods may be warranted, providing additional benefits in terms of determining sources contributing FIB and pathogens to identified critical reaches. Monitoring and source tracking techniques selected may also be affected by budget constraints, regulatory drivers, and available technical expertise.

In urban areas, initial data collection efforts for FIB-impaired streams typically include instream synoptic sampling combined with dry weather screening of storm drain outfalls to identify potential illicit connections to storm drains (CWP and Pitt 2004). Griffith et al. (2013) recommend a six-step process, as summarized in Figure 3. Using this approach, a community would only advance to subsequent steps if the previous step did not provide adequate information to identify sources of FIB pollution with a level of confidence needed to develop management strategies to either reduce FIB or support an alternative regulatory resolution. Steps 1-3 are expected to be feasible in most communities, whereas steps 4-6 represent increasing costs that may or may not be justified, depending on the particular watershed. This section provides an overview of monitoring and source tracking strategies that can be used by local governments, including a variety of methods suitable for a range of budgets and technical expertise. A limited discussion of emerging, advanced techniques is also provided, along with recommended references for more in-depth information.

Figure 3. Six-Step Process of Microbial Source Identification

(Source: Recommendations by Griffith et al. 2013, as presented in UWRRC 2014)



2.3.1 Basic FIB Monitoring in Impaired Waters

The starting point for assessing sources of fecal contamination in receiving waters is to collect basic FIB data to determine which portions of the waterbody have elevated FIB. FIB tests are low-cost and can be conducted in-house by most municipal laboratories. One of the keys to an effective FIB monitoring program is to collect samples with adequate spatial and temporal resolution to target stream reaches where FIB targets are exceeded and to identify where significant FIB loading may be occurring. Synoptic sampling of streams, where an upstream to downstream set of locations is sampled on the same day, is preferred. Both instream sources (such as contaminated sediment resuspension) and watershed sources need to be considered.

Due to very high variability of results in FIB data sets, discerning statistically significant trends with acceptable levels of power and confidence is typically not possible without relatively large data sets.[5] Considerations when collecting and interpreting FIB data include:

- Select initial sampling locations to evaluate potential FIB sources. Directly sampling runoff from potential sources allows for the identification of contributing sources or "hot spots" with a minimum number of required samples. Locations may also be selected to bracket potential sources. Examples might include above and below WWTP discharges, off-leash dog parks, areas with heavy bird usage, sewer line crossings of streams, homeless encampments, aging sanitary sewers in proximity to storm drains, etc.

- Extreme variations in FIB concentrations can occur at the same location over relatively short time periods, so multiple samples over time are needed to begin to develop an understanding of potential trends and sources.

- Time of day of sample collection can affect FIB concentrations due to inactivation from natural UV light, flow variations that will affect the transport of bacteria discharged upstream through a sampled reach, and discharge variations of bacteria from potential sources. Early morning samples typically have the highest FIB concentrations.

- Seasonal variations in FIB are common, so erroneous conclusions may be drawn if adequate seasonal representation is not provided (e.g., a stream sampled in winter may meet stream standards, whereas a stream sampled in August may not meet standards). Sampling during dry and wet weather will likely also result in quite different results. When evaluating trends over time, comparable seasonal representation should be present in long-term data sets.

- FIB can persist or grow in the environment, so elevated FIB concentrations do not necessarily represent recent fecal contamination. This is particularly true of organic-rich, moist, dark environments such as sediments, decaying organic litter and biofilms. Scour of contaminated sediment and substrate pore water are also known FIB sources.

- Unless exceptionally high, FIB concentrations typically do not provide information on the source of the contamination, so additional investigations or source tracking techniques are often needed to follow up initial analyses to identify sources.

- When collecting samples, be sure not to disturb stream sediment during sample collection. For example, collect the water sample first and then perform flow measurements.

- It can be valuable to collect sediment samples to help determine if sediment resuspension may be contributing to elevated FIB in the water column.

- FIB results are often above or below the analytical quantification range (e.g., <10 or >24,192 MPN/100 mL), causing difficulties in data interpretation and statistical analyses. When sewage

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[5] For additional guidance on the number of sampling events needed, useful references include Burton and Pitt (2002) and Chapter 6 of UWRRC (2014).

input is suspected, FIB tests should be conducted at several dilutions, including very high dilutions so that concentrations close to those found in wastewater influent can be quantified (City of Santa Barbara 2012). Consult with the laboratory prior to finalizing the chain of custody in order to ensure an adequate range of quantification for FIB.

For standard operating procedures for FIB sample collection, see Standard Methods (APHA 2012) and CWP and Pitt (2004). Sample bottles appropriate to the analytical method should be used and samples should be kept cool (4°C) and quickly transported to the laboratory (6 hours is usually noted as a targeted time period between sample collection and analysis).[6] In addition to FIB analyses, it is also often helpful to include analysis for other water quality parameters that may help to identify human sewage sources and/or conditions that may be contributing FIB growth and persistence in the environment. Table 5 lists these parameters; most of these analyses can be conducted in municipal laboratories. Field data, including flow measurements or estimates, are recommended for all sample locations. Some or all of the additionally suggested water quality parameters should be considered based on the objectives of the sampling program since they may assist in identification of sources of discharges from an MS4. While no single parameter in Table 5 is a perfectly reliable indicator of sewage contamination, a suite of these parameters may provide an initial weight of evidence to identify potential sources or to identify where more advanced molecular methods should be used to confirm sewage contamination.

Table 5. Field and Analytical Parameters for Consideration in Basic FIB Sampling Programs

Field Data	Basic Analytical Parameters
• Flow (either at the sample location or documented from a nearby gage) • pH • Dissolved oxygen • Temperature • Conductivity/Salinity • Weather conditions • Field observation of sources • Narrative flow condition (e.g., spring runoff, storm flows, reservoir releases)	• *E. coli* • Nutrients[2] (e.g., ammonia[1], nitrate/nitrite, total Kjeldahl nitrogen, total phosphorus, orthophosphate) • Organic carbon (total and dissolved)[2] • Turbidity • Fluoride[1] • Potassium[1] • Surfactants (typically measured as Methyl Blue Active Substances [MBAS])[1,3] • Optical brighteners (or fluorescence)[1]

[1]These may be sampled instream, at outfalls, or both as part of flow fingerprinting related to sources. See discussion Section 2.3.3.1 for additional information on why various analytes are recommended.
[2]Analytes that have been correlated to elevated FIB in some studies.
[3]Involves hazardous reagents.

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[6] Some exceptions apply to the 6-hour hold time, depending on the use of the samples. See UWRRC (2014) for a more detailed discussion of allowance of longer hold times for stormwater sampling purposes.

2.3.2 Source Tracking Toolbox

Once basic monitoring has been conducted to bracket areas of concern, then there are many techniques that communities can use to explore and identify sources of elevated FIB in receiving waters. The selection of techniques should be based on initial hypotheses formed from basic FIB monitoring and in most urban areas should include basic dry weather screening of outfalls in stream reaches with elevated FIB. Some of these methods have been available for 20 years or more (e.g., Pitt et al. 1993, CWP and Pitt 2004), whereas others include recently published methods that integrate significant advances in microbial source tracking (e.g., Griffith et al. 2013). There are strengths and limitations of both the older and more recent approaches, and each community will need to balance their source tracking objectives with available budget and technical resources. These budget-related decisions also need to consider the benefits that a well formulated source tracking program may provide relative to the projected costs of the actions specified in TMDL implementation plans. In some communities nationally, multi-million or billion dollar implementation plans have been developed to address FIB impairments; thus, substantial benefits may be gained by a well-developed and clearly targeted monitoring program. In some cases, definitively eliminating human sources may enable some regulatory relief for the MS4 permitee. Although this type of relief has not been evaluated in Colorado to date, EPA's Quantitative Microbial Risk Assessment (QMRA) option for site-specific standards becomes an option when human sources are largely ruled out (See Section 7.2.2.) In some states such as California, regulatory options based on "natural source exclusions" and reference watershed conditions are also available to dischargers when certain conditions are met.

Table 6 provides a summary or toolbox of potential source tracking methods, ranging from simple to complex. This table integrates findings from earlier EPA-sponsored work by the Center for Watershed Protection and Pitt (2004) titled *Illicit Discharge Detection and Elimination Manual* and two recently developed key references on source identification approaches that incorporate use of molecular methods. The two latter references include *The California Microbial Source Identification Manual: A Tiered Approach to Identifying Fecal Pollution Sources to Beaches* (Griffith et al. 2013*)* and *Tools for Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches* (City of Santa Barbara 2012a&b). The primary purpose of the tools in Table 6 is to identify signals of human waste in streams and storm drains and track these signals to their sources. Several of these techniques are discussed in more detail later in this chapter, but the toolbox concept is addressed first because monitoring programs should ideally be designed considering the big picture of how a study could evolve to more advanced techniques if simple techniques are unable to identify the source of contamination (i.e., move forward sequentially).

Table 6. Source Tracking Tools

(Modeled after *Tools for Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches*, City of Santa Barbara 2012a&b; supplemented by Pitt et al. 1993, Center for Watershed Protection and Pitt 2004)

Tool	Best Use	Caveats and Challenges	Cost
Visual Surveys of Potential Sources	Homeless encampments, sites with frequent daytime use, under bridges, obvious contamination associated with inappropriate discharges.	Feces often contained in newspaper or plastic bags.	$
GIS	Essential for planning and analyzing data in relation to infrastructure. Useful prior to initial field investigations, as well as for targeting areas for more detailed investigations.	Requires accurate data for both storm drains and sanitary sewers, including pipe elevations and inverts, where available.	$
Dry Weather Outfall Screening	Identification of flowing outfalls for water quality sampling, along with physical observations (odor, color, floatables, deposits, stains).	Dry weather flows can originate from both contaminated and uncontaminated sources.	$
FIB (*E. coli*)	Basic indicator of potential fecal contamination tied to regulatory receiving water limits.	Recommended in conjunction with additional chemical or molecular tests. Urban wildlife (e.g., raccoons) and pets may be responsible for high values observed. Biofilms and sediment sources may also contribute to elevated FIB. Extensive sampling required to account for variable results.	$
Chemical Indicators (Basic Flow Fingerprinting/ Non-human Chemistry)	Finding illicit connections. Good for understanding nutrient inputs from any type of illicit connection. Example indicators include: detergents, fluoride, ammonia, and potassium. Others may also be useful.	May not identify direct human deposition (e.g., homeless) and small sewage leaks that are significantly diluted by other flows. Background signal of urban runoff can make fingerprinting sewage difficult in some urban areas. Plan repeated sampling to account for variable results.	$
Chemical Indicators (Advanced Markers of Human Waste)	Finding sewage leaks. Advanced analyses may include: sucralose, caffeine, and cotinine.	Some advanced chemical indicators may be present in the environment from surface deposition, rather than sewage sources (e.g., dumping coffee down storm drains). Plan repeated sampling to account for variable results.	$$$
Canine Scent Tracking	Best for use when real time results are desired, such as working up storm drain networks with many branches. Also when broad spatial coverage is sought.	Canines may respond to non-human illicit connections, due to training with detergents. Poor sensitivity and specificity. Requires specially trained canines with trained staff.	$

Tool	Best Use	Caveats and Challenges	Cost
CCTV (Closed Circuit Television) of Storm Drains	Best for use where sampling data suggests sustained input of sewage.	Most operators are trained for sanitary sewer pipe inspection, and may seek to clean the lines first. Plan to guide operators to slow down, look carefully at leaks, and do not clean the lines first (in order to see solids on bottom of storm drain).	$$
Electric Current Flow Method	The method uses the variation of electric current flow through the pipe wall to locate defects that are potential water leakage paths either into or out of the pipe.	See ASTM F2550 – 13. Applies only to electrically non-conducting pipes w/ diameters of 3 to 60 in.	ND
Basic Dye Test	Best for testing laterals or fixtures feeding a single illicit connection that has been observed by CCTV.	Use bright green dye and a UV light to look for dye in storm drains. Usually applied after an illicit connection or leak is suspected.	$
Smoke Test	Best for limited geographic areas with strong evidence for direct connections (e.g., toilet paper).	Difficult in large pipes and densely populated areas. Usually applied after an illicit connection or leak is suspected.	$$
Dye with Rhodamine Probe	Best for testing suspected sewage infiltration to storm drains when persistent human-waste markers are found w/out observing solids such as toilet paper.	A fluorometer is used to detect much lower concentrations of dye compared to visual testing. Wet weather runoff may create a false positive signal. Usually applied after an illicit connection or leak is suspected.	$$
Automated continuous flow gauges and autosamplers	Best for drains with evidence of higher flows (wet walls, signs of water flowing into creek channel). Supports load estimation.	Check specs carefully to find flow gauges suitable for dry weather flows. Requires confined space entry in most cases.	$$ (initial)
Temperature Probes	Can be placed in storm drain outfalls to further verify certain types of suspected illegal connections (e.g., flushing/showering patterns).	Does not identify where the illegal connection is located. More useful in smaller drainage areas.	$
Human-specific waste markers (Advanced Technique)	Best tool for quantifying inputs of human waste. Best for sampling in streams, storm drain outfalls or major nodes in storm drain network.	Plan repeated sampling to account for variable results. Requires more expertise and cost. Reclaimed wastewater may interfere with results.	$$$
Community approach, e.g., Phylochip, Next Generation Sequencing (NGS) (Emerging Advanced Technique)	Best for sampling along a gradient of suspected inputs, (e.g., to test if septage is entering a creek). May provide ability to discern human sources (i.e. sewage vs septage) or identify animal sources for which markers have not been developed or for groundwater, due to low detection thresholds.	Not yet proven under field conditions. Results are not conducive to simple interpretation by a nontechnical audience. Requires more expertise and cost. This work would typically be conducted by qualified university researchers.	$$$$

Notes: Cost—increasing $ indicates more expensive techniques. ND = not determined.

2.3.3 Dry Weather Outfall Screening

Dry weather screening is one of the most important tools available to municipal stormwater managers. Identification and removal of illicit discharges and illegal connections may be the single most important action that municipal stormwater managers can take to reduce human sources of contamination.

The Center for Watershed Protection and Pitt (2004) prepared *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments* under EPA funding to provide guidance to communities in developing effective management programs and field guidance to reduce illicit discharges. The approximately 200-page manual provides detailed guidance for those embarking on dry weather surveys. The discussion which follows provides a significantly condensed version of steps required to conduct an Outfall Reconnaissance Inventory (ORI) and some aspects of indicator monitoring. ORI field forms, which have been effectively used by many communities, are provided in Appendix D of the Center for Watershed Protection and Pitt (2004) manual (accessible at: http://www.epa.gov/npdes/pubs/idde_manualwithappendices.pdf). The minimum list of monitoring parameters for use in dry weather screening includes flow rate (estimated or measured), water temperature, the regulated FIB parameter, and pH. Additionally recommended parameters for source fingerprinting include ammonia and potassium (for calculating ammonia/potassium ratios), fluoride, phosphorus, surfactants and/or optical brighteners (as summarized in Table 5). The basic steps for an outfall reconnaissance inventory include:

1. **Collect background data**. At a minimum, this includes an initial map of storm drain outfalls. Other background information, when available, can include more detailed sanitary and storm drain infrastructure mapping, age-related and maintenance information for the sanitary sewer system, citizen complaints, known hotspots draining to the outfall and other information. As GIS is increasingly used by local governments in many urban areas, a significant amount of information can be compiled prior to fieldwork. Ideally, the "storm sewershed" and tributary land use should be shown on maps to support field investigations.

2. **Develop outfall descriptions**. This includes information on the size and pipe material of the outfall, among other information. Many communities have GIS or asset databases that can be used to support this effort.

3. **Conduct quantitative characterization of flowing outfalls.** This includes estimates of flow rates. For techniques useful for measuring or estimating flow rates, see Center for Watershed Protection and Pitt (2004).

4. **Assess and document physical indicators for flowing outfalls.** Examples of physical indicators of potential FIB contamination include odor, staining, and evidence of sanitary waste (e.g., feces, toilet paper).

5. **Assess and document physical indicators for non-flowing outfalls.** Visual indicators present at non-flowing outfalls imply intermittent inappropriate discharges, although water samples for analyses may not be available.

6. **Complete initial outfall designation and follow-up sampling actions.** Based on the initial screening activities, flowing outfalls (for practical purposes, the Division defines flowing outfalls as > 5 gallons per minute) with indicators of potential FIB contamination should be sampled several times. If an outfall is identified as possibly contaminated, additional sampling and investigations are conducted along the main storm drainage system to isolate the likely reaches

of contamination to narrow the watershed investigations to identify the sources. Several different sampling approaches can be used at this stage, including a chemical tracer approach (discussed below), molecular methods, and use of advanced chemical markers.

Prior to discussing various approaches for dry weather investigations, general guidance on dry weather sample collection is important. As is the case with instream sampling, the timing of sample collection from outfalls can affect their results. Center for Watershed Protection and Pitt (2004) provide these recommendations regarding timing of sample collection:

- Sample in the late fall/early spring because outfalls are easiest to spot during leaf-off or dormant vegetation conditions. In Colorado, irrigation runoff is less prevalent before May and after September. Once identified and located, the outfalls should be re-visited at other seasons as inappropriate discharges may be seasonal. It is common for outfalls to continue to be found even after several surveys. Small outfalls draining streamside businesses may be especially problematic as they are not likely identified on city drainage maps, but have been found to be more frequently contaminated than large outfalls in some parts of the country.

- Sample after a dry period of at least 48 hours (trace rainfall activity may be acceptable depending on the size of the watershed). Periods of regional high groundwater should also be included during surveys to identify possible groundwater intrusion sources.

- Sample in the early morning/late afternoon, when feasible. Checking outfalls when people are home may increase the chances of catching an inappropriate connection (e.g., flushing, showering).

- Avoid conditions during snow melt and/or if salt has been applied to the road system draining to the outfalls. Also note that some tests (e.g., ammonia, chlorine) are affected by cold temperatures or confounded by the presence of salt (e.g., detergents).

Following initial identification of flowing outfalls, several different source tracking approaches may be used. Examples of several approaches that have been used successfully in various locations follow.

2.3.3.1 Flow Fingerprinting/Chemical Tracer Methodologies[7]

A chemical tracer methodology can be used to conduct a mass balance of all dry weather flows at an outfall or in a drainage system in order to identify and quantify the flow sources, including sanitary sewage. It is not specifically used to directly identify the sources of FIB, but the presence of wastewaters and other flows that may be contaminated with FIB. An investigation of non-stormwater discharges into storm drainage needs to proceed along a hierarchy of procedures and locations, progressing from exploratory techniques to confirmatory procedures. The methodology briefly summarized here was developed over many years for the EPA and verified in numerous communities (CWP and Pitt 2004). This procedure recognizes that limited resources are available to municipalities and makes maximum use of information typically available, prior to proceeding to advanced methods.

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[7] The discussion in this section was prepared by Dr. Robert Pitt for use in *Pathogens in Urban Stormwater Systems* (UWRRC 2014) building upon discussions in CWP and Pitt (2004). For more detailed discussion and additional examples, see those reports.

The purpose of the investigative procedures is to separate storm drain outfalls having dry weather discharges into at least three general categories (with a known level of confidence) to identify which outfalls (and drainage areas) need further analyses and investigations. These categories are outfalls affected by non-stormwater discharges from: (1) pathogenic or toxic pollutant sources, (2) nuisance and/or aquatic life threatening pollutant sources, and (3) unpolluted water sources. The pathogenic and toxic pollutant source category would be considered the highest priority due to potential human health impacts or significant impacts on receiving water organisms. Nuisance and aquatic life threatening pollutant sources may include laundry wastes, landscaping irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix concrete trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters. Clean water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic water from water line leaks, etc.

Ideal tracers should have the following characteristics:

- Significant differences in concentrations between possible pollutant sources;
- Small variations in concentrations within each likely pollutant source category;
- A conservative behavior (i.e., no significant concentration change due to physical, chemical or biological processes); and
- Ease of measurement with adequate detection limits, good sensitivity and repeatability.

Samples are collected from all flowing outfalls using the procedures described by CWP and Pitt (2004). That report also has detailed guidance on ancillary observations while in the field. The surveys should be repeated several times during the first year as intermittent flows may change seasonally. After potentially problematic outfalls are identified, similar sampling and analyses is conducted at various manhole locations in a drainage system to isolate the reach where the problem flows are entering the drainage system.

Several options can be used to evaluate the collected screening data. A flow chart method (shown as Figure 4) is simple to use and has been shown to be quite accurate. It is also possible to estimate the outfall source flow components using a set of simultaneous chemical mass balance equations. Once problem outfalls are identified, these fingerprinting techniques can be applied to the contributing storm drain system to further focus source identification and correction measures, as illustrated in Figure 5. Hand-held probes for constituents such as ammonia, fluorimeters and other test kits are commercially available that can provide real-time measurements that may be useful in such investigations. For more information on these techniques see UWRRC (2014) or CWP and Pitt (2004).

