Synopsis of Recreational Water Quality Issues in Colorado:

White Paper Summarizing Results of

E. coli Work Group 2007-2009





Prepared by
***E. coli* Work Group of the Colorado Water Quality Forum**
and Wright Water Engineers, Inc.

Prepared with Support from a
Colorado Healthy Rivers Grant for the
Colorado *E. coli* Assessment and Management Project

October 2009

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Acknowledgements

This white paper was developed over a two year period by participants in the *E. coli* Work Group with financial support from the Colorado Healthy Rivers Fund, the Colorado Stormwater Council, and the Big Dry Creek Watershed Association. Many individuals contributed to development of this white paper, as acknowledged below.

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Additionally, the Work Group would like to thank Dave Moon and Sandra Spence, U.S. Environmental Protection Agency Region 8, for providing helpful feedback on a variety of topics.

Frequently Used Acronyms

CAFO	Confined Animal Feeding Operation
CDPHE	Colorado Department of Public Health and Environment
CDPS	Colorado Discharge Permit System
CHEERS	Chicago Health, Environmental Exposure, and Recreation Study
CWQCC	Colorado Water Quality Control Commission
CWQCD	Colorado Water Quality Control Division
EPA	U.S. Environmental Protection Agency
LA	Load Allocation
LID	Low Impact Development
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
MST	Microbial Source Tracking
NEEAR	National Epidemiological and Environmental Assessment of Recreational Waters Study
NPDES	National Pollutant Discharge Elimination System
QMRA	Quantitative Microbial Risk Assessment
qPCR	Quantitative Polymerase Chain Reaction
SCCWRP	Southern California Coastal Water Research Project
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WERF	Water Environment Research Foundation
WLA	Wasteload Allocation

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Executive Summary

In 2008, the Colorado Water Quality Control Commission (CWQCC) identified 22 stream segments throughout Colorado as "impaired" due to elevated *Escherichia coli* (*E. coli*) on Colorado's 303(d) list, with an additional 16 streams listed on its monitoring and evaluation list. *E. coli* is a subgroup of fecal coliform bacteria and is used as an indicator of fecal contamination in a waterbody. Where elevated concentrations of indicator bacteria exist in recreational waters, humans may face increased health risks from pathogens. Watershed groups, local governments, regional planning agencies, and the Colorado Water Quality Control Division (CWQCD) are working to address this statewide issue. For these entities to successfully work towards meaningful and effective restoration approaches for watersheds designated as "impaired" by elevated *E. coli*, they need a sound understanding of fecal indicator bacteria sources, control methods, monitoring approaches for properly identifying sources, and site-specific factors that affect *E. coli* viability in the environment. If these subjects are not properly understood, then effective, practical plans to manage and protect watersheds and address *E. coli* 303(d) listings are unlikely to be developed.

Through the vision of participants in the Water Quality Forum, an *E. coli* Work Group was formed in 2007 to work collaboratively on a voluntary basis to address the multi-faceted factors associated with these *E. coli* issues. The participants in the Work Group are active in nearly ten different local watershed organizations that must respond to *E. coli* 303(d) listings or concerns. Misconceptions regarding *E. coli* sources and control strategies are common and pose challenges to watershed groups trying to identify and reduce sources of *E. coli* for 303(d) listed streams. The purpose of this white paper is to provide a sound base of technical information that will provide a common foundation for entities working to address *E. coli* caused stream impairments. A brief summary of topics addressed in this paper include:

- **Regulatory Background:** The federal Clean Water Act requires the U.S. Environmental Protection Agency (EPA) to establish Ambient Water Quality Criteria for bacteria. The currently applicable criteria were issued in 1986, but are scheduled to be updated by 2012. Significant research is underway in support of the updated criteria. The CWQCC promulgates recreational use classifications and numeric standards based on EPA criteria (the Colorado Basic Standards) and assigns appropriate standards to stream segments in basin-specific regulations. The CWQCD assesses attainment of stream standards biennially, developing the state's "303(d) list" of waters not attaining stream standards. Listed stream segments are assigned a high, medium or low priority ranking for Total Maximum Daily Loads (TMDLs). Human health related listings such as bacteria are given a "high" priority. For streams not attaining stream standards, the TMDL process is initiated to assign pollutant loading allocations to various sources discharging to the stream. The TMDL process has been a key driver in development of this *E. coli* Work Group because many questions exist regarding identifying sources of *E. coli* and developing implementation plans for reducing *E. coli* loading to streams.

- **Colorado Case Studies:** Streams listed for *E. coli* impairment in Colorado have widely varying characteristics and have been studied using approaches ranging from conventional sampling to deduce logical proof of *E. coli* sources to complex, cutting-edge

microbiological techniques. Five case studies were selected for purposes of this white paper to illustrate *E. coli* listings, including:

- **South Platte River Segment 14—**this stream segment through the heart of the metro Denver area receives significant recreational use by kayakers and children. This segment was the first *E. coli* TMDL issued in Colorado. The TMDL focuses primarily on controlling dry-weather discharges from storm sewer outfalls and is using an iterative, adaptive management approach that focuses first on controllable sources of *E. coli*. The City and County of Denver has continued to conduct a variety of special studies to identify sources of bacteria, as well as to assess the benefits of various management approaches such as storm sewer cleaning.

- **Boulder Creek Below 13th Street—**this stream segment through the City of Boulder area also receives significant primary contact recreational use by tubers, children and others. The CWQCD is in the process of working with the City of Boulder to develop an *E. coli* TMDL. A "toolbox" approach to identifying sources of bacteria loading has been completed using cutting edge microbial and chemical source tracking approaches, working closely with the U.S. Geological Survey (USGS) and Colorado School of Mines. These source tracking approaches have identified specific outfalls contributing fecal indicator bacteria, but have also identified environmental sources of bacteria (e.g., sediment) as potentially significant contributors to elevated instream concentrations. Specifically, studies suggest that indicator bacteria can persist in outfall sediments for long periods of time and can affect *E. coli* concentrations in the water column.

- **Big Dry Creek, Segment 1—**this stream segment extends from the Standley Lake dam to the South Platte River near Fort Lupton. This warm-water stream flows through open space areas in Broomfield and Westminster into agricultural areas in Weld County. Unlike Boulder Creek and the South Platte River, it is not a recreational destination for kayakers, tubers, swimmers, etc. However, because the stream is located in an urban area and is potentially accessible for water play by children, it has a "potential primary contact" recreation standard. Studies to identify sources of bacteria have focused on synoptic sampling in combination with dry weather screening of stormwater outfalls. As part of this process, one illicit connection to a storm sewer was identified and corrected. Studies to date suggest that nonpoint sources are the likely source of *E. coli* in the watershed. Observations in the watershed suggest that wildlife (particularly in open space areas), domestic pets and agriculture in the lower watershed are likely contributors of *E. coli*. Instream sediments have not been evaluated.

- **Fountain Creek—**Fountain Creek, from its source above Green Mountain Falls to immediately above the confluence with Monument Creek, has elevated *E. coli*. Advanced microbial source tracking techniques were used by the USGS to identify likely sources of *E. coli* loading. Although agriculture and humans were expected to be identified as key sources prior to the study, initial results suggest that pigeons are a likely key source; however, final study results have not been formally published.

  - **Elkhead and First Creeks, Routt National Forest—**these creeks are located in the Yampa River Basin on Colorado's Western Slope. These streams were listed on the 2006 303(d) list, but are anticipated to be "delisted" in 2010 based on change of recreational use classification and resegmentation as a result of a Use Attainability Analysis conducted for the stream that demonstrated that "Not Primary Contact" was a more appropriate use classification for this remote area. Primary likely sources of elevated *E. coli* in this area included a large elk herd and cattle and sheep grazing. The U.S. Forest Service has refined grazing management plans for this area to help control impacts to the stream. Conventional water quality sampling approaches were used to identify stream reaches with elevated *E. coli*.

- **Sources of Fecal Indicator Bacteria:** Sources of fecal indicator bacteria in streams vary widely. Representative sources of fecal indicator bacteria include illicit connections to storm sewer systems, failing or improperly located onsite wastewater treatment systems (septic systems), wastewater treatment plants, wildlife, domestic pets, agriculture and wet weather discharges. Recently, environmental sources of fecal indicator bacteria such as bacteria in streams or outfall sediments have received attention. Although some of these sources can be reasonably controlled (e.g., wastewater discharges, illicit connections), other sources are much more difficult to control such as raccoons in storm sewers, wildlife in open space areas, birds on bridges, and bacteria in stream sediments. Currently, water quality criteria do not differentiate risks to human health due to sources of bacteria. Expert panels convened by EPA (2007a) and the Water Environment Research Foundation (WERF 2009) have generally agreed that human sources of bacteria are *expected* to pose a greater health risk than animals and environmental sources, but have also recommended additional research to better quantify this risk. Because the EPA (2007a) Expert Panel did not *conclusively* state that non-human sources were less risky to humans, EPA's position nationally is currently that non-human sources of bacteria must be addressed unless those non-human sources are shown to pose *no risk* to human health (i.e., through an epidemiological study).

- **Monitoring, Assessment of Data and Modeling:** Monitoring strategies to develop an understanding of sources of *E. coli* to streams can range from simple and relatively inexpensive sample collection of *E. coli* and basic water quality parameters to complex microbial source tracking approaches relying on advanced molecular methods. Due to cost and expertise required for advanced methods, it is recommended that entities facing *E. coli* TMDLs begin with simple methods to isolate reaches of concern, then determine whether advanced methods are warranted or would provide additional benefits in terms of defining bacteria sources. In urban areas, data collection efforts for impaired streams typically include instream synoptic sampling combined with dry weather screening of storm sewer outfalls to identify potential illicit connections to storm sewers. Additionally, other relatively inexpensive methods such as use of florescence to identify optical brighteners from detergents potentially indicative of wastewater discharges can also be helpful in refining understanding of sources.

Interpretation of *E. coli* data can be challenging due to large variability in data sets that make trend analysis and drawing statistically significant conclusions difficult. Even when a toolbox of monitoring strategies is implemented, seemingly contradictory findings can result.

Modeling of *E. coli* loading and management strategies is also challenging due to many questions regarding *E. coli* fate and transport. Although ongoing research may enable refinement of existing water quality models, currently, those using models for *E. coli* should do so with care and a clear understanding of the strengths and limitations of the models, as well as data and calibration requirements. Evaluation of existing models was not independently completed as part of this white paper; however, an evaluation of models that was developed by the Texas Task Force has been incorporated for general reference.

- **Best Management Practices (BMPs):** Given that wastewater treatment plant discharges represent regulated point sources with readily available disinfection processes, the focus of this white paper is on the use of BMPs to reduce *E. coli* loading from municipal separate storm sewer systems (MS4s) and nonpoint sources (e.g., agriculture). BMPs can include non-structural and structural approaches. In urban areas, the general consensus of the work group is that illicit discharge detection and elimination programs and pet waste ordinances are key non-structural strategies to help reduce controllable sources of bacteria loading. Maintenance and cleaning of storm sewers is an additional measure that may provide benefits. (The City and County of Denver is conducting a study of this approach.)

  Structural stormwater quality treatment BMPs such as extended detention basins, grass swales, wetland channels, porous pavement, bioretention and other measures that provide stormwater quality benefits for many water quality constituents show mixed results with regard to their ability to remove bacteria. Even for those practices that do show potential such as bioretention and media filters, it remains unlikely that these practices could consistently meet numeric limits at primary contact recreation levels. For example, data available in the International Stormwater BMP Database (www.bmpdatabase.org) show that detention basins and grass swales do not significantly reduce bacteria in effluent and may in some cases increase bacteria loading. Hypotheses explaining this range from the presence of geese/dogs within these BMPs to regrowth and resuspension of bacteria associated with sediment in these BMPs. Practices that incorporate unit processes based on infiltration (e.g., media filters and bioretention) appear to have a greater potential to reduce bacteria loads, but these practices also have some limitations related to allowable tributary area, maintenance, groundwater pollution and/or appropriateness in certain soil conditions. Retention ponds may also help to reduce bacteria loading; however, water rights constraints in Colorado limit implementation of this practice. Low Impact Development (LID) strategies that reduce surface volume runoff from developments may potentially help to reduce bacteria loading, if for no other reason than they can help reduce the volumetric component of the load; however, a relatively small number of development-scale LID monitoring studies are available to date. Additional research is being conducted nationally by various entities regarding fate and transport mechanisms related to BMP performance, which is critical to advancing the state of the science.

Agricultural BMPs that provide stream buffers, manage grazing and other practices provide both water quality and channel stability benefits to streams. A variety of federal agencies have developed guidance on such BMPs. However, as is the case with urban BMPs, results can be mixed with regard to bacteria reduction in streams, even when other pollutant loading is reduced. The reasons for this are unclear but may relate to wildlife and other environmental sources of bacteria.

- **Unresolved Issues Related to *E. coli* in Colorado:** One of the primary benefits of the *E. coli* Work Group process to date has been that it has provided opportunities for the regulated community, CWQCD staff and EPA staff to exchange ideas and perspectives related to *E. coli* issues in Colorado. In some cases, consensus was reached, but in other cases, unresolved issues exist. These unresolved issues are briefly described below. Some of these topics may benefit from ongoing discussion, whereas others may require waiting to see the results of the multiple studies being conducted in support of EPA's revised criteria anticipated in 2012.

    - **Inland Flowing Waters and Relation to 1986 Ambient Water Quality Criteria:** Work Group members expressed concerns regarding the applicability of the epidemiological studies forming the basis of the 1986 Ambient Water Quality Criteria to inland flowing streams. Essentially, the studies used as the basis of the criteria were located in lake settings where sanitary sewage contamination was present. In contrast, many of the Colorado-listed streams are not in swim beach settings and may not have sanitary sewage sources of contamination. Both EPA and WERF have acknowledged these types of concerns and are conducting additional research in this area in support of the recreational criteria update in 2012. Because Colorado stream standards and TMDLs must comply with the existing federal criteria, this is currently an unresolved issue.

    - **Use of *E. coli* as Basis of Recreational Stream Standard:** Concerns regarding *E. coli* as the basis of the recreational stream standards generally relate to its relationship with human illness and the occurrence of *E. coli* in the environment from natural, non-human, largely uncontrollable sources. Specifically, recent research raises doubt as to the correlation of indicator bacteria such as *E. coli* with fecal contamination from humans. Ultimately, the questions and uncertainties in accurately assessing naturalized strains versus anthropogenic sources of fecal contamination create difficulties in determining human health risks associated with exposure. Because Colorado stream standards and TMDLs must comply with the federal criteria, this is currently an unresolved issue within the context of the Work Group. However, both the EPA (2007) and WERF (2009) Expert Panel reports validated may of the concerns expressed by Work Group participants and the participants look forward to the multi-faceted research currently being conducted as a result of the reports.

- **Wildlife Contributions and Implications for TMDLs:** A topic of discussion during several Work Group meetings related to the impact of wildlife on the attainability of recreational stream standards. Specifically, the concept of "wildlife off-ramps" for water quality standards was discussed, including a summary of provisions present in several other states. Essentially, the group recognizes that open space and national forest areas may have elevated bacteria due to wildlife. Such sources are largely uncontrollable and/or wildlife removal conflicts with other community objectives (e.g., wildlife in urban open space areas is desirable). In order to enable regulatory flexibility for this issue, changes to the Colorado Basic Standards would be required. Given a number of high priority issues associated with the Basic Standards unrelated to bacteria and the expectation that the Basic Standards may change as a result of the 2012 EPA criteria update, this issue was left unresolved. An additional factor resulting in this issue being set aside is that EPA's current position[1] that non-human source exclusions to the criteria can only be allowed when both of the following criteria are met: 1) the sources are only from non-human sources (supported by sanitary surveys/watershed characterization studies) AND 2) Those non-human sources are shown to pose no risk to human health (i.e., through an epidemiological study). Although states may use existing epidemiological data in lieu of conducting their own study, the second component of this test is difficult to meet.

- **Recreational Use Classifications:** Multiple streams in Colorado are currently assigned primary contact or potential primary contact recreation standards due to actual or potential water play by children. This standard is protectively applied in urban/residential areas to include streams where access to the stream is not restricted by a fence or other private property restrictions. Many states do not explicitly address this issue, and for states that do address this issue, the manner in which it is addressed varies. *E. coli* Work Group participants expressed a variety of opinions regarding whether water play by children was believed to be a primary versus secondary contact use, but ultimately identified this issue as unresolved. Given work in progress with regard to EPA's Ambient Water Quality Criteria, the group believed it was appropriate to await the outcome at the national level before exploring this issue further. Epidemiological data emerging from on-going studies may help to resolve outstanding questions regarding risks to children and delineation of risks for primary and secondary contact uses. Appendix A provides information on recreational standards in other states.

- **TMDL "Endpoints":** The endpoint of a TMDL is the identification of pollutant sources and the differentiation and allocation between point and non-point source

[1] Based on communication with Shari Barash, EPA, on September 24, 2009.

contributions. The outcome, or implementation, of the TMDL is intended to result in the elimination of pollutant sources contributing to exceedances of the *E. coli* standard (e.g., removal of sanitary cross-connections, repair of leaking pipes or septic systems, etc.). As it pertains to TMDL implementation, Work Group participants devoted considerable discussion to whether *E. coli* standards are realistically attainable, even after controllable sources of *E. coli* are addressed. If this is the case, implementation of the TMDL is a concern, particularly to MS4 permit holders. Based on Work Group discussions, one possible step in the regulatory process would be the proposal of a site-specific standard based on "natural or irreversible human induced conditions," or a Use Attainability Analysis (UAA), which would be addressed through the triennial review process on a segment-by-segment basis. A key issue in such cases would include determination of acceptable risk.

At the time this paper was completed (October 2009), significant research was underway in support of the forthcoming EPA update to the federal ambient water quality criteria expected in 2012. Although this research may result in significant changes to the federal water quality criteria in the near future, Colorado is required to move forward in implementing the requirements of the federal Clean Water Act that are currently in place.

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APPENDICES

A 2005 CDM White Paper Summarizing State Stream Standards

B Outfall Reconnaissance Inventory Dry Weather Field Screening Form

C Example Monitoring Plan for Dry Weather Screening

D EPA Region 8 TMDL Review Form (October 2009 Draft Form)

Other Resources Associated with Project, available on the Work Group website (http://projects.ch2m.com/cwqf/Workgroups/ecoli.asp) include:

2008 Bibliography of Technical Resources (Task 1 Deliverable)

E. coli Work Group Meeting Minutes 2007-2009 (Task 7 Deliverable)

Powerpoint Presentations/Outreach (Task 8 Deliverable)

Other *E. coli*-related resources

1 INTRODUCTION

In 2008, the Colorado Water Quality Control Commission (CWQCC) identified 22 stream segments throughout Colorado as "impaired" due to elevated *Escherichia coli* (*E. coli*) on Colorado's 303(d) list, with an additional 16 streams listed on its monitoring and evaluation list. *E. coli* is a subgroup of fecal coliform bacteria and is used as an indicator of fecal contamination in a waterbody. Where elevated concentrations of indicator bacteria exist in recreational waters, humans may face increased health risks from pathogens. Watershed groups, local governments, regional planning agencies, and the Colorado Water Quality Control Division (CWQCD) are working to address this statewide issue. For these entities to successfully work towards effective restoration approaches for watersheds designated as impaired by elevated *E. coli*, they need a sound understanding of fecal indicator bacteria sources, control methods, monitoring approaches for properly identifying sources, and site-specific factors that affect *E. coli* viability in the environment. If these subjects are not properly understood, then effective, practical plans to manage and protect watersheds and address *E. coli* 303(d) listings are unlikely to be developed.

Through the vision of participants in the Water Quality Forum, an *E. coli* Work Group was formed in 2007 to work collaboratively on a voluntary basis to address the multi-faceted issues associated with these *E. coli* issues. The participants in the Work Group are active in nearly ten different local watershed organizations that must respond to *E. coli* 303(d) listings or concerns. Misconceptions regarding *E. coli* sources and control strategies are common and pose challenges to watershed groups trying to identify and reduce sources of *E. coli* for 303(d) listed streams. The purpose of this white paper is to provide a sound base of technical information that will provide a common foundation for entities working to address *E. coli* caused stream impairments. Topics addressed in this paper include:

- Regulatory background
- Case studies of streams in Colorado identified as impaired due to elevated *E. coli*
- Sources of fecal indicator bacteria
- Monitoring and assessment of data, including modeling
- Best management practices to reduce fecal contamination of waterbodies
- Unresolved issues related to *E. coli* in Colorado

This white paper includes lessons already learned in Colorado, as well as national guidance and experiences. At the time this paper was completed (October 2009), significant research was underway in support of the forthcoming U.S. Environmental Protection Agency's (EPA's) 2012 update to the federal ambient water quality criteria. Although this research may result in significant changes to the federal water quality criteria in the relatively near future, Colorado is required to move forward in implementing the requirements of the federal Clean Water Act that are currently in place.

2 REGULATORY BACKGROUND[2]

The basic regulatory framework for bacteria-related water quality issues in Colorado includes these steps, in simplified terms:

1. The federal Clean Water Act requires EPA to establish Ambient Water Quality Criteria for bacteria to protect recreational uses. The currently applicable criteria were issued in 1986, but are scheduled to be updated by 2012.

2. The CWQCC develops recreational use classifications and numeric standards (the Colorado Basic Standards) based on EPA criteria and assigns appropriate standards to stream segments in basin-specific regulations (e.g., Regulation 38 for the South Platte River Basin). Additional criteria are applicable for natural swimming areas where fees are charged for use (CWQCD 1998).

3. The CWQCD assesses attainment of stream standards biennially, developing the state's "303(d) list" of water quality limited waters (i.e., not attaining stream standards) and needing Total Maximum Daily Loads (TMDLs). The CWQCD proposes the listings based upon Listing Methodology guidance approved by CWQCC in an Administrative Action Hearing. The list of impaired waters is subsequently adopted as Regulation 93 in a biennial rulemaking hearing. Listed stream segments are assigned a high, medium or low priority ranking for developing TMDLs. Human health related listings such as bacteria are given a "high" priority.

4. For streams not attaining stream standards, the TMDL process is initiated to assign pollutant loading allocations to various sources discharging to the stream. For nonpoint sources receiving a load allocation (LA), implementation and enforcement of load reducing measures is largely voluntary. For point sources receiving a wasteload allocation (WLA), implementation and enforcement mechanisms are typically tied to permits issued under the Colorado Discharge Permit System (CDPS) administered by the CWQCD. Failure to comply with permit requirements is enforced by a variety of measures, including potentially substantial monetary penalties. To date, the CWQCD has not undertaken any such action with regard to *E. coli*. Permits may also include monitoring requirements.

The remainder of this section provides additional background on these general regulatory components. (Note: Section 2.4.4 discusses other regulatory issues that go beyond TMDLs.) The primary driver for the *E. coli* Work Group is the TMDL process and particularly its

[2] This section serves as the Task 2, subtasks i and ii deliverables under the Healthy Rivers Scope of Work.

relationship to CDPS Municipal Separate Storm Sewer (MS4) permit requirements. (*Municipal sanitary wastewater CDPS permits may also become involved; however, most wastewater dischargers are capable of meeting numeric effluent limits due to the ready availability and widespread use of UV disinfection or chlorination to disinfect sanitary wastewater*.)

2.1 Federal Ambient Water Quality Criteria for Recreation--1986

Section 304(a)(1) of the Clean Water Act requires the EPA to promulgate criteria for water quality. EPA released recreational water quality criteria in 1976, updated the criteria in 1986, and the criteria are scheduled for update again in 2012 (see discussion in Section 2.5). The EPA Water Quality Criteria form the basis for development of State Water Quality Standards.

EPA's currently applicable Ambient Water Quality Criteria for Bacteria-1986 set numeric criteria for indicator bacteria believed to be indicative of health risks associated with recreational use. The overall goal of the criteria is to provide public health protection from gastroenteritis (gastrointestinal [GI] illness) associated with exposure to fecal contamination during water-contact recreation. The criteria are derived from epidemiological studies conducted at these locations:

- Marine studies (Cabelli 1983) at beaches: New York City, Boston and Lake Pontchartrain.
- Freshwater studies (Dufour 1984) at beaches: Lake Erie, PA and Keystone Lake, Tulsa.

All of these studies were conducted in locations with contamination from effluent discharged from single point-sources, essentially addressing the question: "Does swimming in sewage-contaminated water carry a health risk for bathers; and, if so, what type of illness?"

Selected Basic Terms Related to Pathogens and Indicator Bacteria
(Adapted from EPA 2001)

Pathogen: Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Bacteria: Single-celled microorganisms that lack a fully defined nucleus. Bacteria of the coliform group are considered the primary *indicators* of fecal contamination and are often used to assess water quality.

Indicator organism: Organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.

***Escherichia coli* ("*E. coli*"):** A subgroup of the fecal coliform bacteria. *E. coli* is part of (<1%) the normal intestinal flora in humans and animals and is, therefore, used by EPA as an indicator of fecal contamination in a waterbody.

***E. coli* 0157:H7:** An enteropathogenic strain of *E. coli* that can cause serious infection resulting in gastroenteritis. Presence of the *E. coli* subgroup does not necessarily mean that this pathogenic strain of *E. coli* is present.

Fecal Coliform: A subset of total coliform bacteria that are present in the intestines or feces of warm-blooded animals. They are often used as indicators of the sanitary quality of water.

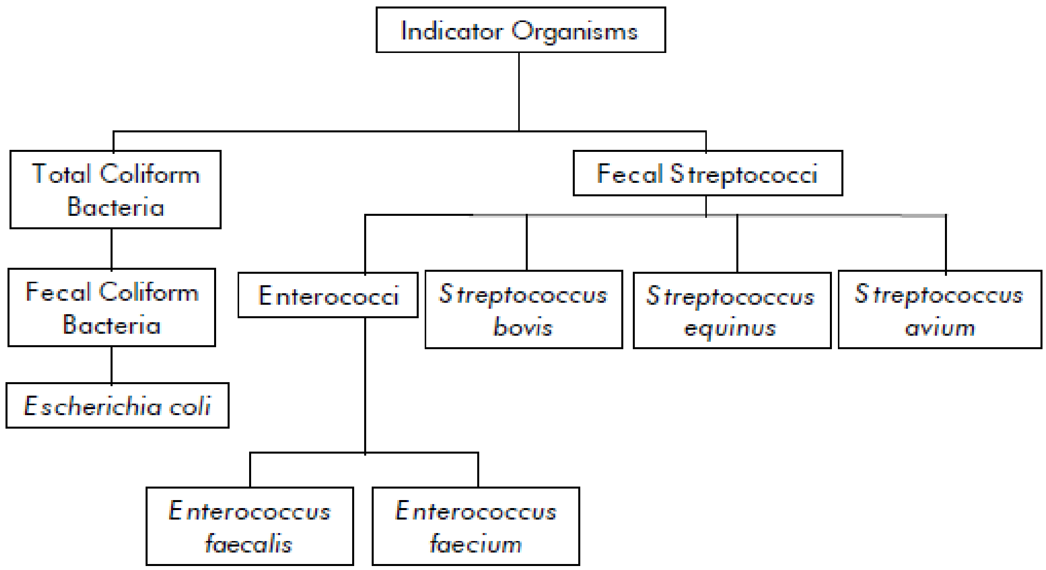
Total coliform bacteria: A particular group of bacteria, found in the feces of warm-blooded animals, that have been used as indicators of possible sewage pollution. Many common soil bacteria are also total coliforms, but do not indicate fecal contamination.

Enteric: Of or within the gastrointestinal tract.

For freshwater primary contact recreation, EPA recommends use of *E. coli* as an indicator of the potential presence of pathogens. (Enterococci are recommended for use in marine water criteria.) A geometric mean value of 126 colony forming units (cfu) per 100 mL ("126/100 mL") is recommended as the primary contact criterion based on a risk factor of acute gastrointestinal illness corresponding to eight illnesses per 1,000 swimmers. *E. coli* are a subgroup of fecal coliform bacteria that are present in the intestinal tracts and feces of warm-blooded animals and humans (EPA 1986; EPA 2001). Because fecal matter can be a major source of pathogens in ambient water, and because it is not practical or feasible to monitor for the full spectrum of all pathogens that may occur in water, water quality criteria are specified throughout the world in terms of fecal indicator organism densities (EPA 2009). The EPA Pathogen TMDL Guidance (EPA 2001, http://www.epa.gov/owow/tmdl/pathogen_all.pdf) provides information regarding the relationships of various indicator organisms, as shown in Figure 1. Prior to the use of *E. coli* as an indicator, fecal coliform was recommended.

At the time of publication of the 1986 criteria, high counts of *E. coli* were believed to indicate the presence of fecal contamination in water. More recently, this assumption has been called into question (WERF 2009; EPA 2007) based on multiple studies demonstrating that *E. coli* can reproduce in the environment. Additionally, questions have been raised regarding the relationship between *E. coli* and pathogens. (See Section 2.5 for more information). Several members of the Colorado *E. coli* Work Group have expressed similar concerns based on monitoring in Colorado. Despite questions related to the use of *E. coli* as an indicator of fecal contamination, until EPA issues new ambient water quality criteria, the *E. coli* criteria will continue to serve as the basis of recreational water quality criteria and compliance with water quality standards in Colorado. Once EPA issues new criteria, scheduled for 2012, it will likely take several additional years for incorporation into Colorado Water Quality Standards.

Figure 1. Relationships Among Indicator Organisms
(Source: EPA 2001)



2.2 State Stream Standards

2.2.1 Colorado Recreational Use Classifications and Standards

The CWQCC 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. Historically, Colorado had definitions for Primary and Secondary Contact Recreation; however, streams are now classified according to whether primary contact is present, potentially present, not present or undetermined. The definition of Primary Contact Recreation in the Basic Standards and Methodologies for Surface Water; (www.cdphe.state.co.us/regulations/wqccregs/100231wqccbasicstandardsforsurfacewater.pdf; 5 CCR 1002-31; CWQCC 2008) is:

> *Primary Contact Recreation means 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.*

In 2005, water play by children was adopted as part of the primary contact recreation definition for application in developed areas where there is easy access to a stream for children and it is likely that children will desire to play in the stream. Water play by children was added due to the concern that children may ingest small quantities of water playing in streams, even where whole body immersion is not likely. The CWQCC has adopted this designation only where the evidence demonstrates a likelihood of such activity on a frequently occurring basis. Factors such as lack of adequate flow, excessive flows, remoteness from developed areas, physical limitations to access, steep banks, and visibly poor water quality may make it unlikely that child's play will take place on a frequently occurring basis. The CWQCC anticipated that these classification decisions would require case-by-case judgments until more experience is gathered with this issue (Frohardt 2002).

Over the years, nomenclature and standards have been periodically adjusted, with the current classification system including these uses:

- Existing Primary Contact Use (E): the CWQCC intends that this classification receive the highest level of protection (with an anticipated risk level of 8 swimmer illnesses per 1000 swimmers). It is to be adopted where evidence has been presented that these waters are used for primary contact recreation or have been used for such activities since November 28, 1975 (per the Federal Regulatory definition of “existing uses”). This use category applies to a subset of waters previously (prior to 2005) classified as recreation class 1a.

- Potential Primary Contact Use (P): The CWQCC intends that this classification be used where a reasonable level of inquiry has failed to identify any existing primary contact use, but a full scale Use Attainability Analysis has not been conducted, or such analysis shows that primary contact uses may potentially occur in the future. The classification will receive a slightly elevated numeric value (with an anticipated risk level of 10 swimmer illnesses per 1000 swimmers). This use category replaces the previous recreation class 1b.

- Undetermined Use (U): The CWQCC intends that this classification be used where little or no effort has been undertaken to determine the level of recreational use of a waterbody. This classification will receive the highest level of protection (with an anticipated risk level of 8 swimmer illnesses per 1000 swimmers) and will be the default classification until the CWQCC has determined that another classification is appropriate.

- Not Primary Contact Use (N): The CWQCC intends that this classification be used only where a Use Attainability Analysis has been conducted that demonstrates that there is not a reasonable likelihood that primary contact uses will occur in the waterbody within the next 20 years. This classification will receive the lowest level of protection (five times the existing primary contact use standard). This use category replaces the previous recreation class 2.

Table 1 summarizes the numeric criteria associated with these standards. The CWQCC has adopted a single value standard that is applied on a year-round or a seasonal basis. The Colorado *E. coli* standard does not currently include a short-term or a single value maximum criterion. As of October 2009, attainment of the standard is applied based on the geometric mean of available data over a five year period; however, changes to the averaging period have been suggested as part of the June 2010 Basic Standards Rulemaking.

Table 1. Colorado Recreational Use Classifications and Standards

CLASS E (Existing Primary Contact) and **CLASS U** (Undetermined Use)	**CLASS P** (Potential Primary Contact Use)	**CLASS N** (Not Primary Contact Use) (5 x Class E)
126/100 mL	205/100 mL	630/100 mL

In addition to these standards, the CWQCD (1998) also has "Water Quality Requirements for Natural Swimming Areas" in the *State Board of Health Regulations Pertaining to Swimming Pools and Mineral Baths* (5 CCR 1003-5). Under these regulations, "Natural swimming area" means 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." These regulations identify specific standards and sampling frequencies and procedures. Under these requirements, managers of natural swimming areas must take bacteriological samples at a minimum of once every seven (7) days and no less than five (5) times in a calendar month during use periods, among other requirements. If a single sample exceeds 235/100 mL *E. coli*, then the portion of the swimming area producing the elevated sample must be closed (CDPHE 1998).

2.2.2 Recreational Criteria in Other States

The *E. coli* Work Group explored how recreational water quality standards vary among the states, particularly with regard to issues such as wildlife, primary versus secondary contact and other factors. This section provides some general observations followed by an excerpt from EPA's draft *Implementation Guidance for Ambient Water Quality Criteria for Bacteria* regarding primary versus secondary contact uses.

2.2.2.1 General

Although EPA establishes minimum criteria for recreational water quality, there is significant variation among the states in how the criteria are adopted into state water quality standards. For example, some states use a geometric mean value as the standard, whereas other states use both a geometric mean value and some type of maximum value. Similarly, some states specify a 30-day geometric mean of no less than five samples, whereas others do not have such a specification or use alternative specifications such as 60 days. States vary in terms of seasonal, wildlife and high flow exemptions, as well as with regard to how they categorize primary and secondary contact recreation. The *E. coli* Work Group explored some of these standards variations with regard to several topics such as wildlife "offramps" for streams with elevated *E. coli* due to natural sources, approaches to differentiating between primary and secondary contact recreation uses, and seasonal assessment periods. Initially, the Work Group considered suggesting revisions to the Colorado standards as part of its effort, but ultimately decided against doing so, primarily due to timing issues associated with upcoming revisions to the federal recreational water quality criteria (2012) and lack of support for such an effort due to the many complex issues already being discussed for the Basic Standards hearing in 2010. Nonetheless, this section serves to document selected findings of standards approaches used in other states.

To develop a sense of the types of recreational contact standards in other states, the *E. coli* Work Group considered a variety of sources of information, including a 2005 survey conducted by CDM on this topic. The CDM work included a comprehensive review of state water quality standards to characterize freshwater recreational beneficial uses and associated water quality objectives for bacteria. Appendix A provides the full report, which should be reviewed for more detailed information on each state. The purpose of the review was to identify the following information:

- The range of approved recreational uses and their associated bacteria standards.
- How water quality standards for states compare with recommended EPA federal water quality standards for bacteria.
- Alternative approaches to implement bacteria water quality objectives or assess compliance.

A few selected findings from the CDM survey include:

- States use various terminologies to recognize two basic types of recreational uses. These types and examples of alternative terminology include: primary contact (full-body contact, immersion recreation) and secondary contact (partial-body contact, incidental contact). The former refers to situations where water ingestion or submergence is likely as a result of recreational activity; the latter refers to situations where ingestion or submergence is unlikely.
- EPA has not provided clear guidance on the establishment of secondary contact recreation objectives for *E. coli*, but does indicate that objectives that are five times higher than the primary contact objectives may be acceptable. A review of the states' objectives found that states have a variety of objectives for secondary contact recreation ranging from only slightly less stringent than primary contact objectives to substantially different.
- EPA guidance allows the establishment of seasonal exemptions for application of bacteria objectives to surface waters. Establishing this exemption recognizes that when water temperatures are too cold, the likelihood of recreational activity taking place in a manner that ingestion or body submersion occur decreases substantially. Approximately 20 states have some form of seasonal exemption, typically existing for the months November 1 through March 31[3].

[3] CWQCD staff note that seasonal exemptions are not envisioned as an option in Colorado due to the almost year-round recreational opportunities available in the state.

- Most states have geometric means as part of their bacteria objectives and apply them on a 30-day basis.
- Some states also have provisions for wildlife and elevated bacteria due to natural conditions. EPA's implementation guidance on this issue is discussed separately in Section 4.5.2.

2.2.2.2 Recreational Use Classifications (Primary vs. Secondary)

Differentiation of primary and secondary contact uses is an area of significant variation among states and a topic of interest to the *E. coli* Work Group. Appendix A provides information on how each state has handled this issue. Although never formally adopted, EPA's (2004) *Implementation Guidance for Ambient Water Quality Criteria for Bacteria* [4] includes this discussion of secondary contact uses:

- *EPA defines secondary contact uses as including recreational activities where most participants have very little direct contact with the water and where ingestion of water is unlikely. States and authorized tribes may be able to justify the adoption of a secondary contact use, in lieu of a primary contact use, by completing a use attainability analysis. Subject to the provisions of 40 CFR 131.10, a secondary contact recreation use may be appropriate for waters that are, for example, impacted by human caused conditions that cannot be remedied, or where meeting the criteria associated with the primary contact recreation use would result in substantial and widespread social and economic impact.*
- *Less than "swimmable" standards may be considered, for example, where flowing or pooled water is not present within a waterbody during the months when primary contact recreation would otherwise take place and the waterbody is not in close proximity to residential areas, thereby indicating that primary contact uses are not likely to occur. Also, if a state or authorized tribe can demonstrate that natural, ephemeral, intermittent, or low flow conditions or water levels prevent attainment of the primary contact recreation use, a secondary contact recreation use may be appropriate. Another example would be a discharger that is not able to meet the limits necessary to protect the primary contact recreation use without causing substantial and widespread social and economic impact, but can meet limits that would assure protection of a secondary contact recreation use. In addition, as discussed in {section 3.4.2 of EPA's report}, designating a secondary contact recreation use may be appropriate where primary contact recreation is not an existing use and high levels of natural or uncontrollable fecal pollution exist. These demonstrations would fulfill the requirements of and address one of the six conditions contained in 40 CFR 131.10(g) supporting the removal of a designated use.*

- *EPA defines secondary contact uses as including activities where most participants would have very little direct contact with the water and where ingestion of water is unlikely. Secondary contact activities may include wading, canoeing, motor boating, fishing, etc.*

- *EPA is unable to derive a national criterion for secondary contact recreation based upon existing data, because secondary contact activities involve far less contact with water than primary contact activities. During the development of this guidance document, EPA explored the feasibility of deriving criteria for secondary contact waters and found it infeasible for several reasons. In reviewing the data generated in the epidemiological studies conducted by EPA that formed the basis for its 1986 criteria recommendations, EPA found that the data would be unsuitable for the development of a secondary contact criterion. The data collected were associated with swimming related activities involving immersion. Secondary contact recreation activities generally do not involve immersion in the water, unless it is incidental (e.g., slipping and falling into the water or water being inadvertently splashed in the face).*

- *Despite the lack of epidemiological studies/data necessary to develop a risk-based secondary contact recreation criterion, waters designated for secondary contact recreation should have an accompanying numeric criterion…Accordingly, states and authorized tribes may wish to adopt a secondary contact criterion which is five times their primary contact criterion. EPA recommends that secondary contact criteria be geometric mean values using a 30 day, seasonal, or annual averaging period…*

2.3 Assessing Attainment of Stream Standards: Colorado 303(d) Listing Methodology

In May 2009, the CWQCD released the Section 303(d) Listing Methodology for the 2010 Listing Cycle, which provides the most current guidance regarding procedures for assessing attainment of *E. coli* standards. Evaluation of attainment of these standards is subject to the same procedures as other constituents, with the following two exceptions:

> ***C. Data Interpretation, (1.) Chemical Data-General, (e.) E. coli Standards***
>
> *Attainment of the E. coli standards is assessed using the geometric mean of representative stream samples. Notwithstanding the criterion at item d above, E. coli data that are reported as less than detect will be treated as a value of one to allow calculation of a geometric mean. For evaluation of ambient water quality*

[4] EPA's 2004 implementation guidance was never officially finalized or adopted due to a shift in agency resources to implementing the requirement of the Beach Act. Nonetheless, the document provides helpful discussion on a variety of topics of interest to the *E. coli* Work Group.

> *data, in the event of a conflict between attainment status based upon fecal coliform and E. coli data, the E. coli data shall determine attainment. The E. coli standard is determined by the designated recreation use. Recreation typically occurs in the summer and it may be appropriate to assess the data on a seasonal basis. The season of May through October will be used unless there is evidence that a different period is more appropriate.*
>
> ***D. Determination of Impairment, (4). Impairment of Numeric Standards – General, (c.) Seasonal Evaluation of Recreational Use Standards***
>
> *If evaluation of a data set for an entire period of record does not indicate impairment, but if the applicable recreation season within the period of record exceeds the standard, the segment may be listed for the specific season.*

A significant change to the 303(d) Listing Methodology in 2009 was the addition of a seasonal evaluation approach to focus evaluation of standards attainment on the time period associated with greatest exposure risk. This change will have the effect of increasing the number of impaired stream listings for *E. coli* for two reasons: 1) more exceedances of the *E. coli* standard tend to occur in the summer; and 2) this approach removes the lower *E. coli* winter concentrations, which tend to decrease the geometric mean value used to assess attainment. Initial estimates by the CWQCD staff are that the change to include a seasonal assessment will result in the listing of approximately 10 new stream segments (for a total of 32 listings), as well as1 additional segment to the Monitoring and Evaluation (M&E) list. (Communication with Becky Anthony 2009).

Other potential changes to the Basic Standards and/or assessment methodologies relate to the period used to calculate the geometric mean values. Currently, Colorado allows five years of data to be included in the geometric mean calculation, whereas EPA has commented that the Colorado assessment period should be based on a 30-day geometric mean of five samples. For many municipalities or watershed associations that conduct voluntary instream sampling programs, time and workload constraints make monthly sampling more common than weekly sampling on a long-term basis. Results from such monthly monitoring can be difficult to apply to the calculation of a 30-day geometric mean, which is used by many states as the basis for assessing attainment.

2.4 Total Maximum Daily Load (TMDL) Process

In developing TMDLs to address 303(d) listed streams, Colorado must work within the requirements of the Clean Water Act specified by the EPA. This section describes EPA's general requirements for TMDLs, the basic approach suggested by CWQCD staff for TMDLs in Colorado, and a summary of the basic format of the first *E. coli* TMDL developed to date in Colorado (i.e., South Platte River, Segment 14). Since issuance of the South Platte Segment 14 TMDL, Region 8 EPA has issued additional guidance requiring more detailed development of certain aspects of the TMDL; therefore, the EPA guidance should be referenced for more information for those anticipating a TMDL in their watershed.

2.4.1 EPA's General Requirements for TMDLs[5]

According to the federal Clean Water Act, each state must develop TMDLs for all the waters on their 303(d) list. EPA provides a variety of supporting resources on their TMDL website (http://www.epa.gov/owow/tmdl/), including guidance specific to pathogen TMDLs. EPA provides this basic description of TMDLs:

> *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 load among the various sources of that pollutant. Pollutant sources are characterized as either point sources that receive a wasteload allocation (WLA), or nonpoint sources that receive a load allocation (LA). Point sources include all sources subject to regulation under the National Pollutant Discharge Elimination System (NPDES) program, e.g. wastewater treatment facilities, some stormwater discharges and concentrated animal feeding operations (CAFOs). Nonpoint sources include all remaining sources of the pollutant as well as anthropogenic and natural background sources. TMDLs must also account for seasonal variations in water quality, and include a margin of safety (MOS) to account for uncertainty in predicting how well pollutant reductions will result in meeting water quality standards.*

The TMDL calculation is:

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

where

WLA is the sum of wasteload allocations (point sources),

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

MOS is the margin of safety.

Under the Clean Water Act, states are primarily responsible for developing TMDLs, but EPA is required to review and approve or disapprove TMDLs developed and submitted by states within 30 days. If EPA disapproves a state TMDL, then EPA must establish such TMDL within 30 days. EPA has developed a basic "TMDL Review Checklist" with the minimum recommended elements that should be present in a TMDL document. Some of these requirements are legally required under 40 C.F.R. Part 130, whereas others are recommendations. EPA's TMDL checklist includes the following items, with an asterisk (*) indicating legally required components. Additionally, EPA Region 8 has developed a draft TMDL review form, which is provided in Appendix D of this white paper.

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[5]Information in this section is taken directly from the EPA TMDL website: http://www.epa.gov/owow/tmdl/overviewoftmdl.html, which should be referenced for more information.

EPA's Recommended TMDL Checklist

(Source: http://www.epa.gov/owow/tmdl/overviewoftmdl.html)

- Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking
- Applicable Water Quality Standard & Numeric Water Quality Target*
- Loading Capacity*
- Load Allocations and Waste Load Allocations*
- Margin of Safety*
- Consideration of Seasonal Variation*
- Reasonable Assurance for Point Sources/Non-point Sources
- Monitoring Plan to Track TMDL Effectiveness
- Implementation Plan
- Public Participation

Once EPA approves a TMDL, there are varying degrees of impact to communities involved in the process, generally differentiated among whether point sources or non-point sources of pollution are identified in the TMDL. Section 303(d) of the Clean Water Act does not specifically require implementation plans; however, in the case of point sources, it requires that wasteload allocations be implemented through the NPDES program. This means wastewater or stormwater permit limits consistent with WLAs must be implemented and are enforceable under the Clean Water Act through NPDES permits. Since Colorado is a state with delegated Clean Water Act authority, this is accomplished through the CDPS program. In the case of non-point sources of pollution, there is currently no federal regulatory enforcement program and implementation is primarily through state/local nonpoint source management programs, which are largely voluntary. For example, under state 319 programs, states receive grant money, and often pass the funding along to counties and other local groups to support a wide variety of activities for managing nonpoint sources. Additional information on nonpoint source and 319 funding is available on Colorado's and EPA's Nonpoint Source websites (www.npscolorado.com/ and www.epa.gov/owow/nps).

2.4.2 Initial Framework for Colorado E. coli TMDLs

The CWQCD's approach to *E. coli* TMDLs in Colorado must meet the minimum requirements for TMDLs under the federal Clean Water Act, but there is some latitude in the form and approach to development of these TMDLs. Section 2.4.2.1 provides a general outline of the types of data and decision-making process currently envisioned by the CWQCD, followed by an example of the general format used to develop the Segment 14 South Platte River TMDL.

2.4.2.1 Basic Approach to Developing Colorado E. coli TMDLs

CWQCD staff members have participated in multiple work group meetings to discuss wide-ranging issues related to *E. coli*. A key aspect of discussion has been the general approach that the CWQCD envisions using to develop TMDLs. A general framework for this process follows with a key focus being development of adequate information to provide "logical proof of source," which forms the underlying basis for the TMDL. The process below should not be viewed as fitting all watersheds, but is provided to give entities facing an *E. coli* TMDL a basic sense of what the CWQCD will need in order to develop an *E. coli* TMDL. The key components informally presented by CWQCD staff (Anthony et al. 2009) include:

1. Compile relevant data from various sources. This includes land use, flow, water quality, permit information, etc.

2. Calculate screening-level Load Duration Curves (LDCs) for affected segments to identify flow conditions under which the standard is exceeded. See EPA's 2007 guidance *An Approach for Using Load Duration Curves in the Development of TMDLs* for more information (http://www.epa.gov/owow/tmdl/duration_curve_guide_aug2007.pdf).

3. Implement a source survey for the watershed, including two steps: 1) determine presence or absence of the source, then 2) determine whether the source is considered to be significant. General sources of interest to the CWQCD include:

   (1) Agriculture

   a. Identify agricultural land uses by type (animal, crop, etc.).

   b. Identify agricultural land uses with significant potential to contribute bacteria,

Load Duration Curves
(Source: EPA 2007)

The duration curve approach allows for characterizing water quality concentrations at different flow regimes. The method provides a visual display of the relationship between stream flow and loading capacity. Using the duration curve framework, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions are easily presented and can be better understood.

The duration curve approach is particularly applicable because stream flow is an important factor in the determination of loading capacities. An underlying premise of the duration curve approach is correlation of water quality impairments to flow conditions. The duration curve alone does not consider specific fate and transport mechanisms, which may vary depending on watershed or pollutant characteristics. Practitioners should consider using a separate analytical tool to develop a TMDL when factors other than flow significantly affect a water body's loading capacity.

including, but not limited to, land used by farm animals and horses.

c. Determine percent of watershed that is agricultural land with significant potential to contribute bacteria.

d. If > 10% of total tributary area, then agricultural land use is assumed to be significant and assigned a LA (unless there is information provided to prove otherwise).

(2) Sanitary to storm sewer system

a. Dry weather flows exceeding 5 gpm with E coli densities exceeding 126/100 mL are assumed to be contributed from sanitary sewer sources such as sanitary sewer seepage to storm sewer pipes and cross connections, unless additional information is available indicating otherwise. (Discharges < 5 gpm or <126/100 mL are considered to be from other diffuse sources.)

b. Outfall loads are based on the stream standard (126/100 mL) times the average flow rate.

c. Percent contribution to stream flow is an aggregate of all outflows with values of > 126/100 mL and > 5 gpm flow as a percentage of stream load. These sources will receive a WLA.

(3) Sanitary – Septic systems

a. Estimate number of septic systems present (based on # of households/sq. mile).

b. Consider > 1 household on septic per 40 acres to be a potential significant source requiring additional evaluation. These will be given a LA allocation based on watershed specific information.

(4) Single known point source(s)

a. Considered on a case by case basis.

b. If considered significant, then given a WLA.

(5) Diffuse urban stormwater flow (wet weather)

a. To be determined.

(6) Wildlife

a. Refers to natural, undisturbed areas (non-urban areas).

b. Given a LA (on a case by case basis).

(7) Urban farms (<10% agriculture)

a. If > 10% of watershed area, then given a LA consistent with (1).

4. Develop a GIS inventory of watershed (agriculture, septic, NPDES, etc.) in conjunction with #3.

5. Develop Load Duration Curves (LDCs), GIS, and Mass Balance Models for TMDL based on steps 1-4. Based on these data sources, a draft TMDL can be developed and refined based on input from stakeholders and affected parties.

Following the CWQCD staff's presentation of this general approach, several aspects were identified as potentially warranting more discussion or perhaps not fitting conditions in all watersheds. These issues were not resolved in the context of the work group, but may be the subject of future discussion in the Work Group, or on a case-by-case basis for individual TMDLs. These items include:

- Load Duration Curves: How is interpretation of these curves affected in situations with highly managed streams?
- Urban Wildlife: How are sources attributed to pigeons, geese, raccoons, etc., handled and what are the implications for the implementation phase of TMDLs?
- Wet Weather Flows: It is a "given" that wet weather flows in urban areas will have elevated bacteria. For now, the assumption is that dry weather sources of bacteria will be the primary focus of TMDLs.

2.4.2.2 Example Format for Colorado TMDLs

Only one *E. coli* TMDL has been finalized in Colorado to date, which was for Segment 14 of the South Platte River. The general outline of the substantive portion of the TMDL included:

1) problem identification

2) water quality goal and target

3) analysis of pollutant sources according to non-point sources/tributaries, CDPS-permitted process water discharges, CDPS-permitted MS4 discharges and other sources

4) TMDL allocations addressing these topics:

   a. allocation of loads for the TMDL with Load Allocations (LAs) assigned by pollutant source and Wasteload Allocations (WLAs) assigned by wastewater and MS4 discharge permits (Note: see discussion below regarding "density-based" approach, as opposed to load approach used for other constituents.)

   b. "example" of load reductions required

c. explanation of "implicit" margin of safety

d. implementation discussion focused on an iterative approach

e. definition of TMDL endpoint, which is attainment of the stream standard (126/100 mL)

f. post-implementation monitoring, focused on dry-weather monitoring and provision for a compliance schedule in affected CDPS permits for attainment of the standard

Best Management Practices

Best Management Practices (BMPs) include a wide variety of source controls and structural practices that help to reduce pollutant loading to waterbodies. A BMP is a device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters.

5) Documentation of public process

Rather than assigning a "load," the allocation methodology for Segment 14 was described by the CWQCD as follows:

> *Traditional TMDL assessments utilize a mass per time accounting of pollutant sources. However, E. coli sources are not additive like other pollutant sources due to natural processes in the stream. Also, flows in segment 14 fluctuate on a non-seasonal basis due to the intensive water management of the South Platte system. Therefore, developing traditional mass-based load allocations for segment 14 is not possible.*
>
> *For this TMDL, the CWQCD has used density-based load allocations. Density-based load allocations do not add up to equal a TMDL as a mass per time, such as pounds per day. Rather the load allocations assign targets for known and potential sources as density. To achieve the water quality goals of a density-based TMDL, each source must meet its density-based load or wasteload allocation. [Tables] present the density-based pathogen load and wasteload allocations proposed for segment 14.*

At this time, it is anticipated that the WQCD would analyze all of the available data and determine whether a load-based or a density-based approach is most appropriate. Although the discussion above is focused on the South Platte River, the discussion related to highly managed streams applies to many streams in Colorado.

2.4.3 Implications for CDPS Permit Holders

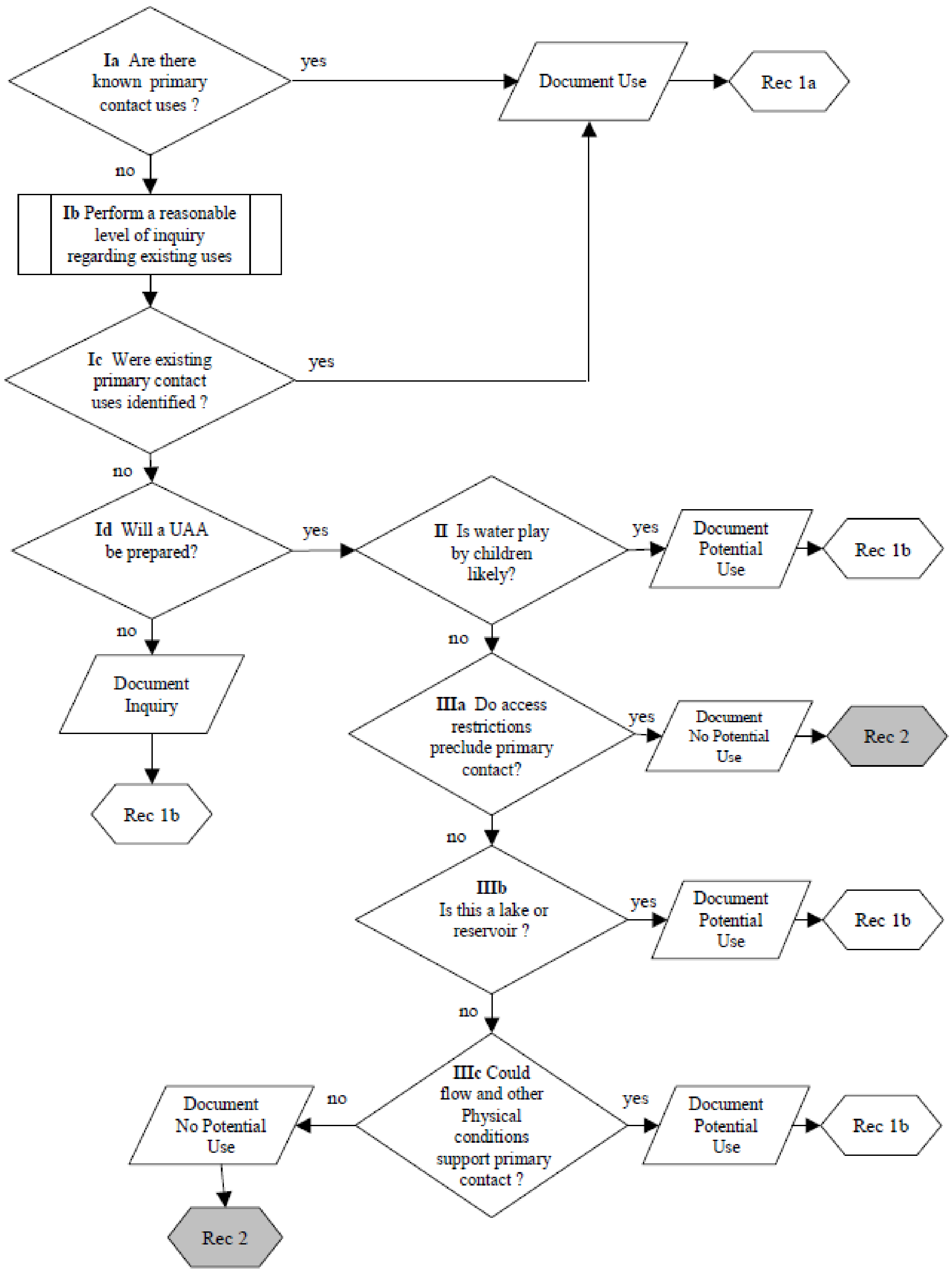
Due to the clear federal regulatory nexus between TMDLs and the NPDES program under the Clean Water Act, both wastewater and stormwater CDPS permit holders may be affected by TMDLs, depending on specific conditions present in the watershed. State and federal regulations restrict permit issuance in instances where "a discharge contributes to the exceedance of a water quality standard" (See 5 CCR 1002-61.6(1) and 40 CFR 122.4 and 122.44). (For wastewater discharge permit holders, achievement of effluent limits can be achieved through readily available, commonly used technology such as chlorination and UV disinfection. For stormwater discharge permit holders, the solutions are much more challenging. In the South Platte Segment 14 TMDL, a BMP-based approach was selected. It should be noted that the CWQCD has the option to require numeric effluent limits; however, available national BMP performance data indicate that numeric effluent limits for bacteria would be very difficult to consistently attain (See discussion in Section 6.3.). Additionally, the number of discharge points for most MS4s makes BMP implementation much more challenging and costly than for wastewater discharge permit holders where treatment occurs at a single collection point. This creates a significant challenge for both regulators and the regulated community that has not been resolved as of the publication of this white paper.