Figure 4. Flow Chart to Identify Most Likely Significant Flow Component Contributing to Elevated FIB

(Source: Shergill and Pitt 2004, modifies Pitt et al. 1993)

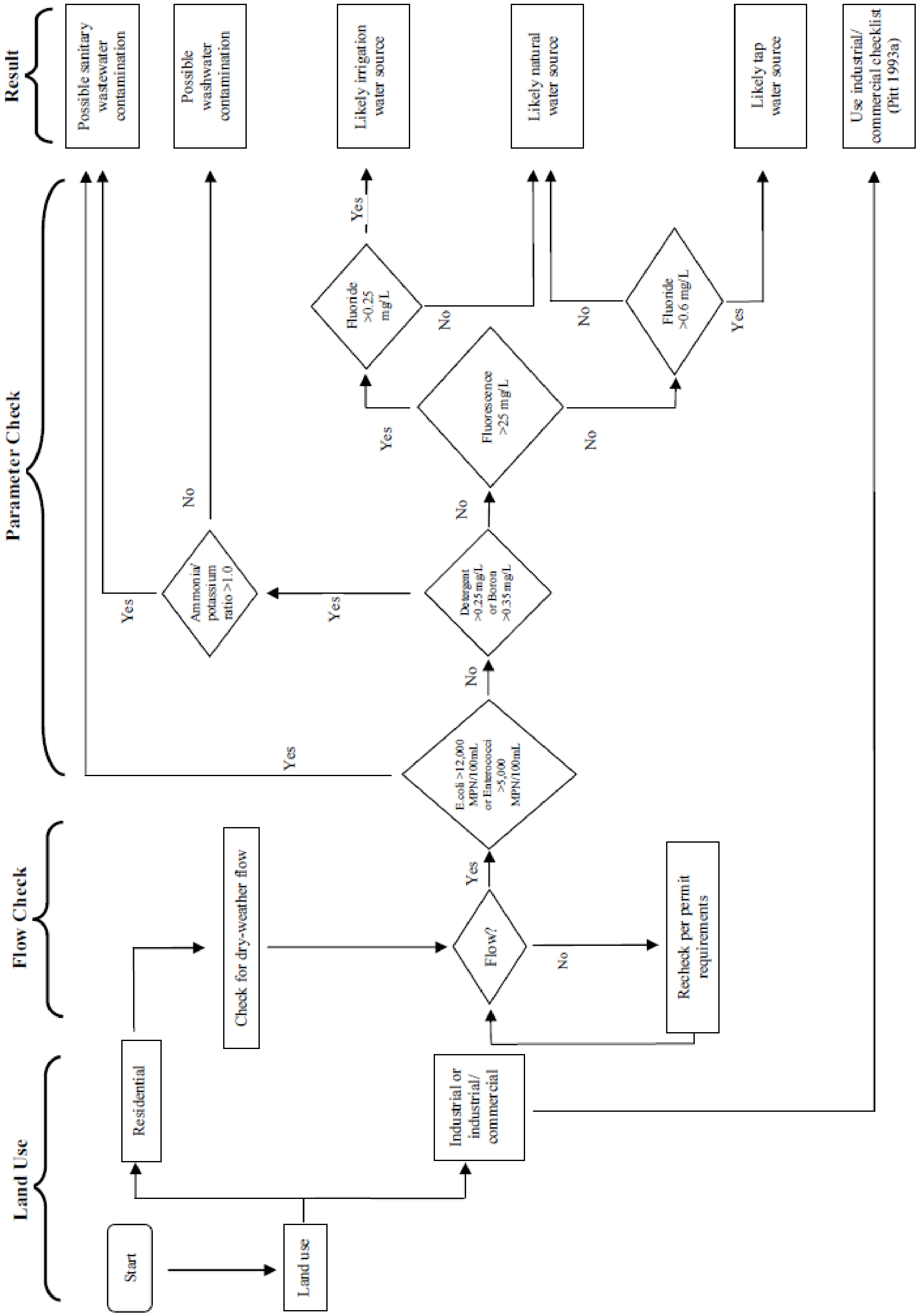
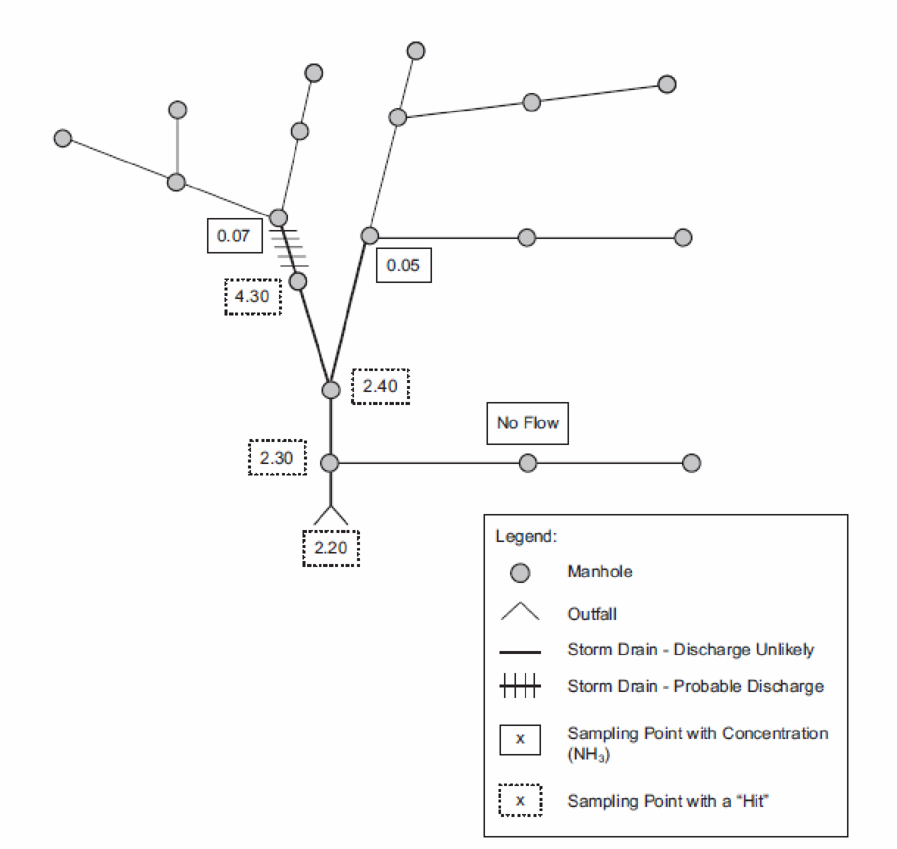


Figure 5. Use of Ammonia as a Tracer to Identify Drainage System Sections Contributing Contaminated Flows

(Source: CWP and Pitt 2004)



2.3.3.2 Advanced Monitoring Using Microbial Source Tracking

Advanced MST tools capable of detecting human fecal contamination are typically employed for one of two purposes: one is implementation-oriented, and the other is oriented to regulatory relief. For implementation-oriented MST efforts, human and non-human fecal markers are used in combination with traditional source tracking tools to evaluate hypothesized sources of fecal contamination (often with samples collected within the MS4 or at an outfall). An example of this is the incorporation of MST markers into enhanced IDDE program activities. The goal of this type of application would be to identify and locate specific fecal inputs into a MS4 and to identify targeted management actions capable of remediating the confirmed sources (i.e., elimination of illicit discharges and/or leaks, or other structural and nonstructural BMPs). Such a project may also incorporate confirmatory sampling within the MS4 or at the outfall to verify successful elimination of human fecal contamination in the discharge after the remedial action is completed. This section describes the use of MST tools for this purpose.

The second, regulatory-focused purpose of MST studies involves use of MST tools to demonstrate the absence (or near absence) of human fecal contamination in a receiving water, often to confirm its eligibility for a site-specific standard (since it is generally understood that the default recreational criteria values are conservatively low for non-sewage impacted receiving waters). In this case, human markers may be used to support a natural source exclusion request,[8] or they may be used in combination with the direct measurement of pathogens to quantify the illness risk associated with water contact recreation to support the development of a risk-based criteria calculated using QMRA. The use of advanced MST tools for QMRA is described in more detail in Section 7.2.

Recent progress in the use of advanced molecular methods as part of a source tracking toolbox has led some communities nationally to move towards routine use of these methods as part of dry weather monitoring at storm drains discharging to impaired waterbodies in urban areas. These methods are able to directly measure source-specific fecal bacteria (i.e., do not require the creation of a library to identify sources). Furthermore, the EPA has recognized the increased reliability of these methods for characterizing fecal pollution and is currently developing a standardized method for the measurement of human markers in environmental waters. Methods for the detection of general fecal markers (not source specific) have been developed by the EPA for enterococci (Methods 1609 and 1611) and *Bacteroidales* (Method B). Many human and nonhuman source-specific markers have been tested and method recommendations for human, dog, gull, cow, and other markers can be found in the California Microbial Source Identification Manual (Griffith et al. 2013). The use of these advanced molecular markers is a fecal source tracking exercise. Source-specific markers are often not correlated with FIB in the MS4 due to the presence of non-fecal FIB sources (e.g., soil, sediments, decaying plant matter) and non-anthropogenic fecal sources (e.g., wildlife) contributing to the overall FIB concentration measured. Differential decay of markers compared to FIB and FIB regrowth may also result in weakly correlated data.

Figure 6 provides an example flow chart illustrating how such methods can be applied. Initial steps in this process focus on desktop review of available data, including GIS mapping of sanitary sewers and storm drains, to identify potential problem areas. Next, initial field investigations focus on identifying and mapping outfalls with dry weather flows. This approach then moves directly to sampling outfalls with dry weather flows for human markers using molecular methods, with a key objective being to quickly determine the presence or absence of human sources of fecal contamination. Where human markers are identified, then additional investigations regarding sources of the flows are initiated, using a toolbox of methods such as those listed in Table 6. Once sources of human contamination are determined, then mitigation of these sources can begin. Where human sources are absent, it may still be possible to reduce flow sources, in some cases (e.g., excessive irrigation).

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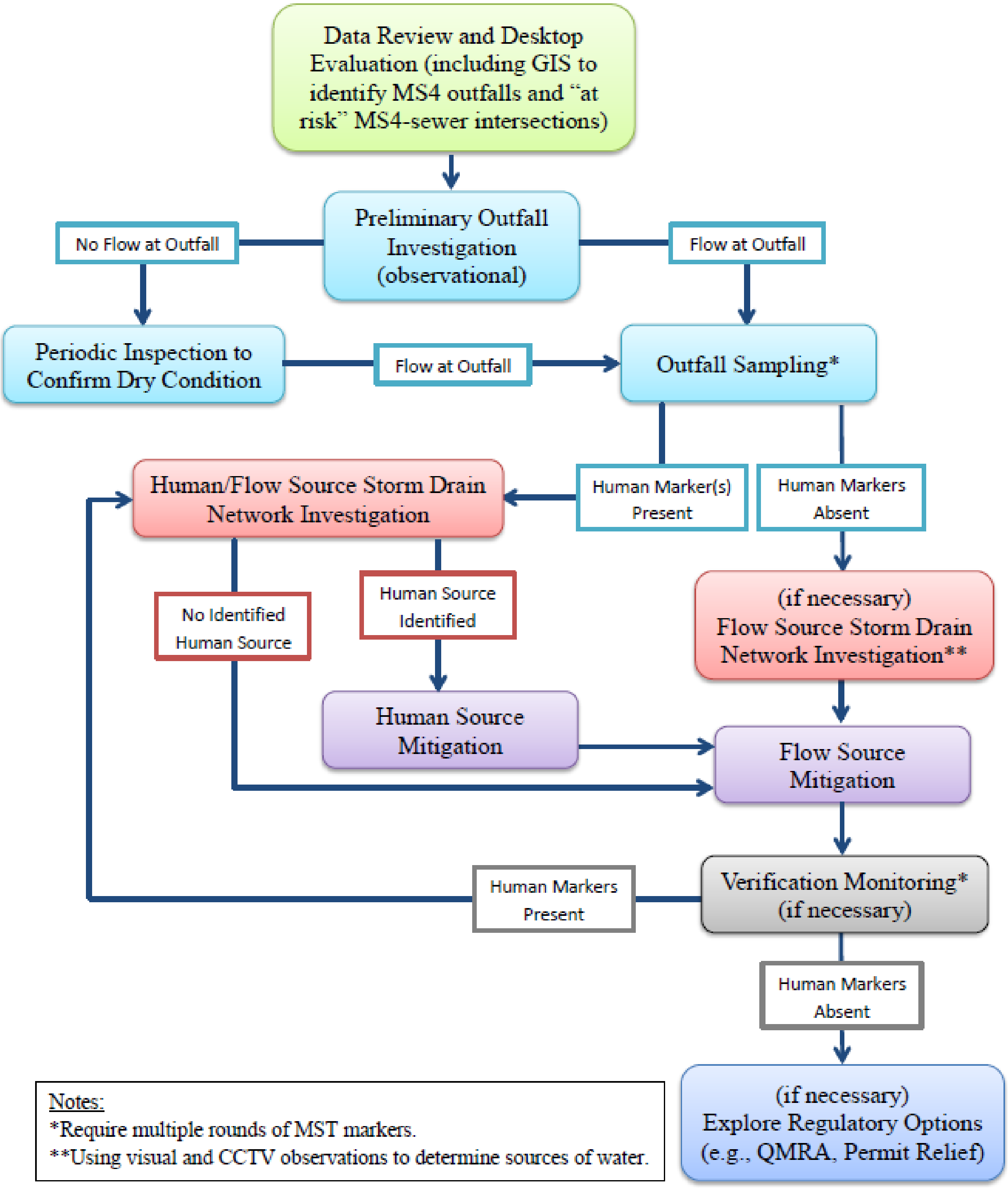
[8] Currently, Colorado does not offer a natural source exclusion; however, this may be a topic warranting further exploration. In California, the Natural Source Exclusion Approach recognizes natural sources such as direct inputs from birds, terrestrial and aquatic animals, wrack line and aquatic plants, or other unidentified sources within the receiving waters. The Natural Source Exclusion Approach requires the control of all anthropogenic sources of bacteria and the identification and quantification of natural sources of bacteria. Exceedances are allowed based on residual exceedances due to natural sources.

Figure 6. MS4 Microbial Source Identification Investigation Approach
(Source: Geosyntec Consultants, as presented in UWRRC [2014])

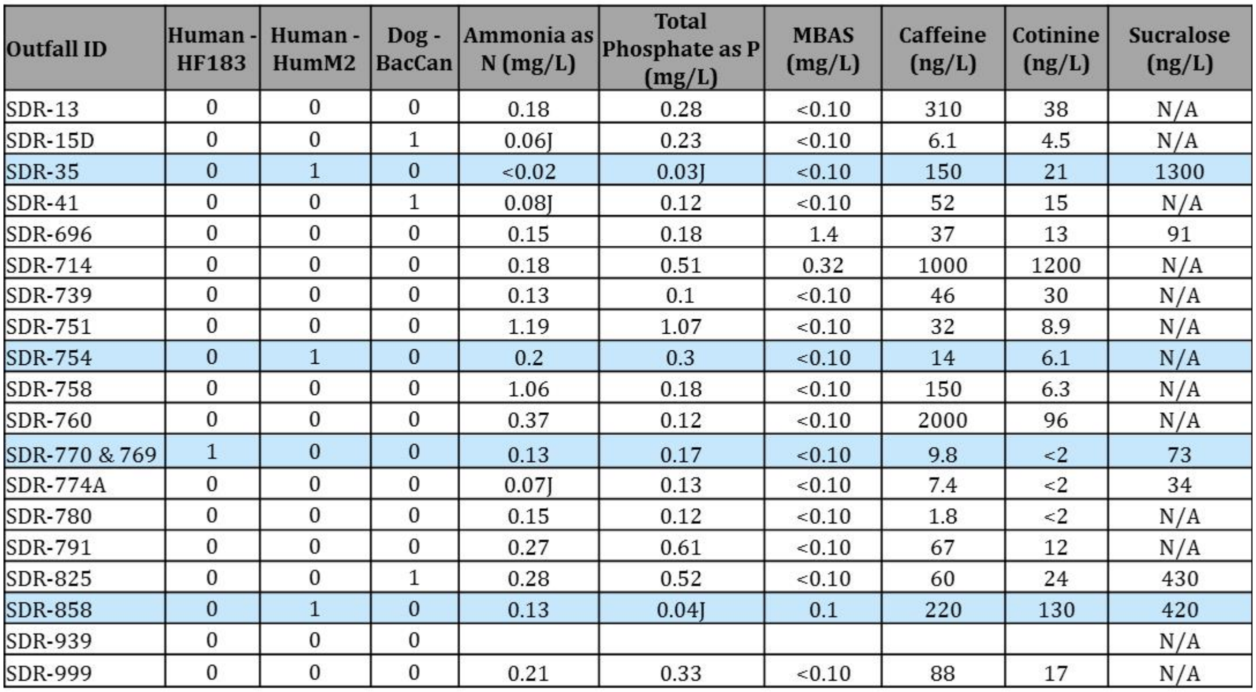


Notes:
*Require multiple rounds of MST markers.
**Using visual and CCTV observations to determine sources of water.

Weber et al. (2013) provide an example application of a microbial source tracking toolbox approach in response to the San Diego River TMDL. A process similar to Figure 6 was followed in this investigation. The regulatory driver for the investigation was the San Diego Regional MS4 Permit, which implements requirements of a FIB TMDL. The requirements focus on dry weather sources associated with TMDL compliance goals, with actions oriented toward prioritizing human fecal sources, as well as "controllable anthropogenic" sources (domesticated animals, etc.). Reconnaissance activities associated with this study included identifying areas with potential for human fecal inputs and categorizing outfalls based on proximity to receiving waters, and sewer mains/septics. As part of the reconnaissance effort, approximately 110 outfalls were visited, with 19 determined to be flowing. Electronic field forms (i.e., a mobile "app" for use on field tablets) were used to document key field conditions and directly associate collected data with GIS mapping of the storm drain system (automatically uploaded to a database), which enabled development of consolidated information. Tabular review of data enabled a "weight of evidence" approach to assess the likelihood of human sources, as shown in Table 7.

Table 7. Example Tabulation of Results from Microbial Source Tracking Using a Toolbox Approach in San Diego

(Source: Weber et al. 2013)

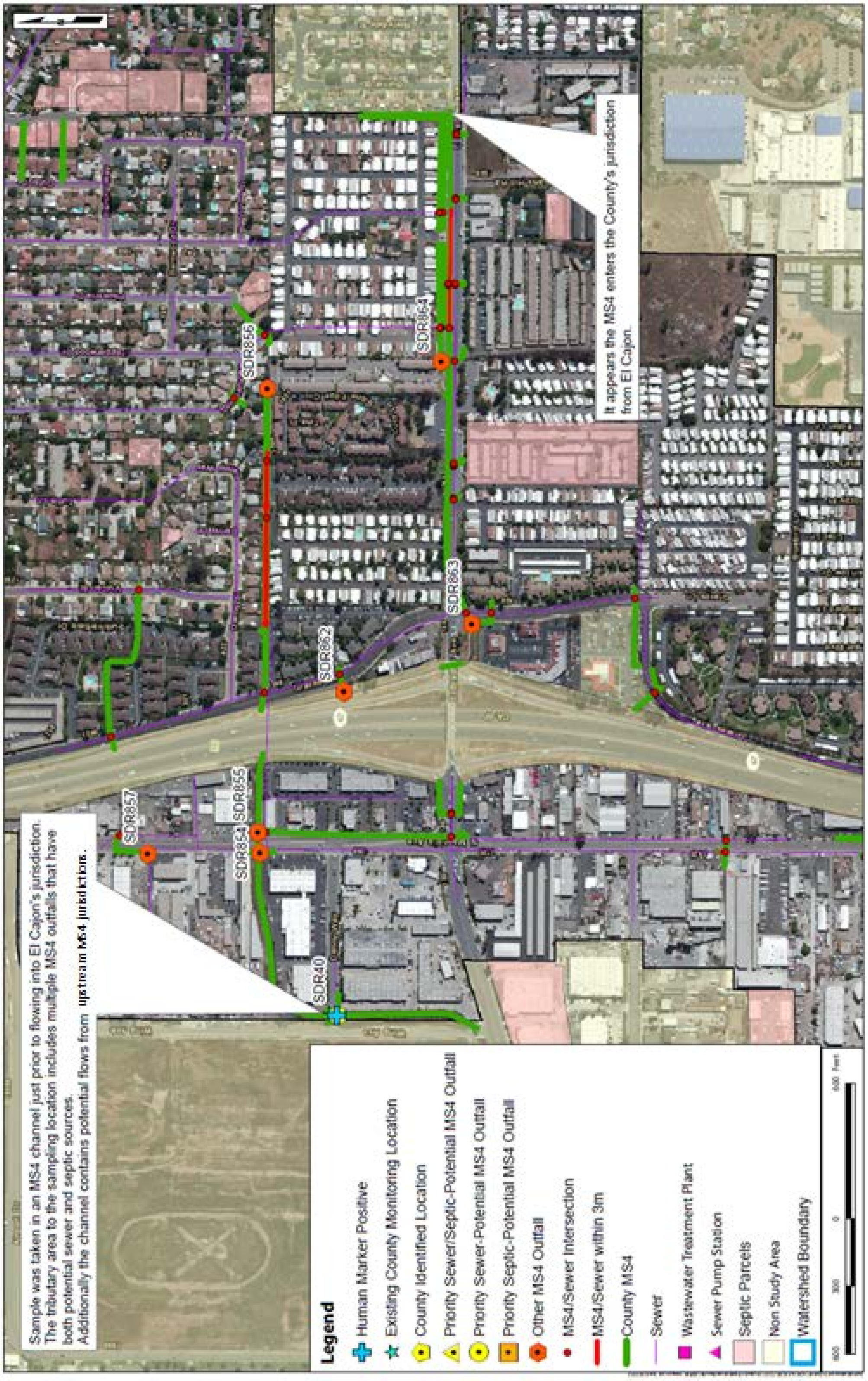


Outfall ID	Human - HF183	Human - HumM2	Dog - BacCan	Ammonia as N (mg/L)	Total Phosphate as P (mg/L)	MBAS (mg/L)	Caffeine (ng/L)	Cotinine (ng/L)	Sucralose (ng/L)
SDR-13	0	0	0	0.18	0.28	<0.10	310	38	N/A
SDR-15D	0	0	1	0.06J	0.23	<0.10	6.1	4.5	N/A
SDR-35	0	1	0	<0.02	0.03J	<0.10	150	21	1300
SDR-41	0	0	1	0.08J	0.12	<0.10	52	15	N/A
SDR-696	0	0	0	0.15	0.18	1.4	37	13	91
SDR-714	0	0	0	0.18	0.51	0.32	1000	1200	N/A
SDR-739	0	0	0	0.13	0.1	<0.10	46	30	N/A
SDR-751	0	0	0	1.19	1.07	<0.10	32	8.9	N/A
SDR-754	0	1	0	0.2	0.3	<0.10	14	6.1	N/A
SDR-758	0	0	0	1.06	0.18	<0.10	150	6.3	N/A
SDR-760	0	0	0	0.37	0.12	<0.10	2000	96	N/A
SDR-770 & 769	1	0	0	0.13	0.17	<0.10	9.8	<2	73
SDR-774A	0	0	0	0.07J	0.13	<0.10	7.4	<2	34
SDR-780	0	0	0	0.15	0.12	<0.10	1.8	<2	N/A
SDR-791	0	0	0	0.27	0.61	<0.10	67	12	N/A
SDR-825	0	0	1	0.28	0.52	<0.10	60	24	430
SDR-858	0	1	0	0.13	0.04J	0.1	220	130	420
SDR-939	0	0	0						N/A
SDR-999	0	0	0	0.21	0.33	<0.10	88	17	N/A

Note: Rows highlighted in blue detected one or more human molecular markers.
Human HF183, Human HumM2, and Dog BacCan are tests for molecular markers.
MBAS is a methylene blue active substances assay, which is a colorimetric analysis test method that uses methylene blue to detect the presence of anionic surfactants (such as a detergent or foaming agent) in a sample of water.
Caffeine, cotinine and sucralose are chemicals commonly associated with human waste.

Figure 7. Example Use of GIS in Microbial Source Tracking Studies

(Source: Weber et al. 2013)



It appears the MS4 enters the County's jurisdiction from El Cajon.

Sample was taken in an MS4 channel just prior to flowing into El Cajon's jurisdiction. The tributary area to the sampling location includes multiple MS4 outfalls that have both potential sewer and septic sources. Additionally the channel contains potential flows from upstream MS4 jurisdictions.

Some of the questions that can be asked using a weight of evidence approach, once data are tabulated, include:

- What is the method sensitivity and specificity (likelihood of false negative and false positive results due to poor detection limits and potential cross-reaction, respectively)?[9] Conducting several sampling events for key markers may help to reduce likelihood of false negatives or positives.
- What are the marker concentrations and frequencies of detection?
- Do the molecular or chemical marker results correlate with FIB concentrations? [10]
- Was the presence of a human marker due to a single fecal contamination event (e.g., a discrete SSO) or representative of persistent pollution (e.g., a leaking sanitary sewer)?
- Do the results match up with visual information (e.g., from surveys, CCTV, dye tests)?

In the example shown in Table 7, the appropriate next steps for the project were determined to be follow-up on the four outfalls where human markers were detected. Activities considered for follow-up included additional investigation of flow sources to and within the storm system networks using techniques such as CCTV and dye testing of the target area, as well as additional sampling within the storm system network for FIB, sucralose, and human markers.

Studies of storm drains in Santa Barbara, San Diego and elsewhere (e.g., Monroe 2009) have consistently found a lack of correlation between FIB and human markers, confirming the understanding that urban sources of FIB are ubiquitous and typically not controlled by human contamination. At the same time, these and other recent advanced source tracking studies and ongoing nationwide MS4 IDDE programs have shown that human fecal contamination within urban stormwater infrastructure is not uncommon; therefore, elevated FIB and detectable human waste may be two persistent but separate issues that urban MS4 permittees need to address.

2.3.3.3 MST Study Design Basics

The success of any MST study depends on proper study design. A hypothesis-driven study approach is essential to producing scientifically conclusive results. Numerous examples exist where agencies have conducted poorly planned MST investigations, resulting in inconclusive and unsatisfying results, wasted money, and unmet project objectives. These examples reinforce the need for clear study objectives and proper study design in order to maximize the likelihood of achieving desired project outcomes. To guide proper study design, study hypotheses are generated concerning the potential sources of fecal contamination through the following activities (Griffith et al. 2013):

- Consulting with local experts and others stakeholders with knowledge of the watershed and its potential contamination sources;

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[9] The occurrence of false negative and false positive results may be mitigated through the use of validated markers, proper QA/QC techniques for sample collection and processing, an experienced source tracking laboratory, and robust technologies such as droplet digital PCR (ddPCR).