2.4.4 Other Regulatory Considerations

Working within the regulatory framework in place in Colorado as of 2009, there are several considerations beyond bacteria TMDL development for 303(d) listed streams, generally including reclassification of the stream based on a use attainability analysis, development of a site-specific numeric standard, and the “Category 4b” listing alternative. These approaches are briefly described below with references for additional guidance, as appropriate.

1. **Use Attainability Analysis**: The CWQCD provides guidance on conducting a Use Attainability Analysis (UAA) to determine the appropriate recreational use classification for a stream. See CWQCD (2003) *Recreational Use Classification Guidance, Version 1.1* for these requirements (http://www.cdphe.state.co.us/wq/Assessment/Assess_pdf/RecUAAGuidev11.pdf). Figure 2 provides a decision-tree that highlights key aspects of this process. If the current Recreational Use classification for a segment is demonstrated to be inappropriate, completion of a UAA to support a change of classified stream uses during the water quality standards triennial review process may result in a change to the *E. coli* standard. This change might eliminate the need for a TMDL if it results in the segment attaining the standard. As an example, a UAA was completed by the U.S. Forest Service to support reclassification of a portion of Elkhead Creek.

Figure 2.
2003 Recreational Use Classification Assessment Decision Process (CQWCD 2003)



Note: Replace Rec 1a with Primary Contact, replace 1b with Potential Primary Contact, and replace Rec 2 with Not Primary Contact to be consistent with the 2005 updates to the Basic Standards language.

2. **Site-specific Ambient Quality Based**: The *Colorado Basic Standards and Methodologies for Surface Water* (5 CCR 1002-31) provide for assignment of site-specific ambient quality based standards under these conditions:

   > *For state surface waters where evidence has been presented that the natural or irreversible man-induced ambient water quality levels are higher than specific numeric levels contained in [Basic Standards tables] but are determined adequate to protect classified uses, the [CWQCC] may adopt site-specific [standards]…*

   For example, some portions of Colorado have elevated selenium concentrations due to naturally occurring geologic conditions; therefore, site-specific selenium standards have been adopted where adequate studies have been completed demonstrating such conditions and establishing a site-specific criterion approvable by the CWQCC. Entities proposing site-specific water quality standards should anticipate rigorous requirements in order for a site-specific standard to be approved. Such standards for bacteria have not been considered to date in Colorado other than for temporary modifications to stream standards, so it is not clear what would be required for CWQCD support and CWQCC and EPA approval for such standards. It is notable that the basis for the *E. coli* Table Value Standards is human health. Virtually all ambient quality-based standards approved by the CWQCC to date have represented relaxations of protection for aquatic life, not human health.

3. **"Category 4b":** Category 4b is an alternative listing classification under the 303(d) listing process for impaired waterbodies "for which other required control mechanisms are expected to address all waterbody-pollutant combinations and will attain water quality standards in a reasonable period of time." In order to be considered for Category 4b, an entity must submit a Category 4b demonstration plan to EPA within timeframes specified in the 303(d) listing methodology. A Category 4b demonstration plan, when implemented, must ensure attainment of all applicable water quality standards through agreed upon pollution control mechanisms within a reasonable time period. These pollution control mechanisms can include approved compliance schedules for capital improvements or plans enforceable under other environmental statutes (such as CERCLA) and their associated regulations. Both the CWQCD and EPA must accept a Category 4b demonstration plan for the affected segment to be placed in Category 4b. General factors considered in a Category 4b request include: (1) appropriate regulatory or legal authority to implement the proposed control mechanisms (through permits, grants, compliance orders for CDPS permits, etc.); (2) existing commitments by the proponent(s) to implement the controls; (3) adequate funding; and (4) other relevant factors appropriate to the segment. See the 2010 303(d) Listing Methodology (http://www.cdphe.state.co.us/op/wqcc/SpecialTopics/303(d)/303dLM2010.pdf) for more detailed information on submittal requirements and deadlines.

2.5 Ongoing Research in Support of the 2012 Criteria

Research is occurring on multiple fronts in support of EPA's forthcoming updated Ambient Water Quality Criteria for Bacteria. This section briefly describes research being conducted by EPA, the Water Environment Research Foundation (WERF) and others.

2.5.1 EPA Research Projects and Reports

2.5.1.1 Expert Scientific Workshop 2007

In March 2007, EPA convened a panel of 43 experts to identify critical path research needs for the development of new or revised recreational water quality criteria. The product of the workshop was published in June 2007 as *Report of the Experts Scientific Workshop on Critical Research Needs for the Development of New or Revised Recreational Water Criteria* (EPA 2007a). Review of the findings of this lengthy report has helped to focus the Colorado *E. coli* Work Group discussions. Based in part on input from this Expert Panel report, EPA published the *Critical Path Science Plan for the Development of New or Revised Recreational Water Criteria* (EPA, 2007b) and *Criteria Development Plan & Schedule: Recreational Water Quality Criteria* (EPA, 2007c). Brief descriptions of the main research needs outlined in the EPA Expert Report (EPA 2007a) include:

- Conduct epidemiology studies for subtropical and tropical waters.
- Conduct epidemiology studies for urban runoff and nonpoint source pollution.
- Validate qPCR methods.
- Assess fate and transport of molecular indicators in treatment plants.
- Assess health risks from secondary contact recreation.

Key Concepts Related to Research Needs Identified in EPA (2007a)

Microbial source tracking: (MST) refers to a variety of techniques that differentiate among the origins of fecal material found in natural waters from different sources (e.g. human, livestock, and wildlife) by using microbial indicator species with specificity to only certain host organisms.

qPCR: A molecular laboratory analysis method using a real-time polymerase chain reaction to amplify and simultaneously quantify a targeted DNA molecule. This method enables both detection and quantification of a specific sequence in a DNA sample. As opposed to culture-based methods, qPCR detects both culturable and non-culturable bacteria and is a key tool in microbial source tracking (MST).

***Bacteroides*:** Anaerobic bacteria useful in MST because only found in feces, rumen, and body cavities with limited survival in environment and exhibit host-specific variation in animals. Comprises a third of the human gut flora.

QMRA: Quantitative Microbial Risk Assessment: A formal process, analogous to chemical risk assessment, used to estimate human health risks due to exposures to microbial pathogens. QMRA is important because epidemiology cannot always provide sufficient sensitivity to measure risks directly using human health data. For more information on QMRA, see Soller (2008) at http://www.epa.gov/waterscience/criteria/recreation/feb2008/risk-assessment.pdf

The Beach Act

In October of 2000 the US Congress passed the Beaches Environmental Assessment and Coastal Health Act of 2000 (the "Beach Act"). The Act modified Sections 104(v) and 304(a)(9) of the Clean Water Act and requires EPA to:

- Conduct studies associated with pathogens and human health in coastal recreation waters;
- Publish new or revised recreational water quality criteria for coastal waters based on those studies; and,
- Publish a report every 4 years with recommendations and a status update to Congress.

- Develop tools to discriminate between human and non-human sources.
- Quantify pathogens in runoff and in recreational waters (using high volume sampling if needed).
- Determine ingestion (exposure) rates while recreating.
- Determine pathogen fate and transport.
- Identify human and environmental strains of Enterococci.
- Determine if *Bacteriodes* can be a human-specific indicator.
- Develop and validate rapid indicator and pathogen analytical methods.
- Determine risk from animal source exposure.
- Identify specific pathogens causing illness.
- Use QMRA to estimate risks for various climates, waters, and flows.
- Determine bather pathogen shedding rates and bather densities.
- Review literature to support QMRA.
- Assess risk from sand, sediment resuspension, soils, etc.

Closely related to these general research priorities is the September 4, 2008 Settlement Agreement and Consent Decree filed in US District Court for Central District of California (Consent Decree CV06-4843 PSG), among the Natural Resources Defense Council (NRDC), County of Los Angeles, Los Angeles County Flood Control District, National Association of Clean Water Agencies, and EPA. The Consent Decree emerged as a negotiated settlement agreement associated with a lawsuit filed by the NRDC against the EPA for failure to implement provisions of the Beach Act of 2000. Under the consent decree, the EPA must complete specific studies and must make available new or revised water quality criteria for pathogens or pathogen indicators by October 2012. To achieve this objective, EPA committed to conduct the following specific studies:

- Conduct epidemiological studies at POTW-impacted marine beaches in Fairhope, Alabama and Goddard Rhode Island.

- Provide technical assistance in support of an epidemiological study at a beach in Avalon, California (in conjunction with the Southern California Coastal Water Research Project [SCCWRP]) considered to be impacted primarily by untreated human fecal contamination.

- Conduct QMRA (based on measurement of pathogenic organisms and indicators) to estimate illness at a freshwater beach impacted by agricultural animal sources of fecal contamination.

- Study various parameters that affect performance of the qPCR signal for enterococci and compare with other methods and pathogens in treated wastewater mixed with ambient waters (enterococci, *E. coli*, Cryptosporidium, and enterovirus).

- Design and evaluate a monitoring approach that will characterize the quality of beach waters that takes into account the spatial and temporal variability associated with water sampling.

- Evaluate multiple indicator/method combinations to develop quantifiable relationships.

- Study the effects of sample holding time, sample storage, and preservation on sample integrity.

- Develop, refine, validate, and publish one or more new ambient test methods) and (2) develop, refine, validate, and publish one or more new wastewater test methods) … [if necessary].

- Evaluate the suitability of individual combinations of indicators and methods for different Clean Water Act programs.

- Re-analyze archived NEEAR samples using molecular methods for other indicators, including at least *E. coli*, provided the samples have not degraded during storage (depending on the

NEEAR and Other Recent Epidemiologic Studies Sponsored by EPA

2002-2004 Freshwater National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water Studies at four Great Lakes Beaches– Indicators/Methods studied: Enterococci (qPCR and culture), *Bacteroides* (qPCR), chemical indicators

2005 Marine NEEAR Study in Biloxi, MS (interrupted study)- Indicators/Methods studied: Enterococci (qPCR and culture), *Bacteroides* (qPCR), chemical indicators

2007 Marine NEEAR Studies in Goddard, RI and Fairhope, AL– Indicators/Methods studied: Enterococci (qPCR and culture), *Bacteroides* human total and human-specific (qPCR), E.coli (qPCR), Clostridium spp. (qPCR), coliphage (antibody assay)

2007 and 2008 SCCWRP Studies at Avalon Beach, CA– Impacted by mixed sources of fecal contamination including bird droppings, urban runoff, and leaking sanitary sewers (human source)

2008 SCCWRP Continuation Study at Doheny Beach, CA– Predominately a non-human source (birds and runoff)

Other Studies Planned for 2009: Urban runoff" impacted marine waters in a temperate region – Surfside Beach, SC & POTW-impacted marine waters in a tropical region - Boquerón Beach , PR

(**Source**: Keehner 2009)

outcome of [other research] and the nature of the indicator/method).

- Pilot test the Virtual Beach model for beach notification and advisories/closures.
- Refine and validate existing water quality models for freshwater beach notification and advisories/closures.
- Refine and validate other existing water quality models for marine beach notification and advisories/closures.
- Develop a technical protocol for site-specific application of predictive models to be used in making beach advisory decisions.
- Compare EPA's 1986 Bacteria Criteria recommendations to NEEAR studies to better understand the relationship between fecal contamination and illness in these data sets, provided EPA can obtain the raw data used to develop the 1986 Criteria.
- Evaluate applicability of NEEAR Great Lakes data to inland waters.
- Conduct statistical analysis of child-related data from epidemiological studies.

Over the next two to three years, a significant amount of new information is expected to become available to help guide decisions related to update of the Recreational Water Quality Criteria. The EPA website should be checked periodically for the latest findings of these efforts (http://www.epa.gov/waterscience/criteria/recreation/).

2.5.1.2 Review of Zoonotic Pathogens in Ambient Waters

In February 2009, EPA published *Review of Zoonotic Pathogens in Ambient Waters* (EPA 2009a, http://www.epa.gov/waterscience/criteria/recreation/pdf/zoonoticpathogensreview.pdf). The report summary concludes:

> *Contamination of recreational waters with feces from warm-blooded animals poses a risk of zoonotic infection of humans with some of the pathogens in those waters. Although the risk and severity of human illness due to contamination with animal feces and zoonotic pathogens is most likely lower than the risk and severity of illness from treated or untreated human sewage, currently available data are insufficient to quantify the differences. At present, the six most important zoonotic waterborne pathogens are the following: Pathogenic E. coli; Salmonella; Campylobacter; Leptospira; Cryptosporidium; and Giardia.*
>
> *All of these waterborne pathogens are likely to cause more severe symptoms in children and immunocompromised individuals and subpopulations than in the remainder of the population. Of these six, pathogenic E. coli has the most potential for severe adverse health effects that can even be fatal. Potential debilitating chronic sequelae such as Guillain-Barré Syndrome and reactive arthritis have been associated with Campylobacter infections. Although the most*

> *common recreational illnesses are probably due to human viruses causing short-term GI illness, the waterborne zoonotic pathogens discussed in this report have the potential to cause serious health effects. While serious health outcomes are likely to be rare in comparison with self-limiting illnesses as a result of ambient (recreational) water exposure, the adverse health impacts of the rare, but more serious illnesses remain an important public health challenge.*

Other interesting aspects of this report include Appendix C "Incidental Ingestion of Ambient Waters during Recreation Activities." The appendix provides information from available studies regarding water ingestion rates during recreation, but notes, "There is a paucity of data concerning rates of incidental ingestion of surface water during recreational activities. Most of the available estimates address exposures during swimming in swimming pools, which may not necessarily be representative of typical 'incidental' exposures in ambient waters."

2.5.1.3 Review of Published Studies to Characterize Relative Risks from Different Sources of Fecal Contamination in Recreational Water

In *Review of Published Studies to Characterize Relative Risks from Different Sources of Fecal Contamination in Recreational Water* (EPA 2009b) EPA documents epidemiological research identifying sources of contamination associated with waterborne disease outbreaks (see http://www.epa.gov/waterscience/criteria/recreation/pdf/fecalcontamrecreationalwaters.pdf). The report supports research recommendations identified in the Expert Scientific Panel report (EPA 2007a). Currently, EPA's recreational water quality criteria do not differentiate between fecal sources of pathogens. Thus, EPA's regulatory premise concerning recreational water quality has been that nonhuman-derived human pathogens in fecally contaminated waters are as hazardous as their human-derived counterparts. The World Health Organization's (WHO) recommended approach ("the Annapolis Protocol") for classifying the water quality of recreational waters is based on the premise that microbiological indicators of fecal contamination can be "interpreted" using evidence of the presence or absence of human fecal contamination (WHO 2003). This approach assumes that in general, sources other than human fecal contamination are less of a risk to human health (EPA 2009).

In the review, EPA notes that the critical question is whether exposure to different fecal sources from recreational waters translates to significant differences in the risk of human infection or disease severity. EPA's (2009) white paper describes the existing knowledge base available to characterize the relative risks of human illness from various sources of fecal contamination in recreational water based on review of scientific literature and disease outbreak investigations. Selected key findings extracted directly from the white paper include:

- *Numerous epidemiological investigations have been conducted since the 1950s to evaluate the association between illness risk to recreational water users and the density of suitable fecal indicators. These studies have been conducted in Australia, Canada, Egypt, France, Hong Kong, Israel, the Netherlands, New Zealand, Spain, South Africa, United States, and the United Kingdom. Importantly, most of these studies investigated waters that were impacted or influenced by wastewater effluent.*

- *Taken as a whole, the weight of evidence from these studies indicates that fecal indicator bacteria are able to predict GI and respiratory illnesses from exposure to recreational waters. However, as indicated above, most of these studies investigated waters that were impacted or influenced by wastewater effluent, and close inspection of this base of information reveals that few studies addressed sources of contamination other than wastewater effluent in the investigated waters.*

- *Review of the epidemiological studies that address recreational water predominantly impacted by sources other than wastewater effluent indicates that the results are equivocal* [uncertain]. *For example, Colford et al. (2007) found that the incidence of swimmer illness was not associated with any of the traditional fecal indicators at a marine beach with primarily avian contamination. This result is substantially different than those studies described above on wastewater impacted waterbodies. Whereas, a study from New Zealand (McBride et al., 1998) indicated that illness risks posed by animal versus human fecal material were not substantially different.*

- *… Unfortunately, the drinking water outbreak literature does not substantially enhance the current ability to quantitatively differentiate risks from animal- versus human-related pathogen sources for recreational water exposures.*

- *The recreational water outbreak literature (Craun et al., 2005) indicates that of the 259 recreational water outbreaks that occurred in the United States between 1970 and 2000, only approximately half included any information about possible sources of the contamination or the sources contributing to it. Approximately 18 percent of the total outbreaks were associated with animals, likely etiologic agents included E. coli spp., Schistosomes spp., and Leptospira spp. E. coli was associated with cattle, deer, or duck feces; Schistosomes spp. were associated with snails; and Leptospira spp. were associated with rat urine. Similar to the drinking water outbreak compilation, the recreational water outbreak literature does not appear to substantially enhance the current state of knowledge on quantitatively characterizing risks from animal-related pathogen sources compared with human sources for recreational water exposures.*

- *Given that relatively few investigations worldwide have evaluated the risk to human health from recreational exposure to waters primarily impacted by sources of contamination other than wastewater effluent, and that the potential range of those sources is broad, the findings from this literature review are not surprising.*

- *In summary, both human and animal feces in recreational waters continue to pose threats to human health. Although the public health importance of waterborne zoonotic pathogens is being increasingly recognized, it is still not well characterized. Policy makers and researchers have often assumed that the human health risk from pathogens associated with domestic and agricultural animal and wildlife feces is less than the risk from human feces, in large part because viruses are predominately host-specific. This literature review illustrates a lack of detailed and unequivocal information concerning the relative risks of human illness resulting from exposure to various sources of fecal contamination in recreational waters. Because of their retrospective nature, waterborne* *disease outbreak investigations rarely produce the data needed to draw conclusions about the impact of a pathogen source. Finally, the ability to measure how the infectivity and virulence of known waterborne zoonotic pathogens are affected when passaged through animal hosts remains in its infancy.*

2.5.2 WERF Inland Flowing Waters 2009 Report

The Water Environment Research Foundation (WERF) is a leading independent scientific research organization dedicated to wastewater and stormwater issues. A recently completed WERF project that directly affects Colorado as a state with inland flowing waters is the *Report on the Experts Scientific Workshop on Critical Research and Science Needs for the Development of Recreational Water Quality Criteria for Inland Waters* (WERF 2009). In February 2009, WERF collaborated with EPA to hold a workshop to consider the significance of differences between inland and coastal recreational waters within the context of national recreational water quality criteria for primary contact recreation users. The objectives were to determine if coastal research can be extrapolated to inland waters, and to identify and prioritize research needs for development of criteria applicable to inland waters. Thirty-one invited experts from the academic, state and federal agency, utility, consultant, and nongovernmental organization communities participated in the Inland Waters Workshop and produced a 125-page report summarizing their findings. Findings were reported according to five topic groups:

- indicators and pathogens: biology, ecology, and methods
- health risks: epidemiology and risk assessment
- water matrix: hydrology, chemistry, geology, and modeling
- sources: human *v*. nonhuman and point *v*. nonpoint
- implementation realities

Representative findings and conclusions reported by each group on topics of interest to the Colorado *E. coli* Work Group are briefly summarized below.

<u>Indicators and Pathogens Group</u>

- Sources of fecal indicator bacteria were identified as humans, animals, and the environment through reproduction and regrowth.
- Characteristics of inland water sites vary widely; therefore, the factors that control the fate, survival, transport, regrowth potential, and ecology of indicators and pathogens are not likely to be the same for all inland water sites and will likely differ from those factors found at the Great Lakes or marine coastal beaches.
- The group evaluated two implicit assumptions in using fecal indicator bacteria as the basis of existing criteria and concluded that these assumptions were invalid:

- The first is that waterborne pathogens co-occur with the fecal material and that there are no significant environmental (i.e., non-enteric) sources of these microorganisms. The group concluded that this assumption is not valid, citing recent studies in both tropical and temperate areas that have shown growth and persistence of environmental sources of fecal indicator bacteria. Studies cited include: Fujioka and Byappanahalli, 2003; Rivera et al., 1988; Byappanahalli and Fujioka, 1998; Solo-Gabriele et al., 2000; Byappanahalli and Fujioka, 2004; Byappanahalli et al., 2006; Ishii et al., 2006a; Whitman et al., 2006; Yamahara et al., 2009. The group concluded that a significant consequence resulting from growth and presence of environmental sources of *E. coli* and enterococci in inland waters is that they falsely indicate recent fecal contamination.

- The second assumption concluded to be invalid is that indicator fate and behavior, ecology and persistence, and performance of indicator bacteria in all types of recreational waters remain consistent and are similar to those of pathogens of fecal origin. The group concluded:

> *Inland waters found throughout the United States are very diverse in terms of water flow, water volume, size, and morphology, as well as physical and biological composition of water quality. As indicated [in the report], no set of characteristics can be applied to describe all inland waters. Due to such differences in inland water sites, the indicators and pathogens group concluded that the factors that control the fate, survival, transport, growth and regrowth potential, and ecology of indicators and pathogens will not be the same for all inland water sites and will differ from those factors found at the Great Lakes. From this perspective, the indicators and pathogens group inferred that the available state of science indicates that criteria developed for coastal Great Lakes cannot be directly and broadly applied to all inland waters.*

- In summary, the general consensus of the indicators and pathogens group is that it may not be appropriate to extrapolate health risks from POTW-impacted waters to waters with elevated concentrations of [fecal indicator bacteria] impacted primarily from nonpoint sources such as animal feces, general urban discharges, and environmental sources until further research confirms comparable health risks.

<u>Health Risks Group</u>

- After review of relevant epidemiologic studies of recreational water to identify differences between coastal and inland water settings, this group concluded that the scientific literature does not provide a clear answer to the question of whether the epidemiologic results from the Great Lakes can be applied to inland flowing waters. Only a handful of studies have been conducted in small lakes and even fewer in inland flowing waters, and none of the latter are readily comparable to studies conducted in coastal settings.

- The group concluded that it is not known whether and in what ways the predominant source of fecal contamination (human, livestock, wildlife, and environmental) influences the water quality/health risk relationship.

Water Matrix Group

- This group concluded that the only way to understand all the important factors that may affect the relationships between health effects and indicators/water quality is through modeling efforts. However, the group also concluded that such modeling requires a fundamental understanding of the fate and transport of indicators and pathogens, which is currently lacking in the literature and, therefore, limits the ability to apply modeling approaches to support regulatory purposes.

- Questions regarding differences between pathogens and indicators in terms of their regrowth and persistence in sediments/soils and associated waters need to be answered before epidemiologic data from Great Lakes and marine coastal areas can be applied with confidence to inland flowing waters.

Sources Group

- The Sources Group characterized the differences between sources that impact Great Lakes and marine coastal waters as compared to inland waters in three categories: types of fecal contamination, scale issues, and inland environment issues, with representative findings including:

    - The types of fecal contamination are important because animal feces are prevalent sources in inland waters and are generally thought to present less of a risk to human health than human feces, but the extent of the reduced risk has not been quantified and varies depending on a number of factors such as the animal source, level of treatment, animal density, and climate.

    - Scalar level differences between coastal and inland waters include: 1) proximity of sources of fecal contamination to receiving waters, 2) the quantity of fecal material (particularly livestock) that contains specific types of pathogens and the virulence of those pathogens, 3) the mechanisms of delivery of fecal contamination, 4) the land use types surrounding inland waters, and 5) the effect of manure and biosolids on inland waters.

    - It is possible that indigenous fecal indicator bacteria sources are more important quantitatively in inland waters than in marine or Great Lakes environments.

- The Sources Group's concluding statement was:

> *In conclusion, lack of data about the prevalence, concentration, and ecology of pathogens and the relationship to fecal indicator bacteria in NPS runoff, particularly from livestock and wildlife make it difficult to extrapolate from Great Lakes and coastal epidemiology studies to inland regions because the sources are different. The knowledge gaps are so profound and the inherent variability in NPS-impacted systems is so great that we do not know if water quality criteria based on Great Lakes/coastal studies can be extrapolated to inland waters. These criteria could be either over- or under-protective of human health, depending on the circumstances.*

<u>Implementation Realities Group</u>

- Implementation challenges facing inland waters include wet weather, high flow events, the increased potential for animal sources of fecal indicator bacteria in rural areas, and the increased influence on indicator concentrations by resuspension of sediment containing environmental strains of indicators. These issues were discussed in the context of implementation flexibilities.

- The practicalities of implementing new criteria highlight the need for states (and territories) to have implementation flexibility for the new criteria while ensuring that state water quality program resources remain focused on achieving the greatest public health benefits with the available resources.

Recommendations from the various work groups included the following short-term research needs in five areas:

<u>Short Term Research</u>

1. Identify and quantify human pathogens in animal feces. The purpose of this activity would be to quantitatively characterize the human pathogenic potential of agricultural and wildlife feces. This research activity would be useful within the context of understanding epidemiologic studies with predominant sources of contamination that are nonhuman and for understanding the potential risks to human health for a broad range of waters impacted by nonhuman sources.

2. Examine relationships between qPCR and culture-based fecal indicator bacteria.

3. Optimize and anchor QMRA models to observed health effects data obtained from epidemiologic studies and develop QMRA tools for implementation of new criteria.

<u>Longer Term Research:</u>

1. Characterize fate and transport of animal pathogens in relation to indicators.

2. Conduct epidemiologic studies in inland waters.

2.5.3 Other Research

In addition to research described or recommended in the WERF (2009) and EPA (2007) reports, research is being conducted by a variety of entities. Representative examples, which are by no means all inclusive, are:

- WERF Sponsored Studies (underway in 2009):
    - **Quantification of Pathogens and Sources of Microbial Indicators for QMRA in Recreational Waters:** WERF researchers will quantify the risks from waterborne pathogens from a variety of sources and use the data in QMRA models. The results will help managers make decisions on where to put their limited resources.
    - **Comparison of Molecular and Culture Methods for Fecal Indicator Bacteria for Use in Inland Recreational Waters:** This cooperative research project will examine relationships between qPCR-based and culture-based test results, and identify appropriate pathogens and indicators in subtropical waters. Microbial source tracking using genetic markers and analysis of predictive modeling of health impacts will be included.
    - **Measuring Water Ingestion During Water Recreation**: This effort supports the Chicago Health, Environmental Exposure, and Recreation Study (CHEERS), will measure water ingestion rates during primary and secondary contact recreational activities and help to identify risks of ingestion.
    - **Concentration Dynamics of Fecal Indicators in Hawaiian Coastal and Inland Sand, Soil, and Water During Rainfall Events:** WERF researchers will examine the fate and transport of fecal indicators in tropical sand and seawater during rainfall contamination events and look at how land-use patterns affect the abundance levels of these indicators in stream water and bank soil. The project will help lead to understanding regarding how indicators move in the watershed and will provide base data for management of risk.
- **Chicago Health, Environmental Exposure, and Recreation Study (CHEERS):** CHEERS is an ongoing research project evaluating the connection between recreational water quality and health (www.cheerschicago.org/). The study is being conducted by a team of epidemiologists, environmental scientists, infectious disease researchers, and statisticians at the University of Illinois at Chicago School of Public Health, under the leadership of Dr. Sam Dorevitch and is funded by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). The study is designed to evaluate the health risks of water recreation activities other than swimming and jet skiing. People who enroll in CHEERS fall into one of two groups: 1) those who canoe, kayak, row, fish and go boating, and 2) those whose outdoor activities don't involve water contact (like jogging, cycling or playing tennis). CHEERS researchers interview people "in the field" (before and after their outdoor activity) and again over

the phone. The research also involves concurrently testing water at rivers, channels, lakes, and lagoons in the greater Chicago area. The study closely relates to the Chicago Waterways Study.