[10] Correlations are often not observed due to multiple sources of FIB (human, non-human, and non-fecal) contributing to FIB concentrations.

- Gathering information about MS4 and sanitary sewer infrastructure (e.g., GIS location data, age, material);
- Gathering historical FIB and other relevant monitoring data;
- Conducting field reconnaissance and sanitary surveys;
- Synthesizing all information gathered to generate hypotheses as to the primary sources responsible for elevated FIB concentrations.

Formulated hypotheses as to what sources are suspected and where they are located will then guide the selection of source-specific markers (e.g., human, bird, dog etc.), representative sampling locations (e.g., outfalls, receiving waters, source areas), the number of samples needed, and the timing of sample collection. When infrastructure sources are suspected, it is generally preferable to collect samples as close to the source as possible, thereby reducing the chances of not detecting markers due to sample dilution in the receiving water. All potential sources of DNA should be considered early in study design as markers may cross-react with other fecal sources (when present at high concentrations). Where reclaimed water is used for irrigation, irrigation runoff (e.g., overspray, over-irrigation) may also be a source of human markers to MS4 (i.e., "dead" or not viable human DNA remaining in the disinfected wastewater). Source samples (e.g., animal feces, reclaimed water) can be collected and analyzed to evaluate the potential for cross-reaction or confounding sources of DNA.

The collection of samples for advanced molecular methods requires that special collection and handling procedures be followed to prevent sample contamination. Similarly to procedures used for FIB sampling, sterile sampling techniques must be used including sterile sample containers and clean gloves being used for each sample collected. Any equipment used to collect samples must be discarded after use (e.g., disposable syringes) or sterilized between samples (by autoclave or acid washing). While standard sample holding times have not been established, it is recommended that samples for molecular analysis be immediately placed on ice and filtered as soon as possible.

Quality assurance and quality control (QA/QC) procedures are also critical during sample processing and analysis. Sample filtration may be performed by those collecting the samples, by the lab performing FIB analysis, or by the lab performing the molecular analysis (water samples can be shipped overnight on ice). To ensure that sterile techniques are being followed during filtration, field or filter blanks (sterile water filtered in parallel with samples) should be prepared and analyzed along with collected samples. Experienced source tracking labs that have participated in multi-lab validation studies (such as those sponsored by EPA and SCCWRP) should be selected for analysis. Molecular analyses performed at these labs should include analysis of control samples including: DNA extraction blanks, negative and positive reaction controls, and inhibition analysis. Lab selection will also depend on the availability of desired markers. Several markers including the HumM2 human and CowM2 cow markers require licenses obtained from the EPA for use.

Advanced MST tools are most successfully used as part of a weight-of-evidence approach to identifying fecal sources. The use of two human markers, such as the HF183Taqman and HumM2 markers, can help provide an additional line of evidence that human fecal sources are present or absent. Because these two markers have slightly different molecular targets, a positive detection for both markers gives increased confidence in the results and greatly reduces the chance of false positive results. Additionally, the HF183Taqman marker has been shown to be more sensitive to low concentrations of human fecal contamination, while the HumM2 marker is more specific to human fecal sources (Griffith et al. 2013). It is often useful to use multiple human markers in combination with non-human markers, chemical indicators, and other traditional tools such as dye testing to fully evaluate hypothesized sources.

2.4 MANAGING DATA

When embarking on a source identification program or routine monitoring program, the importance of data management cannot be overstated. An easily corrected, but common, shortcoming of monitoring programs is lack of systematic data management in a manner that enables future access of study data. Data management protocols should be part of any sampling and analysis plan; however, effective data management is often lacking in practice. Some simple considerations that help to maximize investment in monitoring programs include:

- Systematic naming and structure of electronic files supporting the study.
- Timely review of samples to enable identification and correction of errors or follow-up for unusual results (including explanatory comments when unusual results are observed).
- Developing a standard spreadsheet or database format that all data entries will follow, regardless of the individual conducting data entry. Usually, a database format with column headers such as location, date, analytical parameter, result, qualifier, detection limit, and comments is needed, along with other explanatory information. If the collected data will be used as model inputs, then storage of the data in a format easily uploaded to a model can also be helpful. The Colorado Data Sharing Network format (accessible at http://www.coloradowaterdata.org/) can be used as a template and can be used in Excel, Access, or imported to a geospatial database.
- Clear identification and nomenclature for sample locations that carries through various study types, even if different entities are conducting the studies. Changing sample location names from year-to-year causes confusion in data analysis. Include latitude and longitude coordinates for all sampling locations and a narrative name to accompany short location labels (e.g., site 120A is located at 120th Avenue upstream of bridge).
- Ensure staff entering or managing data have clear direction on how to record values above or below quantitation limits. For example, < and > values should be stored as qualifiers with the data. A common problem with E.coli data sets is dropping the > qualifier if results exceed the upper quantitation limit.
- Record and store field conditions along with water quality data. These anecdotal observations can be critical components for identifying sources of FIB. In Colorado, seasonal flow regimes related to spring runoff from snowpack, highly managed flow regimes due to reservoir releases and irrigation diversions, and others should be documented.
- Measurements of flow and precipitation records should be stored along with water quality data.
- Obtain copies of electronic records with clear description of contents from consultants conducting special studies. For special research studies, be sure that researchers use the same nomenclature for existing monitoring locations and that the GPS coordinates are provided for special sampling locations.

2.5 INTERPRETING DATA: COMMON OBSERVATIONS FOR FRONT RANGE *E. COLI* DATA

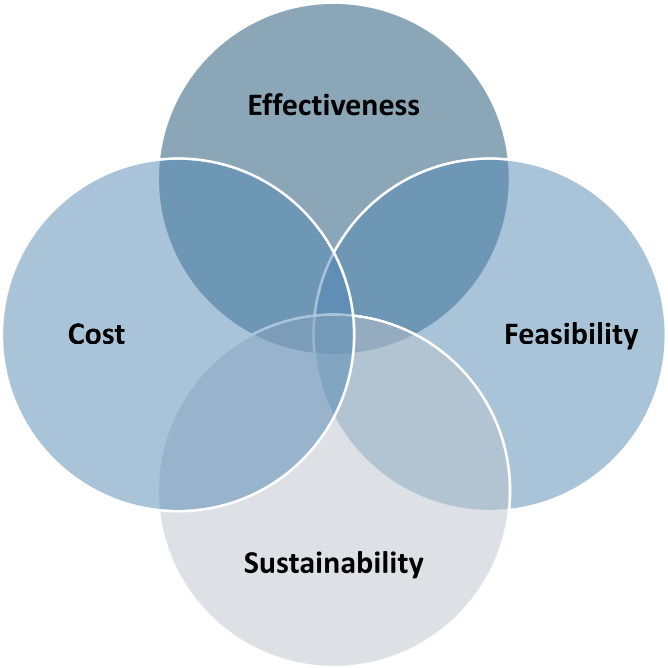
Although a wide range of trends can occur for *E. coli*, a common trend in warm-water streams along the Front Range is elevated *E. coli* during the summer and/or early fall months and attainment during the winter. Similarly, as mountain snowpack melts in the spring and increases instream flows, *E. coli* concentrations tend to be lower. While these trends may or may not be true for any particular stream, they are commonly observed in multiple streams along the Front Range. Similarly, most urban streams will demonstrate *E. coli* elevated above the stream standard following summer storm events. Flow conditions are an important variable to consider when interpreting *E. coli* data, but are often omitted from records associated with monitoring data. (For example, field notes may be collected but not entered into the database or spreadsheet with the water quality data, making it more difficult to interpret the data.)

When evaluating trends over time, a common mistake in evaluating whether conditions in the stream are improving, remaining the same or declining, is failure to compare data sets that are collected under comparable hydrologic and seasonal conditions. For example, a Front Range data set that includes six summer sample events and two winter events is likely to show poorer *E. coli* annually than a data set that includes half of samples collected in the summer and half in the winter. Unrepresentative data (or data collected over a limited range of hydrologic conditions) can result in false “success” stories, as well as false conclusions that a BMP has not provided benefit to the receiving water.

3 DEVELOPING A CONTROL STRATEGY

Development of a realistic control strategy to reduce *E. coli* involves balancing BMP effectiveness, cost, feasibility and sustainability over the long term. This chapter provides some basic recommendations related to the progression of controls, along with a brief discussion of how models can be used to select the optimal combination of practices. Additionally, Chapters 4 and 5 discuss Source Control Practices and Structural Control Practices that can support a control strategy. A significant challenge for *E. coli* TMDLs is that many unknowns remain regarding both structural and non-structural BMP performance. Additionally, in developed areas, feasibility of implementation will be affected by public vs. private property ownership, space constraints, and physical constraints within watersheds (e.g., high groundwater). Because communities have many responsibilities to their citizens in addition to receiving water quality, cost is a practical constraint when selecting a control strategy, particularly with regard to whether practices implemented will be sustainable over the long run. When developing a control strategy that is enforceable under CDPS permits, it is important to include provisions for adaptive management and adjustment of practices implemented, due to the practical uncertainties currently surrounding *E. coli* load reductions.

Figure 8. Balance of Priorities for Selection of Controls in Watersheds

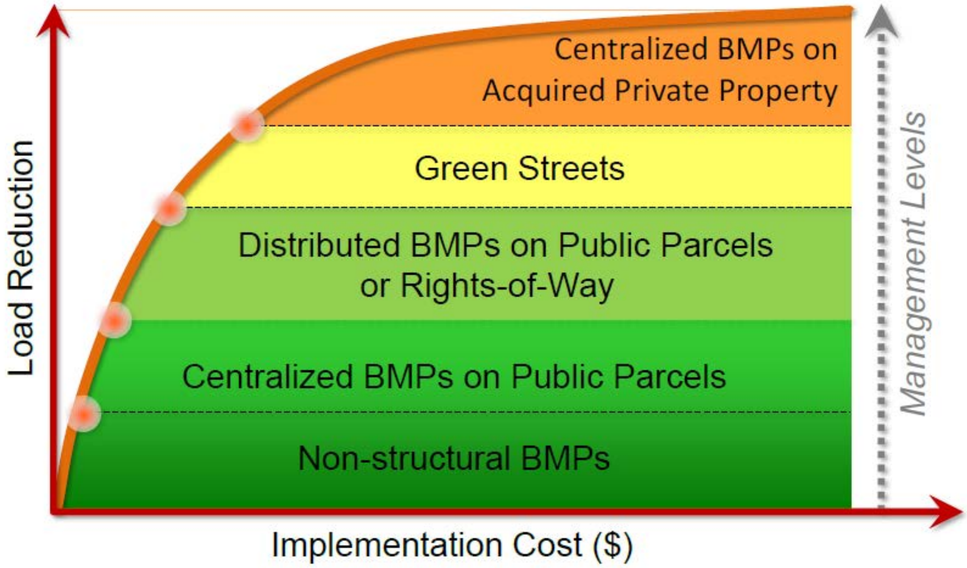


3.1 PROGRESSION OF CONTROLS

Control strategies for reducing bacteria loading at a watershed scale can be extremely costly. For this reason, it is important to develop a control strategy that builds incrementally, following the progression conceptually illustrated in Figure 9. The progression begins with lower cost non-structural practices, progresses to centralized BMPs on public parcels, then to distributed practices and green streets on public parcels, and culminates with centralized BMPs on acquired private property (or easements). Non-structural practices are the foundation of the control strategies, focusing on source controls.

Because elevated *E. coli* relative to primary contact recreation standards during wet weather flow conditions is a relatively ubiquitous phenomenon, it is often more cost-effective for communities to focus first on control of dry weather sources of bacteria. Dry weather sources of fecal contamination represent a more persistent human health risk, whereas wet weather sources of bacteria tend to result in more limited duration of exposure.

Figure 9. Conceptual Cost-Benefit Curve and Managements Levels
(Source: San Diego River Watershed Comprehensive Load Reduction Plan Phase II [TetraTech 2013])



During dry weather, these plans rely heavily on source control and nonstructural BMPs first, and then structural BMPs, often as a last resort. Effective dry-weather nonstructural BMPs are those that address sources of human fecal contamination to the MS4, as well as sources of dry-weather urban runoff that mobilize other sources (e.g., catch basin sediments and stormdrain biofilms) and contribute to monitorable (i.e., flowing) outfall discharges. Examples of nonstructural BMPs include:

- Enhanced commercial inspection (noting that food outlet dumpster leaks, grease trap leaks, commercial catch basins, and pavement washdown have been identified as potent sources through various source investigations).

- Water conservation programs (targeting residential over-irrigation through smart controller distribution, free home water-use audits, and potentially fines for causing runoff to storm drains).

- Homeless waste control programs (e.g., enhanced inspection/enforcement, outreach, additional public restrooms, and even programs where homeless themselves are paid to collect trash and wastes from encampment areas).

- Identification and control of sewer inputs into the MS4 (particularly where aging leaking sewer lines run near and above storm drains and a hydraulic pathway exists for sewage to enter the MS4 drip by drip over miles of pipe).

Challenges to including these nonstructural BMP approaches in TMDL implementation plans is that robust data to quantify anticipated effectiveness of these nonstructural practices is generally lacking.

During wet weather, implementation plans primarily rely on nonstructural BMPs that address human and anthropogenic non-human sources of bacteria that are located throughout the urban area, because wet weather runoff may mobilize any or all of these. These nonstructural BMPs include homeless waste control programs; enhanced pet waste control programs (education/outreach, mutt mitts, and ordinance enforcement); pre-storm-season catch basin cleaning (noting that sediments, trash, and decomposing organic matter all contribute to bacteria levels); and others. However, nonstructural BMPs are not expected to be able to fully reduce wet-weather MS4 bacteria loads; therefore, strategic implementation of structural BMPs is also a key component of wet-weather plans. Few of the passive treatment BMPs alone, such as those in the USDCM Volume 3, are able to consistently achieve effluent concentrations meeting primary contact recreation limits; therefore wet-weather plans must recognize these risks and uncertainties, and also must lean more on runoff volume reduction strategies such as infiltration. Potential enhancements to structural BMPs are an evolving area of research and are discussed further in Section 5.1.3.

Even when BMPs are implemented, bacteria TMDL limits, established with the endpoint of meeting primary contact recreations standards instream, are very difficult to meet. For example, in Southern California, reference (i.e., natural condition) streams and beaches, which serve as the basis for allowable exceedance days for WLAs assigned in TMDLs, often themselves do not meet the TMDL WLAs. Other cases where WLAs have not been met include 1) streams and beaches in subwatersheds with >95% undeveloped open space, 2) streams and beaches during dry weather where 100% of flows are diverted to sewer or to UV disinfection treatment, and 3) streams and beaches where several million dollars have been invested in aggressive wet-weather controls. In cases where BMPs are not achieving the desired TMDL endpoint and human sources of bacteria have been mostly controlled, communities may need to consider developing the groundwork for a site-specific standard, as discussed in Section 6.

3.2 USE OF MODELS TO SUPPORT BMP IMPLEMENTATION

Models can be extremely valuable for simulating alternative practices, spatial relationships, various conditions, and future scenarios. For confidence in decision making using models, ideally both monitoring and modeling will be utilized since neither provides all of the information needed for decision-making (Harmel 2016a). When considering use of a model to support BMP planning, it is helpful to ask basic questions regarding the model objectives, keeping in mind that the purpose of a model is to help answer: “What is the best way to solve this water quality problem?” As noted by Harmel (2016a), models can help to answer this question, by providing a framework for questions such as:

- What are the important contributors to this problem?
- What are the best practices to implement?
- Where are the best locations to install these practices?
- How can practice effectiveness be evaluated (post-implementation)?

Water quality models are used by MS4 managers and regulators for a variety of purposes, such as for TMDL development and implementation planning. For TMDL development, watershed models and/or load duration curve calculations are used for development of WLAs and LAs for assignment to responsible dischargers. For implementation planning, watershed models are used for systematic siting/placement, selection, and prioritization of management actions to meet TMDL or other MS4 permit requirements, and/or to quantify expected water quality performance (e.g., bacteria load reduction) to demonstrate compliance with a TMDL WLA or other WQS (often referred to as "reasonable assurance analysis"), as well as to quantify costs and other benefits (e.g., water supply capture, urban greening area added, illness rate reduction, etc.).

For implementation planning purposes, which is the focus of this document, numerous public domain models are available and have been successfully used across the country to support management action selection and prioritization throughout bacteria TMDL-regulated watersheds. These watershed models include Hydrological Simulation Program – Fortran (HSPF, found at www.epa.gov/exposure-assessment-models/hspf), System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN, found at www.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain), and the Structural BMP Prioritization and Analysis Tool (SBPAT, found at www.sbpat.net). Model selection for any given application should be based on functionality needs (selecting a model that is only as complex as necessary), scale of the proposed application, and available data. For detailed guidance on model selection and good practice, see EPA's watershed academy resources such as http://cfpub.epa.gov/watertrain/pdf/modules/wshedmodtools.pdf. Consideration should always be given to model calibration needs (water quality monitoring data will be needed to support this), and steps should be taken to perform uncertainty and sensitivity analysis (to understand the limitations of a model's accurate predictive capability). And while most watershed models are capable of modeling structural BMP implementation scenarios, non-structural BMP modeling capabilities are more limited but evolving. For examples of watershed modeling for bacteria TMDL implementation planning, see the coastal Watershed Management Plans of the Los Angeles region (www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/watershed_management/) and the Water Quality Improvement Plans of the San Diego region (www.waterboards.ca.gov/sandiego/water_issues/programs/stormwater/wqip.shtml), where collectively approximately $20 billion in new green infrastructure has been planned.

A variety of privately developed models are also available. As one example, WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in urban areas using small storm hydrology. The model determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. The model then evaluates various stormwater control practices (BMPs) and determines how effectively these practices remove runoff volume and pollutants, also providing cost estimates (http://www.winslamm.com/winslamm_overview.html).

Understanding the limits of modeling technology and properly accounting for model uncertainty are fundamental to developing a model useful for management decisions (UWRRC 2014, Harmel et al. 2016b, among others). Harmel et al. (2010) provide a concise synopsis of the issues affecting uncertainty for bacteria modeling:

> …there remains a large degree of uncertainty in simulating *E. coli* fate and transport, which is due to several factors. First, relatively few *E. coli* data sets are available for model calibration and validation. Data collected from watersheds of varying scales and land uses with different management practices are especially rare, which severely limits the ability of models to predict *E. coli* fate and transport from various sources in response to management alternatives. In addition, the uncertainty in measured *E. coli* data also

> contributes to the uncertainty in bacterial modeling (Harmel et al. 2006, McCarthy et al. 2008). Second, large variations in reported values for *E. coli* persistence in the environment result largely from a lack of understanding of the fundamental processes controlling fate and transport mechanisms. For example, it is unclear what proportion of *E. coli* cells are transported via surface flow as single cells as opposed to attached to soil particles (Muirhead et al. 2006a&b; Oliver et al. 2007; Mankin et al. 2007; Soupir et al. 2008a, 2010). Similarly, *E. coli* survival kinetics in different environments (Wang et al. 2004; Soupir et al. 2008b), the resuspension of streambed sediment and associated *E. coli* (Rehmann and Soupir 2009), and the potential for establishment of naturalized populations in soils or sediments (Ishii et al. 2006, Jamieson et al. 2004) are not well understood. Despite numerous laboratory and small-scale studies investigating many of these factors, there is a need for additional studies that compare *E. coli* fate and transport at multiple watershed scales.
>
> …increased attention should be given to the basic science of fecal indicator bacteria in the environment. Only with a sound scientific understanding of fundamental processes can the substantial uncertainty associated with bacterial transport assessment and modeling be reduced. Only then can effective and efficient management and regulation of bacterial contamination become a reality.

Ultimately, models are only as useful as the data available to support them ("garbage in equals garbage out") and the knowledge of the user. Models need measured data to give stakeholders confidence in predictions. Many watershed models are powerful tools to support BMP selection and prioritization, and when combined with cost information, can provide an objective basis for developing a plan of action that maximizes cost-effectiveness of the proposed compliance strategy and minimizes long-term cost to comply with TMDLs. Model outputs should include estimates of uncertainty and should be treated as a planning resource, subject to change as more is learned in a particular watershed.

4 SOURCE CONTROL BMPS

Source controls of FIB are the first strategies that should be pursued when impairments are identified. Examples of these strategies are summarized in Table 8 with additional discussion of several of these practices provided in the remainder of this section.

In Colorado, source control guidance is relatively well developed by entities such as UDFCD, the Colorado Stormwater Council, Partners for a Clean Environment (PACE), the Green Industries of Colorado (GreenCO, for landscape-related practices), and various local governments. Many source controls may already be part of minimum control measures being implemented by MS4s (Public Education and Outreach, Public Involvement/Participation, Illicit Discharge Detection and Elimination, Construction Site Stormwater Runoff Control, Post-Construction Management, and Pollution Prevention/Good Housekeeping). For this reason, new fact sheets on these practices have not been created for this Toolbox.

For cases where human sources of FIB are present, controlling and correcting the source of the contamination is a basic first step for protecting human health. Once these sources are corrected, diffuse non-human sources typically remain and can be challenging to control. Nonetheless, tools such as pet waste ordinances, bird controls, other urban wildlife controls, and storm drain maintenance activities are tools that should be considered by local governments working to reduce FIB, depending on the sources of elevated FIB in the particular watershed. Limited data are available to evaluate the effectiveness of source controls quantitatively. Effectiveness of source controls on reducing instream FIB is dependent on the dominant sources of FIB in a watershed and the consistency with which source controls are implemented.

Resources/Websites Providing Source Control Fact Sheets

UDFCD, Urban Storm Drainage Criteria Manual, Volume 3 for fact sheets related to source controls and structural BMP design and maintenance: http://udfcd.org

Partners for a Clean Environment (PACE) for facts sheets and Standard Operating Procedures for businesses and municipal operations: http://pacepartners.com/resources/additional-resources

Green Industries of Colorado (GreenCO) for landscape and water conservation BMPs: http://www.greenco.org/current-bmps.html

City of Westminster for Standard Operating Procedures (SOPs) for municipal operations and other BMPs: http://www.ci.westminster.co.us/Environment/StormwaterProtection/StandardOperatingProcedures

Colorado Stormwater Center for training regarding BMP inspection and maintenance and other stormwater infrastructure related training: http://stormwatercenter.colostate.edu/

Colorado Stormwater Council for Standard Operating Procedures (SOPs) for municipal operations and other BMPs: http://www.coloradostormwatercouncil.org/ (*access restricted to council members*)

Center for Watershed Protection for illicit discharge detection and elimination guidance and other fact sheets: http://www.cwp.org/)

Table 8. Sources and Strategies for Bacteria Reduction

Bacteria Source	Stormwater Control/Management Strategy
Domestic Pets (dogs and cats)	Provide signage to pick up dog waste, providing pet waste bags and disposal containers. Adopt and enforce pet waste ordinances. Place dog parks away from environmentally sensitive areas. Protect riparian buffers and provide unmanicured vegetative buffers along streams to dissuade stream access.
Wildlife in Urban Areas (e.g., rats, bats, raccoons, beavers, deer, coyotes, foxes)	Reduce food sources accessible to urban wildlife (e.g., manage restaurant dumpsters/grease traps, residential garbage, feed pets indoors). Implement and enforce urban trash management practices. Consult with state wildlife offices (CPW) on strategies to reduce food, shelter and habitat for overpopulated urban wildlife.
Illicit Connections to MS4s	Implement an illicit discharge detection and elimination (IDDE) program to identify and remove illicit connections.
Leaking Sanitary Sewer Lines/Aging Sanitary Infrastructure	Conduct investigations to identify leaking sanitary sewer line sources and implement repairs.
Onsite Septic Systems and Package Plants	Implement a program to identify potentially failing septic systems. Enforce discharge permit requirements for small package plants.
Illegal Dumping	Implement a reporting hotline for illegal dumping and educate the public/industries that dumping to the storm drain system is illegal.
Storm Drain System and Stormwater Quality BMPs	Proper maintenance of the storm drain system and water quality BMPs is needed for proper functioning of the system. For example, sediment, organic deposits and biofilms in stormwater facilities can be sources of elevated FIB.
Storm Runoff from Urban Areas	Encourage site designs that minimize directly connected impervious areas (e.g., Green Infrastructure, Low Impact Development).
Dry Weather Urban Flows (irrigation, carwashing, powerwashing, etc.)	Implement public education programs to reduce dry weather flows from storm drains related to lawn/park irrigation practices, carwashing, powerwashing and other non-stormwater flows. Provide irrigation controller rebates. Implement and enforce ordinances related to outdoor water waste and/or collaborate with water utilities to promote water-wise landscapes and irrigation practices. Inspection of commercial trash areas, grease traps, washdown practices, along with enforcement of ordinances.
Birds (e.g., Canada geese, gulls, pigeons)	Identify areas with high bird populations and evaluate deterrents, population controls, habitat modifications and other measures that may reduce bird-associated FIB loading.
Homeless Populations	Support of city shelters and services to reduce homelessness. Periodic cleanup of homeless camps near streams. Police enforcement. Providing public restrooms. Fencing to prevent access to frequently used encampment areas. Partnering with non-governmental organizations to address homelessness.