- **Chicago Waterway System (CWS) Disinfection vs Non-Disinfection Microbial Risk Assessment For Recreational Use of Chicago Area Waterways** (Petropoulou et al. 2008, see http://www.mwrdgc.dst.il.us/RD/UAA/default.htm): The purpose of this study was to estimate human health risks from recreational use of the CWS receiving treated, but non-disinfected, effluent from the MWRDGC North Side, Stickney and Calumet water reclamation plants. Dry and wet weather samples were collected and analyzed for indicators and pathogens, and results were integrated in a probabilistic microbial risk assessment (MRA). Recreational activities considered included canoeing, boating and fishing. Exposure parameters for the model were developed from the primary literature and local use surveys. Key findings of this study[6] included:

    - Overall rates of illness for receptors were all below the EPA limits for freshwater recreational use.
    - Higher rates of illness were predicted during wet weather events.
    - Disinfection of WRP effluent alone has marginal effects on overall recreational illness rates.
    - Despite elevated levels of fecal indicator bacteria, the concentrations of actual pathogenic organisms in the waterway are low.

- **Stormwater BMP Performance:** Researchers at a variety of universities are conducting BMP performance research (e.g., North Carolina State University, University of Alabama, University of New Hampshire and others). The International Stormwater BMP Database (www.bmpdatabase.org) project continues to compile and evaluate BMP performance data sets.

- **Fate and Transport Issues**: Although a comprehensive review of research related to fate and transport issues was not completed for purposes of this report, research is ongoing related to issues such as microbial partitioning, particle settling and biofilms at universities such as Northwestern University, University of California-Davis, University of Montana, North Carolina State University and others (e.g., Searcy et al. 2005, 2006a&b; Characklis and Camper 2009).

[6] EPA has expressed some concerns about the findings of the report; at the time this white paper was completed it was not known whether these comments/concerns had been resolved.

3 CASE STUDIES OF *E. COLI* IMPAIRED STREAMS IN COLORADO[7]

This section provides an overview of *E. coli* listed streams in Colorado followed by five case studies with varying characteristics in terms of recreational use, tributary land use, complexity of source identification studies, and stage in the regulatory process.

3.1 Overview of 2008 *E. coli* Listings in Colorado

Table 2 provides a summary of streams included on the 2008 303(d) list as impaired for *E. coli*. Additional segments are listed on the CWQCD's Monitoring and Evaluation list. Due primarily to the change in assessment methodology for the 2010 303(d) list, an additional 10 streams are anticipated to be added.[8] (The 2010 listing methodology looks at the most recent five years of data for segments both year-round and seasonally, whereas previous listings were based on the geometric mean of all data within a five-year assessment period.)

Table 2. *E. coli* Listed Streams on 2008 303(d) List[9]

Segment	303(d) listed segments for *E. coli*/Fecal Coliform
Arkansas River Basin	
COARFO01a	Fountain Creek and tributaries above Monument Creek
COARFO02a	Fountain Creek, Monument Creek to Hwy 47
COARFO04	All tribs to Fountain Creek, which are not on National Forest or Air Force Academy Land
COARLA09a	Mainstem of Adobe Creek and Gageby Creek… (Adobe Creek portion)
COARMA04a	Wildhorse Creek
Lower Colorado River	
COLCLC13b	Tributaries to Colorado River from Government Highline Canal Diversion to Salt Creek (Adobe Creek portion)
Rio Grande	
CORGRG28	Rito Seco, from source to Salazar Reservoir (portion: Upper Rito Seco blw Battle Mtn)
South Platte River	
COSPBD01	Mainstem of Big Dry Creek, including all tributaries, lakes, reservoirs and wetlands, from the source to the confluence with the South Platte River
COSPBE02	Bear Creek below Bear Creek Reservoir to South Platte River
COSPBO02	Boulder Creek, Indian Peaks Wilderness to South Boulder Creek (below 13th Street in Boulder)
COSPBO07b	Coal Creek, HWY 36 to Boulder Creek
COSPBO10	Boulder Creek, Coal Creek to St. Vrain Creek

[7] This section serves as the Task 5 deliverable in the Healthy Rivers Scope of Work.

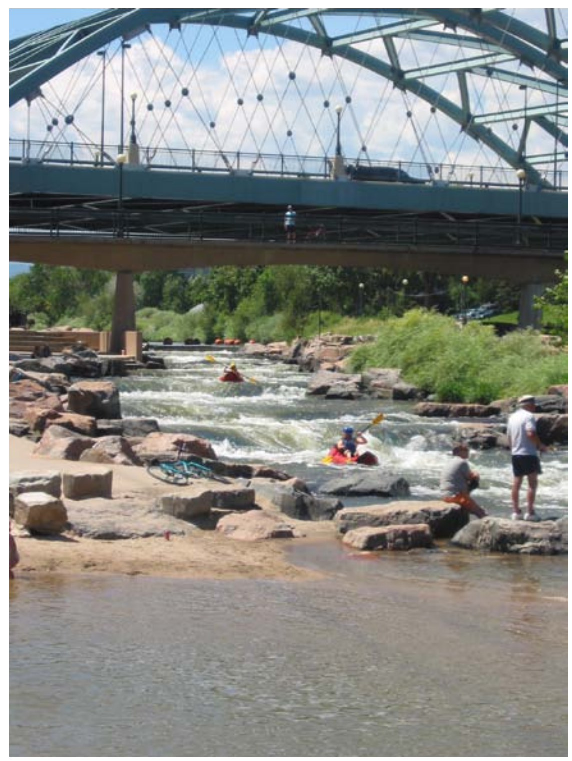
[8] Additional listings due to seasonal averaging period were originally estimated at 25 segments. The actual number of listings was smaller than anticipated because the Colorado River Basin segments were not re-evaluated using the seasonal criterion.

[9] Segment 14 of the South Platte River is no longer listed due to completion of a TMDL.

Segment	303(d) listed segments for *E. coli*/Fecal Coliform
COSPBT09	Little Thompson River, Culver Ditch to Big Thompson River
COSPCL15	Clear Creek, Youngfield St. to S. Platte River
COSPCL18a	Ralston Creek and tributaries below Arvada Reservoir (Ralston Creek)
COSPCP12	Cache la Poudre River, Box Elder Creek to S. Platte River (below Eaton Draw)
COSPLS02b	Tributaries to S Platte River, Beaver Creek, Bijou Creek and Kiowa Creek (Beaver Creek)
COSPSV06	Tributaries to the St Vrain River (Dry Creek)
COSPUS15	S. Platte River, Burlington Ditch to Big Dry Creek (Clear Creek to Fulton Canal diversion and Burlington canal headgate to MWRD.)
COSPUS16a	Sand Creek
Upper Colorado River	
COUCYA08	Elk River source to Yampa River (Portion: Elk River below Morin Ditch)
COUCYA20	Tributaries to the Yampa River above Elkhead Creek within National Forest (First Creek below Second Creek, Elkhead Creek below First Creek)

3.2 South Platte River Segment 14[10]

Segment 14 of the South Platte River is described in CWQCC Regulation 38 as the mainstem of the South Platte River from Bowles Avenue in Littleton, Colorado, to the Burlington Ditch diversion in Denver, Colorado. The stream segment, which is largely channelized, passes through metropolitan Denver. Most of the year, flow on the segment is controlled by releases from upstream reservoirs, but during low flows may be also be dominated by discharges from wastewater treatment plants. Land use surrounding the segment is primarily urban. The stream segment is used for recreation (kayaking, wading, and swimming) and as a drinking water supply and is also designated for agricultural and aquatic life use. A number of tributaries enter Segment 14 of the South Platte River. The largest of those tributaries are Bear Creek and Cherry Creek. All of the tributaries drain largely urban areas and have hydraulics with have been extensively modified as a result of channelization and / or the presence of upstream reservoirs.



Confluence Kayak Course looking upstream from the Confluence of Cherry Creek and the South Platte River

[10] Description of South Platte River Segment 14 issues prepared by Jon Novick, Denver Department of Environmental Health, August 2009.

<u>*Bacteria in Segment 14*</u>

Segment 14 of the South Platte River has been on the 303(d) list of impaired waters for bacteria since 1998. Long-term monitoring suggests overall improvement in *E. coli* levels since 2001 (Figures 3 and 4), however; *E. coli* levels still routinely exceed instream standards, in particular during warmer weather (Figure 5).

Figure 3. Five-Year Geometric Mean *E. coli* Results from Instream Sampling of Segment 14 of the South Platte River

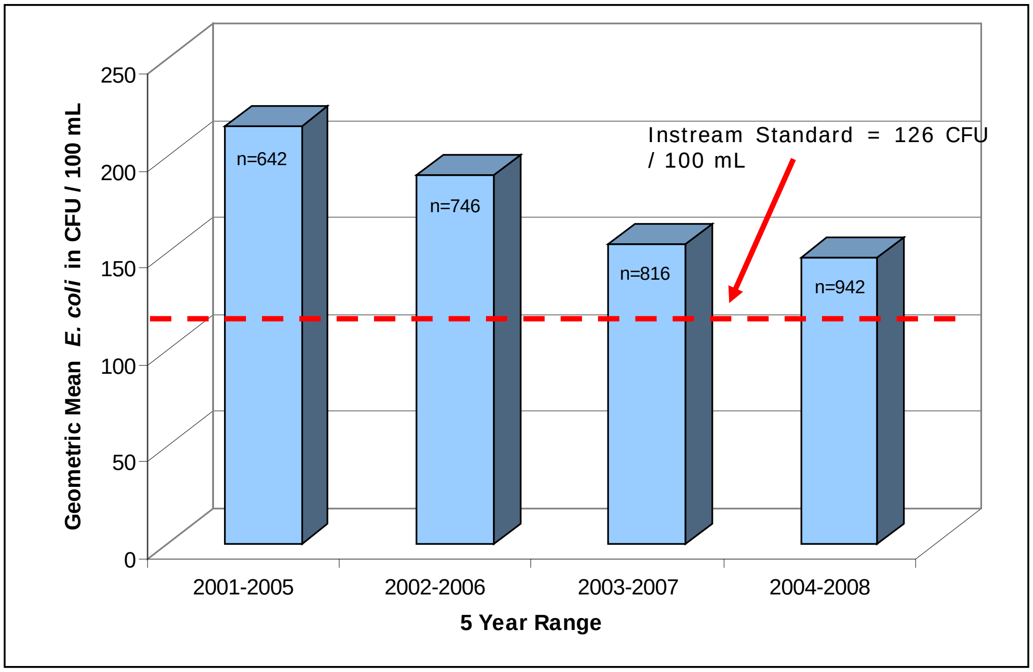


Figure 4. Box and Whiskers Plots Showing Year by Year Changes in *E. coli* Results from Instream Sampling of Segment 14 of the South Platte River

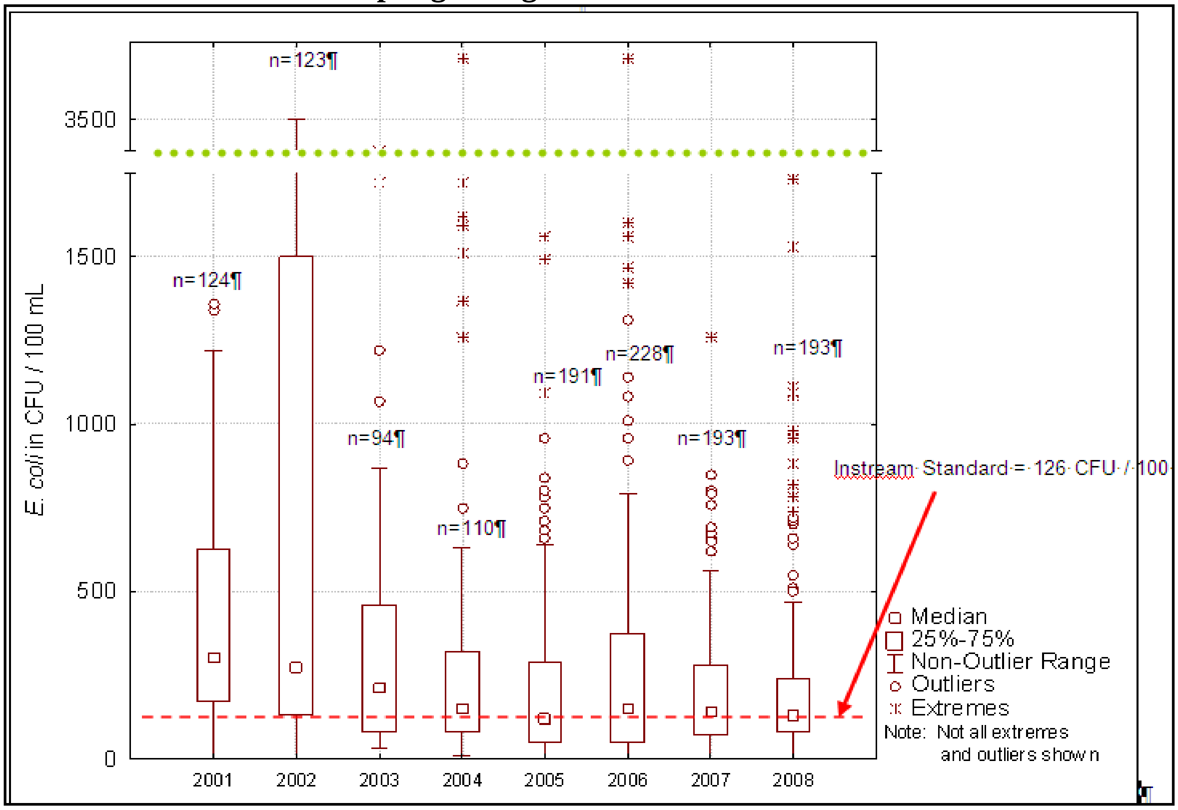
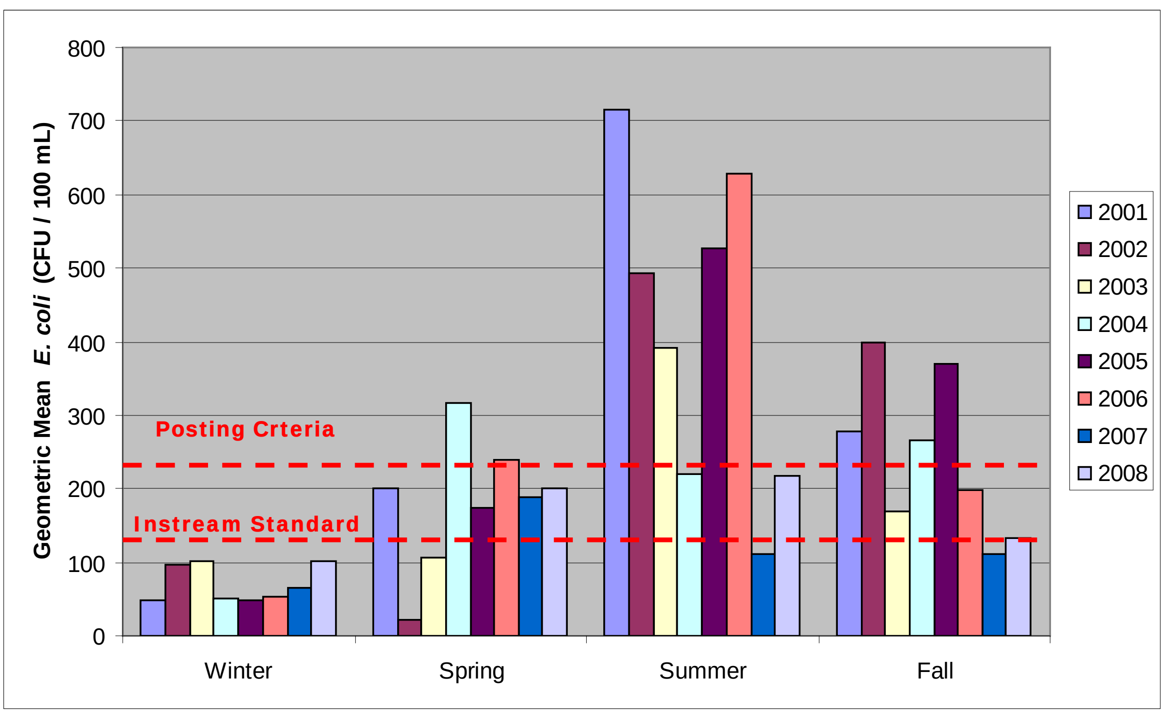


Figure 5. Seasonal Variations in *E. coli* Levels in the South Platte and Cherry Creek at their Confluence



Segment 14 E. coli TMDL

A few highlights of the Segment 14 TMDL include:

- **Load Allocations**: The TMDL assigns a numeric limit to all sources equal to the instream standard for *E. coli* of 126/100 mL. This includes CDPS permitted discharges, wildlife, humans and pets in the riparian zone, and tributaries to Segment 14. The analysis of pollutant sources identifies dry weather discharges from the MS4 as "a significant and controllable source of *E. coli*." All MS4 CDPS permit holders are listed in the TMDL and the density-based (i.e., numeric) limit of 126/100 mL is assigned to each.

- **Implementation Approach**: The TMDL emphasizes an "iterative process involving the CDPS permittees that discharge to Segment 14 and other non-point source pollution control programs." The first iteration of the permit focuses on dry weather discharges from MS4s with elevated *E. coli*. Once all dry weather flows from stormwater collection systems that drain to segment 14 with elevated *E. coli* are considered controlled, then the CWQCD will reevaluate the TMDL.

- **Endpoint**: The TMDL endpoint is attainment of the *E. coli* standard.

Management efforts implemented or planned

The City and County of Denver (CCoD) is the largest MS4 discharging to Segment 14 of the South Platte River. The following management efforts are being implemented by CCoD under its MS4 program. Adequate implementation of the programs is ensured by an Environmental Management System.

- Focus sanitary and storm sewer maintenance on drainage basins with elevated bacteria contributions into the South Platte River.

- Use new GIS capabilities to identify and improve sanitary sewer lines that have potential to contaminate the stormwater system.

- Execute and document additional storm sewer maintenance and cleaning to identify illicit discharges, repair inappropriate taps, and remove sediment containing bacteria.

- Utilize GIS in combination with water quality data to evaluate pollutant loading sources, intervene appropriately, and develop a process to identify potential point source polluters.

- Complete a microbial analysis to identify contamination sources.

- Implement a concentrated water quality education program to foster behavioral change among residents.

Results from management measurements implemented

CCoD has identified several "*E. coli* compromised" outfall basins on which the above efforts will be focused. Baseline conditions for these outfalls have been established and some efforts, including storm sewer maintenance have been implemented; however, the period of record for post-implementation monitoring has not been sufficient to determine how effective actions have been at reducing *E. coli* levels in dry weather discharges from the "*E. coli* compromised" outfall basins.

Source Identification Efforts and Special Studies

CCoD has conducted two small studies to identify *E. coli* sources in Segment 14 of the South Platte River: an antibiotic resistance study, and a study focused on contaminants that might be associated with human sources of *E. coli*. Neither of the two studies was conclusive.

CCoD has conducted or is in the process of conducting several other small-scale special studies intended to further understand the fate and transport of *E. coli* in Segment 14. The first study found that instream *E. coli* levels tend to peak in the early afternoon. Decreases in *E. coli* levels in the late afternoon were attributed to increases in the intensity of ultraviolet radiation in sunlight. The second study, which is currently ongoing, is examining the occurrence of *E. coli* in instream sediment. Initial observations suggest that *E. coli* levels are higher in finer grained sediments and in water overlying finer grained sediment. A third study has been examining the actual affects of dry weather discharges containing elevated levels of *E. coli* on instream water quality. The results of that study are not yet available. A fourth study is evaluating the impact of precipitation in the watershed on instream *E. coli* levels. Initial results of the study suggest that precipitation anywhere within the watershed can result in elevated *E. coli* levels at downstream locations up to three days after the precipitation event.

3.3 Boulder Creek[11]

Boulder Creek is listed on the 303(d) list for *E. coli* as a "high priority," but no TMDL has yet been released for public comment. Like the South Platte River, it also experiences significant recreational use. The Boulder Creek watershed is diverse and has great variation in geology, climate, and land cover. Primary tributaries of Boulder Creek include North, Middle, and South Boulder Creeks, Fourmile Creek, Coal Creek, and Rock Creek, along with several smaller

[11] Description of Boulder Creek issues prepared by Donna Scott and Megan Monroe, City of Boulder, August 2009.

streams. The Boulder Creek watershed is approximately 447 square miles in area and ranges in elevation from over 13,000 feet in the Silver Lake watershed to approximately 5,000 feet at the mouth of Boulder Creek as it enters the St. Vrain River near Longmont, approximately 20 miles northeast of the city of Boulder. The Boulder Creek watershed is located in the South Platte River watershed and is bordered by the St. Vrain River and Clear Creek watersheds.

The watershed can generally be divided into three portions: the upper watershed, which is mostly undeveloped, forested land, in the Roosevelt National Forest; the urban portion of the watershed; and the lower watershed, which includes agriculture, rural areas and estate residential development. The City of Boulder's 75th Street wastewater treatment facility (WWTF) also discharges to Boulder Creek below the listed portion of the segment, and during most months of the year is a primary source of water in Boulder Creek. The WWTF is required to meet multiple state and federal regulations to control pollutants in the effluent discharge.

In 2006, the segment of Boulder Creek through the City of Boulder was listed as impaired for exceeding the water quality standard for *E. coli* bacteria. The source of the *E. coli* contamination in Boulder Creek is currently unknown, to some extent, but is suspected to be from wildlife (raccoons), domestic pets (dogs), human waste products and naturalized bacteria within sediments. In 2006, city staff initiated a monitoring program to evaluate potential sources of *E. coli*. In addition to *E. coli* sampling, a simple screening of optical brighteners (OBs) was used to identify possible human waste sources, as OBs are ubiquitous in sanitary waste sources.

In 2008, the city was awarded an EPA grant to evaluate sources and persistence of *E. coli* in Boulder Creek's urban corridor. The study objectives included 1) the evaluation of *E. coli* concentrations as well as alternative wastewater chemicals; 2) the evaluation of persistence of *E. coli* within stream and outfall sediments; and 3) stakeholder involvement and the development of best management practices.

Intensive *E. coli* monitoring of outfalls and in-stream samples established a clear seasonal trend and identified affected stream segments. Temporal and spatial identification narrows both the timeframe of interest (summer season with low flow, warm water temperatures; see Figure 6) and sampling locations (urban stream segments from 13th Street to 30th Street; see Figure 7). In addition, the monitoring successfully identified outfalls of concern in relation to elevated *E. coli*. It is important to note that extreme variability exists between outfalls and sampling events.

Figure 6: 2006-2007 *E. coli* Geometric Mean at Boulder Creek and 30th Street, Representing Seasonal Trend, Boulder, CO

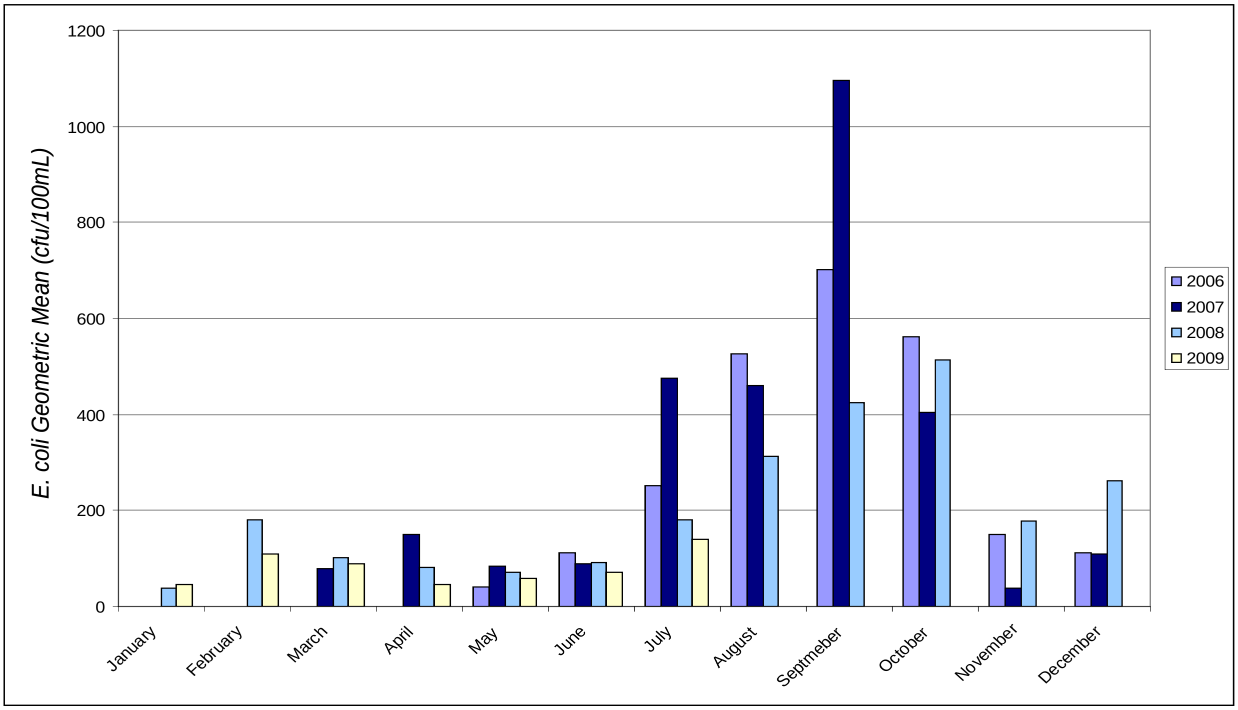
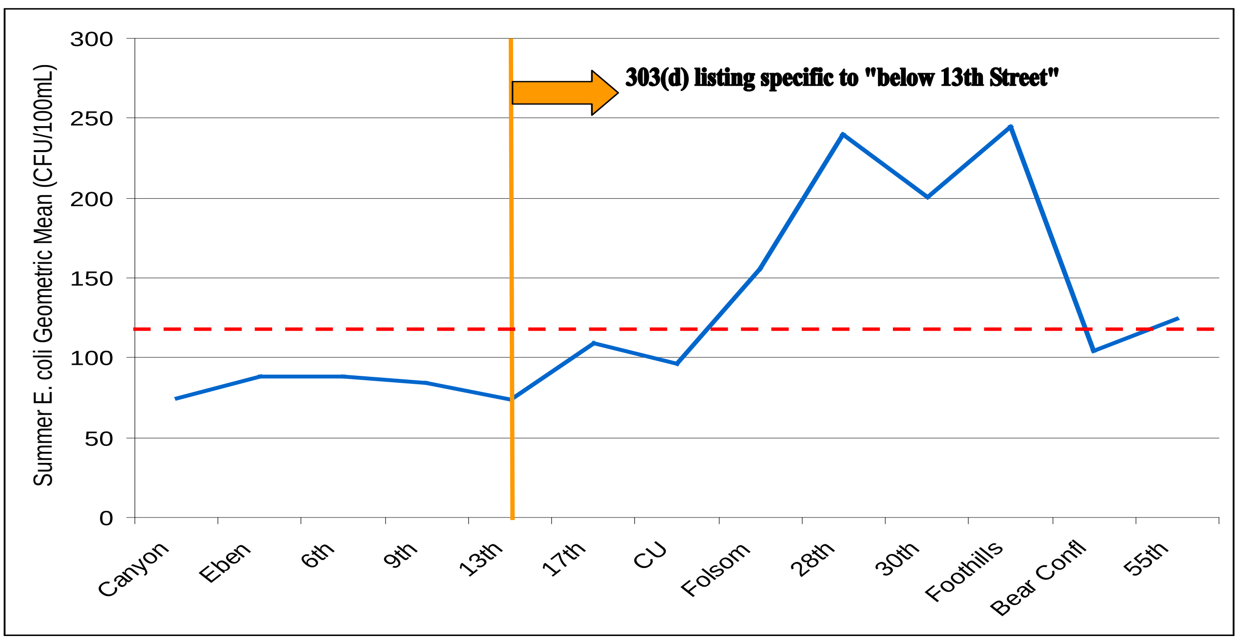


Figure 7: Targeted Sampling During Summer of 2007 Focused on Section Below 13th Street 303(d) Listing Specific to "Below 13th Street"



The second phase of the study included looking at alternative wastewater constituents using "ELISA" analysis of triclosan and estradiol, Gas Chromatography-Mass Spectrometry (GC-MS) organic chemical scans, and analysis of human specific *Bacteroides*. ELISA methods were used to isolate areas of concern in relation to one another. GS-MS analysis was used to identify concentrations of bisphenol-A, 4-methylphenol, 4-tert-butylphenol, N,N-diethyl-m-toluamide (DEET), 4-n-octylphenol, caffeine, and triclosan. Although GS-MS analysis allowed for a more definitive view of pollution levels within both the stream and outfall environment, no trends have been established between alternative wastewater indicators and *E. coli*. It is possible that no relationship has been established due to the extreme variability in constituents present within stormwater events; however, it is also possible that with additional sampling, stronger relationships could be established.