4.1 EDUCATION AND OUTREACH

Education and outreach to citizens and businesses is a general overarching source control practice that is needed for other types of source controls to be effective. Education and outreach activities may include brochures, posters, websites, event attendance, utility bill inserts, television advertisements, articles in homeowner association newsletters and other approaches that effectively reach citizens and promote behavioral changes. There may be opportunities for stormwater managers to work in a cross-disciplinary manner with other city utilities to maximize public education dollars. For example, campaigns to reduce water waste by reducing over-irrigation help communities to meet both conservation and water quality objectives. Similarly, drinking water departments often focus on source water protection strategies, but due to departmental "silos", opportunities for integrating stormwater and drinking water program objectives may not be fully maximized. As more communities pursue Integrated Planning approaches, *E. coli* load reduction may benefit from more coordinated efforts.

"Live Like You Love It" logo for branded water campaign. (http://lovecoloradowater.org/)

A recent statewide campaign that integrates water conservation and water quality practices (both of which benefit *E. coli* load reductions) is the "Live Like You Love It" campaign. An important aspect of effectively communicating with the public involves use of engaging materials, as well as proper facts. This campaign includes graphically designed materials and a toolkit to support outreach efforts.

4.2 REPAIR OF AGING INFRASTRUCTURE AND CORRECTING ILLICIT CONNECTIONS

Nationally, local governments and regulatory agencies are increasingly recognizing that aging infrastructure is contributing to contamination of MS4 discharges, as evidenced by findings from microbial source tracking studies, IDDE programs and consent decrees with EPA. (For an example consent decree, see http://www.epa.gov/sites/production/files/documents/bwsc-cd.pdf.) In 2013, the American Society of Civil Engineers (ASCE) gave the nation a "D+" on its "Report Card for America's Infrastructure" and estimated that a $3.6 trillion investment was needed by 2020 to address the most pressing aging infrastructure issues. ASCE's report card for wastewater and stormwater sector was a "D" and concluded:

> Capital investment needs for the nation's wastewater and stormwater systems are estimated to total $298 billion over the next twenty years. Pipes represent the largest capital need, comprising three quarters of total needs. Fixing and expanding the pipes will address sanitary sewer overflows, combined sewer overflows, and other pipe-related issues. In recent years, capital needs for the treatment plants comprise about 15%-20% of total needs, but will likely increase due to new regulatory requirements. Stormwater needs, while growing, are still small compared with sanitary pipes and treatment plants. Since 2007, the federal government has required cities to invest more than $15 billion in new pipes, plants, and equipment to eliminate combined sewer overflows.

Consistent with ASCE's findings, aging sanitary pipes can be a significant source of FIB loading in urban areas (Sercu et al. 2011, Corsi 2014, Sauer et al. 2011). Many communities have implemented "Asset Management Programs" that provide a systematic strategy to manage, maintain and operate infrastructure. The EPA's Capacity, Management, Operation, and Maintenance (CMOM) is probably the most well-known asset management program. Asset management programs provide a framework for self-evaluation and planning for the function, condition, and performance of a sanitary sewer system (TCEQ 2013).

Aging and leaking sanitary sewer and stormwater conveyance pipes can introduce pollutants to the MS4 through SSOs caused by blockages, line breaks, or other sewer defects; exfiltration of sewage from sanitary sewers; and infiltration of groundwater when the MS4 lies below the water table (Sercu et al. 2011). Upgrading, repairing, or slip-lining faulty sanitary sewer pipes will reduce pollutant loads by eliminating the leaks in those pipes. Additionally, upgrading or repairing storm drain pipes can minimize the infiltration of contaminated groundwater into the MS4 (Geosyntec 2012).

Measures to reduce SSOs include field inspections and using CCTV to inspect sewer lines, which can reveal blockages from debris to roots to grease and show pipeline cracks, breaks, or deterioration. Once such issues are identified, they can be integrated into planning efforts to maintain, rehabilitate or replace aging sanitary infrastructure.

Accelerated repair or upgrade of sanitary sewer and storm drain systems can be a key measure to reduce human sources of FIB. The location and design of upgrades can be optimized to decrease pollutant loads using information gathered in IDDE programs, GIS analysis of high-risk sewers, and/or special source tracking studies. Strategically planning upgrades to older, clay sanitary sewer laterals that cross or run next to and above storm drains is cost-effective and offers multiple benefits, including benefits to water quality and reduced operations and maintenance costs from newer infrastructure (Geosyntec 2012). For example, a key component of the City and County of Denver's *E. coli* load reduction plan has included investigating and lining sanitary sewers in need of repair, prioritizing locations where sanitary sewers cross above storm drains or where sanitary sewers are parallel within 5 feet.

Sanitary sewer overflow. (Photo Courtesy Brandon Steets.)

If sanitary infrastructure sources are identified, they must be corrected because they represent a direct source of raw sewage discharged to receiving waters. Enhancements to basic IDDE programs may include a tiered dry weather source investigation including: (1) visual surveys of MS4s to identify dry weather flow locations, (2) GIS-based prioritization where aging sewer laterals are above and near storm drains that are observed to occasionally flow during dry weather, (3) video survey of the storm drains to identify leaks from the top of the pipe and/or sewer dye tracing studies, (4) field test kits for ammonia, surfactants and residual chlorine in dry weather MS4 flows as an initial low-cost screening tool, and (4) fecal source tracking studies that use microbial source tracking or other methods (Geosyntec 2012, CWP and Pitt 2004).

4.3 MAINTENANCE OF STORM DRAINS AND STORMWATER CONTROLS

A variety of maintenance activities related to storm drainage infrastructure may help to reduce FIB loading.[11] Unfortunately, quantitative data and evaluation of the benefits of these practices is generally lacking. Practices that may be considered include:

- **Storm Drain Cleaning:** Storm drains can accumulate trash, sediment, organic matter and animal waste over time. As a result they can become secondary reservoirs of FIB and other pollutants. Cyclical storm drain cleaning using water jetting and vacuuming of jetted water is one tool that some communities have implemented as a source control BMP. Storm drain cleaning is typically done on a several year cycle and can be done more frequently in "priority basins" where elevated FIB at storm drains is identified. Sampling results may be used to help target areas in need of more frequent cleaning such as siphon conditions.
- **Catchbasin Cleaning:** Catchbasins and drain inlets play an important role in the prevention of trash and other sediment from entering the storm drain system. Catchbasin cleaning is an important institutional BMP, but the FIB load reduction benefits of increased frequency of catchbasin cleaning have not been rigorously studied. A survey conducted as part of the San Diego River source study found that nearly 50% of commercial catchbasins had moderate buildup and over 30% had ponded water. Signs of washdown and food scraps were frequently associated with catchbasins near restaurants (Weston 2009a). However, studies to evaluate the potential benefits of catchbasin cleaning did not show significant reductions in FIB (Weston 2009b). However, in a study conducted in the Telecote Creek watershed in San Diego, commercial catchbasins had significantly higher FIB than residential catchbasins (Weston 2010b); thus, if catchbasin cleaning is being considered as a BMP, it may be more beneficial in commercial areas.
- **Structural Stormwater BMP Maintenance**: Maintenance of structural stormwater quality BMPs can also help to remove secondary reservoirs of FIB in urban areas. Routine sediment removal from dry extended detention basins and manufactured devices can reduce the likelihood of sediment resuspension and FIB release during storm events.

4.4 STREET SWEEPING

Street sweeping removes sediment, debris, and other pollutants from road and parking lot surfaces. The major factors that impact the effectiveness of a street sweeping program in reducing pollutant loads are frequency and timing of cleaning and the type of street cleaning equipment used. Effectiveness is also dependent on the speed the sweeper travels, the amount of sediment on the street, and how much of the street is swept (e.g., whether parked cars prevent sweepers from accessing the curb).

High-efficiency street sweeping equipment, such as regenerative air sweepers or vacuum assisted sweepers can significantly increase the amount of sediment removed from roadways. Geosyntec (2012) summarized findings from several studies comparing mechanical broom sweepers to newer high efficiency alternative equipment. These comparative studies showed increases in sediment removal of 35% (Pitt 2002), 15 to 60% (Minton 1998), and up to 140% (Schwarze Industries). Additionally, regenerative air and vacuum sweepers were designed specifically to better capture fine particles. Bacteria, as well as metals and other pollutants, adsorbed to sediments are typically associated with smaller sized particles due to a larger surface-to-volume ratio and greater adsorption properties of clay

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[11] Recommendations are based on discussion in the San Diego Comprehensive Load Reduction Plan, Attachment E Non-structural BMPs (Geosyntec Consultants 2012).

particles (Xanthopoulos and Hahn 1990, Krumgalz et al. 1992). Although measured reductions in discharges of pollutants and FIB to receiving waters due to street cleaning have rarely been observed, street cleaning is an important public works activity to minimize sediment accumulation in drainage systems.

4.5 DOWNSPOUT DISCONNECTIONS AND SITE DESIGNS MINIMIZING DIRECTLY CONNECTED IMPERVIOUS AREA (GREEN INFRASTRUCTURE SITE DESIGNS)

Roof runoff collected in downspouts that are directed to the storm drain system can be disconnected to reduce runoff volumes and potentially *E. coli* concentrations from rooftops. Shergill and Pitt (2004) found that roofs with birds and squirrels in overhead tree canopy had higher FIB than those without animal activity. Simply disconnecting roof downspouts can help to redirect runoff to pervious areas, thereby potentially reducing both runoff volumes and FIB loads. Implementation options include redirecting downspouts to lawns, gardens or swales. Downspout retrofit can be an effective stormwater control for commercial, industrial, and public buildings as well.

In addition to downspout retrofits, new developments or redevelopments can be designed to integrate multiple measures that reduce effective impervious area by disconnecting impervious surfaces. These Low Impact Development (Green Infrastructure) site designs can integrate both non-structural practices, as well as structural stormwater controls such as bioretention, permeable pavement and other practices (see UDFCD's USDCM Volume 3 and Denver's Ultra-Urban Green Infrastructure Guidelines). Reducing runoff peaks and volumes during frequently occurring storm events may help to reduce FIB loading, as well as reduce other pollutant loading.

Denver's Ultra-Urban Green Infrastructure Guide

In 2016, the City and County of Denver released the Ultra-Urban Green Infrastructure Guidelines, providing enhanced implementation guidance for Green Infrastructure practices, building upon Volume 3 of the USDCM. The guidelines provide site-scale Green Infrastructure practice selection, design and maintenance guidelines. A series of fact sheets is provided for Streetside Stormwater Planters, Bumpout (curbside) Stormwater Planters, Green Gutters, Green Alleys, and Tree Trench/Pits.

All of these practices help to disconnect impervious area and reduce stormwater runoff volumes, when properly designed, installed and maintained.

4.6 PET WASTE DISPOSAL AND PET CONTROL ORDINANCES

The density of pets in urban areas can be quite high; therefore, proper disposal of pet waste is a basic component of FIB control plans in urban areas. Elements of pet control programs may include:

- Providing park and trail signs regarding pet waste disposal requirements and leash laws.
- Providing disposal cans at conveniently spaced intervals on trails and in open space areas. Some communities allow advertising on signs placed at pet waste bag dispensers and disposal cans to partially offset the cost (e.g., Poo Free Parks®).
- Providing and properly maintaining off-leash dog parks, preferably at locations that do not directly drain to receiving waters. Improperly maintained dog parks can become a source of FIB, rather than a stormwater control, if not properly managed.
- Allowing natural riparian buffers to grow alongside streams to dissuade pet access.
- Providing educational materials regarding the impact of improperly disposed pet waste. These materials can be made available in locations such as pet stores, animal shelters, veterinary offices, and other sites frequented by pet owners.
- Enforcing pet waste ordinances and leash laws (or developing them, if they do not exist). While most communities have pet waste ordinances "on the books", enforcement of these ordinances may not routinely occur in many communities. In areas with significantly elevated FIB, allocation of resources to park and open space rangers to enforce pet waste disposal controls and leash laws may be needed.

Effectiveness of pet waste control programs is not well documented in terms of instream responses to implementation of such programs although several surveys and reports exist that attempt to quantify behavioral change associated with such programs. For example, the Phase I Report for the San Diego River Kelp and Dog Waste Management Plan for Dog Beach and Ocean Beach found that public compliance with the "scoop the poop" policy was highly dependent on awareness of the policy and availability of waste disposal bags and trash cans (Weston 2004). Public surveys in the City of Austin indicated their educational campaign resulted in a nearly 10% improvement in the number of pet owners who claim to regularly pick up waste (City of Austin 2008). Studies in San Diego have shown that installation of pet waste stations has resulted in a nearly 40% reduction in the total amount of pet waste in city parks (City of San Diego 2011).

Pet waste cans and signage at a Denver-area park. (Photo Courtesy Jane Clary.)

4.7 ANIMAL FACILITIES MANAGEMENT

A variety of animal-related facilities may be located in urban areas. Examples include "Doggy Daycares," veterinary clinics that board pets, small horse properties, and zoos (including petting zoos). The primary BMPs for these facilities include dry shoveling and disposal of solid waste and washdown practices that direct washwater to the sanitary sewer system. Particularly for older facilities, it may be worthwhile to confirm that floor drains and washdown areas are not being directed to the storm drain.

For hobby farms or ranchettes along streams, fencing, stream setbacks and drainage management from pens and barns are also important.

4.8 BIRD CONTROL

High densities of resident Canada geese are common in Front Range parks and ponds. (Photo Courtesy Jane Clary.)

Birds are a common source of FIB. In particular, geese are considered a public nuisance due to large populations, creating large amounts of feces, especially in open-space areas (e.g., parks, playing fields, ponds) (Manny et al. 1975, French and Parkhurst 2009, Bowen and Valiela 2004, Kear 1963). Clark (2003) reported that non-migratory Canada geese increased eight-fold in a 20-year period (1980s to early 2000s) in North America. Pigeons, blackbirds, starlings, ducks, and other birds also can pose similar problems when they roost on public buildings and bridges. Birds are documented sources of elevated FIB in many studies. Examples include research by Alderisio and Deluca (1999), Stoeckel (2010), Kolb and Roberts (2009), Kirschner et al. (2004), Shergill and Pitt (2004), Hussong et al. (1979), Fleming and Fraser (2001) and many others. For this reason, a fairly detailed discussion of potential control strategies for birds follows, since most urban areas are expected to have at least some contribution of FIB from birds.

The University of Nebraska at Lincoln (2010), USDA APHIS (1994a&b, 2003), the Internet Center for Wildlife Damage Management (www.icwdm.org) and others provide guidance on control strategies for geese. Canada geese are protected by federal and state laws. While it is illegal to intentionally kill a wild goose (other than during licensed hunting seasons) or to harm nesting geese and eggs without a permit, there are a number of methods used to discourage geese from congregating in specific areas. Non-lethal control activities do not require federal or state permits, and most non-lethal activities can be conducted throughout the year, except using trained dogs for hazing. Any activities that result in handling, damage, or destruction of geese, their eggs or nests require permits (CPW 2014).

Effective geese control often requires early detection of the problem, persistence, and use of multiple methods (CPW 2014).

Table 9 summarizes measures that have been used for geese control, followed by additional discussion of several of these measures. Overall, USDA APHIS (2009) recommends that the most efficient and effective way to manage resident geese is to harass them before nests are built. If this is not possible, nest destruction and egg oiling are the best options.

Table 9. Summary of Selected Waterfowl Management Techniques

(Adapted from Smith et al. 1999, Smith 2006, NYCDEP 2004, as summarized in UWRRC 2014)

Technique
Public Education
Discontinuance of feeding
Habitat modification
Porcupine wires (for roosting waterfowl and pigeons)
Eliminate shorelines, islands, peninsulas (in constructed waterbodies)
String wire lines or place Mylar tape grids above roosting and pond areas
Fence barriers
Vegetative barriers (taller grasses)
Rock barriers
Floating plastic balls (may wash away during storms)
Reduce or eliminate mowing (adjacent to waterbodies)
Place walking path near water
Place playing fields away from water
Deterrence Measures (may have short-term effectiveness)
Sprinklers and motion-detected activated sprayers
Pyrotechnics
Sonic Devices: ultrasonics, distress calls, sirens, horns whistles, propane cannons
Active Visual Deterrents: strobe lights, lasers, light beams
Passive Visual Deterrents: "eye-spot" balloons or kites, flags, scarecrows, floating predator decoys (benefits may be temporary, as waterfowl may habituate over time)
Dispersion Measures
Dogs
Swans (can also be a source of FIB)
Falcons (often impractical to maintain)
Radio-controlled aircraft or boats
Chemical Repellents (methyl anthranilate)
Reproductive Controls
Removing nesting materials (before egg laying)
Oil/addle/puncture eggs (during incubation)
Replace eggs with dummy eggs
Sterilization (oral contraception or surgical neutering)
Removal
Relocate (may not be effective)
Various lethal measures (e.g., hunts, kill permits)

Remote controlled goose hazing device, "Goosinator," used to deter resident waterfowl in Denver Parks.

Questions remain as to the long-term benefits of various control measures; however, several case studies suggest that combinations of these control measures can be successful in reducing FIB concentrations (e.g., NYCDEP 2014, Swallow 2010).

The USDA has developed control strategies for other bird species, including pigeons (Williams and Corrigan 1994), blackbirds (Dolbeer 1994), and swallows (Salmon and Gorenzel 2005), as a few examples. Of these birds, pigeons are often a dominant concern in urban areas. Measures listed as alternatives by the USDA-APHIS for pigeons are summarized in Table 10. Some of these measures would not be expected to be appropriate in urban areas (e.g., shooting, certain toxicants).

In summary, birds can contribute substantially to FIB loading to receiving waters, posing challenges to attainment of numeric water quality limits for FIB. The extent of the impact of birds and the success of control measures varies based on site-specific conditions. A variety of source control measures have been developed by state and federal agencies to help manage the impacts of birds. These measures typically require on-going attention and the effectiveness of these measures may vary over time and require adjustments to reduce the likelihood of habituation to the technique

Table 10. Summary of Pigeon Control Measures

(Adapted from Williams and Corrigan 1994)

Measure Type	Description
Exclusion	• Screen eaves, vents, windows, doors, and other openings with 1/4-inch (0.6-cm) mesh hardware cloth. • Change angle of roosting ledge to 45 degrees or more. • Attach commercially available porcupine wires to roosting sites. Install electrical shocking device/repelling systems on roost sites. • Construct parallel or grid-wire (line) systems.
Habitat Modification	• Eliminate food supply. Discourage people from feeding pigeons in public areas. • Eliminate standing water.
Frightening	• Visual and auditory frightening devices are usually not effective over time.
Repellents	• Tactile: various commercially available nontoxic, sticky substances manufactured for this purpose. • Odor: naphthalene flakes.
Toxicants	• Consult with local and state agencies on allowed toxicants.
Fumigants	• Generally not practical.
Trapping	• Several live trap designs are effective.
Shooting	• Where legal. Not a viable option in most urbanized areas.
Other Control Methods	• Alpha-chloralose (immobilizing agent used under the supervision of certified personnel only). • Nest removal.

4.9 URBAN WILDLIFE (MAMMALS)

Urban wildlife can be a key source of FIB loading to urban streams. Fecal matter from wildlife can enter streams through direct overland flow into streams as well as become concentrated by animals living in storm drains and stormwater facilities. Raccoons can be particularly problematic in the storm drain system itself. Beavers can be a source of pathogens, including *Giardia* and *Cryptosporidium*, as well as a source of elevated FIB instream (Wade and Ramsey 1986, AWWA 2006).

While it is likely impossible to completely control urban wildlife, there are strategies that can be considered to reduce FIB loading from urban wildlife, including:

- Develop a wildlife management plan, working with city wildlife conservation staff and/or state division of wildlife.

- Modify habitat and reduce urban food sources. Raccoon problems may be alleviated by making the habitat less favorable. Because raccoons have fairly large territories, a neighborhood or community-wide effort may be more successful than isolated control measures in urban areas. Removing potential sources of food, water, and shelter is the first step in eliminating the problem. In areas with raccoon activity, garbage cans should be tied down to a solid structure so they cannot be overturned, and lids should be tight fitting, tied or weighted down to deny access to garbage (Pierce 2001). Reduce food sources for urban wildlife through better management of dumpsters, garbage cans and restaurant waste. Additionally, pet food should be stored indoors and pets fed inside (or at least not left out overnight).

- Install storm drain inlet/outlet controls through grates and trash rack. Where raccoons are an issue in storm drains, some communities have successfully reduced end-of-pipe FIB concentrations through installation of grates on storm drain inlets and outlets. These should only be implemented when public safety is not jeopardized by increased flooding or danger of entrapment in a storm drain. By placing grates on storm drain inlets, the inlet capacity is reduced, which may require fairly costly retrofitting to maintain design capacities (HDR 2013). The effectiveness of this practice on receiving waters is not well-documented. For example, if grates are only placed on certain drains, then raccoons may simply relocate to other areas, which may also drain to the stream. For example, the home range for male raccoons is 3 to 20 square miles for males, and 1 to 6 square miles for females (Clark 1994), so eliminating a home in one storm drain will likely result in displacement to another nearby location within the home range.

- Clean out storm drains to remove animal waste. When storm drains are power-washed (“jetted”), it is important the discharge be collected by a vacuum truck, otherwise, pollutants are simply flushed into the receiving water.

- Relocate wildlife by trapping. If no other control methods are effective, the problem animals may need to be removed from the area by trapping (Pierce 2001).

For raccoons, there are no chemical repellents registered for controlling or repelling raccoons, although a variety of materials have been tested. Similarly, the use of scare tactics or devices is not effective or practical in controlling raccoons, particularly in urban areas.

When managing urban wildlife, it is important to recognize that states retain primary authority over resident wildlife. When considering possible manipulation of an urban wildlife species, it is important to be aware of the legality of such actions. When in doubt, always contact a wildlife resource agency for consultation (University of Illinois Extension 2014).

Due to uncertainty associated with the effectiveness of these practices on receiving waters, it is important to conduct baseline and follow-up monitoring to assess their effectiveness.

Raccoons inhabiting storm drain system (a) and retrofitted storm drain inlet (b).
(Photos courtesy of Andy Taylor, City of Boulder, CO)

4.10 Irrigation, Car Washing and Power Washing[12]

Over-irrigation, car washing and power washing discharges can mobilize FIB deposited on impervious surfaces, as well as contribute to continually moist conditions in storm drain systems conducive to biofilms. Public education regarding the water quality impacts of these practices is important for changing public behavior.

Irrigation runoff from lawns, gardens, parks, and other vegetated areas can result in dry-weather nuisance flows with high concentrations of nutrients and also mobilize and transport pollutants accumulated on ground surfaces. The contribution of dry weather inflows from irrigation runoff to a stagnant pool has also been known to foster in-situ bacterial growth (Geosyntec 2010). Effective methods to reduce irrigation runoff may include development of educational outreach, increased inspections, fines for overwatering, tiered water rates, or distribution of smart irrigation controllers and/or other financial incentive programs that decrease watering volume. By promoting better irrigation runoff management, communities may find that they are able to reduce water waste (increase conservation), as well as improve water quality.

Two studies in Orange County measured the effectiveness of advanced irrigation systems for reducing irrigation runoff. A residential runoff study conducted in five neighborhoods found dry-weather runoff decreased by 50% in areas where weather-based irrigation controllers were installed (IRWD and OCMWD 2004). Berg et al. (2009) found dry-weather runoff reductions of 25% to 50% for a similar study of 4,100 Smart Timers installed in residential and commercial areas. In addition to potentially elevated *E. coli* concentrations in irrigation runoff from parks and yards, the increased flows also allow for regrowth in the MS4 and mobilization of pollutants in the MS4 to the receiving waters. Based on these studies, it is anticipated that increased irrigation runoff controls, such as inspection, enforcement, and incentives

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[12] Adapted from San Diego Comprehensive Load Reduction Plan, Attachment E Non-structural BMPs, prepared by Geosyntec Consultants (2012).

in commercial and residential land uses will generate pollutant load reductions. Irrigation controller rebates are periodically offered by water providers such as Denver Water.

In 2010, the Division provided Low Risk Discharge Guidance: Discharges from Surface Cosmetic Power Washing Operations to Land in accordance with Water Quality Policy 27, Low Risk Discharges (Division 2010). The Division has not developed a general permit for this type of discharge, and is instead managing the discharge through the development of guidance. The guidance sets forth a variety of BMPs and also states that if washwater reaches the street, curb flow line, impermeable channels, or other open impermeable areas, it must remain in the operators' control and be immediately collected (including all deposited pollutants) for discharge in accordance with all conditions of the Division's guidance. The Division (2010) outlines the following alternatives for disposing of power washing wastewater:

- Contact the local wastewater treatment facility to determine whether or not discharge of the wash water to the sanitary sewer system is allowed. If discharge to the sanitary sewer is approved by the wastewater treatment facility, collect the wash water and send it to the sanitary sewer system in accordance with the requirements of the wastewater treatment facility.

- Collect the wash water and dispose of it appropriately at a disposal facility.

- Remove solids and any pooled liquids prior to washing, fully contain the wash water on an impervious area, and allow it to completely evaporate. This activity must be conducted under the control of the operator, and in a manner that prevents any potential discharge to a storm drain or other conveyance to surface water.

- Apply for coverage under a CDPS Individual Permit.

Similarly, individual car washing can increase dry weather urban runoff and mobilizes FIB present on impervious surfaces. To reduce FIB loads, educational outreach could be increased to encourage car owners to minimize washing activities that increase runoff to storm drains.

4.11 Good Housekeeping/Trash Management (Dumpsters, Restaurants, Garbage Cans)

Good housekeeping practices involve establishing and enforcing ordinances for commercial, industrial and multi-family residential facilities. An ordinance requiring covered trash enclosures and frequent cleaning can help to reduce the FIB load associated with dumpsters. Some local governments such as City and County of Denver are actively providing sturdy plastic trash cans with hinged lids, which may help to reduce exposure of garbage to rain and leakage from the bottom of the can.

For restaurants, it may be beneficial to increase inspection and enforcement of grease removal equipment for restaurants, monitoring trash enclosures for proper waste disposal, and cleaning of private catch basins and drain inlets. The wet weather sources targeted by these BMPs include dumpsters and grease traps. A source tracking study performed in the San Diego River Watershed found that approximately 20% of all dumpsters or grease traps had evidence of liquid leaks. These leaking containers are of especially high importance as a result of the significant concentrations of bacteria in the leaking liquid (Weston 2009a).

Municipalities can also implement restaurant inspection and trash management programs. Uncontained restaurant and grocery store wastes can be a significant FIB source in urban runoff, especially during wet weather. An expanded education and outreach program would increase restaurant and store operator awareness of this potential FIB source and provide solutions to trash management concerns. Local governments may also be able to leverage inspections conducted under Industrial Pretreatment Programs (for the sanitary collection system) as an opportunity to promote BMPs for storage of fats, oil and grease (FOG).

a) Exposed commercial waste bins in commercial areas allow rainwater to infiltrate and leak from dumpsters. B) Improved waste management through providing good-quality residential garbage containers with hinged lids may help to reduce bacteria loading in residential areas. (Photos courtesy of Jane Clary.)

4.12 Mobile Sources of Human Waste: Portable Toilets and RV Dumping

Temporary sources of FIB can include portable toilets and illicit RV dumping. The relevance of these sources to FIB impairments is dependent on the particular watershed.

BMPs for portable toilets should address site location cleanout frequency and transportation/hauling requirements. The location where the portable toilet is placed is particularly important. Guidelines for portable toilet placement could include requirements such as:

- Locate portable toilets away from high-traffic vehicular areas.
- Locate portable toilets at least 20 feet away from all storm drains: never locate a portable toilet on top of a storm drain inlet. Place portable toilets on a level ground surface that provides unobstructed access to users and servicing pump trucks.
- Wherever possible, locate portable toilets on natural ground and not on or within 5 feet of a paved surface such as asphalt, concrete or similar.

Improperly placed portable toilet with biocide running down gutter toward storm drain. (Photo courtesy of Wright Water Engineers.)

- If portable toilets must be placed on a paved surface exposed to rainwater or stormwater runoff, extra care must be taken during servicing to ensure any wastewater spilled onto the paved surface is rinsed and adequately collected so as not to leave any residue. A wet shop vacuum or similar device would provide for adequate collection.

- As a minimum, portable toilets should not be located within the 75 foot buffer of any stream or lake, or within any other larger stream/lake buffer that may have been established.

For an example of a portable toilet BMP fact sheet, see https://www.gwinnettcounty.com/static/departments/publicutilities/pdf/WQ-04%20Portable%20Toilet%20Management-%20Final.pdf).

Illicit RV dumping to storm drains can be managed in recreational areas by providing public education on appropriate practices, publicizing RV dump locations, by proving a citizen's reporting hotline, and by publicizing fines (e.g., $1,000 fine for illegal dumping in San Diego). Educational materials can include tips such as:

- Use only designated dump stations.
- Never dump into the curb, gutter or sand.
- Connect to sewer with the correct size hose, and an airtight connection.

For an example of an RV dumping brochure, see the brochure developed by "Think Blue San Diego": http://www.sandiego.gov/thinkblue/pdf/rvdumpcard.pdf.

4.13 SEPTIC SYSTEMS AND OTHER ONSITE WASTEWATER TREATMENT SYSTEMS

Onsite wastewater treatment systems (OWTSs) include a variety of on-site systems for the collection, storage, treatment, neutralization, or stabilization of sewage that occurs on a property. In some cases, OWTSs are present in urbanized areas, particularly within urban growth boundaries in areas near city limits. OWTSs include traditional septic systems, as well as other small on-site treatment systems.

In addition to approving and tracking OWTS permits, local governments can provide guidance on OWTS maintenance and on signs of failing OWTSs. As an example, Boulder County, Colorado operates a "Septic Smart" program that provides guidance to septic system owners about signs of failing septic systems, including:

- Test results of well water show the presence of bacteria.
- The ground in the area is wet or soggy.
- Grass grows greener or faster in the area.
- Sewage odors in the house or yard.
- Plumbing backups into the house.
- Slowly draining sinks and toilets.
- Gurgling sounds in the plumbing.

If one or more of these warning signs exist, Boulder County recommends that the homeowner should contact a licensed septic system cleaner to have the system inspected and pumped. Additionally, the County recommends that homeowners have septic tanks pumped out by a licensed OWTS cleaner every three years. Additionally, in order to optimize outreach and public education related to potentially problematic OWTSs, the county has inventoried OWTS locations using GIS and ranked and prioritized permitted sites, high risk sites, etc. For more information on this Septic Smart program, see: http://www.bouldercounty.org/env/water/pages/qandaows.aspx.

4.14 HOMELESS ENCAMPMENT OUTREACH AND ENFORCEMENT

Homeless encampments and gathering areas can be a source of human waste posing potential human health risks in recreational waters. Homelessness is a serious social issue in many communities and often a sensitive public policy issue that stormwater and water resource managers have limited experience in addressing. Based on experience gained in Southern California addressing this issue (Geosyntec 2014), recommendations for an effective homeless encampment enforcement/outreach program may include:

- Collaboration with other agencies.
- Targeted MS4 channel cleanups.
- Enhancing programs to reduce the number of homeless people in encampments.
- Establishing ordinances that reduce encampments.
- Enforcing new and existing laws to decrease the negative impact on water quality.

Homeless encampment beneath bridge with human excrement on concrete. (Photo courtesy of Darren Mollendor.)

The Contra Costa County Flood Control and Water Conservation District undertook an extensive research project to understand the best approaches for addressing water quality pollution from homeless encampments (DeVuono-Powell 2013). They found collaboration with other agencies to be the most effective approach for addressing the long-term concerns of homeless encampments.

Options to reduce water quality impacts of homeless encampments should ideally be combined with efforts to reduce homelessness. One example is a grant-funded pilot program on Coyote Creek in San José, CA that employs homeless persons living in creek encampments to remove trash and litter and to engage in peer-to-peer outreach with others living in the encampment. Participants are housed temporarily and given food vouchers, case management services, employment skills, and assistance at transitioning to permanent housing (EPA 2011).

Targeted enforcement during the night hours is of special importance, in order to cite and fine those caught camping illegally.

Ultimately, the long-term solution to the water quality related aspects of homelessness lies in the social arena, for examples of Colorado-based efforts to reduce homelessness see: This program includes 10-year plan to end homelessness (see http://denversroadhome.org/files/DRH_Report_FinalFINAL.pdf).

5 STRUCTURAL CONTROL PRACTICES

Structural control practices to reduce *E. coli* loading include options for treating urban runoff through "passive" stormwater BMPs such as those included in the USDCM Volume 3 (UDFCD 2012). Active treatment options, which are typically considered a last resort for managing dry weather flows, include low-flow diversions to the sanitary sewer and active treatment using disinfection at the outfall.

5.1 PASSIVE STORMWATER STRUCTURAL BMPS

Urban stormwater BMPs can be implemented to improve water quality for a variety of pollutants transported in wet weather flows. This section provides an overview of BMPs typically used in Colorado, expected performance of BMPs, considerations for enhancing BMP performance, and considerations for evaluating proprietary devices.

5.1.1 Urban Stormwater BMPs and Expected Effectiveness for Bacteria

In Volume 3 of the *Urban Storm Drainage Criteria Manual*, UDFCD provides BMP selection, design, construction and maintenance guidance for structural BMPs suitable for use in urban areas in most of Colorado. (Some adaptations are needed in mountain areas.) This guidance is reviewed and updated periodically, with the most current guidance accessible at www.udfcd.org. This guidance is oriented to settings found in urban areas in Colorado and considers state-specific constraints, such as Colorado water rights. The menu of structural BMPs in Volume 3 is summarized in Table 11 along with general characterization of expected effectiveness for bacteria and a summary of unit treatment process, or removal mechanisms, provided by the BMP.

Removal mechanisms for FIB in stormwater control practices include both passive and active processes. Based on a literature review conducted for the Water Environment Research Foundation (WERF) Stormwater Challenge (Strecker et al. 2009), the dominant passive removal mechanisms for FIB include natural inactivation, predation, inert filtration and sedimentation, sorption and chemical inactivation (via contacting products). Key passive pollutant removal processes that may be present in various stormwater control types are described below (Strecker et al. 2009, Leisenring et al. 2013, WERF 2007, UWRRC 2014).

- **Natural inactivation** is a general removal mechanism that refers to FIB die-off or inactivation due to a wide range of environmental factors. Unless provided with suitable conditions for reproduction, the number of live cells will tend to decrease with time. Growth and decay rates are highly dependent on environmental factors, which are continually changing. The most important environmental factors affecting rate of inactivation are exposure to sunlight, water temperature, and exposure to air (drying or desiccation). Additionally, FIB bound to particulates have been found to be inactivated at slower rates because particulates are hypothesized to provide both nutrients and shelter (WERF 2007).

- **Predation** of FIB by other microorganisms is interrelated with natural inactivation and has been found to be a major removal mechanism. The most important predators of FIB are believed to be protozoa and other eukaryotic organisms. Studies have found that predation may account for approximately 90 percent of overall mortality rates of FIB (WERF 2007). Additional studies such as Zhang et al. (2011) have begun to explore changes in microbial ecology in bioretention cells, but more research is needed in this area.

Table 11. Structural BMPs in USDCM Volume 3

BMP Type	Expected Effectiveness for FIB	Dominant Removal Processes for FIB for BMP Type	Additional Considerations
Grass Buffer	Poor	Infiltration	Swales may increase bacteria concentrations if frequented by urban wildlife and pets.
Grass Swale	Poor	Infiltration	Swales may increase bacteria concentrations if frequented by urban wildlife and pets.
Bioretention	Moderate to High	Infiltration Filtration Biological Processes	Proper design and maintenance are important to avoid media clogging.
Green Roof	Not Well Characterized	Evaporation Filtration Biological Processes	Green roofs in Colorado typically require irrigation.
Extended Detention Basin	Poor to Moderate (*highly variable*)	Sedimentation Infiltration (limited)	The performance of EDBs for FIB reduction varies widely.
Sand Filter	Moderate	Filtration	See Section 5.1.3.1.1 for media adaptations to enhance bacteria reduction.
Retention Pond (Wet Pond)	Moderate	Sedimentation Biological Processes (predation)	Many wet ponds demonstrate significant bacteria reductions. In Colorado, water rights constraints and land requirements may limit application.
Constructed Wetland Pond	Moderate	Sedimentation Biological Processes (predation)	Wetland ponds can potentially provide bacteria reductions; however, some wetlands have been documented to export bacteria when birds and other wildlife utilize these areas for habitat.
Constructed Wetland Channel	Poor to High, depending on design	Sedimentation Biological Processes (predation)	See additional discussion in Section 5.1.3.2 for adaptation to a subsurface constructed wetland channel.
Permeable Pavement (various types)	Not Well Characterized	Infiltration Filtration	The primary benefit of permeable pavement is volume reduction.
Underground BMPs (Proprietary Practices)	Variable	Device-dependent	Proprietary practices continue to evolve. Effectiveness depends on the practice. See additional discussion in Section 5.1.4.

- **Inert filtration**[13] **and sedimentation** of solids are mechanisms that would be expected to remove FIB bound to particulates from the water column. The effectiveness of particle removal at reducing FIB concentrations is a function of the partitioning of FIB between particulate-bound and free-floating forms, and the association of FIB across the particle size distribution. Once again, the removal of FIB from the water column through sedimentation or filtration does not necessarily constitute an ultimate removal mechanism because the survival of FIB is expected to be greater when FIB are bound to sediment, and resuspension of communities of FIB sheltered by sediment could represent a significant later source of FIB in some systems. Typical trapping efficiencies for sand filters and bioretention cells are estimated to be in the range of 60 to 80% for well-designed devices, with trapping efficiency decreasing as untreated runoff bypasses the devices and is discharged through the overflow structures during periods of high flows or when the filter is clogged (Barfield et al. 2010, Hayes et al. 2008).

  Additionally, Clark and Pitt (2012) note that most bacteria are in the lower limits of the size range for effective physical filtration using a sand medium (Figure 10). However, as the filter ages, removals will tend to increase, partly due to reduction in the effective pore size and due to the exopolymers that many bacteria excrete. These exopolymers provide surface reactive sites, even on a relatively inert sand media. Because of their negative surface charge, bacteria can be removed by attaching to these surface reactive sites. Organic media provide a location for captured bacteria to reside and grow (with potential for predation, as well). The challenge in filtration media selection is to encourage capture and potential growth to create reactive sites, but without excessive growth that sloughs off the media and is flushed out of the media with successive storms.

- **Sorption** involves the bonding of microorganisms to the surface of particles. This bonding is affected by parameters related to electrostatic charge, polarity and other factors. Sorption may be reversible as conditions change (WERF 2007). Partitioning of FIB to particles is expected to depend on a variety of environmental factors, stormwater characteristics and hydrodynamics and is expected to change drastically with time and likely from site to site.

- **Chemical inactivation** of FIB through contact with antimicrobial products is an approach used in a variety of proprietary BMPs. A common agent in these types of treatment devices is an organosilane derivative (C-18 organosilane quaternary), which is reported to inactivate most FIB without being consumed or dissipated and without producing toxic byproducts (Nolan et al. 2004). It is presumed that effectiveness of stormwater controls relying on a fixed microbial agent would depend on the degree of contact and contact time between stormwater and the microbial agent, dilution, and the amount of FIB bound to particulates. It is not clear whether C-18 organosilane degrades over time and needs to be recharged/replaced. If so, the time since installation or last maintenance would be expected to influence the effectiveness of such proprietary devices. Silt films on the microbial agent would also be expected to decrease their performance.

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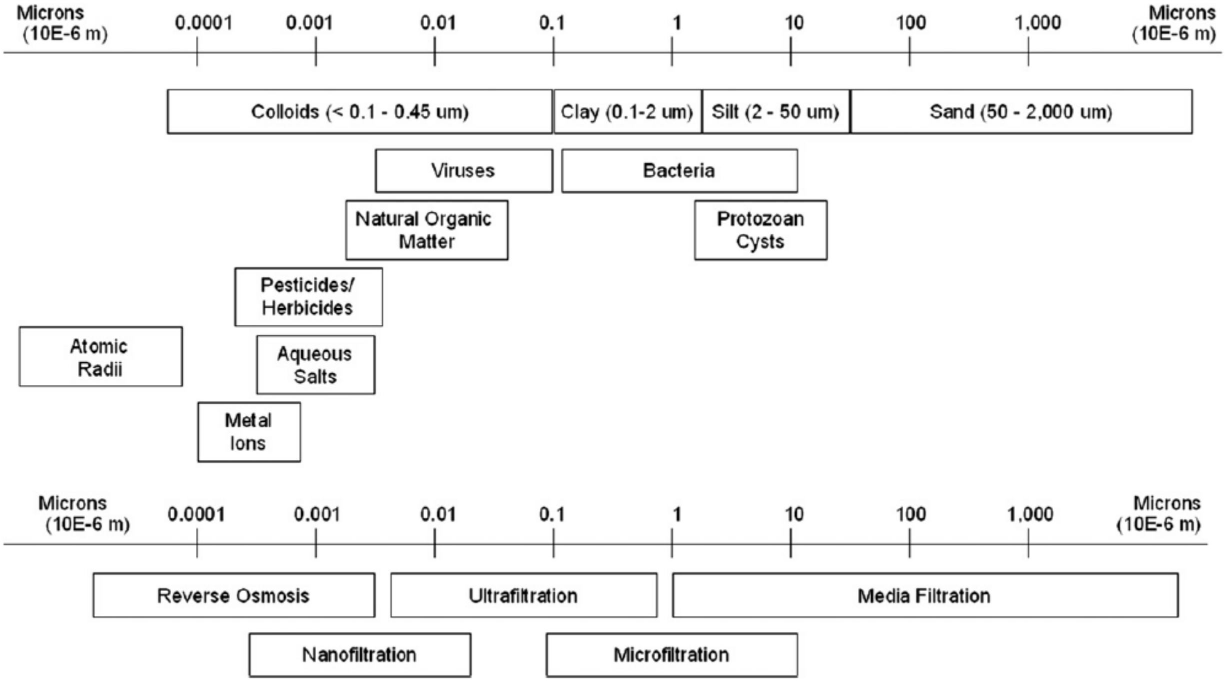
[13] Inert filtration includes physical filtration processes, but does not encompass sorption and other chemical-physical processes that may occur in filter media.

In addition to these treatment mechanisms, volume-related management practices, such as infiltration, reduce FIB loads reaching waterbodies by controlling the volume component associated with pollutant loading in runoff. For considerations related to groundwater contamination associated with stormwater infiltration, see Pitt et al. (1994).

Figure 10. Particle Sizes of Viruses, Bacteria and Protozoan Cysts

(Source: Clark and Pitt 2012)

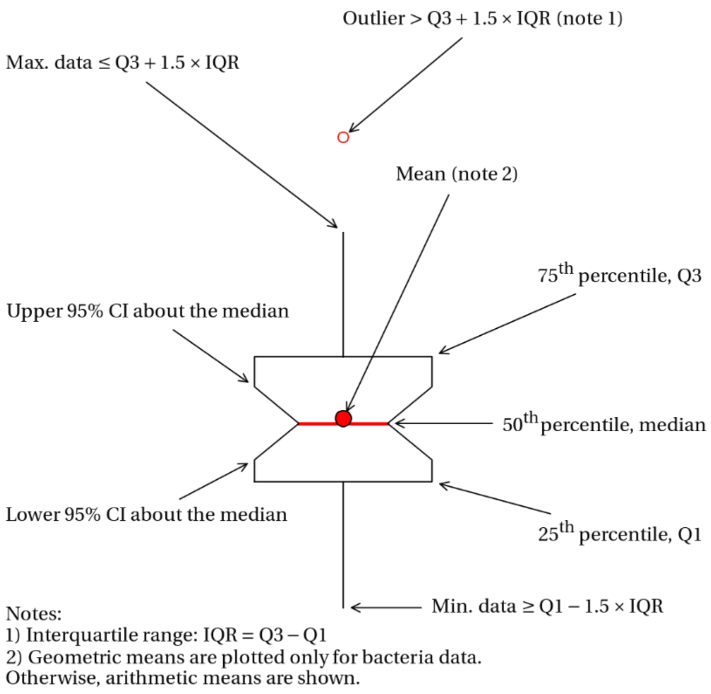


5.1.2 BMP Performance Findings from the International Stormwater BMP Database

The International Stormwater BMP Database (www.bmpdatabase.org)[14] provides a growing repository of BMP performance data, including performance results for various FIB such as *E. coli*, enterococcus and fecal coliform. Performance analysis summaries are generated periodically to summarize expected performance of various categories of BMPs. This section provides a summary of the 2014 analysis of the BMP Database (Geosyntec and WWE 2014).

Side-by-side box plots for the various BMPs measurements were generated using the influent and effluent concentrations from the studies, as provided in Figure 12 and Figure 13, for *E. coli* and fecal coliform, respectively. For each BMP category, the influent box plots are provided on the left and the effluent box plots are provided on the right. A key to the box plots is provided in Figure 11. In addition to the box plots, Table 12 and Table 13 summarize influent/effluent medians, 25th and 75th percentiles, and number of studies and data points are provided, along with 95% confidence intervals for the medians. The median and interquartile ranges were selected as descriptive statistics for BMP performance because they are non-parametric (do not require distributional assumptions for the underlying data set) and are less affected by extreme values than means and standard deviations. Additionally, the median is less affected by assumptions regarding values above upper quantification limits. See Geosyntec and WWE (2014) for more detailed information on the analysis.

Figure 11. Boxplot Key



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[14] Sponsored by the Water Environment Research Foundation (WERF), the Federal Highway Administration (FHWA), and the Environmental and Water Resources Institute (EWRI).