Finally, an investigation of *E. coli* persistence using dialysis membranes within stream and outfall sediments is on-going, yet has suggested elevated *E. coli* for greater than 90 days after sampling. The extent to which *E. coli* settle, re-grow and are re-suspended after release into the secondary environment is highly debated (Davis et al. 1995, Bernhard & Field 2000); however, these factors are of great interest, as each can dramatically affect the degree of coliform concentration and therefore, the EPA's assessment of risk. In order to accurately address the level of risk due to fecal contamination, regulators must be able to characterize and accurately account for the natural background strains. For this reason, the City of Boulder investigated *E. coli* concentrations within stream and outfall sediments.

Microcosms were collected and held at room temperature in which the naturalized *E. coli* was shown to persist for more than 90 days at considerably high concentrations within sediments collected in storm drain outfalls; raising additional questions surrounding the utility of *E. coli* as an indicator for fecal contamination. *In situ* microcosm (dialysis membranes) results also suggested that inoculated cultures are strongly affected by stream constituents. The persistence of *E. coli* within the secondary environment suggests that the sediments could act as both a source and a sink of *E. coli* contamination.

Currently, the city is working towards identifying possible maintenance activities for outfalls with high concentrations of *E. coli*. With the knowledge gained from routine MS4 line video surveillance (TV-ing), the city will be implementing a targeted sampling (McDonald et al 2006) regimen to isolate areas within drainage catchments that are resulting in elevated levels of *E. coli* at end of pipe. Grab samples will be taken throughout the catchments of concern during early fall (coinciding with seasonal peak *E. coli* levels), concentrations will then be compared to give city staff a better understanding of relative contribution at the sub-catchment level.

3.4 Big Dry Creek[12]

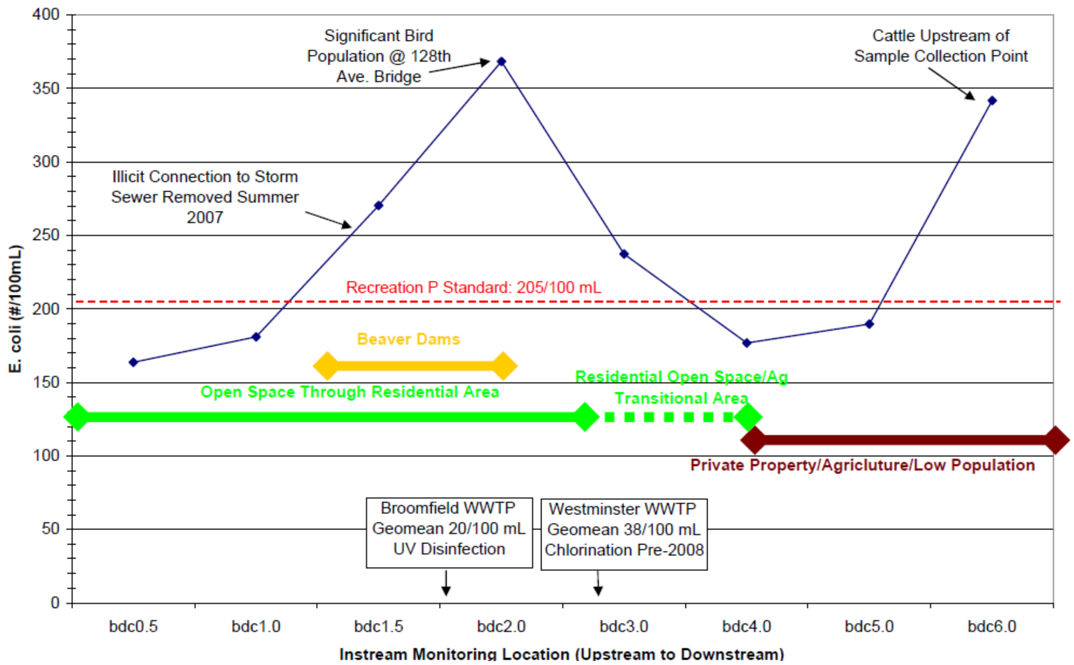
The 110-square mile Big Dry Creek watershed is located in the South Platte River Basin. Segment 1 of Big Dry Creek, which includes the main stem of the creek from below Standley

[12] Description of Big Dry Creek issues prepared by Jane Clary, Wright Water Engineers, Big Dry Creek Watershed Coordinator.

Lake to the confluence with the South Platte near Fort Lupton, is listed as impaired for *E. coli*. Based on a UAA conducted in 2000, the stream is classified as Recreation P (potential primary contact recreation) with an *E. coli* stream standard of 205/100 mL. The stream segment is listed as "high priority" for development of a TMDL to reduce *E. coli* contributions to the creek. The CWQCD, EPA and Big Dry Creek Cities have begun discussions regarding development of a TMDL for Big Dry Creek and a variety of voluntary source identification efforts have been completed by the Watershed Association.

During 2006-2008, the Big Dry Creek Watershed Association conducted targeted studies on several reaches of Big Dry Creek to identify potential sources of *E. coli*. These special studies were conducted in addition to the routine monthly instream sampling program, which has monitored *E. coli* since 2002. Routine monitoring locations and geometric mean *E. coli* concentrations from 2003-2007 are summarized in Figure 8.

Figure 8. Geometric Mean *E. coli* (2003-2007) from Upstream to Downstream on the Main Stem of Big Dry Creek (Source: WWE 2009)



Some trends observed from the routine monthly instream sampling program include the following observations:

- Based on review of geometric mean concentrations from 2003-2007, *E. coli* concentrations are consistently the lowest in grab samples from the Broomfield and Westminster WWTP effluent and are well below the stream standard. For this reason, elevated geometric mean concentrations at in-stream locations below the discharges cannot be directly attributed to WWTP discharges during the majority of the sampling events.

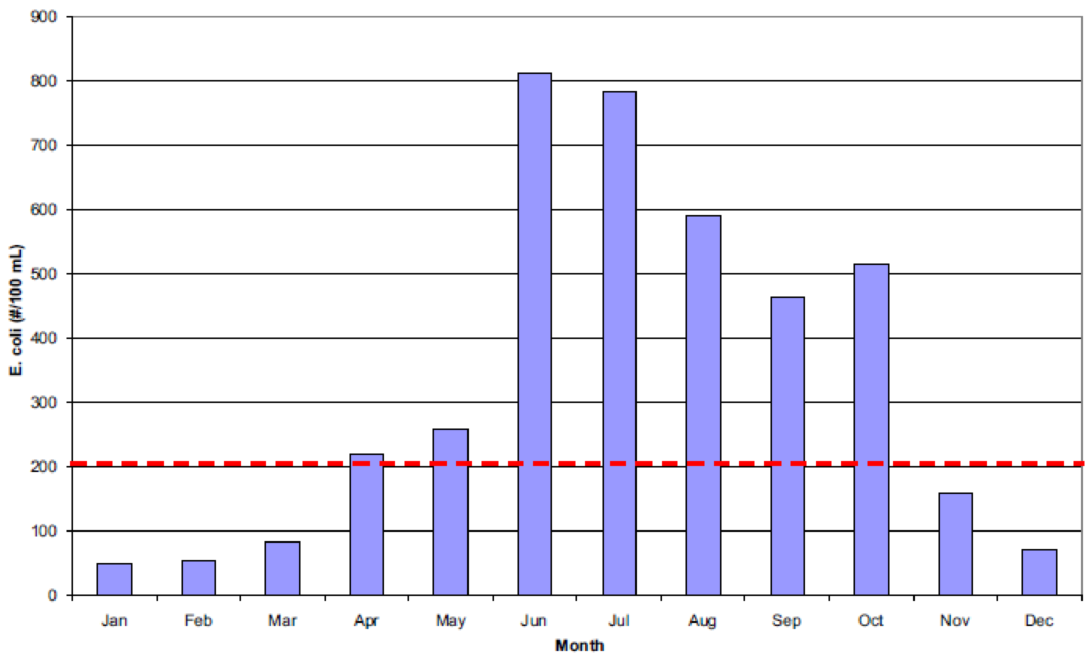
- Half of the instream monitoring locations had geometric mean *E. coli* concentrations above the stream standard. The highest geometric mean concentration of *E. coli* is present at bdc2.0, below the Broomfield WWTP. Monitoring station bdc6.0 in the agricultural area upstream of the confluence with the South Platte River had the second highest concentration.

- Significant variability in *E. coli* concentrations exists at each monitoring location. An upstream to downstream trend is not evident.

- Seasonal variation is evident (Figure 9) for the 2003-2007 *E. coli* data set, with geometric mean concentrations above the stream standard during April through October.

- For most locations on the stream, *E. coli* concentrations are about one-quarter to one-half of those measured during drought conditions in 2002, with the exceptions of bdc1.0 and bdc.1.5, which appear to be less variable over time.

Figure 9. Seasonal *E. coli* Trend on Big Dry Creek (Monthly Geometric Mean *E. coli* 2003-2007)



Targeted special *E. coli* studies conducted on the creek include three reaches, according to priorities established by the Watershed Association, include:

1. Highest Priority: Big Dry Creek Open Space in Westminster Between 112th and 128th Ave. (monitoring locations bdc1.0 to bdc2.0). In this reach, dry weather outfall screening was conducted following Center for Watershed Protection protocols (2004). This reach of stream was focused on first due to elevated *E. coli* at bdc1.5 and 2.0, open space access and the cooperation of the Phase II stormwater permit holders along this reach (Westminster and Broomfield). Study results identified one illicit residential sanitary

sewer connection to the storm sewer system upstream of 120th Avenue (bdc1.5), which was corrected in the summer of 2007. Other dry weather storm sewer discharges attained the stream standard, as did the Broomfield Wastewater Treatment Plant (WWTP) discharge in this reach. No other human sources of *E. coli* were identified during dry weather investigations[13]; however, significant wildlife presence (e.g., beavers, coyotes, foxes, waterfowl, prairie dogs) was documented, as would be expected due to the wildlife corridor concentrated in the Open Space area.

2. Medium to High Priority: Big Dry Creek Open Space in Westminster Between 128th Ave. and I-25 (bdc2.0 to bdc3.0). The second phase of the targeted special studies focused on this reach of stream for reasons similar to #1 above, although this reach of stream had decreasing *E. coli* concentrations along its length. Dry weather screening in this reach identified no illicit discharges to Big Dry Creek, and the Westminster WWTP discharge in this reach attains stream standards. Significant wildlife (e.g., coyotes, ducks, geese) evidence was also present in this reach.

3. Lower Priority: Big Dry Creek from I-25 to Near Confluence with South Platte River (bdc3.0 to bdc6.0). The vast majority of Big Dry Creek in this area is on private property and is dominated by agricultural land use. Population density is significantly lower in this area, particularly downstream of bdc4.0 at E-470 and York St. The only point where a bike path currently intersects the stream is at the I-25 overpass at Thorn Creek golf course. The remainder of the stream reach is not expected to be used for recreation and is fenced in most locations, so the public health risk due to recreating in or on the stream is currently expected to be minimal. Because of private property access constraints, this reach of stream has been reviewed based on aerial photography combined with observations of field staff who conduct routine monthly sampling. Cattle access is believed to contribute to elevated *E. coli* at bdc6.0, based on previous observations and presence of cattle in aerial photography.

4. Miscellaneous Follow-up Items: As research regarding potential sources of *E. coli* in the Big Dry Creek Watershed has progressed, several miscellaneous follow-up items have been completed.

[13] During an August 28, 2008 interview of city staff responsible for sampling, it was determined that evidence of a transient encampment existed for several months under the bridge at bdc2.0 during the summer of 2006. This encampment no longer exists and was not present during the 2007 dry weather investigation.

- First, City of Westminster staff have verbally reported that video inspection of sewer lines in the Big Dry Creek Open Space area has not indicated evidence of exfiltration or breaks. This is important because sewer lines cross the creek in several locations and/or parallel the trail along the creek.

- Secondly, the City of Westminster provided additional information to the CWQCD regarding improvements to the Big Dry Creek Wastewater Reclamation Facility that have been recently completed. This information was provided due to some elevated *E. coli* concentrations on Discharge Monitoring Reports during 2006 and 2007, when the WWTP was undergoing upgrades and expansion. Since implementation of the UV disinfection system and discontinued use of uncovered, outdoor storage ponds prior to discharge, *E. coli* concentrations in Westminster's discharge have been consistently well below the stream standard, with 30-day geometric mean *E. coli* values ranging from 5/100 mL to 36/100 mL, during 2008.

- Finally, two community facilities are present along the creek in areas where *E. coli* has been elevated were investigated to confirm connections to the sanitary sewer.

Based on the studies conducted to date, non-point sources appear to be the primary source of elevated *E. coli* along Big Dry Creek. The nature of the non-point source contributions in the watershed vary according to land use, with non-point sources in the upper portion of the watershed being those associated with open space and non-point sources in the lower portion of the watershed being primarily associated with agricultural land use. Wildlife is documented throughout the watershed and is expected to contribute to *E. coli* in Big Dry Creek. Although wading has been documented to occur in locations in the upper portion of the watershed, a UAA conducted in 2000 and a 2003 student survey of recreational uses did not identify primary contact recreational uses. Although the total cost of the *E. coli* source identification effort on Big Dry Creek has not been fully calculated, the level of effort for the special studies component of work is estimated to be less than $50,000 to date. However, this cost does not include the substantial instream sampling that has occurred on a routine basis from 2002 through 2008.

Photos 1 and 2. A dry weather sanitary survey resulted in identification of an illicit discharge to the storm sewer due to a plumbing error at a residential home. Toilet paper, odor, elevated temperature and other factors lead to identification and removal of this discharge.

3.5 Fountain Creek[14]

The Upper and Lower portions of Fountain Creek in the Colorado Springs area have elevated concentrations of fecal indicator bacteria from above the Colorado Springs City limits to the confluence with the Arkansas River at Pueblo. Upper Fountain Creek is on the 2006 303(d) list as a high priority for *E. coli*. This will require that a TMDL process be initiated in the watershed. Supporting data show that *E. coli* concentrations in excess of 126/100 mL were commonly measured throughout the watershed from May through October. *E. coli* concentrations in excess of 100,000/100 mL have been measured in Fountain Creek during precipitation events.

Upper Fountain Creek is a 12-mile segment, with a 120-square mile tributary area within the Fountain Creek Watershed. This segment originates in eastern Teller County and extends southeast through Manitou Springs to the confluence of Monument Creek and Upper Fountain Creek in Colorado Springs. Upper Fountain Creek is used for recreational purposes, including hiking, fishing, horseback riding, and shopping in and near the resort town of Manitou Springs. There are no wastewater treatment plants that discharge to Upper Fountain Creek.

The U.S. Geological Survey (USGS), CDPHE, City of Colorado Springs, Colorado Springs Utilities, and Pikes Peak Area Council of Governments initiated the Upper Fountain Creek *E. coli* Study in 2007, which focuses on a 12-mile segment of Upper Fountain Creek, from Green Mountain Falls to the confluence of Fountain Creek and Monument Creek. The purpose of the 3-year study was to identify sources of *E. coli* contamination in Upper Fountain Creek and test a strategy for gaining information about sources of contamination. Measurement of microbial source tracking (MST) molecular markers was used to detect the presence of fecal contamination from various sources (human, ruminant, or other). Microbial source tracking tools were included in this investigation to provide supporting evidence about sources of fecal contamination to complement hydrology, patterns in fecal indicator bacteria concentration, and patterns of other constituents such as land use and wastewater organic chemical concentrations. The goal for the sampling effort was to measure spatial and temporal patterns of *E. coli* concentrations in the Upper Fountain Creek to detect when, how and where fecal contamination enters the streams. The estimated level of effort associated with this study was approximately $450,000. To achieve this goal, the following study objectives and associated tasks were conducted:

Objective 1: Identify general areas of *E. coli* concern and how concentrations are affected based under three different flow regimes under which elevated concentrations have been detected including: (a) spring snowmelt, (b) summer dry-weather conditions, and (c) summer runoff-flow conditions. This included longitudinal sampling at 12 sites in May, July and August 2007 (dates selected correspond to different hydrologic conditions). Thirty-six samples were collected and analyzed for flow, field parameters (dissolved oxygen, pH, conductivity, temperature and turbidity) and *E. coli*. Data gathered from the longitudinal samples were used to select five critical sites for further evaluation.

[14] Fountain Creek description developed based on communication with Lisa Ross, P.E., City of Colorado Springs Stormwater Enterprise.

Objective 2: Determine temporal patterns of flow, field parameters, *E. coli*, wastewater organic compounds and nutrients. Ancillary data (hydrologic condition, land use, precipitation, water physicochemical properties, and nutrient concentrations) were collected along with the fecal contamination data. Fecal contamination data (including *E. coli* concentration, wastewater analyte concentration, and MST marker detection rates and patterns) were interpreted in the context of ancillary data to evaluate potential sources and pathways of fecal contamination to Upper Fountain Creek. Hydrologic condition and precipitation data were used to indicate potential pathways of fecal contamination to the stream (for example, overland flow during runoff; subsurface seepage during ice cover, or direct deposition during dry-weather flow). Land use information was collected from stakeholders and used to evaluate potential sources of fecal contamination. Physicochemical properties and nutrient concentrations were used to evaluate the extent to which samples at various times and locations represent similar water sources.

Fecal indicator bacteria data were collected at 5 sample stations during 21 interval sample events over one year. Interval samples were collected every other week in spring 2008 (April-June) and summer 2008 (July-September) and every month in fall/winter 2008 (October-March).

- On normal (usually during the summer-dry weather conditions) dates, which represent about half of the total number of samples, flow and multi-parameter field measurements were taken and samples were analyzed for *E. coli*. Samples were analyzed for nutrients and shipped to the USGS Denver lab for analysis of wastewater analytes.

- On snowmelt and rain dates, five samples were collected across the event hydrograph to represent the rising limb, peak and falling limb). Chemical analyses were done at the Denver lab on only one of these samples per event (rising limb or peak).

Objective 3: Determine human and ruminant markers to evaluate whether a particular source contributed fecal contamination to selected samples. To achieve this objective, MST host-associated molecular markers were measured to detect the presence of fecal contamination from human and ruminant sources. The specific markers that were measured include *Bacteroides*-based markers for human and ruminant contamination and *Enterococcus faecium*-carried *esp* marker of human fecal contamination. The MST markers were library-independent and have not yet been validated in the study area. By way of explanation, library-dependent MST is used to classify bacteria to host of origin, isolate-by-isolate, based on comparison to a library of known-source isolates. In contrast, the presence of fecal contamination from a particular source (host) is detected by library-independent MST based on the presence of host-associated genetic markers. Library-dependent methods for MST were not applied because they have been shown to be inaccurate relative to library-independent methods. Wastewater organic chemical concentrations (such as caffeine, fecal sterols, and detergents) also were measured to indicate potential presence of human wastewater.

Measurement of human and ruminant-specific molecular markers was completed in 50 of the archived MST samples, selected to allow confirmation of pattern interpretations from the integrated data set. The molecular markers are human and ruminant-specific DNA sequences in *Bacteroides* anaerobic bacteria and a human-specific DNA sequence in *Enterococcus.* Ninety (90) samples were collected during the interval sampling conducted as part of Objective 2 and 50 were selected for analysis depending on needs identified in the data set. Only 50 were analyzed due to the cost involved in MST sample analysis.

Final results of the study are not yet available, but initial sampling indicates that sites most likely to exceed standards are downstream from Manitou Springs rather than in the rural areas upstream. Although *E. coli* concentrations in about half of the samples did not violate standards, concentrations in the creek sometimes spiked to levels more than 50 times over the standard. The initial MST data indicate multiple animal and human sources of *E. coli* contamination. Data are being further analyzed to evaluate the amount of fecal contamination that comes from each source, as well as where and how the fecal contamination gets into the stream. Preliminary findings indicate that the *E. coli* issue on Upper Fountain Creek is primarily from non-human and non-ruminant sources. Although the MST method used is good for rejecting (ruling out) sources, it is less definitive at identifying specific sources. At this time, the source could be birds, chipmunks, squirrels, bats, rats, etc. Horses were eliminated through one test. At one location, a significant pigeon source was identified.

3.6 Elkhead Creek Watershed[15]

Colorado stream segment COUCYA20 includes tributaries to the Yampa River above Elkhead Creek within the Routt National Forest boundaries. A portion of segment COUYA20 was placed on the 2006 303(d) list for *E. coli* impairment based on exceedance of the Recreation 1a criteria. The listed portion of the segment is "First Creek below Second Creek, Elkhead Creek below First Creek" within the Elkhead Creek watershed. These streams run through California Park, a remote area located approximately 18 miles north of Hayden, Colorado. California Park is managed for multiple uses including wildlife habitat, livestock grazing, and dispersed recreation.

Vegetation in the open parklands of California Park is predominantly sage community – a sagebrush canopy interspersed with bunchgrasses and forbs. Willow thickets line the stream in some portions of the riparian areas, but most of the stream reaches are in exposed areas with little shade. First Creek and Elkhead Creek are typical pool-riffle streams; there are no water features such as falls or plunge pools to draw visitors. Table 3 shows the mean width and depth of these streams.

Table 3. Physical Characteristics of First Creek and Elkhead Creek

	Mean Width (ft)	Mean Depth (ft)	Max. Pool Depth (ft)
First Creek	31.6	1.6	2.5
Elkhead Creek	61.6	2.0	4.2

Elkhead Creek has long stretches of vertical raw banks which make access to the stream difficult. Lower First Creek and Elkhead Creek develop algae on the substrate in late summer due to low

[15] Description of Elkhead Creek Watershed issues prepared by Joan Carlson, U.S. Forest Service, August 2009.

flow conditions and high water temperatures. The algae make these reaches unattractive for water recreation. Photos 3 and 4 show typical stream views.

Photos 3 and 4. Lower Elkhead Creek and Lower First Creek, respectively in California Park.

Description of Stream Uses

California Park is predominantly National Forest System (NFS) lands, although there are several private inholdings and a section of Colorado State Land Board land. Access to California Park is via NFSR 150, a dirt/gravel road that is closed from December 1 to July 1 each year to protect wildlife. The nearest paved road to California Park is 20 miles away. The most direct access to the listed sections of First Creek and Elkhead Creek is a 2+ mile one-way hike from the nearest open road. This hike is across the Colorado State Land Board land, which requires permission to enter.

The majority of the recreation use in California Park is by hunters during hunting season. There are no developed recreation sites (i.e., campgrounds or picnic areas) in the watershed. Dispersed camping is mostly upstream of the listed reaches, east of NFSR 150. There is occasional horse use west of NFSR 150, but it is rare to encounter people camping off of the main road outside of hunting season. The fisheries are poor for sport fishing, except for higher reaches of the watershed upstream of the listed reaches. During the summer, there is some use by people "driving for pleasure" or on ATVs. A traffic counter on NFSR 150 recorded 12 vehicle passes in a 24 hour period on August 16, 2007. In contrast, higher recreation use areas on the Forest had 4 to 5 times more vehicle passes during the same period with traffic counts of 45 to 62 vehicles in 24 hours. There has been one known kayak run on Elkhead Creek (originating in California Park) in the spring of 2005 – no additional kayaking has occurred. Access to Elkhead Creek is difficult during the high runoff period due to snowdrifts on the road and closure of the main road until July 1. Snowmobiles use the area in the winter.

E. coli Data Summary

The U.S. Forest Service (USFS) has collected *E coli* data from First Creek and Elkhead Creek in the summers of 2003, 2004, 2007, 2008 and 2009. The USFS uses the IDEXX Colilert and Quanti-Tray 2000 analysis method. Table 4 and Figures 10 and 11 present data for these four sample locations:

- First Creek # 1 – upstream of Elkhead Creek (within listed reach)
- First Creek # 6 – upstream of Second Creek (upstream of listed reach)
- Elkhead Creek #1 – downstream of First Creek (within listed reach)
- Elkhead Creek New – upstream of First Creek (upstream of listed reach – added in 2007)

Table 4. Geometric Means of *E coli* data (#/100 ml)

Years	First Cr. #1	First Cr. #6	Elkhead Cr. #1	Elkhead Cr. New
2003-2004	216	23	235	--
2007-2009	83	77	208	56

Figure 10. *E. coli* in California Park Streams (2003-2004)

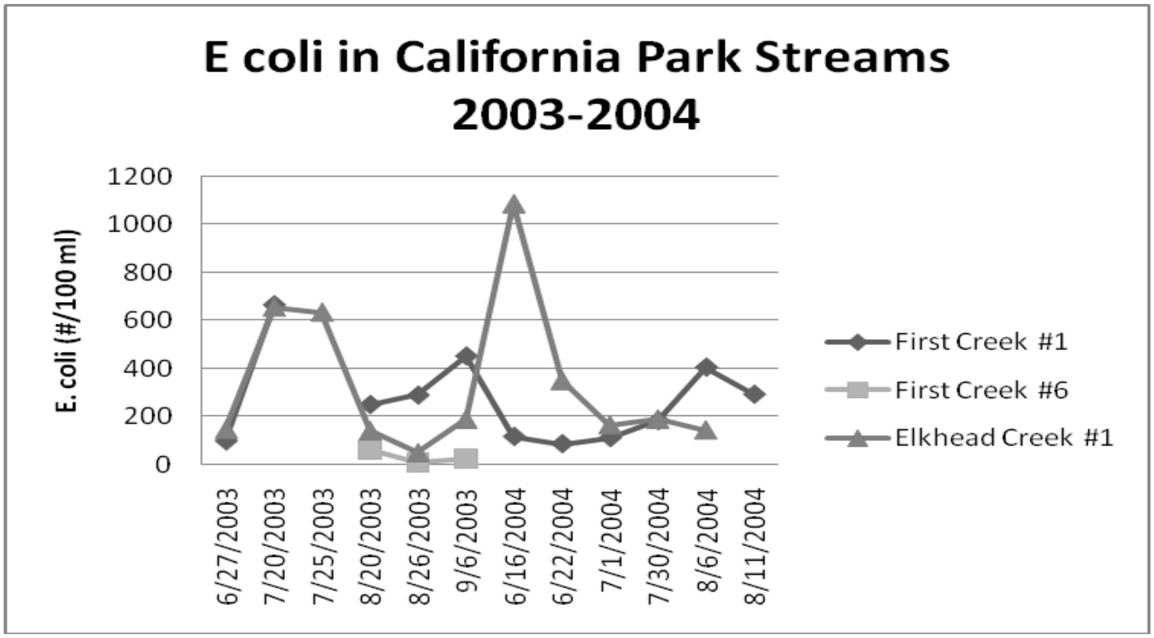
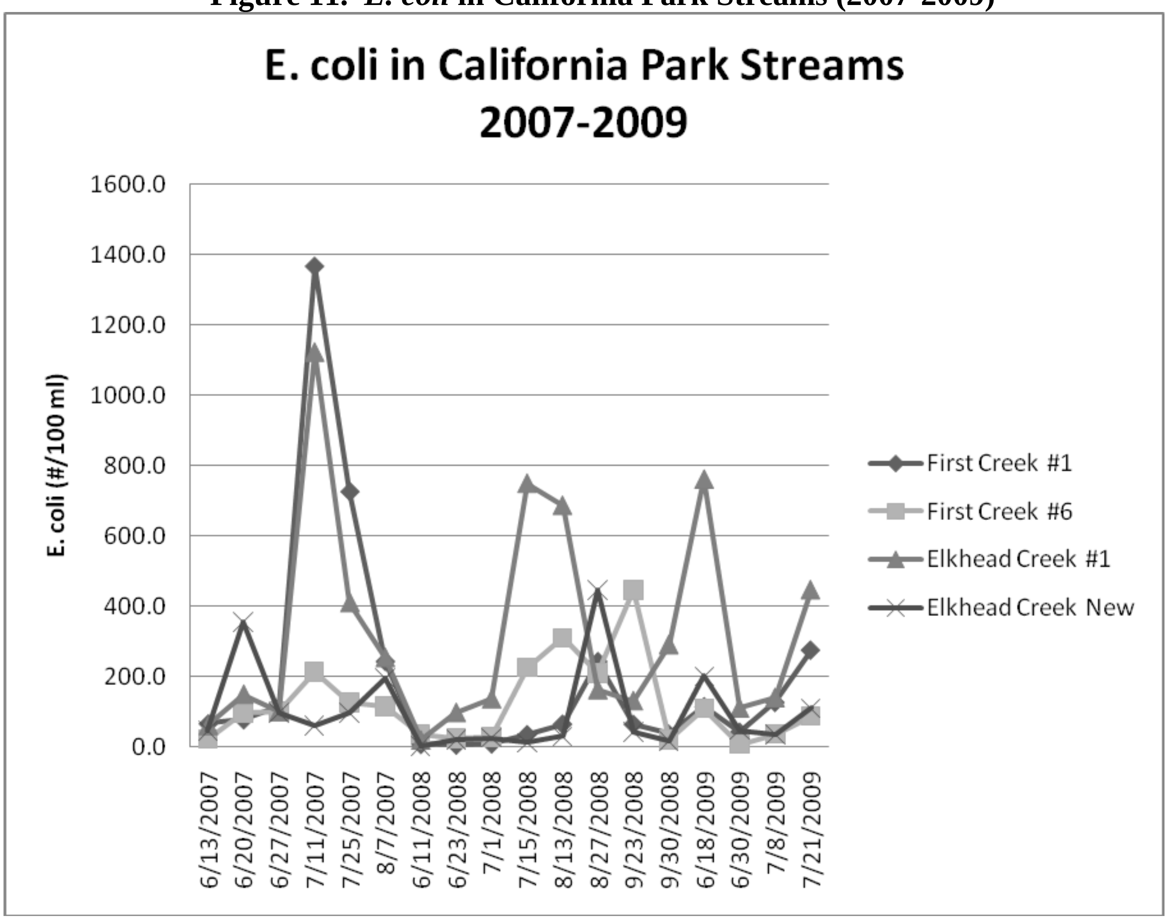


Figure 11. *E. coli* in California Park Streams (2007-2009)



It should be noted that there is great variability in the samples that have been collected. In the 2007-2009 sampling, for 67 duplicate sample pairs, cases existed where one sample was above the standard and the other was below the standard. Some discrepancies in sample pairs were quite large (e.g., 84/100 mL and 1,011/100 mL; 102/100 mL and >2,420/100 mL). Approximately 70% of the duplicates were within 50/100 mL agreement, and about 51% of the samples were within 20/100 mL agreement. The data presented in the tables and figures is the geometric mean of the duplicate sample pair for each sampling date.

Description of Sources

Several potential sources of bacteria to First Creek and Elkhead Creek have been identified in the watershed. These are predominantly wildlife and livestock, with some small contributions from human sources.

There are two known septic systems in the watershed. One is located at the California Park Guard Station, a Forest Service administrative facility located in upper Elkhead Creek. The Guard Station also has a horse pasture that is used at most three weeks in a season to pasture four horses. The other septic system is at a private residence in the First Creek watershed. There are no developed recreation sites in the watershed. Overall recreation use in the watershed is low with most of the use occurring during hunting season in the fall. The hunters generally camp in the upper portion of the watershed in wooded areas near tributary streams and springs. There is a small amount of horseback use for recreation.

Wildlife in California Park includes elk, deer, antelope, sandhill cranes, grouse, waterfowl, beaver and other animals. The elk herd that uses California Park is approximately twice the size of the management objective for herd size. These animals use the lower reaches of Elkhead Creek extensively during May and June. There are numerous beaver dams and complexes in First Creek and especially in the upper portions of Elkhead Creek. Wildlife use of California Park is high because of the lack of urban development and human presence.

Both sheep and cattle are permitted to graze in California Park. One band of sheep (approximately 1000 head) is permitted by the State Land Board to graze the State land for 13 days per year. The sheep generally come on the State land in early June before moving onto sheep allotments on NFS lands in the wooded areas of the upper watershed. Cattle are permitted by the Forest Service to graze the California Park Allotment on National Forest System lands. This allotment is 3,964 acres located in the non-wooded open rangeland area of California Park along First Creek and Elkhead Creek, and surrounds the state land. The state land is not fenced and cattle occasionally drift from NFS lands onto the state land. Currently permitted and actual numbers (as of 2006) for the California Park Allotment, including Animal Unit Months (AUMs) are summarized in Table 5. (One AUM is the amount of forage required by an animal unit for one month.)

Table 5. Livestock Usage in California Park

Livestock Class		Number	Season	AUMs
Current Permitted Use	Cow/calf pairs	400	July 6 – Sept 25	1078
Current Grazing Management	Cow/calf pairs	250	July 6 – Sept 25	674

Management Efforts

In September, 2006, the USFS issued a decision on a new Allotment Management Plan for the California Park Allotment. This decision establishes an adaptive management framework for managing livestock grazing in the California Park Allotment. Adaptive management is defined as a process where land managers implement management practices, guided by design criteria, which are designed to meet Forest Plan standards and guidelines, and would likely achieve the desired conditions in a timely manner. However, if monitoring shows that desired conditions are not being met, or if movement toward achieving the desired conditions in an acceptable timeframe is not occurring, then an alternate set of management actions would be implemented to achieve the desired results.

The desired conditions established for the California Park Allotment include improving trends in riparian condition, increasing species composition and diversity in upland vegetation and sustaining or improving habitat for aquatic and terrestrial species. The decision also establishes a management unit on Lower Elkhead, located downstream of the State Land, which is to be managed to address key watershed issues including condition of the riparian area and bacterial water quality.

Design criteria for the California Park Allotment include the following measures:

- Manage the allotment as a three-unit deferred rotation grazing system.
- Domestic livestock grazing use is not to exceed the currently permitted AUMs.
- Riders are to be used to move cattle that are congregating in riparian areas.
- Work with the State Land Board to improve grazing practices on State and NFS lands.
- Limit sheep use in the cattle allotment one day each for trailing into and out of the adjacent sheep allotments.
- Identify and develop new water sources in the Lower Elkhead unit.
- Use salt near developed livestock watering locations to reduce impacts to riparian areas.
- Limit streambank trampling to no more than 20% greater than the reference area.

- Measure utilization of riparian graminoids (e.g. sedges, etc) by average stubble height – six inches of stubble must be present in the riparian community at the end of the grazing event or the end of the growing season (whichever occurs later).

In addition, watershed improvement projects to accelerate riparian condition recovery are to be implemented in Lower Elkhead and First Creeks (re-shaping and replanting of vertical banks, fencing riparian areas devoid of vegetation, etc).

The decision also establishes a monitoring process to determine whether or not progress is being made toward the desired conditions. Stubble height and streambank alteration are to be monitored annually. Revegetation of point bars and riparian area as effective ground cover are to be monitored bi-annually. Greenline and bank erodibility hazard are to be measured in the third and fifth years. Width/depth ratio and stream type are to be evaluated in the fifth and tenth years. The 2007 grazing season was the first season under the new Allotment Management Plan and adaptive management framework. The USFS expects that implementation of these design criteria will move the allotment over time towards the desired conditions of improving riparian and upland rangeland condition, and ultimately reducing the contribution of bacteria from the livestock grazing on NFS lands.

Other

In 2007, the Forest Service completed a UAA for the listed portion of the segment to determine the appropriate recreation use classification. The UAA concluded that primary contact recreation is not occurring and is not likely to occur due to the remote location and inaccessibility of the listed reach (20 miles from nearest paved road, seasonal road closure, 2+ mile one-way hike, restricted access across State land, etc.) and therefore a classification of "N" would be appropriate. At the 2008 Triennial Review Hearing for the Upper Colorado River Basin Regulation, the Forest successfully petitioned to the CWQCC to resegment COUCYA20 into two segments: COUCYA20a and COUCYA20b (the listed segment). Segment COUCYA20b was designated as Rec Use Class "N" and Segment COUCYA20a as Rec Use Class "U". Based on *E. coli* data collected in 2007 – 2009, the CWQCD will propose removing COUCYA20b from the 303(d) list in 2010.

3.7 Summary

Colorado streams identified as impaired due to elevated *E. coli* concentrations have widely varying characteristics. As a result, the level of inquiry required to determine "logical proof of source" and the conditions of TMDLs will vary, as well. A beneficial task in the future would be to more closely compare and contrast trends identified on streams with similar characteristics. For example, several streams show strong seasonal trends and indicated non-human sources of elevated indicator bacteria. Environmental regrowth of bacteria is suggested in the Boulder Creek watershed, but has not been evaluated in other streams. The 2002 drought peak tended to have the highest *E. coli* concentrations in several of the watersheds. Additional information would be helpful in determining whether currently applicable stream standards can be attained, even following removal of human-caused sources of contamination.

4 SOURCES OF BACTERIA[16]

4.1 General Overview

Many sources of *E. coli* exist in natural, urban and agricultural settings. In Colorado, streams in all three settings have been listed on the 303(d) list as being impaired due to elevated bacteria. This section describes potential sources of bacteria, followed by a discussion in Section 5 regarding screening and monitoring techniques that can be used to identify which sources are most likely to contribute to impairment. Although currently the Ambient Water Quality Criteria do not differentiate risk to human health based on source of bacteria, experts participating in both the EPA (2007) and WERF (2009) expert panels described in Section 2 concur that human sources of fecal contamination are generally expected to pose a greater human health risk than animal sources. For example, WERF (2009) states:

> The sources group characterized the differences between sources that impact Great Lakes and marine coastal waters as compared to inland waters in three categories: types of fecal contamination, scale issues, and inland environment issues. The types of fecal contamination are important because animal feces are prevalent sources in inland waters and are generally thought to present less of a risk to human health than human feces, but the extent of the reduced risk has not been quantified and varies depending on a number of factors such as the animal source, level of treatment, animal density, and climate. Scalar level differences between coastal and inland waters include: 1) proximity of sources of fecal contamination to receiving waters, 2) the quantity of fecal material (particularly livestock) that contains specific types of pathogens and the virulence of those pathogens, 3) the mechanisms of delivery of fecal contamination, 4) the land use types surrounding inland waters, and 5) the effect of manure and biosolids on inland waters. With respect to environmental issues, the sources group indicated that it is possible that indigenous fecal indicator bacteria sources are more important quantitatively in inland waters than in marine or Great Lakes environments. (WERF 2009, Executive Summary, p. ES-3)

Similarly, the EPA Expert Panel Report (EPA 2007a) provided a general characterization of anticipated risks as shown in Table 6 and provided the following context for these estimates in Chapter 4, Estimating Risks from Different Sources:

- *It is widely believed that human feces poses a larger health risk than animal feces to swimmers and other primary contact recreational water users. This belief derives from the basic concept that virtually all enteric pathogens of humans are infectious to other humans, while relatively few of the enteric pathogens of animals are infectious to humans.*

- *…there remains a paucity of data on the risk of illness for swimmers at beaches exclusively (or primarily) impacted by feces from animals. The absence of such*

[16] This section serves as the Task 3 deliverable under the Healthy Rivers grant.

data makes it difficult to interpret the health significance of the frequent and persistent elevated fecal indicator levels in such waters that have been attributed to animals in many locations throughout the United States.

- *The bottom line is that there are few data to demonstrate whether animal feces pose a lower, greater, or equivalent health risk to bathers than human feces. If there is a difference, it would be helpful to know the magnitude of that difference in order for EPA to make appropriate public health recommendations.*

(Note: Because the Expert Panel did not conclude that there was *no* risk from non-human sources, EPA has moved away from "wildlife off-ramp" concepts that have been approved in some states unless the following conditions are met per the BEACH Act rule (69 FR 67226-67227; November 16, 2004) which states that non-human source exclusions to the criteria can be allowed when: 1) the sources are only from non-human sources (supported by sanitary surveys/watershed characterization studies) AND 2) those non-human sources are shown to pose no risk to human health (i.e., through an epidemiological study). States may use existing epidemiological data in lieu of conducting their own studies.

EPA's (2004) guidance regarding wildlife issues is discussed in more detail in Section 4.5.2.)

Table 6. Comparison of Expected Risks to Humans from Different Pathogen Sources[a]
(Source: *Report of the Experts Scientific Workshop on Critical Research Needs for the Development of New or Revised Recreational Water [EPA 2007a]*)

Source	Viruses	Protozoa	Bacteria	
Wildlife				
Aquatic birds	N	L	L-M	
Other (e.g., deer)	N	M	M	#2 priority
Agricultural animals				
Poultry	N	N	M-H	
Other (e.g., cattle, sheep)	N	M	M-H	#1 priority
Domestic animals				
Pets (e.g., dogs, cats)	N	L	L	
Fecal shedding by bathers				#3 priority
Adults	L	L	L	
Children	H	H	H	
Sewage				
No treatment (combined sewer overflows)	H	H	H	
No treatment (separate storm sewer overflows)	?*	?*	?*	
Secondary treatment**	H	H	M	
Plus chlorine**	H	H	L	
Plus UV	M-H (L with increased energy)		L	
Secondary environments***	L	L	M	

a Does not have an explicit fate and transport component
* Risk largely depends on amount of human feces present
** Focus of most (U.S.) recreational water epidemiological studies
*** Sediment suspension and contact with beach sand
N = estimated no or negligible risk, L = estimated low risk, M = estimated medium risk, H = estimated high risk

In *Protocol for Developing Pathogen TMDLs* (EPA 2001), EPA provides a summary of potential bacteria sources, as summarized in Table 7. The remainder of this section focuses on a subgroup of the various sources including: illicit connections, wastewater treatment plant discharges, failing septic systems, domestic pets, wildlife, agriculture, environmental sources and wet weather flows.

Table 7. Bacteria Sources, Possible Management Activities and Transport Processes
(Source: EPA 2001)

Source/land use	Operation/activity	Samples of management activity	Frequency	Transport process(es)
Agriculture	Livestock-feedlot	Manure removal	weekly	runoff; erosion
	Livestock-manure storage	Storage structures; leachate control Spreading schedules; storage	variable	runoff; erosion; seepage
	Crop-manure/sludge application	Rotation	variable	runoff; erosion
	Pasture		variable	runoff; erosion; direct
Urban/ Residential	Domestic pets	Waste pickup law	variable	runoff
	Wildlife	Management; population control Pumpout; education	constant	runoff; direct
	Septic systems	Compliance	annual	leaching; interflow
	Illicit connection		constant	direct
	Landfills	Disposal	constant	runoff; leaching
Forest	Wildlife	Management; population control	constant	runoff; erosion; direct
Point Sources	WWTP	Waste treatment	constant	direct
	Slaughterhouse	Waste treatment	variable	direct
	CSOs; SSOs	Storage/transport redesign	variable	direct; rainfall-driven

4.2 Illicit Discharges/Connections

EPA identifies a variety of illicit discharges to storm sewer systems; some of which potentially contain fecal indicator bacteria. Representative examples include sanitary wastewater, effluent from septic tanks, and laundry wastewater. Federal regulations define an illicit discharge as "...any discharge to an MS4 that is not composed entirely of stormwater..." with some exceptions. These exceptions include discharges from NPDES-permitted industrial sources and discharges from fire-fighting activities. Illicit discharges are considered "illicit" because MS4s are not designed to accept, process, or discharge such non-stormwater wastes. (See http://www.epa.gov/npdes/pubs/fact2-5.pdf for more information on illicit discharges.) Although other non-stormwater discharges to the MS4 may exist, MS4 operators are not required to address these unless they have been identified as significant contributors of pollutants. These non-stormwater discharges include: water line flushing; landscape irrigation; diverted stream flows; rising ground waters; uncontaminated ground water infiltration; uncontaminated pumped ground water; discharges from potable water sources; foundation drains; air conditioning condensation; irrigation water; springs; water from crawl space pumps; footing drains; lawn watering; individual residential car washing; flows from riparian habitats and wetlands; dechlorinated swimming pool discharges; and street wash water. In the context of bacteria, the primary illicit discharge of concern is sanitary wastewater. Even in new developments, plumbing errors can result in erroneous connection of sanitary sewers to storm sewer systems. See Section 5.2.3 for information on conducting dry weather outfall screening to identify illicit discharges/connections.

4.3 Wastewater Treatment Plant Discharges

In the context of bacteria loading, wastewater treatment plants can be discussed in terms of 1) municipal wastewater treatment facilities (publically owned treatment works [POTWs]) and 2) small package plants. As a broad generalization, most municipal wastewater treatment facilities are capable of consistently reducing indicator bacteria to very low levels through use of chlorination or UV disinfection. CDPS discharge requirements may be occasionally violated in case of an upset or perhaps on a short-term basis during construction, but this should not be a long-term issue. Smaller package plants may face more operational challenges, but this is highly dependent on site-specific conditions. Despite greater operational challenges, small package plants in Colorado do not currently experience more permit violations than larger plants.

4.4 Onsite Wastewater Treatment Systems (Septic Systems)

Septic systems are used in rural areas and along the fringe of urban areas lacking sanitary sewer access. In some cases, septic systems may also exist on small farms in urban areas that have not been connected to the sewer system as development has occurred around them. Many factors can lead to septic system failure including unsuitable soil conditions, poor installation, inadequate maintenance, overuse of garbage grinders and placement too close to a stream.

Conventional OWTS systems have septic tanks that remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter. Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils. Conventional systems work well if they are installed in areas with appropriate soils and hydraulic capacities; designed to treat the incoming waste load to meet public health, ground water, and surface water performance standards; installed properly; and maintained to ensure long-term performance (EPA 2002).

EPA (2002) reports that these criteria, however, are often not met, with only about one-third of the land area in the United States having soils suited for conventional subsurface soil absorption fields. System densities in some areas exceed the capacity of even suitable soils to assimilate wastewater flows and retain and transform their contaminants. In addition, many systems are located too close to ground water or surface waters and others, particularly in rural areas with newly installed public water lines, and are not designed to handle increasing wastewater flows.

Failure rates of OWTSs vary widely. Under a typical conventional system management approach, untrained and often uninformed system owners assume responsibility for operating and maintaining their relatively simple, gravity-based systems. Performance results under this approach can vary significantly, with operation and maintenance functions driven mostly by complaints or failures. In fact, many conventional system failures have been linked to operation and maintenance failures. Typical causes of failure include unpumped and sludge-filled tanks, which result in clogged absorption fields, and hydraulic overloading caused by increased occupancy and greater water use following the installation of new water lines to replace wells and cisterns. Full-time or high use of vacation homes served by systems installed under outdated practices or designed for part-time occupancy can cause water quality problems. Landscape modification, alteration of the infiltration field surface, or the use of outdated technologies like drywells and cesspools can also cause contamination problems (EPA 2002).

For more guidance, see *Onsite Wastewater Treatment Systems Manual* (EPA 2002; (http://www.epa.gov/nrmrl/pubs/625r00008/html/625R00008.htm).

4.5 Domestic Pets, Wildlife and Agriculture

This section first provides general information on animal sources of fecal indicator bacteria and pathogens and then provides the current EPA implementation guidance related to these sources.

4.5.1 General

Domestic pets such as dogs and cats can contribute to elevated bacteria levels in waterbodies. This can occur when dogs are off leash in open space areas or along streamside trails and when owners do not collect and dispose of pet waste. Additionally, pet waste that is not properly disposed of in residential areas that comes in contact with urban runoff can contribute to elevated bacteria in the storm sewer system. See Section 6.1 for a discussion of measures to reduce impacts of domestic pets.

Wildlife such as deer, elk, beavers, raccoons, water fowl and other wildlife are known to influence bacteria concentrations in even pristine watersheds. The USFS (Peterson 2006) notes that use of the streams by elk and deer, beaver, waterfowl, etc., can contribute to increased bacteria concentrations. Similarly, raccoons have been documented to increase *E. coli* concentrations in urban watersheds (Schueler and Holland 2000). A Trust for Public Land/American Water Works Association (2001) report states: "Even in the most pristine watersheds, natural pollutants such as animal waste and organic matter can impair the quality of water."

Agricultural sources of pollution can be characterized as originating from both point and non-point sources. Point source agricultural loading may occur at Confined Animal Feeding Operations (CAFOs), which are permitted under CWQCD CDPS permits through Regulation 81 (it should be noted that CAFOs are somewhat narrowly defined and not all animal feeding operations are regulated via the CDPS Program). Non-point sources of agricultural loading may include cattle, horses, etc., that graze along streams, as well as manure and biosolids applications to fields. When considering agricultural impacts from grazing (as opposed to concentrated feeding and watering areas), some research has shown that the effects of range cattle on a watershed are often indistinguishable from the effects of wildlife (Dixon 1983 and Buchanan 1992, cited in Harker 1997).

4.5.2 EPA 2004 Implementation Guidance Related to Animal Sources of Fecal Contamination

As noted in Section 2.5.1, there has been much debate over the relative health risks of non-human, warm-blooded sources of bacteria. EPA's (2004) Implementation Guidance regarding this issue is important background on the regulatory context for this issue. Although somewhat lengthy, it is quoted in its entirety below because it is believed to provide EPA's perspective on several issues of interest to the *E. coli* Work Group and some potential regulatory alternatives to addressing these sources.

What is EPA's policy regarding high levels of indicator organisms from animal sources?[17]

In the 1994 Water Quality Standards Handbook, EPA established a policy that states and authorized tribes may apply water quality criteria for bacteria to waterbodies designated for recreation with the rebuttable presumption that the indicators show the presence of human fecal contamination. This 1994 policy stated:

> *States may apply bacteriological criteria sufficient to support primary contact recreation with a rebuttable presumption that the indicators show the presence of human fecal pollution. Rebuttal of this presumption, however, must be based on a sanitary survey that demonstrates a lack of contamination from human sources. The basis for this option is the absence of data demonstrating a relationship between high densities of bacteriological water quality indicators and increased risk of swimming-associated illness in animal-contaminated waters.*

In short, under this policy a state or authorized tribe could justify a decision not to apply the criteria to a particular waterbody when bacterial indicators were found to be of animal origin. This policy was based on the absence of data correlating non-human sources of fecal contamination and human illness and on the belief that pathogens originating from animal sources present an insignificant risk of acute gastrointestinal illness in humans.

The position taken in the 1994 Water Quality Standards Handbook is no longer supported by the available scientific data. The available data suggest there is some risk posed to humans as a result of exposure to microorganisms resulting from non-human fecal contamination, particularly those animal sources with which humans regularly come into contact, i.e., livestock and other domestic animals. As a result, states and authorized tribes should not use broad exemptions from the bacteriological criteria for waters designated for primary contact recreation based on the presumption that high levels of bacteria resulting from non-human fecal contamination present no risk to human health.

Recent evidence indicates that warm-blooded animals other than humans may be responsible for transmitting pathogens capable of causing illness in humans. Examples include outbreaks of enterohemorrhagic E. coli O157:H7, Salmonella, Giardia, and Cryptosporidium, all of which are frequently of animal origin. Livestock, domestic pets, and wildlife are carriers of human pathogens and can transmit these pathogens to surface waters as well as contribute significant numbers of indicator bacteria to waterbodies.

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[17] Text in bold brackets in the excerpted text was provided by EPA, not the authors of this white paper.

Incidents where these pathogens have been spread to humans through water have been documented in recent years. In the case of E. coli O157:H7, several cases have been cited in which fecal contamination from animals was the probable source of the pathogen. The most prominent examples have included contamination of water supplies, including an outbreak in Alpine, Wyoming, in June 1998, affecting 157 people, and a major outbreak in Walkerton, Ontario, in May and June of 2000 causing more than 2,300 people to become ill and causing seven deaths (CDC, 2002; CDC, 2000; Ontario's Ministry of the Attorney General, 2000). In the former case, contamination by wildlife of the community water supply is the suspected source, and in Walkerton, Ontario, heavy rains causing agricultural runoff to leak into city wells is suspected. The 1993 Milwaukee Cryptosporidium outbreak is a well-known example of water supply contamination that resulted in 403,000 illnesses and approximately 100 deaths. The source of the oocysts was not identified, but suspected sources include agricultural runoff from dairies in the region, wastewater from a slaughterhouse and meat packing plant, and municipal wastewater treatment plant effluent (Casman, 1996; USDA, 1993). In addition, Cryptosporidium was the known cause of 15 other outbreaks associated with drinking and recreational water affecting 5,040 individuals in the U.S. between 1991 and 1994 (Gibson et al., 1998). While many of the reported outbreaks have occurred through the consumption of contaminated drinking water, other incidences of E. coli O157:H7 infection from exposure to surface waters have been documented. ***[For example, in the summer of 1991, 21 E. coli O157:H7 infections were traced to fecal contamination of a lake where people swam in Portland, Oregon (Keene et al., 1994)]***

The relative health risk from waters contaminated by human sources versus non-human sources has been the subject of recent debate, particularly related to the application and implementation of EPA's recommended water quality criteria for bacteria. While ***[EPA believes that]*** *non-human sources are capable of transmitting pathogens that can cause the specific kinds of gastrointestinal illness identified in EPA's original epidemiological studies, the specific risk from these sources has not been fully determined. The risk presented by fecal contamination of waters by non-human sources is possibly less significant; however, the increasing number of cases described above in which animals are the likely cause of the contamination and resulting illness present a compelling case to protect waters where human contact or consumption are likely to occur. In addition, because the presence of bacterial indicators provides evidence of fecal pollution*[18]*, high levels of these indicator organisms originating from animal sources may also indicate the presence of pathogens capable of causing other human illnesses in addition to acute gastroenteritis.*

Animals are more likely to carry or be infected with human pathogens when those animals are in close proximity to humans and their waste. The closer the association

[18] Recent research indicates that this statement is not always true, as discussed in Section 4.6 of this white paper.

between animals and humans, the more likely it is that human pathogens will pass back and forth between humans and animals. The more crowded an animal herd, the more likely it is that human pathogens will be shared between animals of the herd. These pathogens are transmitted to others in the herd because of the direct contact between animals and their fecal matter. Fecal contamination from these infected herds, unless sufficiently treated or contained, can find its way into surface or ground waters and present a potential exposure route for people using the contaminated waters for recreation or drinking. This scenario potentially applies not only to animal feeding operations but also to herds of wildlife (deer, for example). However, the threat from livestock herds is likely to be greater given the typical herd size and the resultant quantity of fecal wastes. Wild herds are typically more dispersed and smaller and therefore likely represent a smaller risk to watersheds. In addition, wildlife are not typically in routine daily contact with humans, as may be the case for livestock and other domestic animals.

It is essential that states and authorized tribes provide recreators with an appropriate level of protection in their water designated for recreational uses. Based on increased knowledge of the potential hazards associated with animal wastes, fecal contamination from all sources should be considered and evaluated for their relative risk contribution. The current state of knowledge regarding risk from wildlife sources is limited: it is apparent there is some risk, but that risk has not been quantified adequately. However, ***[EPA believes that]*** *livestock and other domestic animals have the potential to pose a more substantial risk to humans than wildlife. This is based partly on the quantities of waste generated by herds of livestock, but also on the knowledge that domestic animals are more likely to carry human pathogens in general and carry a larger number of human pathogens than most species of wildlife. Therefore, at a minimum, it is appropriate to account for bacteria from all non-wildlife sources in state and authorized tribal water quality standards. Alternatively, states and authorized tribes may choose to provide their designated bathing areas with a more protective approach which accounts for all sources of bacteria, including wildlife. Such an approach may be appropriate in special cases where states and authorized tribes believe wildlife may contribute to disease in humans because of unique circumstances associated with, for example, their number, species, and/or proximity to human populations.*

There are several ways to accomplish this. The option that takes full advantage of the public participation process would be to create a subcategory of primary contact recreation that accounts for the potential impact of fecal contamination from wildlife sources (i.e., create a separate "wildlife impacted recreation use" with a less stringent criterion). This option would allow states and authorized tribes to refine uses only where necessary. A complete discussion of this option is in {section 3.4.2 of the EPA report}.