Figure 12. International Stormwater BMP Database Performance Data for *E. coli*

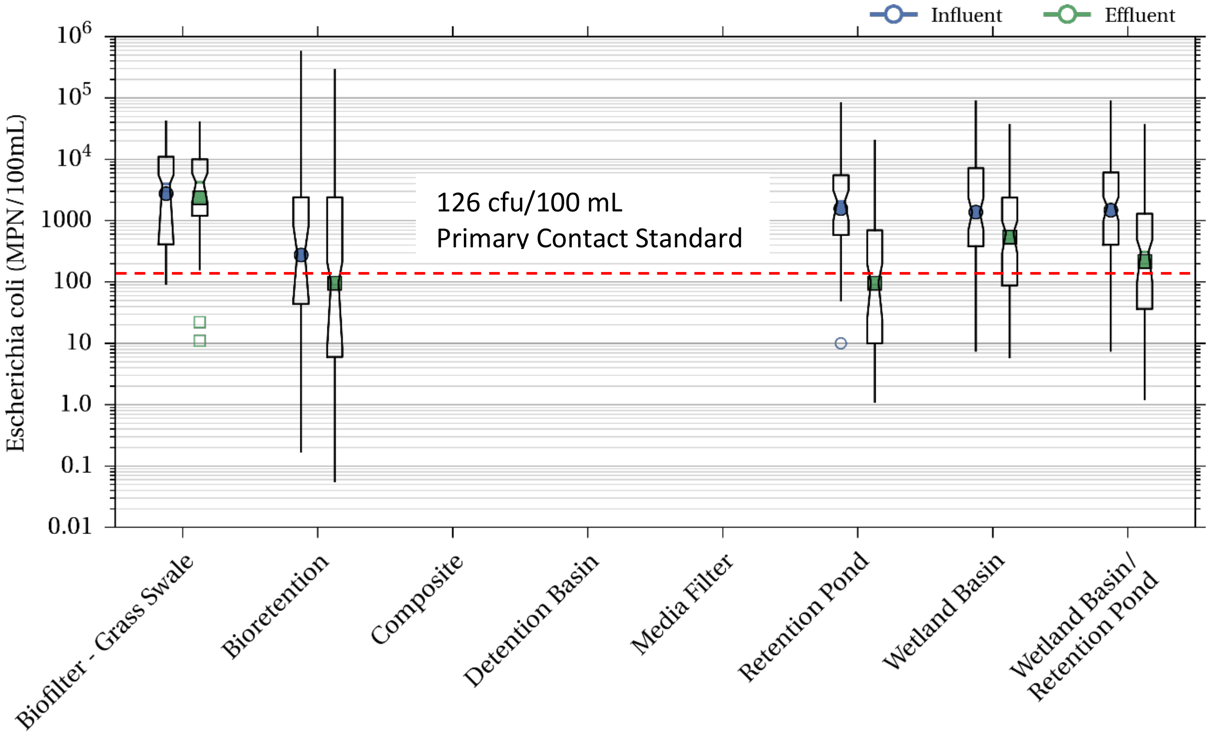


Table 12. International Stormwater BMP Database Performance Data for *E. coli*

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Biofilter - Grass Strip	NA	NA	NA	NA	NA	NA	NA	NA
Biofilter - Grass Swale	5; 39	5; 39	411	1200	3998 (411, 5600)	4201 (1200, 5900)	11000	10000
Bioretention***	4; 61	4; 61	44.0	6.0	295 (52, 820)	**100 (8, 213)****	2400	2400
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	NA	NA	NA	NA	NA	NA	NA	NA
Media Filter	NA	NA	NA	NA	NA	NA	NA	NA
Porous Pavement	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	4; 69	4; 65	582	10	2069 (988, 3106)	**99.6 (20, 200)****	5500	697
Wetland Basin	5; 60	5; 59	383	88	1379 (690, 2346)	**636 (279, 988)****	7169	2376
Wetland Basin/Retention Pond	9; 129	9; 124	403	36	1713 (988, 2433)	**311 (100, 485)****	6100	1300
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

NA – not available or less than 3 studies for BMP/constituent.

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993).

**Hypothesis testing in Geosyntec and WWE (2014) shows statistically significant decreases for this BMP category.

***Due to the unusually low influent concentrations for the bioretention data set, additional results from more studies are needed to draw conclusions regarding statistically significant *E. coli* reductions from bioretention.

Figure 13. International Stormwater BMP Database Performance Data for Fecal Coliform

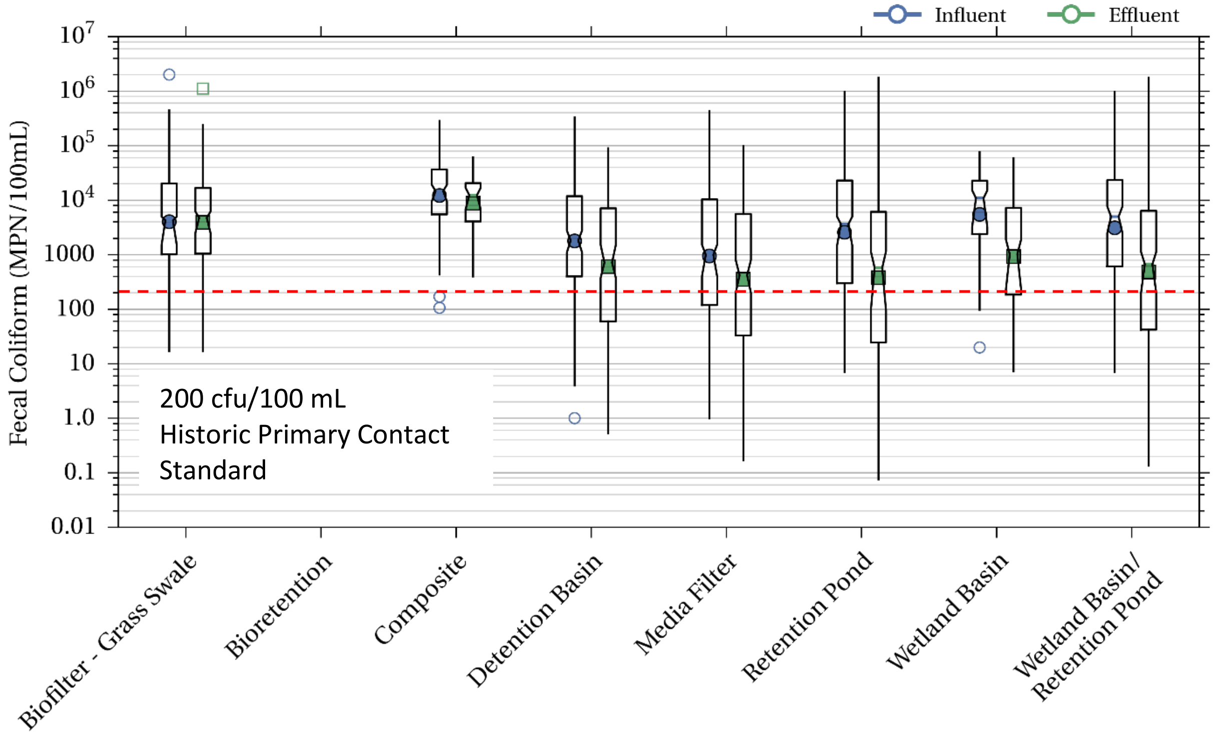


Table 13. International Stormwater BMP Database Performance Data for Fecal Coliform

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Biofilter - Grass Strip	NA	NA	NA	NA	NA	NA	NA	NA
Biofilter - Grass Swale	11; 87	11; 82	1014	1045	4249 (1491, 5000)	4747 (2600, 6100)	20,250	16,750
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Composite	4; 64	4; 56	5477	4075	14,711 (9633, 19191)	12,319 (6785, 16965)	36,690	20,570
Detention Basin	15; 170	15; 194	400	60.0	1825 (1100, 2780)	**726 (374, 1525)****	11,866	7104
Media Filter	15; 184	15; 169	120	33.0	990 (400, 1489)	**420 (200, 800)****	10,333	5573
Porous Pavement	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	10; 121	10; 123	300	24.5	3664 (1470, 5000)	**580 (92, 1160)****	23,000	6110
Wetland Basin	5; 42	5; 39	2400	185	10,976 (3200, 15177)	**1021 (230, 1900)****	22,783	7233
Wetland Basin/Retention Pond	15; 163	15; 162	611	42.3	5013 (2588, 7700)	**671 (223, 1130)****	23,448	6386
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993).

**Hypothesis testing in Geosyntec and WWE (2014) shows statistically significant decreases for this BMP category.

Conclusions that can be drawn regarding stormwater control device performance for FIB based on this analysis are generally consistent with previous analyses completed for the BMP Database (WWE and Geosyntec 2010, 2012). Key findings and observations based on the data set analyzed include:

- Regardless of FIB type, the available data set shows that concentrations in urban stormwater runoff typically exceed primary contact recreation standards, often by one or more orders of magnitude.

- Regardless of stormwater control type or FIB type, both inflow and outflow concentrations are highly variable, typically spanning an order of magnitude or more for the interquartile range.

- Currently available data suggest that it is unlikely that conventional structural stormwater controls using passive treatment can consistently reduce FIB concentrations in runoff to primary contact recreation standards. Sand filters are the only stormwater control category evaluated with effluent concentrations approaching primary contact stream standards for *E. coli*, and retention (wet) ponds approached the primary contact standard for enterococcus (analysis not shown in this report). Although the bioretention data set's median concentration for *E. coli* was below stream standards, this data set had low *E. coli* in the influent relative to other BMP categories; therefore, these findings are inconclusive for bioretention performance.

- Bioretention (potentially), sand filters, retention (wet) ponds, extended detention basins (dry) and composite (treatment train) stormwater controls appear to be able to reduce FIB concentrations to some extent, based on hypothesis testing conducted in the BMP Database analyses. Unit processes such as sorption and filtration are present in bioretention and media filters, whereas wet ponds may provide long holding times that enable sedimentation, solar irradiation and habitat conducive to natural predation. Detention basins rely primarily on sedimentation; however, scouring and resuspension of sediment deposited in detention basins may be a potential on-going source of FIB loading in the effluent. Review of individual detention basin studies shows that some detention basins export FIB, whereas others reduce FIB concentrations.

- Grass strips and swales do not appear to reduce FIB concentrations in their effluent. Instead, increases in effluent concentrations for fecal coliform are shown for grass strips and some grass swales studies. These stormwater control types may be exporting FIB, either from entrainment of previously deposited FIB or from new sources (e.g., animal excrement). (Note: reductions in FIB loading due to infiltration and evapotranspiration are not evaluated in this analysis.)

- Inadequate data sets are available to evaluate the performance of permeable pavements, and green roofs. Previous review of the green roof data in the BMP Database has shown that even though roofs have relatively few sources of FIB (i.e., birds), sample results an order of magnitude above primary contact stream standards are not uncommon (WWE and Geosyntec 2010).

- Although not included in the previous tables and graphs, the manufactured device category in the BMP Database includes a range of proprietary devices that rely on various unit treatment processes; therefore, performance should be evaluated on a unit treatment process basis for purposes of stormwater control device selection. Nonetheless, previous analysis of the manufactured device studies currently included in the BMP Database did not result in FIB effluent concentrations attaining stream standards. Due to ongoing innovation regarding unit processes provided in manufactured devices, general conclusions about manufactured devices, or subcategories of manufactured devices, should be used with caution.

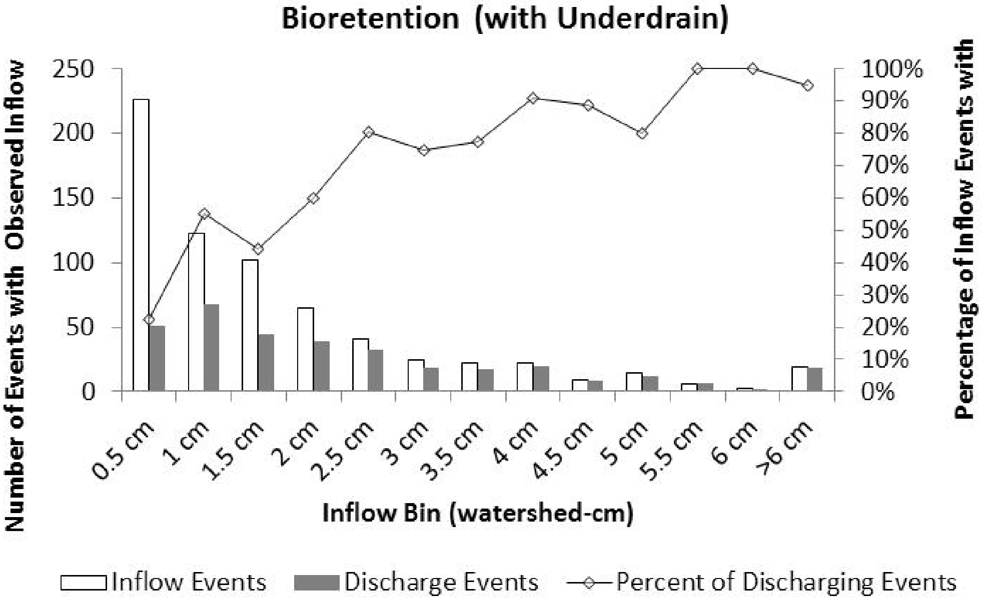
The concentration-based analysis does not account for load reductions that may result from reduced surface volumes discharged from the various stormwater control types. For more information on volume reduction benefits of BMPs, see *International Stormwater Best Management Practices (BMP) Database Technical Summary: Volume Reduction* (Geosyntec and Wright Water Engineers 2011) and *Addendum 1 Expanded Analysis of Volume Reduction in Bioretention BMPs* (Geosyntec and Wright Water Engineers 2012b) for a discussion of volume reduction analyses conducted for the BMP Database. Practices that infiltrate runoff can help to reduce the number of runoff events discharged from a stormwater control device and reduce runoff volumes, which may help to reduce the number of exceedance days associated with wet weather conditions, and will reduce in-stream final concentrations. Figure 14 provides an example of analysis of discharge events for bioretention with underdrains, with inflow concentrations grouped into inflow bins of runoff normalized to watershed-centimeters.

Currently, insufficient permeable pavement studies for FIB have been submitted to the BMP Database for analysis for FIB. To the extent that permeable pavement sites reduce runoff volumes from a site, they would be expected to help reduce discharged pollutant loads under wet weather conditions and to reduce the frequency of exceedance days, similar to bioretention.

UDFCD's BMP RealCost tool provides estimates of expected volume reductions for various BMP types in Colorado, based on a combination of data and professional judgement.

Figure 14. Presence/Absence of Discharge Plots for Bioretention Sites with Underdrains

(Source: Geosyntec and WWE 2011)



5.1.3 Optimizing BMP Designs to Enhance Bacteria Removal

Typically, the most cost-effective BMPs for bacteria removal from urban runoff rely on infiltration; however, infiltration is not always a viable approach when site soils prohibit infiltration, sufficient space is not available for adequate detention of flows prior to infiltration, or high groundwater is present. As noted in the previous section, some BMP types can provide statistically significant reduction of FIB; however, few, if any, can consistently meet primary contact standards, with the exception of disinfection, which is typically unrealistic for most wet weather applications. Two advanced BMP approaches that hold promise for enhanced bacteria removal relative to other passive treatment BMPs include advanced biofilters and subsurface flow wetlands, as explained in more detail below.

5.1.3.1 Advanced Biofilters (Bioretention and Media Filters)

An area of current research relates to optimizing filtration media and design components in bioretention (biofilters) and media filters. Effluent concentrations for fecal coliform and *E. coli* in these BMPs vary depending on climate and design parameters, with removal rates generally greater than 50% (Barrett 2003, Hunt et al. 2008, Rusciano and Obropta 2007, Zhang et al. 2010, Kim et al. 2012, Chandrasena et al. 2014, Chandrasena et al. 2012a, Chandrasena et al. 2012b, Passeport et al. 2009, Mwabi et al. 2012, Prabhukumar 2013, Zhang et al. 2010, Mohanty et al. 2014, Mohanty et al. 2013, Hathaway et al. 2012, Hathaway et al. 2001, Li and Davis 2009,Li et al. 2014a, Li et al. 2014b, Li et al. 2012, Miller 2009). Overall, only a limited number of field studies have been performed. Many of the available studies are laboratory-based utilizing column tests with lab-created ("synthetic") stormwater, which may not reflect all the complexities of a full-scale system with actual stormwater runoff (e.g., low natural organic material (NOM) results in inflated FIB removal rates, and low TSS or unrealistic particle size distributions result in overestimated times to clogging).

The available literature suggests that incorporating the following design components may improve FIB reduction in biofilters:

- Media amendments such as biochar and zeolite;
- Vegetation with specific root structures to promote pollutant removal and infiltration;
- Outlet control with sufficient contact time; and
- The presence of a saturated zone.

The following sections include a more detailed discussion for each of these design components, with specific recommendations from the Facility for Advancing Water Biofiltration (FAWB) at Monash University in Australia, which has developed guidance for advanced biofilter implementation (FAWB, 2009; www.monash.edu.au/fawb).

5.1.3.1.1 Media Selection

Specialty media components currently being researched to determine their effect on biofilter FIB performance include metal-oxide coated sand, organosilane, zeolite, and biochar. Metal-oxide coated sands are not recommended due to Mohanty et al. (2013) raising concerns of fouling with the presence of NOM and remobilization of bacteria, as well as the potential for this media to export metals and toxicity. Organosilane is not recommended due to observed rapid fouling by Torkelson et al. (2012). Additional testing is required to determine the effectiveness of these media and necessary precautions to reduce maintenance and export of other pollutants. Zeolite is a natural mineral that has been shown to reduce FIB concentrations below recreational objectives in studies by Mwabi et al. (2012) and

Prabhukumar (2013). Zeolite also reduced other pollutants such as metals and nutrients due to its ion exchange capability (Pitt and Clark 2010). The lab study performed by Mohanty et al. (2014) evaluated biochar for FIB removal and found consistent reduction in effluent concentration, but effluent concentrations were not consistently below recreational objectives, which may have been due in part to unrealistically high influent concentrations (1.2 – 1.7 x 10^6 cfu/mL). The same study also found biochar has the potential to enhance other methods of treatment. Unlike other advanced media, biochar was less affected by the presence of NOM and was found to reduce the remobilization of FIB (Mohanty et al. 2014). Mohanty and Boehm (2015) also found that in biochar-augmented sand filters, dry-wet cycles (i.e., dry periods between storms) improved FIB reduction. The FAWB recommends keeping nutrients low to avoid leaching and a media depth range between 16 and 24 inches (FAWB 2009). UDFCD's recommendation of 18-inch media depth (UDFCD 2015) aligns well with recommendation.

5.1.3.1.2 Vegetation Selection

In addition to media mixture recommendations, Chandrasena et al. (2012a) found in a laboratory study that the species of vegetation provided in the media also affects FIB removal. While the difference was not statistically significant, they found that *Lomandra longifolia* (basket grass) showed better FIB removal than *C. appressa* (tall sedge). Previous studies had shown the opposite relationship when treating for nutrients (Bratieres et al. 2008, Read et al. 2008). These findings indicate that preferable plant traits may differ when targeting various pollutants. Additionally, Chandrasena et al. (2012b) hypothesized that the creation of macropores and other changes in the soil structure may have resulted in improved performance. They also hypothesized that specific species may produce antibiotic root exudates within the submerged zone that may increase overall removal of FIB. Given the importance of using drought-tolerant plants in Colorado, it may be worthwhile to conduct research to determine how FIB removal may be affected by choice of plants.

The FAWB recommends contacting local plant experts to identify suitable species that promote pollutant removal and infiltration, are drought tolerant, include extensive root structures that penetrate through the entire filter depth, include dense linear foliage, are non-invasive and meet other climate-specific requirements. Although extensive root depth promotes infiltration, it is important to note that the root depths should be limited to the filter media depth and not extend into the drainage layer, which could clog the underdrain. FAWB also recommends selecting a variety of species to increase system robustness and selecting vegetation that is hardy and tolerant of infrequent wetting in the area farthest from the inlet and vegetation capable of tolerating frequent inundation near the inlet.

5.1.3.1.3 Outlet Control and Contact Time

To provide adequate contact time between the stormwater runoff and the media, it is necessary to provide outlet control at the discharge. When providing outlet control, the flowrate through the media alone (controlled by media conductivity) should be greater than the flowrate through the outlet so that the media is not limiting flow through the BMP. Additionally, adding outlet control allows for the selection of larger media particles, with larger pore spaces that will likely reduce clogging frequency and maintenance requirements. The available literature on FIB removal from stormwater includes data on biofilters with contact times from approximately 5 minutes (Li et al. 2014a, Passeport et al. 2009) to over 2 hours (Hunt et al. 2008 , Mohanty et al. 2014) including different media mixtures and outlet configurations. Overall, the available literature show a positive correlation between treatment of FIB and contact time. Pitt and Clark (2010) found that good removal of most pollutants can be expected from a system with approximately 10 to 40 minutes contact time. UDFCD's bioretention design criteria are based on a 12-hour drain time (UDFCD 2015). Additional research is needed to better understand the relationship between contact time and FIB removal in advanced biofilters.

5.1.3.1.4 Saturated Zone ("Internal Water Storage Zone")

Recent published studies have also shown that the presence of a fully saturated zone or internal storage zone, which will also result in increased contact time, can improve treatment of FIB (Passeport et al. 2009; Chandrasena et al. 2014; Li et al. 2012; Roseen and Stone 2013; Rippy 2015). The saturated zone is created in the BMP by raising the outlet elevation by approximately 12 to 18 inches from the bottom of the BMP drainage layer (FAWB 2009) to create a permanently saturated zone below this elevation (i.e., after the storm, the captured water will drain through the elevated outlet, leaving 12 to 18 inches of saturated media or gravel between storms).

Li et al. (2012) found that extended drying, resulting in decreased soil moisture, likely led to increased porosity and less optimal biofilm functionality resulting in less FIB reduction. Conversely, the presence of a saturated zone and a carbon source (e.g., wood chips, pea straw, etc.) maintained optimal *E. coli* removal after antecedent drying periods. Rippy (2015) cautions that the carbon source should be selected to minimize the export of dissolved organic matter, which may reduce FIB reduction in biofilters. Rippy suggests newspaper, wood chips, and sulfur-limestone as suitable carbon sources that release low concentrations of total carbon.

Additional data and field studies are required to conclusively evaluate the benefits of a saturated zone for purposes of FIB reduction. The only field experiment of the studies referenced above is Passeport et al. (2009) for two grassed bioretention cells with internal water storage zones in North Carolina. The results of this field study showed that three of the four samples from one cell and one of the seven samples from another cell exceeded the EPA standard limit of 200 cfu/100 mL for fecal coliform (influent concentrations for both cells ranged from 220 to greater than 20,000 cfu/100 mL).

In summary, the FAWB recommends a saturated zone of 12 to 18 inch thickness (preferably 18 inches), including a mix of medium to coarse sand and carbon mix or fine gravel and carbon (carbon source = 5% mulch and 5% hardwood chips).

5.1.3.2 Subsurface Flow Wetlands

Water Rights and Wetlands in Colorado

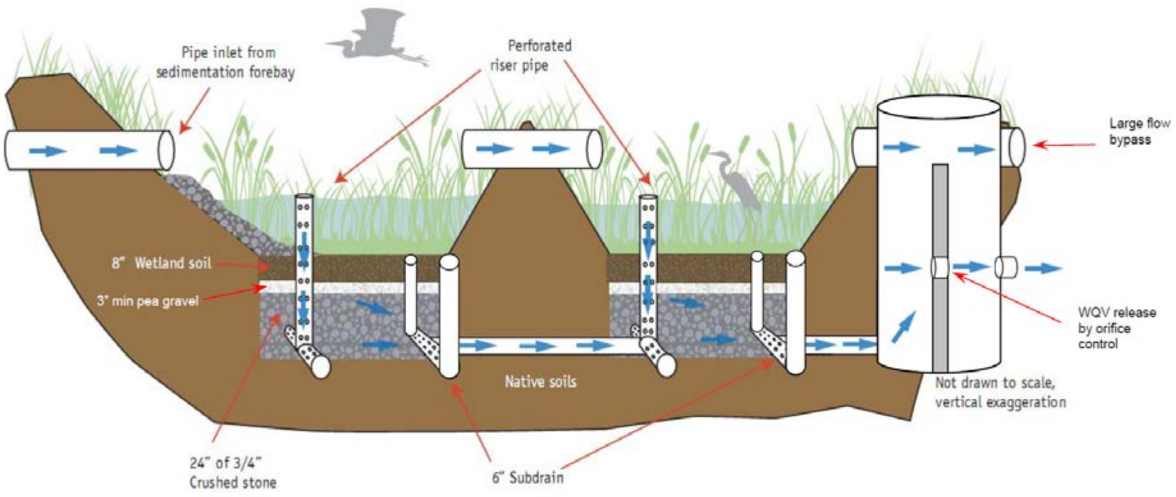
Constructed wetlands in Colorado typically require a water right.