[Another way would be to simply express the criteria as "non-wildlife enterococci" or "non-wildlife E. coli".] *The presumption for interpreting any measurement or permitting any source would be that the enterococci or E. coli is non-wildlife.*

However, if it is strongly suspected that the bacteria are solely or primarily from wildlife, then the responsible authority may conduct analysis (i.e., sanitary survey, source tracking, etc.) to determine the percent contribution of the bacteria measurement that represent wildlife bacteria (in situations where there are no human or domesticated animal sources of fecal pollution, the responsible authority could conclude that wildlife is the source of the measured bacteria). The relative contribution provided by wildlife can then be applied to the measurement prior to comparison with the protective criterion so that wildlife contributions are discounted. This approach has at least two advantages. First, with proper application, it is unnecessary to change the underlying designated use. Second, it allows continued appropriate permitting of unquestioned sources of non-wildlife bacteria, such as sewage treatment plants separate and apart from relying on antidegradation provisions. {Section 3.4.2 of the EPA report} provides more information on source tracking techniques. Other approaches may also be appropriate, in addition to the approaches described here. EPA will work with states and authorized tribes interested in developing such approaches to assure they meet the requirements of the Clean Water Act and federal regulations. In conjunction with the non-wildlife criteria and/or reference waterbody approaches, a state or tribe may issue precautionary bathing advisories in waters where wildlife bacteria exceed the non-wildlife bacteria criteria to warn would-be recreators of the unknown and uncertain risks of exposure to human pathogens that could be associated with wildlife.

4.6 Environmental Sources

When *E. coli* was selected by EPA as an indicator of fecal contamination, an implicit assumption was that waterborne pathogens co-occur with the fecal material and that there are no significant environmental (i.e., non-enteric) sources of these microorganisms; however, recent studies have shown persistence and regrowth of indicator bacteria occur in the environment. As previously noted, several of the findings of the WERF (2009) Inland Waters report indicate that environmental source of bacteria can be important, including:

- The environment is considered to be a source of fecal indicator bacteria.

- Characteristics of inland water sites vary widely; therefore, the factors that control the fate, survival, transport, regrowth potential, and ecology of indicators and pathogens are not likely to be the same for all inland water sites and will likely differ from those factors found at the Great Lakes or marine coastal beaches. This variation in characteristics makes it difficult to extrapolate trends/findings from one location directly to another.

- Recent studies in both tropical and temperate areas that have shown growth and persistence of environmental sources of fecal indicator bacteria. Studies cited include: Fujioka and Byappanahalli, 2003; Rivera et al., 1988; Byappanahalli and Fujioka, 1998; Solo-Gabriele et al., 2000; Byappanahalli and Fujioka, 2004; Byappanahalli et al., 2006; Ishii et al., 2006a; Whitman et al., 2006; Yamahara et al., 2009.

- The group concluded that a significant consequence resulting from growth and presence of environmental sources of *E. coli* and enterococci in inland waters is that they falsely indicate recent fecal contamination.

From a Colorado Front Range perspective, it is also noteworthy that Monroe (2009) concluded that persistence of *E. coli* within the secondary environment on Boulder Creek suggests that the sediments could act as both a source and a sink of *E. coli* contamination. Monroe's review of the literature on persistence of fecal indicator bacteria in the environment resulted in similar finds to the WERF (2009) report. Several examples include:

- Research by Ishii & Sadowksy (2008) has raised questions about *E. coli* as an indicator species due to the environmental persistence of naturalized strains.

- Savageau (1983) claimed that nearly half of the *E. coli*'s life is spent external from the host.

- Evidence has also shown that *E. coli* bacteria can persist within the aquatic environment, soils and substrate (benthic material) (Byappanahalli 2003).

- Environmental strains have exhibited the ability to replicate outside of a host (Power 2005).

- *E. coli* incubated at 25 degrees C in autoclaved filtered water survived for greater than 260 days with no loss of culturability (Flint 1987).

- Genetic transformation/natural competence was shown in laboratory *E. coli* strains cultured in conditions resembling the natural environment (Baur 1996).

- A 2008 National Water Research Institute study investigated contamination and found that fecal indicator bacteria correlated most with total dissolved carbon, suggesting that concentrations of bacteria were more influenced by ecological parameters rather than transport processes alone (Surbeck et al. 2008).

Schueler and Holland (2000) also provide similar statements in *The Practice of Watershed Protection* article titled "Microbes and Urban Watersheds: Concentrations, Sources and Pathways." Examples include:

- Schueler recognizes bacteria regrowth issues and states that "the strong evidence that fecal coliform bacteria can survive and even multiply in sediments indicates that the drainage network itself can become a major bacterial sink and/or source during storm events if sediments are flushed or resuspended."

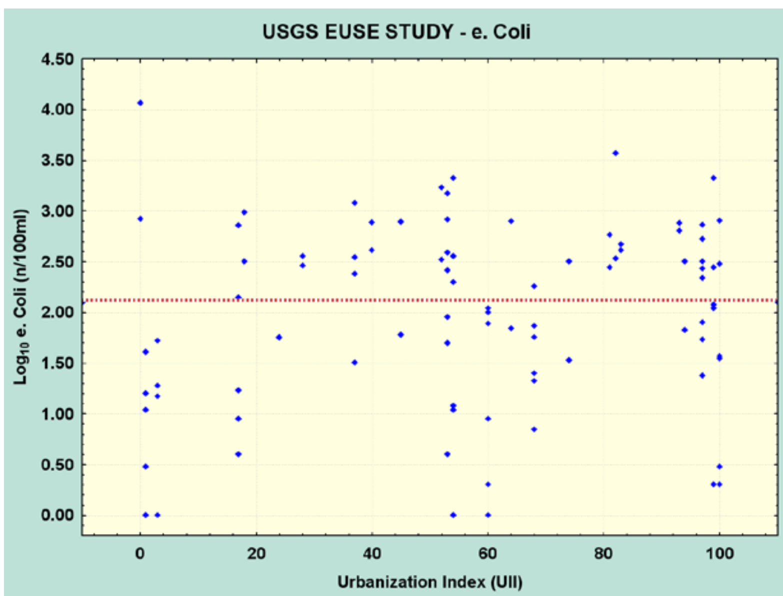
- Studies by Bannerman et al. (1993) and Steuer et al (1997) both reported end-of-pipe bacteria concentrations that were at least an order of magnitude higher than any source area in the contributing watershed, which suggests that the storm drain system was the greatest bacterial source in the watershed, possibly as a result of the resuspension of storm drain sediment or an undetected illicit connection. Pitt and Mclean (1986) documented similar trends.

4.7 Relationship to Urbanization

Although some water quality pollutants have been associated with urbanization (Burton and Pitt 2001), fecal indicator bacteria may or may not be elevated in urban and non-urban areas. This relationship (or lack thereof) is important in terms of setting realistic goals for watersheds with regard to controllable sources of *E. coli*. A few examples illustrating this follow.

In 2006, the USGS released a study on the *Effects of Urbanization on Stream Ecosystems in the South Platte River Basin, Colorado and Wyoming* (Sprague et al. 2005). Instream *E. coli* data were collected as part of this study. Interestingly, *E. coli* concentrations appeared to have no meaningful relationship to the urbanization intensity index (UII), as shown in Figure 12.

Figure 12.
Scatter Plot of Urbanization Index (UII) to *E. coli* (#/100 mL plotted on Log_{10} Scale)
(Data Source: Sprague et al. 2005)



Similar findings resulted from a Flow Science (2005) study titled *Review of Bacteria Data from Southern California Watersheds in 2005* that analyzed available data from 1986 through 2004 from South California watersheds. Their analysis showed that bacterial water quality criteria are routinely exceeded in freshwater creek and river flows, often by one or more orders of magnitude. Exceedences of criteria occur even for flows from largely natural, undeveloped watersheds with little human influence. There is strong evidence that the predominant source of indicator bacteria may be natural, including, for example, bacteria from wildlife, birds and regrowth within the environment, including sediments. The level of development within urban watersheds did not affect bacteria concentrations in receiving waters. No clear trend over time was evident, even in areas where land use characteristics had changed over time. Both the concentrations in runoff and the impacts of elevated bacteria concentrations on downstream water quality appear to vary by site and with the size of the contributing stream and thus are likely a function of the dominant sources of bacteria, local hydrologic conditions and climate and other site specific factors.

Additionally, a study conducted by AwwaRF and EPA (200x) titled "Development of Event-based Pathogen Monitoring Strategies" assessed human health risk from pathogens based on monitoring of 21 storm events and three dry weather events in paired watersheds including residential, pristine wildlife, and dairy/agricultural. Analyses included pathogens, alternatives source-specific indicator organisms and traditional water quality parameters. Study findings regarding land uses posing highest risks were generally:

Cryptosporidium:

- Highest Risk: agricultural land (cattle)
- Moderate Risk: pristine wildlife areas
- Low Risk: residential

Giardia:

- Highest Risk: beaver-influenced areas
- Moderate to High Risk: residential
- Moderate to Low Risk: agricultural/ranging wildlife

Similar to findings related to environmental sources, these types of considerations are important because they can have significant effects on bacteria concentrations ultimately achievable in watersheds.

4.8 Wet Weather Contributions

This section provides a general overview of bacteria concentrations that may be expected under wet weather flow conditions, provides data compiled for the National Stormwater Quality Database, and provides information on wet weather monitoring completed for the South Platte River through the metro Denver area.

4.8.1 General

Several articles from the *Practice of Watershed Protection* by Schueler and Holland (2000) provide a good synopsis of basic wet weather bacteria issues and summarize findings from multiple researchers through the late 1990s. The general findings from review of these sources include:

- Typical concentrations of bacteria (whether measured as *E. coli* or fecal coliform) in urban stormwater are often two orders of magnitude greater than instream primary contact recreation standards (i.e., 126/100 mL for *E. coli* and 200/100 ml for fecal coliform – in Colorado). Even when urban stormwater concentrations are significantly reduced through treatment by BMPs, the concentrations in effluent typically remain an order of magnitude greater than the instream standard during wet weather conditions.

- Concentrations of bacteria in urban stormwater are notoriously variable on a site-specific basis, even for similar land use types and even at the same sampling location. Due to the wide variability of bacterial data, it is difficult to make accurate estimates of expected pollutant loading and pollutant removal that are transferable from site-to-site with any degree of confidence. Even with the significant variability, all of the databases and literature sources agree that bacteria concentrations in untreated urban stormwater are very high (estimates range from 15,000/100 mL to over 50,000/100 mL for fecal coliform) and difficult to reduce to instream standards (as previously noted above).

- Structural BMP performance for bacteria removal is also highly variable and is likely influenced by site-specific conditions such as the presence of wildlife (e.g., geese, raccoons, rats) and pets in the BMP itself, tributary land use, and sample collection and analysis techniques, among others.

- Although it is likely that scientific research on factors that enhance bacteria removal through improved structural BMP designs could help to improve BMP performance in the future, the current state-of-the-practice is not sufficiently advanced to provide this information.

Research continues regarding fate and transport issues related to stormwater and modeling (Characklis and Camper 2009). For example, some have postulated that indicator bacteria bind to fine particles within the stormwater system and that these fine particles are easily transported to receiving waters during storm events (Serdar 1993, cited by Fohn 2009). Additionally, moist, fine material in catch basins and vaults are believed to provide good material for the regrowth of indicator bacteria, providing a perpetual source of bacteria (Fohn 2009; Scott 2009).

4.8.2 National Stormwater Quality Database Wet Weather Characterization

The National Stormwater Quality Database, Version 1.1, was compiled by Pitt, Maestre and Morquecho (2004) (available at www.unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml). In effect, the database supersedes the older National Urban Runoff Program (NURP) data collected in the 1980s. This database contains Phase I stormwater permit monitoring data for over 100 constituents in 65 communities across the U.S. for a total of 3,700 storm events at 350 locations collected over roughly the last 10 years. The database includes fecal coliform, fecal strep and *E. coli* in urban runoff, as summarized in Table 8 and Figure 13 according to land use. This data set shows that the median concentration for fecal coliform would exceed a primary contact standard of 200/100 mL for every land use listed and that over 90 percent of the samples detected fecal coliform. As shown in this table, median fecal coliform and fecal strep concentrations are highest in open space and residential areas (7,200/100 mL and 11,000/100 mL, respectively) and lowest in freeways and industrial areas (1,700/100 mL and 2,500/100 mL, respectively). A much smaller data set (about 1/10th the size of the fecal coliform data set) is available for *E. coli*. The *E. coli* data differ somewhat, showing the highest concentrations from freeways (1,900/100 mL) and the lowest for residential areas (700/100 mL). Comparison of the median concentrations for the overall data set to the primary contact recreational stream standards suggests that median bacteria concentrations in urban runoff are 10 to 25 times the primary contact stream standard in urban areas. Other findings from Pitt et al. (2004) included that first-flush effects did not appear to be significant with bacteria and that bacteria concentrations appeared to be lowest in the winter season and highest in the summer.

Figure 13. Box and Whisker Plots of Fecal Coliform in Stormwater Data
(Source: Pitt, Maestre and Morquecho 2004)

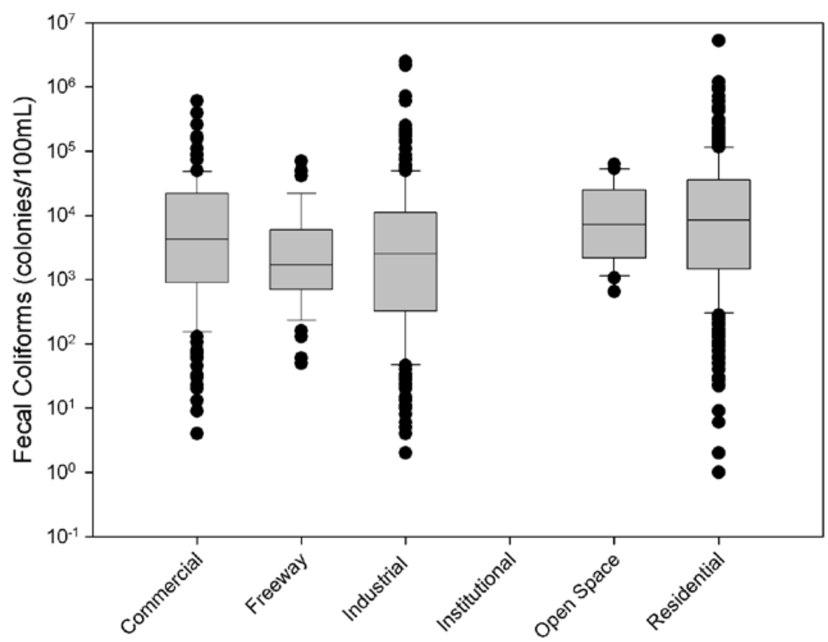


Table 8
Summary of Available Stormwater Data Included in NSQD, Version 1.1

	Fecal Coliform (mpn/100 mL)	Fecal Strep. (mpn/100 mL)	Total Coliform (mpn/100 mL)	Total *E. Coli* (mpn/100 mL)
Overall Summary (3765)				
Number of observations	1,704	1,141	83	67
% of samples above detection	91.2	94	90.4	95.5
Median	5,091	17,000	12,000	1,750
Coefficient of variation	4.61	3.8	2.4	2.3
Residential (1069)				
Number of observations	446	305		14
% of samples above detection	88.3	89.5		100
Median	8,345	24,600		700
Coefficient of variation	5	1.8		1.6
Mixed Residential (615)				
Number of observations	313	156	26	11
% of samples above detection	94.9	98.1	84.6	90.9
Median	11,000	26,000	5,667	1,050
Coefficient of variation	3.3	2.2	1.31	2.1
Commercial (497)				
Number of observations	233	181		
% of samples above detection	88	91.7		
Median	4,300	10,285		
Coefficient of variation	2.8	2.7		
Mixed Commercial (303)				
Number of observations	109	88		
% of samples above detection	94.5	98.9		
Median	4980	11000		
Coefficient of variation	3.3	2.8		
Industrial (524)				
Number of observations	297	195		
% of samples above detection	87.9	93.9		
Median	2,500	13,000		
Coefficient of variation	5.6	6.9		
Mixed Industrial (252)				
Number of observations	115	70	39	
% of samples above detection	95.7	97.1	89.7	
Median	3,033	10,000	16,000	
Coefficient of variation	2.5	2.6	2.4	
Freeways (185)				
Number of observations	49	25	16	13
% of samples above detection	100	100	100	100
Median	1,700	17,000	50,000	1,900
Coefficient of variation	2	1.2	1.5	2.2
Mixed Freeways (20)				
Number of observations	16	12		
% of samples above detection	81.3	93.8		
Median	730	19,000		
Coefficient of variation	2	1.1		
Open Space (68)				
Number of observations	23	22		
% of samples above detection	91.3	90.9		
Median	7,200	24,900		
Coefficient of variation	1.1	1		
Mixed Open Space (159)				
Number of observations	95	75		
% of samples above detection	97.9	100		
Median	2,600	21,000		
Coefficient of variation	2.3	2.4		

Source: Robert Pitt, Alex Maestre, and Renee Morquecho. February 2004.

4.8.3 Bacteria in Metro Denver Area Streams During Wet Weather Flows

The U.S. Geological Survey (USGS) and the Urban Drainage and Flood Control District (UDFCD) released *Summary and Evaluation of the Quality of Stormwater in Denver, Colorado, Water Years 1998-2001* (Scientific Investigations Report 2005-5150) by Clifford Bossong, Michael Stevens, John Doerfer and Ben Glass. The report contains sampling and analysis results for multiple constituents at a network of five monitoring stations in the metro Denver area, with three on the South Platte River and two on tributary streams (Sand Creek and Toll Gate Creek). The data set covers a four-year period from 1998-2001, including fecal coliform and *E. coli* sample analyses, as summarized in Table 9. The overall finding with regard to the 34 bacteria samples collected is that no *E. coli* or fecal coliform sample results during storm flow conditions meet the CWQCC primary contact stream standard of 126 cfu/100 milliliters. Bacteria are elevated in both the rising and falling limbs of the hydrograph, with mean bacteriological concentrations roughly 25 times the stream standard. The table below summarizes the results of the bacteriological samples collected at all five locations. (Samples collected at individual monitoring locations can be obtained in the report from http://pubs.usgs.gov/sir/2005/5150/.)

Table 9. *E. coli* and Fecal Coliform Concentrations in Five Denver-area In-stream Monitoring Locations under Storm Flow Conditions
(Data Source: USGS/UDFCD 2005)

Constituent (#/100 mL)	Hydrograph Position	Number of Samples	Mean	Median	Standard Deviation	Min	Max
E. coli	All samples	34	2,900	2,000	2,500	170	7,900
	Rising limb	16	2,850	2,000	2,300	170	7,900
	Falling limb	18	2,950	2,150	2,730	330	7,900
Fecal coliform	All samples	34	5,490	3,300	7,400	330	35,000
	Rising limb	16	5,050	3,300	5,850	330	24,000
	Falling limb	18	5,880	3,300	8,710	330	35,000

5 MONITORING AND ASSESSMENT OF DATA[19]

A variety of monitoring approaches can be implemented to obtain a better understanding of the sources of bacterial loading to a stream. Costs of monitoring approaches can vary substantially, as well. In general, it is recommended that communities facing *E. coli* TMDLs begin at broad screening level, narrowing down potential sources of contamination and geographic areas of concern in a sequential manner. Communities should first focus on identification and removal of obvious sources of human-caused contributions prior to assessing whether more advanced techniques are necessary to provide “logical proof of source.” This section provides information on monitoring program design, basic sampling approaches and advanced, emerging techniques. More detailed monitoring guidance is beyond the scope of this report; however, a list of supplemental references that may be helpful follows. Much is rapidly changing in terms of advanced sampling and analytical methods, so users of this white paper are encouraged to obtain the latest recommendations for advanced sampling and analysis techniques.

[19] This section addresses Task 3, subtask iii and Task 4 under the Healthy Rivers grant.

Additional References for Monitoring Plan Development

Burton and Pitt 2001. *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*. Lewis Publishers. www.epa.gov/ednnrmrl/publications/books/handbook/index.htm

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EPA 2002. *Guidance for Quality Assurance Project Plans*. EPA QA/G-5, EPA, Office of Environmental Information, Washington, D.C. www.epa.gov/quality/qs-docs/g5-final.pdf

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Keith, L.H. ed. 1996. *Principles of Environmental Sampling*, 2nd ed. American Chemical Society.

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State Water Resources Control Board and the Southern California Stormwater Monitoring Coalition. 2004. *Southern California Coastal Water Research Project, Model Monitoring Program for Municipal Separate Storm Sewer Systems in Southern California*. *Technical Report #419.* ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/419_smc_mm.pdf

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5.1 Monitoring Program Design

The first step in any monitoring program is to clearly define the objectives of the monitoring program. EPA provides detailed guidance regarding Data Quality Objectives (DQOs) (EPA 2006b) and Quality Assurance Project Plans (QAPPs) (EPA 2002). This guidance should be referenced for more detail on developing project plans, which should include the following components:

1) Define Study Objectives
2) Identify Study Goals
3) Identify Information Inputs/Data Needs
4) Define Study Boundaries
5) Develop the Analytical Approach
6) Specify Performance or Acceptance Criteria
7) Develop Detailed Plan of Obtaining Data
8) Assess Reasonableness of Plan and Refine

Representative decisions needed to shape a sampling program for fecal indicator bacteria include:

- Number of samples required
- Number of locations needed
- Frequency of sample collection (e.g., 5 samples within 30 days, monthly, summer season only, etc.)
- Sample types (e.g., dry weather , wet weather or both)
- Sample sources (e.g., stormwater outfalls, instream samples, wastewater discharges)

Pitt (2009)[20] notes that one of the most frequently overlooked factors in designing a monitoring plan is the number of samples required to obtain a statistically valid assessment of water quality. Budget and staff constraints generally limit the number of monitoring events, locations, and parameters to be monitored. Program objectives should be weighed in light of available resources to determine the best mix of monitoring frequency, locations, and parameters. The cost of learning more (i.e., conducting more intensive monitoring) should be compared to the cost

[20] Personal communication with Robert Pitt, University of Alabama, as included in *Urban Stormwater BMP Performance Monitoring* (Geosyntec and Wright Water Engineers 2009).

implications of moving forward too quickly and implementing extensive controls before having learned enough to guide planning, stormwater management commitments, public health risk, and/or negotiations with regulatory agencies.

5.2 Basic Sampling Approaches

The section provides information on basic sampling strategies that communities can use as a reasonable starting point for assessing fecal contamination of waterbodies. Some basics related to sample collection and analysis are provided followed by dry weather screening guidelines.

5.2.1 Sample Collection and Analysis

A variety of microbiological methods are available following ASTM, IDEXX, Standard Methods and EPA methods. A discussion of each method is beyond the scope of this white paper, however, the National Environmental Methods Index (NEMI) website (http://www.nemi.gov), can be referenced for more detailed information on over 30 current methods, including key information such as:

- General method information
- Media
- Method source (e.g., Standard Methods, ASTM)
- Brief method summary
- Scope and application
- Applicable concentration ranges
- Method download (links to websites)
- Interferences from other constituents
- QC requirements
- Sample handling
- Maximum holding time
- Relative cost/effort
- Sample preparation method(s)
- Precision descriptors
- Detection level notes

Representative challenges associated with microbiological sampling (Geosyntec and WWE 2009) include:

- Sample should be analyzed within six hours after sampling and within two hours from receipt of sample in lab for compliance monitoring or within 24 hours for routine monitoring (Standard Methods, 20th ed., Section 9060B); however, a six hour holding time for all samples is highly recommended (EPA 2000).
- Sample preservation requirements include chilling to 1 to 4 degrees C.
- For membrane filtration methods, sources of interference include: high turbidity, toxic compounds, or large numbers of non-coliform (background) bacteria, and organisms

damaged by chlorine or toxic compounds. For example, samples with high levels of colloidal or suspended materials can clog the membrane filter pores and prevent filtration.

For purposes of basic *E. coli* analysis, the IDEXX Colilert method is commonly used in multiple communities in Colorado.

In terms of field equipment requirement for collection of *E. coli* samples, the following equipment list in Table 10 may be helpful.

Table 10. Representative Equipment List for *E. coli* Sample Collection

Sterile plastic sample bottles w/labels and permanent marker
Cooler with ice
Temperature and pH meter
Field data sheets (from Center for Watershed Protection) and pens
Camera
Gallon bucket and stop watch for estimating flow
Measuring tape (for initial dry weather inventory)
GPS unit for documentation of discharge or sample locations
Chest waders to enable stream crossing
Gloves
Outfall System and Other Relevant Maps
Cell phone for emergencies
Nitrile or latex gloves for sampling

5.2.2 Sampling Procedures for Natural Swim Beaches

In Appendix D of State Board of Health Regulations Pertaining to Swimming Pools and Mineral Baths (5 CCR 1003-5), the CWQCD (1998), specifies the following sampling protocol for natural bathing beaches. With the exception of distance spacing procedures along swim beaches, the procedures are also useful for general sampling.

I. Personal Safety and Cleanliness

Good personal safety and cleanliness goes a long way for promoting aseptic sampling. The following measures help to prevent the sampler from becoming part of the sample.

1. Wash hands with a bactericidal soap and water BEFORE and AFTER sampling.

2. Keep all food and drink away from sampling sites, sampling equipment and sample containers.

II. Sampling Method

1. Determine where the samples are to be collected. Collect one sample for approximately every 50 meters of beach. Take the first sample near the middle of the beach and then proceed 50 meters in each direction down the beach to collect each subsequent sample. Collect samples(s) near the beach where swimmers could be exposed to contaminated water entering the lake/reservoir (e.g., storm water drains, natural contours which drain rest room or septic system areas, etc).

2. Collect samples during greatest bather load (i.e., peak usage time). Allow enough time to collect the sample and have it properly shipped or delivered to a lab for analysis. Please be aware that the sample MUST be received by a lab and the analysis begun within 30 hours of collection.

3. Obtain one PRE-STERILIZED sample container for each sample site. Do Not open the container until you are ready to collect the sample. The sample may either be hand collected or a sampling device may be used.

4. Label each container with a water proof marker with the following information: date and clock time of collection, sample location (could be a predetermined ID number specific for each sampling site), and sample number (typically provided by the lab). Complete a Sample Collection Form for Multiple Sampling Sites (again, provided by the lab).

5. Follow the Personal Safety and Cleanliness instructions above. If a sampling device is used, wipe the entire surface of the device with a fresh alcohol swab – allow device to dry before sampling.

6. At each sampling site, wade out into the water far enough so the sample can be collected from where the water is approximately 3 feet deep. Disturb the bottom sediment as little as possible.

7. Open sample container. Be careful not to touch the inside of the container (or lid if present). DO NOT RINSE the container.

8. Collect the sample facing into the wind or current. Make every effort to collect as little disturbed sediment as possible (high levels of turbidity will interfere with the test method).

9a. Hand Sampling – Grasp sample container near the base, invert, and plunge into the water to a depth of approximately 12 inches. Slightly tilt the container into the wind or current and push forward horizontally away from your hand and body to fill. Avoid contact with the bank or bed. Remove container upright and vertically from the water.

9b. Sampling Device – Follow the directions for collection with a sampling device specific for the device.

10. The sample container should be nearly full when it is removed from the water. Pour out some of the sample so the water level is just ABOVE the 100 ml line on the container (about ½ inch of head space in the container is necessary mixing the sample in the lab).

11. Without touching the inside of the container or lid, secure the container shut. Check the container for leakage.

12. When hand sampling, change gloves before collecting another sample. When using a sampling device, wipe the entire surface with a new alcohol swab before collecting another sample.

13. Pack the sample(s) for shipment or delivery to the lab. Ideally, the sample(s) should be shipped with ice (or a frozen gel ice pack) to keep the sample(s) cool during shipment. Be sure to include the sample collection form.