Subsurface flow wetlands are engineered, below-ground treatment wetlands that include many of the natural treatment processes of surface flow constructed wetlands as well as the filtration mechanisms of media filters (Figure 15). Water flows through a granular matrix, which typically supports the growth of emergent wetland vegetation on the surface. The matrix provides a significant surface area for the filtration of particulate-bound constituents and the growth of bacterial biofilms that metabolize and degrade pollutants. Due to the low flow rates required for treatment, an equalization basin is typically needed upgradient of the wetlands to handle peak flows and provide a near constant discharge to the facility, as well as provide solids removal to reduce maintenance frequency and associated cost for the subsurface flow wetland.

Currently, no subsurface flow wetland performance studies for FIB are included in the BMP Database; however, published research is available that suggests that subsurface flow wetlands may be effective at reducing FIB (Kadlec and Knight 1996, EPA 1993, Puigagut et al. 2007, Sleytr 2007, Edwards et al. 1993, Geosyntec 2010, Hathaway et al. 2008). Implementation of a subsurface flow wetland requires a consistent supply of water (and adequate water rights) to maintain aerobic conditions and support vegetation health; continuous water supply may not be available in all settings, particularly in semi-arid and arid climates. Additionally, adequate land area for equalization basins is needed. Subsurface flow wetlands are a treatment alternative often considered in Southern California TMDL plans (Geosyntec 2009, Peninsula WMG 2015). These plans show the typical cost for subsurface flow wetlands ranging from $40,000 to $68,000 per acre treated (including the cost of the equalization basin).

Figure 15. Conceptual Subsurface Flow Wetlands

(Source: Geosyntec 2015)



5.1.4 Considerations for Evaluating Proprietary Devices

The proprietary market for stormwater controls is continually evolving. A systematic evaluation of manufactured devices designed to reduce FIB and pathogens was not completed for purposes of this report. However the following guidance should be considered when reviewing performance data and literature associated with the antimicrobial or bacteria removal claims of a proprietary device.

- **Use “real” stormwater**: It is preferred that “real” stormwater (including NOM and suspended sediment) be used in such evaluations rather than synthetic stormwater; otherwise, performance results may not be representative of installed conditions. If synthetic stormwater is used, NOM and suspended solids should be added to mimic “real” stormwater and influent FIB concentrations should be representative of typical stormwater runoff concentrations.
- **Effluent concentrations reported:** It is preferable to review independently measured quantitative results for each monitored event (including effluent concentrations), rather than simplified percent removal tabulations, since effluent concentration tends to be a more robust predictor of performance.
- **Independently conducted or verified field-based studies:** If only laboratory studies are available, they should include careful control, measurement, and reporting of practical contact

times in order to scale results for field implementation. However, it is highly preferred that field demonstration test results are provided.

- **Availability of study design details:** Studies should provide design details (influent and effluent concentrations for the monitored storm events, precipitation and flow data associated with monitored events, and information on the sampling plan) for careful review and applicability to site-specific applications.

Some proprietary devices with antimicrobial claims may be subject to registration with regulatory agencies (e.g., the USEPA or possibly the Colorado Department of Agriculture). Investigation into these regulatory review processes and registrations is important before making any agreements with suppliers since proper registration and review may be legally required and will aid in protecting the environment from potential uncontrolled exports of toxic material.

Examples of detailed proprietary device evaluations based on field installations can be obtained from the International Stormwater BMP Database (www.bmpdatabase.org), the New Jersey Cooperative for Advance Technology (NJCAT) program (http://www.njcat.org/), the Technology Acceptance Reciprocity Program (TARP), and other sources such as in-depth academic dissertations and publications (e.g., Cai et al 2014), as a few examples.

After a proprietary device is selected, care should be taken to ensure proper maintenance, since they are often underground (out-of-sight). When proper maintenance is not conducted, sediment and organic materials captured in the device can become a source of FIB. Similarly, if devices allow resuspension and scouring of sediment, then export of FIB may be an issue.

5.2 LOW-FLOW DIVERSIONS FOR DRY WEATHER FLOWS

In some states, diverting dry weather flows to the sanitary sewer system for treatment has been used as an option for reducing dry-weather *E. coli* loading if such flows cannot be practically or cost-effectively controlled. Typically, feasible source control reduction measures should be implemented before considering a low-flow diversion. This approach has been used frequently in California for outfalls that discharge to swim beaches. As of 2015, there are over 125 of these projects in response to bacteria TMDLs for California beaches. The range of costs for dry-weather diversions reported by the Surfrider Foundation for 35 diversion projects in California funded under the Clean Beaches Initiative (CBI) was $200,000 to $5 million, with a median cost of approximately $750,000. For examples, see http://www.beachapedia.org/Dry_Weather_Diversions_in_California_-_Diverted_by_Diversions%3F.

In Colorado, local governments should anticipate significant obstacles to implementing this approach for the following reasons:

- Legal prohibition of storm discharges to the sanitary sewer system.
- Possible water rights complications related to changing the point of discharge and ambiguity of flow sources.
- Concerns from WWTP operators regarding other difficult-to-treat pollutants such as selenium and arsenic that may be present in groundwater.

These challenges may be more manageable if the MS4 and the WWTP are operated by the same municipality. In cases where a municipality's wastewater is treated by a special district, this option may not be viable. When discussing potential options with WWTPs, it is important to clarify that the flows being treated are dry weather discharges rather than stormwater dischargers.

Low-flow diversion systems are designed to operate only during periods of dry weather. During significant wet weather, the systems are typically shut off or bypassed. Diversion structures vary in complexity from temporary inflatable dams and portable pumps to complex engineered systems with automatic controls, flow meters, and alarm systems. The systems may be by gravity flow or rely on pumps. In many cases there is some type of screening, filtering, or centrifugal separation device installed as part of the diversion that keeps trash and large solid particles out of the sewer lines. The low-flow diversion can be constructed underground in roadways.

Advantages of low-flow diversions include:[15]

- Effectively and reliably remove low-flow loading from diverted outfalls during dry weather conditions.
- May be more cost-effective that alternatives, depending on site conditions.
- Effective with varying flows up to allowed diversion capacity.

Potential disadvantages in Colorado include:

- Requires pre-treatment to remove trash and to prevent entry of hazardous materials.
- High sanitary tap fees, particularly if the WWTP ownership and the MS4 permittee are different entities.
- Not effective during wet weather.
- In some cases, the capacity of the sewer lines or the unwillingness of the sewer agency to accept the diverted dry weather urban runoff may preclude use of this option.

Representative Requirements Established by WWTPs Allowing Dry-Weather Stormwater Diversions to Sanitary Sewer

- The diversion must be designed to exclude wet weather flow and must have a lockable shut-off device accessible to WWTP agency.
- The applicant must apply for and obtain a permit from the WWTP agency prior to discharging.
- The permit applicant must demonstrate that other disposal alternatives have been considered, evaluated and deemed not feasible.
- Debris and pollutants of concern must be prevented from entering the sewer system.
- The daily total flow must be measured.
- The applicant must employ BMPs designed to minimize or eliminate dry weather urban runoff.
- The quality of the discharge must meet the WWTP agency's standards, the discharger must conduct quarterly self-monitoring and submit reports to WWTP agency.
- Discharges must be shut off no later than the commencement of any measurable rainfall and cannot be resumed without written approval from WWTP agency.

Source: OCSD, 2015

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[15] Source: City of Santa Barbara.

- Capital cost to install diversions varies widely, depending on such factors as the flow, the nearness and relative elevation of sewer lines and the degree of automated control desired. The cost may range from a few thousand dollars to hundreds of thousands of dollars. Depending on the sewer agency, there may also be a continuing cost based on the flow rate and/or the concentration of contaminants.

- Possible disruption of wastewater treatment process due to high pesticides/herbicides, TDS, spilled gasoline or dumped oil.

- Possible ecological effects from decreased baseflows to the stream which could disrupt movement of fish, and/or reduce water supporting downstream riparian habitat.

- Water rights constraints (depending on the stream segment).

5.3 ACTIVE DISINFECTION PRACTICES FOR WET AND DRY WEATHER FLOWS

Active disinfection methods include techniques such as UV light irradiation, chlorination, ozonation, paracetic acid, and others. These methods are well documented as effective treatment techniques for sanitary wastewater (sewage); however, they are typically a last resort for treatment of dry and wet weather discharges and are not currently used in Colorado, although some pilot-scale testing has been conducted. The reasons that these methods are typically a last resort include:

- Disinfection does not provide benefits for reducing nutrients and other pollutants that may be associated with bacterial discharges to streams.

- Most urban streams in Colorado include multiple outfalls rather than a single combined major outfall enabling consolidation of treatment facilities in a central facility. (In contrast, most of the active disinfection examples for California beaches enable use of a single facility for a swim beach.)

- Existing outfalls are inherently located in already developed areas, which present space constraints for end-of-pipe treatment. Although disinfection of low flows may be feasible with a relatively compact treatment facility footprint, wet weather treatment facilities require a substantially greater footprint and capital cost due to the need for flow equalization basins.

- Active disinfection requires active operation and management over the long-term with significantly greater costs than passive BMPs. These costs can include electricity, parts replacement, mechanical repairs, vandalism repairs and labor.

- Although disinfection can effectively treat flows for pathogens, the downstream receiving water may not necessarily attain recreational water quality criteria since new sources of FIB (e.g., wildlife, birds) may be introduced following treatment (Murray and Steets 2009).

For these reasons, when considering use of active treatment, it is generally recommended that source controls should be implemented as a primary stormwater treatment strategy first, followed by carefully selected passive-treatment structural stormwater controls (BMPs). In cases where these practices are not effective and high levels of recreational use are present, disinfection may be a viable alternative, particularly if human sources of FIB have been confirmed and not controlled by other measures.

UWRRC (2014) provides an overview of the strengths and weaknesses of several disinfection practices that may be considered for active disinfection, discussed primarily in the context of treating dry weather flows:

- **UV light irradiation:** UV bulbs used for wastewater disinfection emit energy at a wavelength of about 254 nm, which penetrates the cell wall of a microorganism and is absorbed by cellular materials such as nucleic acids. This absorption will either keep the cell from reproducing or destroy the cell entirely. UV disinfection requires a relatively high level of pretreatment to reduce suspended solids (Field 1996), typically using sand filtration or another method, a pump, and backwashing for filter maintenance. UV disinfection effectiveness requires careful design with regard to flow rate, which is a principal determinant of the dosage of UV light necessary for effective disinfection (Wojtenko et al. 2001). UV disinfection is a safer option than chemical disinfectants and has no known downstream ecological affects. The system may be placed in a pump house and does not require additional land. The capital cost is low compared to other active treatment alternatives. Operation and maintenance (O&M) includes regular inspection, cleaning, bulb replacement, and an energy supply (Geosyntec 2009). Because fouling materials deposited on quartz sleeves of UV bulbs decrease transmittance of UV light and associated disinfection capability (Oliver and Cosgrove 1975), an in-place cleaning system should be considered to remove fouling materials from the quartz sleeves.

- **Ozonation:** Ozone disinfection facilities include an on-site ozone production chamber, a contactor tank, and an ozone destruction device. Due to ozone's molecular instability and dangers associated with having the gas stored on location, an on-site ozone production facility is necessary to produce the chemical throughout treatment. Ozone does not produce disinfection residuals and dissipates when exposed to air. Some pretreatment is also typically required to reduce suspended solids to minimize disinfection interferences. Depending on the influent's chemical composition, ozone treatment could produce brominated disinfection byproducts. The capital cost is greater than UV, and O&M includes inspection, cleaning, and an energy supply (Geosyntec 2009).

- **Peracetic Acid:** Peracetic acid disinfects through oxidation. The chemical mixture is a combination of glacial acetic acid, hydrogen peroxide, and water (EPA 1999). It deactivates bacteria and virus cells by instigating electron transfer when oxidizing a microorganism's cell wall. It has primarily been used in the food and beverage industry. This disinfection alternative is less safe than UV or ozone because of the compound's explosive nature and lacks implementation examples in the stormwater field. The footprint, capital cost, and O&M would be similar to that of a chlorine facility due to its comparable configuration (Geosyntec 2009).

- **Chlorine:** Chlorine is the most widely used chemical disinfectant for wastewater in the United States and is highly effective as a disinfectant. However, it poses on-site chemical storage risks and results in residuals that can threaten aquatic life downstream. Compared to the other alternatives, the land requirements, capital cost, and O&M are low. Capital costs include the treatment tank and initial chlorine supply. O&M consists of regular cleaning of the system and chlorine re-supply. However, due to the risks associated with chlorination, it is typically not a preferred alternative (Geosyntec 2009).

Effectiveness of disinfection is influenced by the water quality (e.g., turbidity and organic matter content), type of disinfectant used, disinfectant dosage and disinfectant contact time. Challenges arise in disinfecting urban runoff due to the extreme variability between dry and wet weather flow volumes (Stinson and Perdek 2003). Disinfection of urban runoff requires some form of filtration, sedimentation prior to introduction of disinfecting chemicals or irradiation (EPA 1973a&b). High levels of particulate matter in urban runoff (particularly during wet weather conditions) can provide a "shielding effect" in which particles protect the microbes from the disinfecting agent (Sakamoto and Cairns 1997). To enhance treatment of wet weather flows, it is essential that mechanical or chemical pretreatment processes are applied prior to disinfection and are subjected further to high-rate filtration processes prior to discharge to waterbodies. Thus, the costs of active treatment for disinfecting stormwater include additional costs for pretreatment and flow equalization prior to the disinfection process itself.

5.4 CONSIDERATIONS FOR CHANNEL DESIGNS

Currently available research related to channel enhancements for bacteria reduction is relatively limited, although research related to wetland channels and stormwater BMPs provides insight into principles and unit treatment processes that may help to reduce bacteria loading (e.g., UWRRC 2014, Kadlec and Wallace 2009, WWE and Geosyntec 2010). Removal mechanisms include solar irradiation, predation/antagonism/competition from other microorganisms, sedimentation and filtration (Kadlec and Wallace 2009). Sorption to filter media, physical straining, and other chemical/biological ecological processes may also be important removal mechanisms that are leveraged by channel designs that incorporate subsurface flow wetlands elements. Additionally, lower nutrient conditions may also be beneficial for controlling bacteria regrowth within the stormwater conveyance system (McCarthy 2008, Surbeck et al. 2010). The survival of *E. coli* in the environment depends on interaction of multiple factors and many questions exist in the scientific community regarding the fate and transport of bacteria, so uncertainty exists regarding how successful any particular design feature will be in a particular location for reducing *E. coli* loading (UWRRC 2014). Nonetheless, the following design and maintenance considerations may be worthwhile to consider as part of channel design features planned in this basin:

- Increase sunlight (UV exposure), which is a benefit of an open channel versus a piped channel.

- Increase hydraulic residence time and minimize channel velocities. For example, a sinuous low-flow channel can help to lengthen the flow path and increase hydraulic residence time. These features enhance natural die-off, sedimentation, and generally improve effectiveness of other treatment processes.

- If possible, use a constructed wetland channel design rather than a grass-lined channel. Grass-lined swale designs generally do not show reductions in bacteria concentrations for urban runoff (although volume reduction may contribute to load reductions) (WWE and Geosyntec 2010, 2014). Wetland channel designs incorporate additional unit treatment processes that may help to reduce bacteria loading.

- Consider integration of a subsurface flow treatment wetland for baseflow (dry weather) conditions. Subsurface flow wetlands consist of a gravel or media bed planted with wetland vegetation where the water is kept below the surface of the bed and flows horizontally from the inlet to the outlet. An advantage that subsurface flow wetlands have over other constructed wetland systems (e.g., free water surface wetland) is that the water is not exposed above the surface during the treatment process, thus reducing the risk associated with human or wildlife exposure to pathogenic organisms. In addition, properly designed and maintained systems do not provide suitable ponded water habitat for waterfowl or mosquitos. Subsurface flow wetland systems typically include inlet piping, a lining system, filter media, emergent vegetation, berms or dividers, and outlet piping with water level controls. For stormwater flows, a constraint for this approach is that a flow equalization basin upstream of the system is usually required, which requires land availability and increases cost.

- If subsurface flow wetlands are infeasible, integrate wetland vegetation in the channel or along channel edges. This has the dual benefit of discouraging geese loafing up to the edge of the channel and provides substrate for predatory microbes. A potential downside of wetland channels in some locations, however, is that they can attract natural wildlife, which may be a potential source of bacteria loading in some conditions. Other wetland features such as a mixture of shallow and deeper water zones may also be beneficial, if site conditions allow.

- Consider features that promote sedimentation and that reduce scour (resuspension). This could be accomplished by sediment traps and/or baffling features. Although dry weather flows typically have relatively low sediment loads, storm runoff would be expected to have higher sediment loads, which can be deposited in the channel, becoming a persistent source of bacteria, particularly if disturbed and resuspended.

- Design the channel with velocity control features so that low-flow channel segments are protected from scour/resuspension during the higher flows expected during storm runoff.

- If wetland features are incorporated into the channel design, water rights must be taken into consideration as part of the feasibility evaluation and design.

- Manage nutrient loading from overland flow areas to the channel by utilizing native or low-maintenance vegetation in landscaped areas draining to the channel. If manicured turf is utilized, fertilizer and irrigation practices should be carefully managed.

- Where parks and trails are components of the drainage feature design and are expected to be frequented by pets, provide and maintain appropriate pet waste disposal cans and signage.

6 PUBLIC HEALTH ADVISORIES

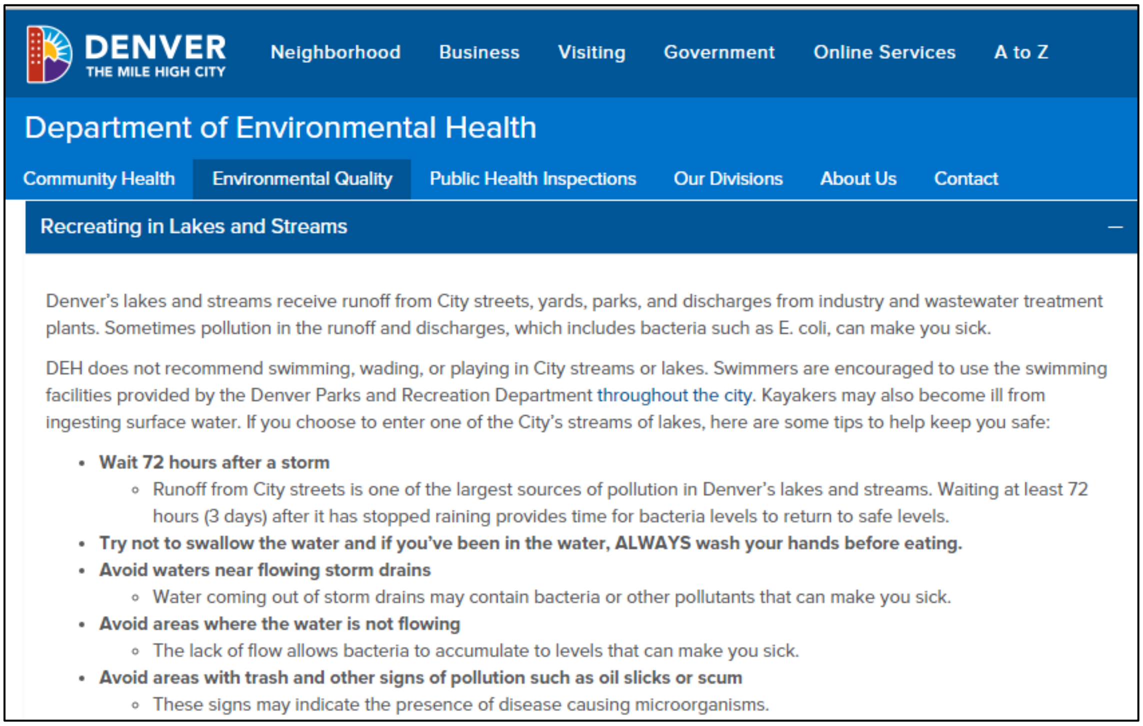
Figure 16. Public Health Signage

The ultimate purpose of recreational water quality criteria and standards is to protect public health; therefore, when standards are exceeded, local governments are encouraged to provide signage or other educational information to educate recreators regarding potential health risks and practices that reduce the inherent health risks from recreating in natural waters.[16] Figure 16 provide examples of signage that can be posted in areas where recreation commonly occurs, and Figure 17 provides an example of public health information that can be posted on a website and/or provided to park rangers for communication with the public.

Although some locations may have consistently elevated *E. coli*, it is more common in Colorado for *E. coli* concentrations to vary seasonally (higher in the summer) and following storm events. Research is underway in various parts of the country related to "now casting" conditions that are correlated with elevated fecal indicator bacteria for purposes of Clean Water Act beach closure notification programs. Variables such as precipitation, temperature, sunlight (UV irradiation), turbidity, humidity and other factors may be part of such predictive tools but the correlations are site specific and not transferable between beaches (Brady and Plona 2012, Huey and Myer 2010).

Figure 17. Example Recreational Advisory Messaging

(See: https://www.denvergov.org/content/denvergov/en/environmental-health/environmental-quality/water-quality.html)



Denver's lakes and streams receive runoff from City streets, yards, parks, and discharges from industry and wastewater treatment plants. Sometimes pollution in the runoff and discharges, which includes bacteria such as E. coli, can make you sick.

DEH does not recommend swimming, wading, or playing in City streams or lakes. Swimmers are encouraged to use the swimming facilities provided by the Denver Parks and Recreation Department throughout the city. Kayakers may also become ill from ingesting surface water. If you choose to enter one of the City's streams of lakes, here are some tips to help keep you safe:

- **Wait 72 hours after a storm**
  - Runoff from City streets is one of the largest sources of pollution in Denver's lakes and streams. Waiting at least 72 hours (3 days) after it has stopped raining provides time for bacteria levels to return to safe levels.
- **Try not to swallow the water and if you've been in the water, ALWAYS wash your hands before eating.**
- **Avoid waters near flowing storm drains**
  - Water coming out of storm drains may contain bacteria or other pollutants that can make you sick.
- **Avoid areas where the water is not flowing**
  - The lack of flow allows bacteria to accumulate to levels that can make you sick.
- **Avoid areas with trash and other signs of pollution such as oil slicks or scum**
  - These signs may indicate the presence of disease causing microorganisms.

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[16] Designated "natural swimming areas" in Colorado, which are typically located at lakes and reservoirs with fee-based access, have additional specific requirements as described in 5 CCR 1003-5.

7 REGULATORY CONSIDERATIONS/SITE-SPECIFIC STANDARDS

Once local governments have identified and corrected controllable sources of *E. coli* to the "maximum extent practicable," it is possible that streams and stormwater outfalls may continue to exceed recreational water quality standards. In such cases, regulatory adjustments to stream standards or discharge permit conditions may be appropriate. Because only a few *E. coli* TMDLs have been completed in Colorado to date, the Division is still gaining experience in such situations. This chapter provides basic information on regulatory alternatives in Colorado, followed by new guidance from EPA that provides additional detail on site-specific standards under EPA's 2012 Recreational Water Quality Criteria.

7.1 COLORADO'S APPROACH TO REGULATORY ALTERNATIVES FOR *E. COLI* STANDARDS

Regulation 31, The Basic Standards and Methodologies for Surface Water, outlines regulatory options for assigning stream standards in Colorado. The primary options for modifying a stream standard include a temporary modification to the standard, changing the designated use based on a Use Attainability Analysis, changing the standard based on a site-specific analysis, or adopting a discharger specific variance. Additional information for the latter two options includes:

- Ambient Quality-Based Site Specific Standards: Regulation 31 allows adoption of "ambient quality-based standards" where evidence has been presented that the "natural or irreversible man-induced ambient water quality levels" are higher than the stream standard, but are determined adequate to protect classified uses. In this case, the Commission may adopt site-specific chronic standards equal to the existing quality of the available representative data. Site specific standards must be supported by a use attainability analysis or other site-specific analysis completed in accordance with EPA-approved methods or in accordance with comparable procedures deemed acceptable by the Commission (paraphrased from Regulation 31, Section 31.7). Section 7.2 of this Toolbox provides information on EPA's current guidance related to site-specific standards for *E. coli*.

- Discharger-Specific Variance: A variance to a water quality standard may be granted by the Commission when certain criteria are met. This discharger-specific variance (DSV) is adopted as a water quality standard (as opposed to a permit limit). DSVs are considered temporary and must be re-examined not less than once every three years. A DSV is authorized only where a comprehensive alternatives analysis demonstrates that there are no feasible alternatives that would allow for the regulated activity to proceed without a discharge that exceeds water quality-based effluent limits. In addition, an applicant for a variance must satisfy both of the following criteria:

    i. Tests to Determine the Need for a Variance

        - Limits of Technology: Demonstration that attaining the water quality standard is not feasible because, as applied to the point source discharge, pollutant removal techniques are not available or it is technologically infeasible to meet the standard;

        - Economics: Demonstration that attaining the water quality standard is not feasible because meeting the standard, as applied to the point source discharge, will cause substantial and widespread adverse social and economic impacts in the area where the discharge is located. Considerations include such factors as the cost and affordability of pollutant removal techniques; or

- Other Consequences: Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place.

ii. Demonstration that the conditions for granting a temporary modification to the stream standard are not met; or, if those conditions are met, determination by the Commission, after considering the site-specific circumstances, that granting a DSV is preferable as a matter of policy.

A limitation of a DSV is that it only applies to dischargers with numeric effluent limits assigned in their CDPS permits. Most MS4 permits in Colorado rely on BMP-based approaches implemented to the maximum extent practicable (MEP), as opposed to numeric effluent limits enforced at the end-of-pipe; therefore, DSVs may not provide regulatory relief for MS4s. Additionally, although DSVs can be renewed, they are considered temporary and require on-going attention to maintain.

7.2 EPA'S GUIDE TO SITE-SPECIFIC ALTERNATIVE RECREATIONAL CRITERIA UNDER EPA'S 2012 RECREATIONAL WATER QUALITY CRITERIA

In the 2012 Recreational Water Quality Criteria (2012 RWQC), EPA provided three alternatives for developing site-specific standards, which are further described in EPA's Overview of Technical Support Materials: A Guide to the Site-Specific Alternative Recreational Criteria TSM Documents (EPA 2014). Detailed Technical Support Materials (TSMs) to further explain and provide guidance on each of these alternatives are currently being developed by the EPA. EPA generally describes these approaches as:

1. alternative health relationships ("Epidemiological Studies")
2. non-human fecal sources ("Quantitative Microbial Risk Assessment")
3. alternative indicators and methods

Each of these alternatives is briefly summarized below, as described by the EPA.[17] From a practical perspective, epidemiological studies are extremely costly and likely beyond the financial means of most MS4s. To achieve regulatory modification to account for non-human sources of bacteria, QMRA is expected to hold the most promise; therefore, additional practical steps for conducting a study to support QMRA are provided in addition to EPA's overview. A TSM document for the development of alternative indicators and methods has already been published by the EPA, while detailed guidance for the development of alternative health relationships through epidemiological studies and performing QMRAs for non-human fecal sources have yet to be released.

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[17] Text adapted from EPA (2014) Overview of Technical Support Materials: A Guide to Site-Specific Alternative Recreational Criteria TSM Documents.

7.2.1 Epidemiological Studies

Epidemiological studies have traditionally been used to describe the probability of illnesses associated with exposure to recreational waters containing fecal contamination as measured by FIB. It is important to note that the FIB do not necessarily cause illness themselves. Instead they are used to gauge the magnitude and extent of fecal pollution in a waterbody. Epidemiological studies, with or without QMRA, could be used to develop an alternative health relationship for a water quality metric. This alternative health relationship could inform the basis of site-specific alternative criteria. EPA's National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) epidemiological study was conducted in water primarily impacted by human fecal contamination, with the exception of one site that was impacted by urban runoff (EPA 2010b; Wade et al. 2006, 2008, 2010). Statistically significant associations between water quality, as determined using EPA's Enterococcus spp. quantitative polymerase chain reaction (qPCR) Method 1611 (EPA 2012b), and reported GI illness were observed in the temperate marine and fresh water beaches impacted by WWTPs. In the U.S. other agencies have also conducted recreational water epidemiological studies. For example, epidemiological studies of recreational water exposures have been conducted in Southern California (Colford et al. 2012), Southern Florida (Fleming et al. 2006, 2008; Sinigalliano et al. 2010), and Ohio (Marion et al. 2010). A precedent setting epidemiological study is currently being performed by the Southern California Coastal Water Research Project (SCCWRP) to identify the illness rates of surfers at beaches in the San Diego area during wet weather. The results of this study will be informative due to the focus on beaches with primarily nonpoint sources of contamination, wet weather impacts, and the inclusion of multiple analytes including human fecal markers and coliphage.

Several factors can influence the potential epidemiological relationship between indicator density and the potential for human illness. Some of the potentially important factors include the source of fecal contamination, age of the fecal contamination, solar radiation, water salinity, turbidity, dissolved organic matter, water temperature, and nutrient content. Additionally, numerous factors also affect the occurrence and distribution of FIB and pathogens, including but not limited to: predation of bacteria by other organisms; differential interactions between microbes and sediment, including the release and resuspension of bacteria from sediments in the water column; and differential environmental effects on indicator organisms versus pathogens (EPA 2010b; WERF 2009).

States or local agencies may choose to conduct epidemiological studies in their waterbodies and use the results from those studies to derive site-specific alternative criteria. To derive scientifically defensible alternative WQC for adoption into state standards, ideally the epidemiological studies should be rigorous, comparable to those used to support the 2012 RWQC, and peer-reviewed. However, smaller scale epidemiological studies may also provide a scientifically defensible foundation for alternative criteria. Additionally, QMRA (see Section 7.2.2.1) can enhance the interpretation and application of new or existing epidemiological data (Boehm et al. 2009; Dorevitch et al. 2011; Soller et al. 2016). QMRA can supplement new or existing epidemiological results by characterizing various exposure scenarios, interpreting potential etiological (disease causing) drivers for the observed epidemiological results, and accounting for differences in risks posed by various types of FIB sources. The additional insights QMRA can provide in these situations may help inform site-specific alternative WQC development.

When published, EPA's Site-Specific Alternative Recreational Criteria TSM document for Alternative Health Relationships will discuss detailed approaches that can be used to document potential human health effects from exposure to feces-contaminated recreational waters. The intention is that this TSM could be used for documenting the health relationship of new or existing indicators of fecal contamination and their associated enumeration methods to levels of reported illness, or for determining the site-specific health relationship at any site where site-specific epidemiological studies and/or QMRA are conducted. This TSM will include examples of how epidemiological data and QMRA can be used to derive site-specific alternative WQC. Special circumstances related to the characteristics of a specific waterbody (i.e., biology, chemistry, or physics), the demographics of bathers, or the nature of sources may lead to exploration of health relationship based site-specific alternative criteria.

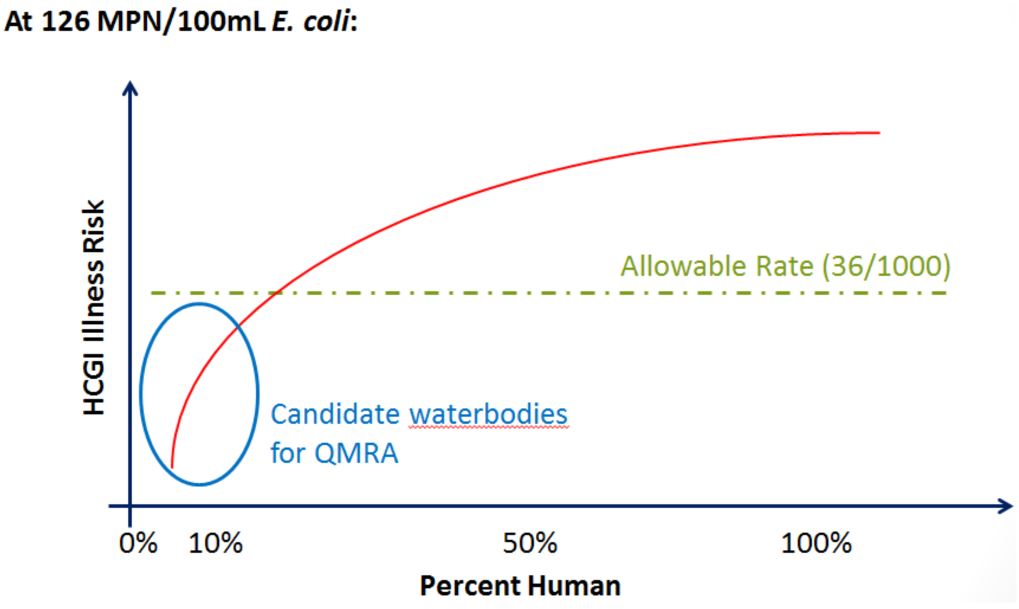
7.2.2 Quantitative Microbial Risk Assessment (QMRA)

In addition to being used for source identification (described in Section 2.3.2), advanced MST tools (i.e., human markers) can be used to demonstrate the absence (or near absence) of human fecal contamination in a receiving water, which is a prerequisite for QMRA eligibility (Figure 18). To perform QMRA, human markers may be used in combination with the direct measurement of pathogens (either by culture or advance molecular methods) to quantify the risk associated with water contact recreation. Estimated illness rates are calculated using concentrations of markers and pathogens along with dose-response relationships and exposures estimates. The outcome of this process could lead to alternative water quality criteria that are equally protective of human health.

This section provides an overview of EPA's guidance regarding the use of QMRA for developing site-specific standards, along with additional practical guidance (at an overview level) for communities that may be considering a QMRA study. Once detailed TSM guidance from the EPA is published, that document should be used for the development of site-specific standards using QMRA.

Figure 18. QMRA Candidate Waterbodies

(Source: Steets et al. 2013, based on Soller et al. 2014)



7.2.2.1 EPA's Framework for Use of QMRA for Developing Site-Specific Standards

EPA believes the 2012 RWQC are protective of the primary contact recreational designated use for waterbodies affected by any source of fecal contamination. The 2012 RWQC were informed by studies conducted in WWTP effluent-impacted waters. Because the pathogens in human feces are highly infectious to other humans, developing criteria recommendations based on these studies represents a prudent and health protective benchmark. However, there are scenarios of contamination from non-human sources and non-fecal sources of FIB that potentially present markedly different probability of illness relative to human sources. QMRA can be used as a basis to develop site-specific alternative criteria, where sources are characterized predominantly as non-human or non-fecal (EPA 2009).

EPA's research indicates that understanding the predominant source of fecal contamination could help characterize the human health risks associated with recreational water exposure. QMRA studies have demonstrated that the potential human health risks from human and non-human fecal sources could be different due to the nature of the source, the type and number of human pathogens from any given source, as well as variations in the co-occurrence of pathogens and fecal indicators associated with different sources (Till and McBride 2004; Roser and Ashbolt 2006; Ashbolt et al. 2010; Schoen and Ashbolt 2010; Soller et al. 2010b; Wuertz et al. 2011; Soller et al. 2016). Further, research demonstrates that swimming-associated illnesses can be caused by different pathogens, which depend on the source of fecal contamination. For example, in human impacted recreational waters, human enteric viruses appear to cause a large proportion of illnesses (Soller et al. 2010a). In recreational waters impacted by gulls and agricultural animals such as cattle, pigs, and chickens, pathogenic bacteria and protozoa are the likely etiologic agents of concern (Roser and Ashbolt 2006; Schoen and Ashbolt 2010; Soller et al. 2010b). The relative level of predicted human illness in recreational waters contaminated by non-human fecal sources can also vary depending on whether the contamination is direct or via runoff due to a storm event (Soller et al. 2010b; EPA 2010a; De Man et al. 2014;Soller et al. 2014; Sunger and Haas 2015). Two QMRA test cases are currently ongoing in southern California: Inner Cabrillo Beach in Los Angeles and Tecolote Creek in San Diego. The outcome of these two QMRA test cases will provide important lessons learned and regulatory precedent to other agencies on the use of this pathway for developing site-specific criteria.

To derive site-specific alternative criteria that are considered scientifically defensible and protective of the designated use, QMRA studies should be well documented, transparently presented, follow accepted practices, and rely on scientifically defensible data. A sanitary characterization can provide detailed information on the potential source(s) of fecal contamination in a waterbody to determine whether the predominant source is human or non-human. EPA developed a QMRA-specific sanitary survey application, which could be included in a sanitary characterization, to capture information directly applicable to a QMRA. At sites where non-human sources predominate, QMRA can be used to determine an alternate enterococci or *E. coli* criteria value that is equally protective of human health compared to the recommended 2012 RWQC. Fundamental to this approach is a thorough understanding of the potential sources of fecal contamination impacting a waterbody.

When published, EPA's Site-Specific Alternative Recreational Criteria TSM document for Predominantly Non-Human Fecal Sources will describe the process that can be used to document likely sources of fecal contamination impacting a waterbody.[18] Fecal source tracking and identification methods will be used to substantiate the findings of the sanitary survey (i.e., human sources do not predominate). The TSM will contain detailed guidance for conducting a sanitary characterization for QMRA. A sanitary characterization consists of conducting a sanitary survey and substantiating water quality data. The results of monitoring for pathogens and indicators can be used to conduct QMRA. EPA will provide QMRA results from several conservative (health protective) scenarios where the predominant sources

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[18] This TSM document is expected to cite heavily and build upon recent QMRA work performed by USEPA researchers and their contractor (Dr. Soller). Until this guidance is available, following the studies cited in this section is a reasonable way to proceed with performing a QMRA.

are from one or more of the following: gulls, pigs, chickens, and non-pathogenic sources. If users document that their site fits one of EPA’s conservative scenarios, then EPA will provide potential criteria values. Users may also have the option of conducting QMRA for other non-human fecal sources and other site-specific parameters documented at a site.

7.2.2.2 Practical Considerations for Monitoring to Support QMRA

QMRA is generally considered a potentially useful approach in moderately urbanized watersheds where significant compliance efforts have already been implemented and where initial source tracking results demonstrate an absence (or near absence) of human fecal contamination. Streams that are relatively close to meeting TMDL WLAs and underlying EPA RWQC and which have had investments previously directed to controlling anthropogenic sources are considered potentially good candidates for QMRA. Figure 19provides an overview of the basic steps involved in QMRA.

The general premise of QMRA is based on concepts of equivalent risk and the fact that risk varies based on sources of FIB. If the sources of FIB are relatively low risk, then a higher (less restrictive) water quality standard for FIB can be implemented while still protecting human health. Risk is based on exposure and potency. Exposure includes concentration of pathogens and ingestion rate, whereas potency is based on documented dose-response rates of illness in published literature. Simply described, the key steps involve:

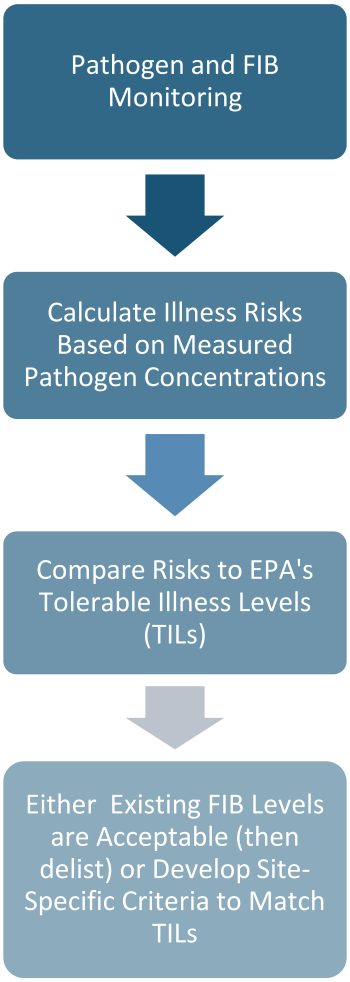
1) Monitoring for <u>both</u> FIB and pathogens to develop a data set suitable for conducting QMRA.

2) Calculating expected illness rates associated with measured pathogen concentrations using QMRA methods.

3) Comparing calculated illness rates to EPA’s tolerable illness levels (TILs) (e.g., 36 illnesses/1,000 exposures).

Figure 19. Overview of QMRA Steps

(Source: Steets 2013)



For examples of QMRA studies, see the Chicago Waterways study (Rijal et al. 2011, Petropolou et al. 2008), Soller et al. (2010b), Schoen (2010), Ashbolt et al. (2010), Wuertz et al. (2011), and Soller et al. (2016).

Communities considering QMRA should be aware that the identification of human sources of FIB during step 1 can be an unanticipated finding that causes a QMRA study to be abandoned, at least until human sources are removed. There are multiple examples of sanitary surveys where human sources have been found in storm drain systems. For example, Sercu (2009, 2011) identified leaking sanitary sewer lines into storm drains as sources of human markers in Santa Barbara, CA. A study by Sauer (2011) identified human markers in at least one sample collected at all 45 outfalls monitored in a Milwaukee study. In Los Angeles, human markers were detected in half of Los Angeles River dry weather storm drain samples (CREST 2008). Divers (2013) and Bradbury (2013) found leaking sewers to be pervasive in the Pittsburg, PA and Madison, WI, respectively. Recent source tracking studies performed in multiple CA watersheds including Cowell Beach in Santa Cruz, CA (Russell et al. 2013), Doheny State Beach in

Dana Point, CA (Layton et al. 2015), and the Monterey Bay region (Schriewer et al. 2010) have detected human markers in samples collected from the surf.

For communities considering QMRA, a potential cost range for a single stream reach or beach site could be on the order of $150,000 to $400,000. Costs would vary depending on the number of sample locations included and whether the study addressed both wet and dry weather conditions. The cost of the Chicago Waterways study, which had a number of complex aspects and was one of the biggest QMRAs performed at the time, was on the order of $1.1 million and included both wet and dry weather conditions. A recent QMRA study begun by EPA in Ventura County, California, which was ultimately abandoned due to evidence of human sources, included costs of approximately $750,000 for a dry weather QMRA at two beaches. This study was likely on the higher end of costs due to the use of a variety of state-of-the-science components. Additional costs for these studies may include an independent expert panel to review results and costs related to source investigations. It is expected that costs will decrease significantly as regulator comfort level grows and the number of laboratories and consultants experienced in performing these studies grows.

7.2.3 Alternative Indicators or Methods

EPA anticipates that scientific advancements will provide new technologies for enumerating fecal pathogens or FIB. New technologies may provide alternative ways to address methodological considerations, such as rapidity, sensitivity, specificity, and method performance. As new or alternative indicator and/or enumeration method combinations are developed, states may want to consider using them to develop site-specific alternative criteria for adoption in water quality standards (WQS) or as the basis for notification when a state does not plan to modify existing WQS. The TSM, Site-Specific Alternative Recreational Criteria Technical Support Materials for Alternative Indicators and Methods, describes a process for comparing enumeration methods that may allow users to take advantage of the rapid and continuing advancements in the science of microbial water quality. As of 2016, Colorado is not pursuing this option, but it is briefly described for sake of completeness.

New methods and additional improvements to currently available methods, platforms, and chemistries may also be developed in the future. Examples of possible alternative indicators include, but are not limited to *Bacteroidales*, *Clostridium perfringens*, human enteric viruses, and coliphages. These possible alternative indicator organisms could be used with new methodologies or methodologies similar to those recommended by the 2012 RWQC. For example, in one case, *Bacteroidales* measured by qPCR were highly correlated with Enterococcus spp. and *E. coli* when either culture-based methods or qPCR methods were used (Wuertz et al., 2011). The pathogens norovirus GI and GII have also been shown to be predictors of the presence of other pathogens such as adenovirus measured by qPCR (Wuertz et al., 2011). Coliphage (viruses that infect *E. coli*) are also currently being evaluated by the EPA as an alternative indicator of fecal contamination due to their fate and transport properties that may be more similar to human viruses in the environment (http://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria#Review of Coliphages).

If a state adopts WQS using alternative indicator/method combinations, EPA will review those standards, including any technical information submitted to determine whether such standards are scientifically defensible and protective of the primary contact recreation use. Due to the highly technical nature of the alternative indicators discussion, readers are directed to EPA's 2014 TSM on this topic (http://www.epa.gov/sites/production/files/2015-11/documents/sitespecific-alternative-recreational-indicators-methods.pdf).

8 CONCLUSIONS

Reduction of *E. coli* loading in urban areas is often challenging and costly. This Toolbox was developed to support communities working towards attainment of instream recreational water quality standards by providing a concise overview of regulations driving TMDLs and MS4 permit conditions and then focusing on approaches to understanding sources of *E. coli*, potential non-structural and structural BMPs, and regulatory alternatives, particularly those resulting from EPA's 2012 update of its *Recreational Water Quality Criteria*. A summary of key points from this Toolbox include:

1. There are many potential sources of *E. coli* in urban areas. In order to effectively control these sources and select BMPs, it is important to develop a reasonable understanding of sources. In urban areas, the highest priority from a human health risk perspective is human sources, particularly persistent leaking sanitary infrastructure.
2. Tools for identifying sources of *E. coli* have expanded as communities around the country have gained experience implementing *E. coli* TMDLs. These tools range from relatively simple techniques to advanced microbial methods. Some of the advanced methods, though relatively expensive, have become more accessible for use to quickly determine whether human sources of fecal pollution are present.
3. The foundation of *E. coli* load reduction plans is source controls, which are non-structural measures that help to reduce the *E. coli* source and/or flow sources that are transporting *E. coli* to the storm drainage systems. Effective implementation of source control practices typically involves coordination with multiple local government departments.
4. Structural stormwater practices, such as those described in Volume 3 of the *Urban Storm Drainage Criteria Manual*, are key tools to help reduce *E. coli* loading in urban runoff. Because existing performance data indicate that consistent attainment of primary contact limits at outfalls from BMPs is unlikely, volume reduction is a key approach for bacteria load reduction. Green infrastructure approaches, such as those further described in Denver's *Ultra-Urban Green Infrastructure Guidelines*, should be considered. Other BMP types with performance data indicating potential ability to reduce *E. coli* concentrations include retention (wet) ponds, media filters, bioretention facilities and subsurface flow wetlands. Site-specific constraints, cost and sustainability (ability to maintain over time) affect selection of BMPs suitable for any particular site.
5. Active treatment, either through diversion of dry-weather low flows to the sanitary sewer system or active disinfection at the end of pipe, is generally a last resort for controlling *E. coli* discharges to receiving waters.
6. EPA's 2012 update of its *Recreational Water Quality Criteria* resulted in several options for site-specific recreational water quality standards. Although application of these approaches requires significant technical expertise, the potential eventual application of these approaches is an important consideration for communities.
7. Research needs in Colorado include:
    a. Additional source characterization of *E. coli* concentrations in urban runoff associated with various land uses.
    b. Additional BMP performance monitoring for current UDFCD-recommended BMP designs.
    c. Characterization of instream concentrations and standards exceedance frequencies in reference (natural) watersheds along the Front Range.

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