5.2.3 Dry Weather Survey and Sampling

The Center for Watershed Protection and Robert 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, which should be referenced by those embarking on dry weather surveys (http://cwp.org.master.com/texis/master/search/+/form/New_IDDE.html). 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. Appendix B provides a copy of the ORI field form, which has been recommended by the CWQCD for use in Colorado and has been effectively used by several of the case studies in Section 3 of this report. Additionally, Appendix C provides an example dry weather sampling program developed by the CWQCD in support of data collection for the Segment 14 South Platte River TMDL. Table 11 provides a minimum list of monitoring parameters for use in dry weather screening. The basic steps for an outfall reconnaissance inventory include:

1. Collect background data.

2. Develop outfall descriptions.

3. Conduct quantitative characterization of flowing outfalls.

4. Assess and document physical indicators for flowing outfalls

5. Assess and document physical indicators for both flowing and non-flowing outfalls

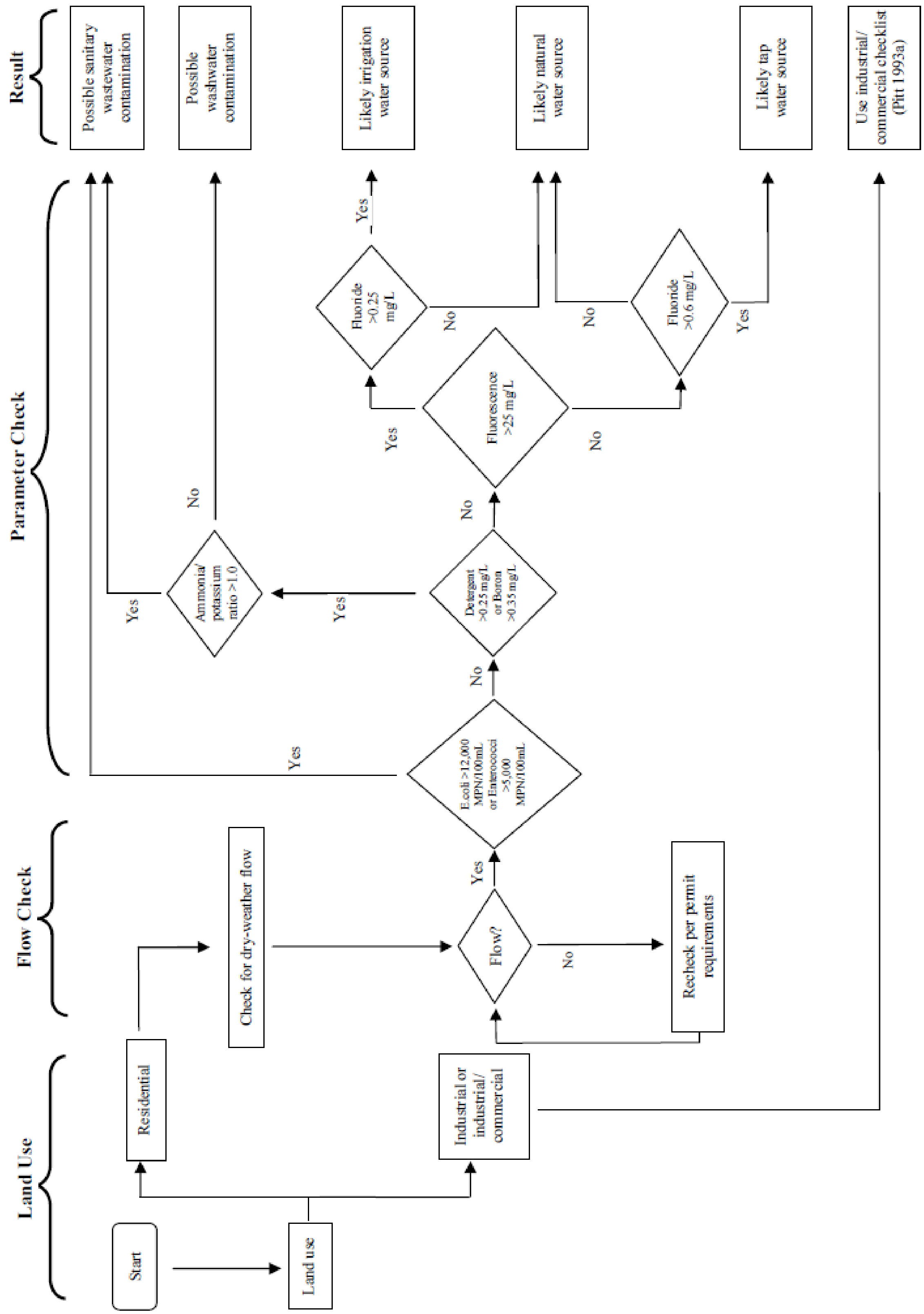
6. Complete initial outfall designation and actions.

Table 11. Representative Monitoring Parameters for Dry Weather Sampling

Analyte	Method	Container	Preservative	Hold Time	Reference
Field Readings					
Flow Rate, gpm	Field	N/A	N/A	N/A	N/A
Discharge Temperature, C	Field	N/A	N/A	N/A	Manufacturer's Specs.
Discharge pH, SU	Field	N/A	N/A	N/A	Manufacturer's Specs.
Other Targeted Constituents	Variable, depending on Monitoring Objectives: Additional monitoring for ammonia, ammonia/potassium ratios, fluoride, phosphorus, and/or the use of optical brighteners may further assist in identifying cross connections.				
Aqueous					
E. Coli, cfu/100 mL	Idexx Colilert	(1) 4 oz. plastic bottle	Cool to 4^o C	6 hrs	Idexx Laboratories, Inc.

Following data collection, a screening procedure can be followed to help guide the next level of source identification, which may or may not require the use of advanced techniques. Shergill and Pitt (2004) suggest such a procedure as shown in Figure 14. Thresholds used for decision making may vary depending on regional or local climate conditions.

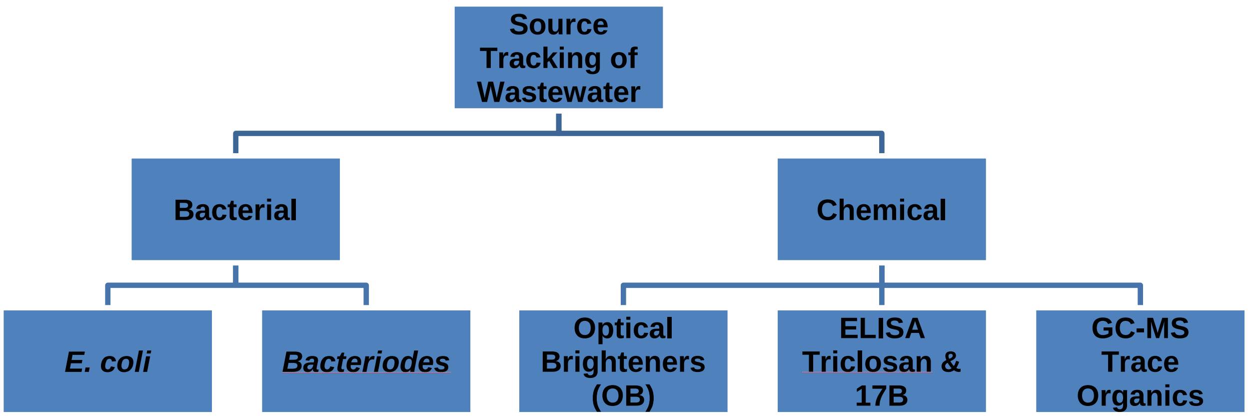
Figure 14. Flow Chart to Identify Most Likely Significant Flow Component Contributing to Elevated Fecal Indicator Bacteria (Source: Shergill and Pitt 2004; Modifies Pitt et al. 1993).



5.3 Advanced Techniques[21]

Advanced techniques are considered to be approaches including microbial and chemical source tracking. Such techniques have been used in various parts of the country with varying degrees of success, and the state of the science continues to evolve on this topic. Figure 15 provides a conceptual overview of how a toolbox of advanced techniques can be combined with conventional *E. coli* sampling with regard to source tracking of wastewater sources, as used by the City of Boulder in recent research.

Figure 15. Example Toolbox of Advanced Techniques (Source: Monroe 2009)



5.3.1 Microbial Source Tracking

Fundamentally, microbial source tracking (MST) falls into two general categories of cultivation-dependent and cultivation-independent methods. Although cultivation is fundamental to numerous methods of MST, the total number of cultivated microbes is relatively low, perhaps as low as 0.1 to 10% of the total biomass of species thought to exist (EPA 2005). For this reason, the ability to accurately collect cultures that truly represent the complete natural microbiota is debatable.

Library-based source tracking (a cultivation dependent method) strives to isolate strains within both the primary (intestinal) and secondary (natural) environment, comparing the two in order to determine origin. However, because both primary and secondary species vary temporally and spatially (Whittam 1989, Gordon 2001, Hansen 2009), specific libraries must be collected within a short time frame for each environment being analyzed. Although the library size is one of the most crucial factors, the number of isolates that constitutes a representative library is still

[21] The discussion of advanced source tracking was adapted from *A Multifaceted Approach to Microbial Source Tracking Within Secondary Environments* prepared by Megan Monroe, City of Boulder, as reported in her Master's Thesis at the Colorado School of Mines.

unknown (Stoeckel et al. 2004). Both library-dependent and independent methods are commonly used in MST.

As an alternative to culture-dependent methods, host-specific MST offers researchers both qualitative and quantitative confirmation of species' existence. Host-specific methods tend to be rapid, specific, sensitive, and most conveniently, do not require the upkeep of a library (Dick 2004). This method can also be used to target a number of host-specific organisms that are difficult to cultivate in laboratory settings (Santo Domingo et al. 2007) and are more resilient regardless of geographic region (Layton 2006). Host specific methods have placed focus on the genus *Bacteroides*, an anaerobic bacterium, within the secondary environment.

Library-independent models have demonstrated high accuracy yet are also prone to false positives (Vogel et al. 2007, Griffith et al. 2005). For this reason, it is important to recognize that natural environmental conditions increase the variability of factors contributing to survival and therefore, possible correlations to traditional indicator species (such as *E. coli*). A 2006 study stated that inconsistencies in *E. coli* and host-specific marker trends suggest that factors controlling the quantity of *E. coli* are different than those controlling *Bacteroides* at specific times of the year (Shanks 2006). This variability and the inconsistencies must be taken into account by regulators when deciding whether host-specific markers or traditional indicator bacteria are more representative of pathogen contamination (Monroe 2009).

Research has acknowledged that currently, there is no reliable stand-alone method for MST, suggesting that the combination of indicators be used in source identification (Savichtcheva 2007). This has led to recent "toolbox" source tracking approaches, which employ multifaceted or "matrix" studies to programmatically identify sources of contamination (Monroe 2009).

5.3.2 Chemical Source Tracking

Chemical source tracking is discussing in the context of trace organics (more expensive) and optical brighteners (inexpensive).

5.3.2.1 Trace Organics

The use of trace organic constituents has been suggested as an alternative indicator to *E. coli* to gauge the likelihood of human waste streams contributing to possible pathogen contamination in an urban environment (Glassmeyer et al. 2005). Trace organics, including many personal care products and contaminants of emerging concern, enter the environment through a number of pathways. For example, only a portion of drugs taken by organisms is subjected to metabolic processes and therefore, a significant amount is excreted via urine and feces (Hirsch et al. 1999) and thus enters the wastewater stream. There are numerous alternate pathways into the environment (Hirsch et al. 1999): constituents such as caffeine are often washed from parking lots, and detergents used in car washing and other outside activities are often wash down storm drains (Hartel et al. 2007).

Anthropogenic constituents have been found to enter, disperse and persist in the environment, perhaps longer than first expected. The 2002 the National Reconnaissance of American Streams Study analyzed 139 streams for organic wastewater contaminants known to be present in high concentrations in human, industrial and agricultural wastewaters (Koplin et al. 2002). The study found that of the 139 streams, 80% contained an organic wastewater contaminant; most frequently found were steroids, insect repellants, stimulants and detergents. Table 12 presents an abbreviated list of trace organic compounds most commonly found in American streams.

Table 12. Abbreviated List of Trace Organic Compounds Indicative of Human Wastewater Streams, Commonly Found in U.S. Streams (Koplin et al. 2002, cited by Monroe 2009)

Constituent	Analysis Method	Class	Possible Concern
Triclosan	ELISA & GC/MS	Antimicrobial	Antibiotic resistance
Estradiol	ELISA & GC/MS	Estrogen	Endocrine disruption
Caffeine	GC/MS	Stimulant	Anthropogenic
Nonylphenol, LAS	GC/MS & ELISA	Surfactant	Endocrine disruption
Steroids	GC/MS	Steroids	Endocrine disruption

Organic wastewater contaminants are commonly anthropogenic and therefore can be used to identify wastewater discharges and/or cross-connections in urban areas and associated stormwater systems. The use of trace organics as an alternative wastewater indicator offers an additional benefit: in general, the signatures of industrial and domestic waste streams vary, with specific constituents indicative of a variety of specific domestic and/or industrial operations. For example, triclosan, a common active ingredient in antibacterial soaps, as well as optical brighteners, used in detergents are ubiquitous in human wastewater streams and are commonly used in domestic operations and personal care products. Conversely, constituents such as nonylphenol are more commonly used in commercial cleaning applications and are more likely to indicate industrial waste streams. Often such constituents are found in extremely low concentrations; different analytical methods offer varying degrees of sensitivity. Two of the most common analytical methods for trace organics that offer detection at very low concentrations include gas chromatography-mass spectrometry (GC-MS) and Enzyme-Linked Immunosorbant Assays (ELISA).

ELISA utilizes a competitive reaction with enzyme labeled constituents. After the competitive reaction is complete, color development can be quantified by a spectrometer at a wavelength of 450 nm. In recent studies (Lietz & Meyer 2006, Farre et al. 2007), the ELISA analysis has proven to be a convenient tool that has the potential to quickly analyze numerous samples in a short amount of time. These characteristics make the ELISA method a useful tool in analysis of trace organic compounds, which can indicate human contamination to varying degrees of certainty.

GC-MS offers a sensitive and more specific alternative to ELISA. Despite the fact that municipalities often have limited access to GC-MS, the research industry can utilize this powerful tool for precise analyses. In general, for the two-stage analysis, GC-MS first utilizes a capillary column to separate volatized compounds based on retention times. After exiting the column, compounds enter the mass spectrometer where they are ionized and can be identified based on their mass to charge ratios. With the precision of GC-MS, samples can reliably be processed to the parts per trillion concentrations.

5.3.2.2 Optical Brighteners

In addition to trace organics, a relatively inexpensive and simple fluorescence method has been shown to be a successful tool in identifying wastewater contamination. For example, possible sources of *E. coli* from cross-connections and illicit discharges can be evaluated utilizing the presence of compounds known as optical brighteners, or fluorescent whitening agents (FWAs). Optical Brighteners are organic compounds added to a large number of car care products and household products, including toothpaste and detergents to enhance color illumination. The aromatic-ring structure of optical brighteners contains double bonds that can absorb UV light (360 nm-365 nm) which then emits light in the blue range (400 nm-440 nm). For this reason, optical brighteners can be detected easily using fluorometry. Furthermore, optical brightener compounds are ubiquitous in human wastewater streams, and are therefore, indicative of human contamination when found in the environment.

Fluorometry has proven to be successful in small water bodies, yet also has known imperfections. For example: optical brighteners photo-decay quickly (Kramer et al. 1996); optical brighteners are often too dilute in the natural system to detect (Dickerson et al., 2007); and natural organic material fluoresces and therefore, must be accounted for (Hartel et al., 2007 & 2008). Despite these flaws, it is generally accepted that screening for optical brighteners offers a feasible and inexpensive method to quickly scan a system.

5.4 Recommended Monitoring Approach

The general consensus of the *E. coli* Work Group regarding monitoring is to proceed in a stepwise fashion from simpler to more complex monitoring approaches until “logical proof of source” can be reasonably concluded. The endpoint will vary depending on the complexity of the watershed conditions. Communities should carefully weigh the costs of additional study to the expected benefit of the findings.

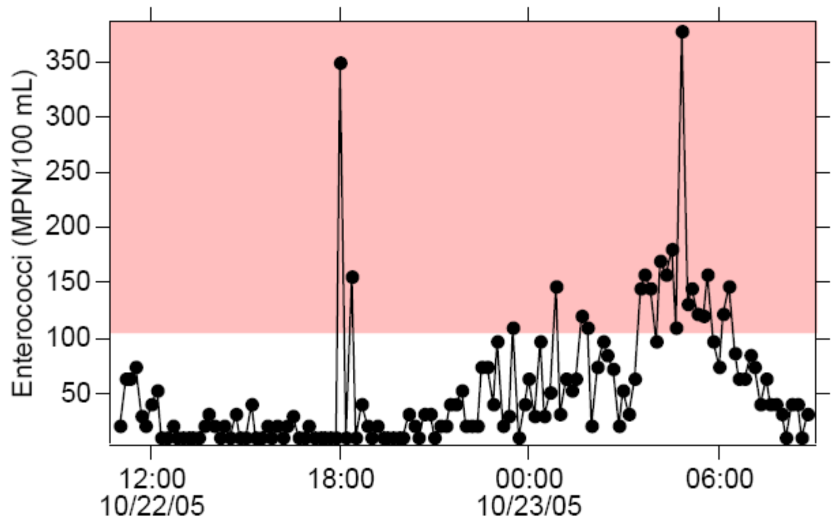
5.5 Interpreting Bacteria Data

From a regulatory perspective, the CWQCD uses the geometric mean value to assess attainment with recreational water quality criteria. The geometric mean is calculated as the n^{th} root of the product of n values. The geometric mean is used for regulatory purposes because it lessens the impact of extremely high or low values, relative to the arithmetic mean. In other words, it reduces overestimation due to sample variation. Interpretation of bacteria data is more complex than for many conventional pollutants. At the simplest level, those interpreting bacteria data should be aware of the following issues:

- Widely varying sample results at the same sample location during the day. See Figure 16 example from EPA (2007a).

- Potentially high relative percent difference (RPD) values for replicate samples.
- Seasonal and temperature effects. The averaging period associated with the data set is significant in this regard.
- Difficulty in drawing statistically significant conclusions due to large coefficients of variation.
- Potential difficulty in correlating indicator bacteria concentrations with pathogens.

Figure 16. Variation in Enterococci Sample Results (MPN/100 mL) at 10 Minute Sample Intervals at a California Beach (Source: EPA 2007a, citing unpublished ENTEROLERT assay results from A.B. Boehm)



5.6 Modeling

Although use of software models for development of TMDLs is common for many conventional water quality pollutants, use of computer models for bacteria is much more controversial due to unknowns associated with fate and transport of bacteria. Additionally, models that predict bacteria removal based on BMPs have further constraints given the uncertainty related to the effectiveness of BMPs to remove bacteria. This section describes some of the models that have been used for bacteria modeling. Prefacing this section, it is important to be aware of opinions expressed by two separate expert panels regarding the role of modeling. For example, in the EPA (2007a) Expert Scientific Panel report, the modeling task group concluded:

- "There is limited understanding regarding the sources of microorganisms and their fate and transport in the aquatic environment, so the use of deterministic, process-based models for criteria development and implementation is not practical for most U.S. water quality managers within the next five years (2012). Rather, simple heuristic, statistical models that do not necessarily require an understanding of processes and mechanisms are more realistic for criteria development and implementation within the next 5 years."

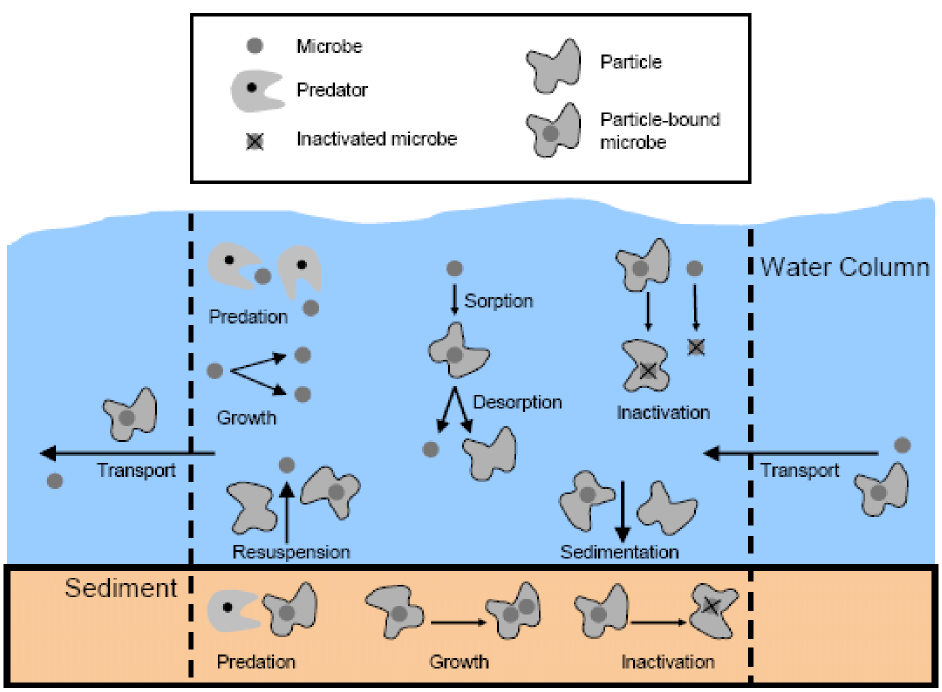
- "Sanitary investigation models that explore the relationship between land use, watershed attributes, and water quality are already in place and have been used in TMDL implementation (criteria implementation); however, they have not been specifically applied to criteria development. Creating a TMDL-like model for a waterbody prior to impairment may be viewed as proactive rather than reactive. Such models in use include deterministic models like Hydrological Simulation Program-Fortran (HSPF) and Stormwater Management Model (SWMM) for watershed loading, and CE-QUAL models for pathogen fate and transport (EPA, 2002). Feedback from some environmental engineers and consultants who apply these models to pathogen and fecal indicator transport suggests they provide highly uncertain predictions for pathogen and indicator concentrations and fluxes (Ali Boehm, Stanford University, personal communication, 2007)." (p. 110)

- "…models developed from large data sets are generally considered better than models developed from smaller data sets." (p. 113)

Figure 17 was provided in the EPA (2007) report based on the work of Olivieri to illustrate the complex issues associated with bacteria fate and transport.

Figure 17. The Possible Fates of Microbes (Fecal Indicators and Pathogens) in Environmental Water and Sediment

(the fate of nucleic acid may be different; this figure does not include those sources) (Source: EPA 2007, as adapted from Olivieri et al. 2007).



Additionally, the WERF (2009) Expert Report provided these conclusions with regard to modeling:

> *The water matrix group was of the opinion that the only way to understand all the important factors that may affect the relationships between health effects and indicators/water quality is through modeling efforts. As no two watersheds are the same, there is a possibility that similar beaches at one location may have a different relationship (between indicators and human health effects) as compared to beaches at another location due to significant differences in the sources, transport, and microbial fate. The water matrix group is of the opinion that the only way to effectively transfer the results from one watershed to another would be to evaluate similarities between watersheds with respect to potential sources and geographic distribution of those sources. Such efforts require a fundamental understanding of the fate and transport of indicators and pathogens, which is currently lacking in the literature and, therefore, limits the ability to apply modeling approaches to support regulatory purposes. This group also indicated that questions regarding differences between pathogens and indicators in terms of their regrowth and persistence in sediments/soils and associated waters need to be answered before epidemiologic data from Great Lakes and marine coastal areas can be applied with confidence to inland flowing waters. (WERF 2009, Executive Summary, p. ES-3).*

5.6.1 Overview of Models—Texas Bacteria TMDL Task Force 2007

An independent, comprehensive evaluation of models for use with bacteria was beyond the scope of the current work group effort; however, the Texas Bacteria TMDL Task Force completed a similar exercise in 2007.[22] The findings of the Texas evaluation effort appear to be reasonable and provide basic information that may serve as a starting point for those considering use of models in evaluating bacteria loading in their watershed. Table 13 summarizes the models evaluated by the Texas Commission, followed by their conclusions regarding the use of models in TMDLs.

[22] The model review was led by Dr. Hanadi Rafai, University of Houston and the overall Texas Task Force was led by Dr. C. Allan Jones of the Texas Water Resources Institute (http://twri.tamu.edu/). Summary used with permission from Drs. Jones and Rafadi.

Table 13. Bacteria Modeling Matrix Developed for Texas Commission on Environmental Quality and Texas State Soil and Water Conservation Board (Source: Bacteria TMDL Task Force Report, June 4, 2007; http://twri.tamu.edu/bacteriatmdl/FinalReport.pdf)

Model		LDC	Spatial Explicit Statistical Models			Mass Balance Models			Mechanistic/Hydrologic/WQ			
			ArcHydro	SPARROW	SELECT	BLEST	BSLC	BIT	HSPF	SWAT	SWMM	WASP
Watercourse Type	Watersheds		x	x	x	x	x	x	x	x	x	
	River/Stream	x	x	x	x	x	x	x	x	x		x
	Lake/Reservoir		x	x	x	x	x	x				x
	Fresh/Saltwater Estuarine		x	x	x	x	x	x				x
TMDL Phase	Development	x	x	x	x	x	x	x	x	x		x
	Implementation		x			x			x	x		x
Model Type	Analytical	x	x	x	x	x	x	x				
	Numerical								x	x	x	x
Spatial Dimensions	1-D			x	x				x	x	x	x
	2-D											x
	3-D											x
Time Scale	Steady-state			x						x		x
	Time Varying								x	x	x	x
	Single Storm Event				x				x	x	x	
	Continuous in time			x					x	x	x	x
Watershed Characteristics	Rural	x	x	x	x	x	x	x	x	x		
	Urban	x	x	x	x	x	x	x	x	x	x	
	Sediment transport			x	x				x	x		x
In-Stream Processes	Bacteria Regrowth											
	Bacteria Die-off			x					x	x		
	Settling								x	x		
	Re-suspension					x			x	x		
WLA Sources	WWTF			x	x	x			x	x		x
	Storm Sewers			x	x	x			x	x		x
LA Sources	Septic Tanks			x	x	x	x	x	x	x		
	Direct Deposition					x	x	x	x	x		x
	Bed Sediment					x			x			x
Cost		$	$$			$$			$$$			

Notes: 1. Shaded areas: not applicable.

The Texas Task Force (2007) stated the following conclusions:

- *The expectations from using a model for TMDL development or implementation must be realistic and commensurate with the level of data and information available for the watershed in question. The model used will only be as good as the data used to develop it.*

- *Models should be used as part of the TMDL framework and not as an only tool for decision-making. Models should continually evolve as the knowledge base used in developing them changes.*

- *In-stream sediment settling and re-suspension processes are not well represented in most models available to date and their roles in bacterial concentrations in water bodies are poorly understood.*

- *Bacteria regrowth and decay are also not well represented in presently available models. Bacteria death is typically approximated using first-order expressions, and the first-order decay constant is determined from controlled laboratory and/or field experiments.*

- *Transient (time-varying) models such as HSPF provide bacterial concentrations on a very detailed time scale (minutes or hours), whereas most bacterial measurements are made much less frequently (once a week or once a month or once a quarter) thus complicating calibration and validation of the model.*

- *The models that are hydrologically driven such as HSPF are biased toward high flow conditions since rainfall is the main driver for flow in the water body. These models have to be fine-tuned to represent bacterial sources in dry weather conditions (under mostly effluent dominated conditions).*

- *The main advantage of simple models such as LDC, SELECT, BLEST or BIT is in determining required reductions to meet the standard.*

- *The main value of detailed models is that they allow for spatial and temporal analysis of different reduction strategies (i.e., BMPs) and their effectiveness in improving in-stream water quality.*

- *Sensitivity and uncertainty in data, parameters and models should be considered and assessed.*

- *The results of modeling exercises are heavily dependent on the precision of the model as determined by calibration activities. For this reason, calibration specifications for model application should be explicitly stated and standardized throughout all applications.*

5.6.2 Recommendations Related to Model Use

Currently, both the EPA and WERF expert panels and others such as the Texas TMDL Task Force have concurred that there are significant limitations associated with use of models to predict bacteria loading and reductions associated with various management measures. Generally, these limitations can be described as:

- Limited understanding of fate and transport mechanisms in the natural environment.
- Highly variable performance of BMPs with regard to bacteria removal.

Ongoing research related to factors affecting fate and transport of BMPs may help to improve models in the future. Until that time, computer models should be used with care and supplemented with monitoring data. Simple spreadsheet models and possibly Load Duration Curves, as a screening tool, may be the best approaches at this time. Novick (2009) reports that USGS and others have had some success using simple regression equations to develop predictive *E. coli* models and that others have had success using neural networks and Bayesian statistics to develop models (Rasmussen 2003; Christensen et al. 2002; Mas and Ahlfeld 2007, Morrison et al. 2003).

6 BEST MANAGEMENT PRACTICES FOR *E. COLI*[23]

Although much has been written and researched on bacteria-related issues, many questions remain on how to most effectively address bacteria in receiving waters and urban runoff. Generally, source controls should be implemented as a primary BMP strategy. Based on available structural BMP studies to date, treatment of runoff using structural BMPs is not expected to reduce *E. coli* concentrations in runoff down to stream standards in many (if not most) cases.

6.1 Urban Source Controls

A variety of general strategies to reduce sources of bacteria loading are summarized in Table 14.

[23] This section serves as the Task 2, subtask iii deliverable under the Healthy Rivers grant.

Table 14. Sources and Strategies for Bacteria Reduction

Bacteria Source	BMP/Management Strategy
Urban Areas	
Domestic Pets (dogs and cats)	Signage to pick up dog waste, providing pet waste bags and garbage cans. Enforcement of pet waste ordinances. Use of dog parks away from environmentally sensitive areas.
Urban Wildlife (rats, bats, raccoons)	Reduce food waste sources from commercial waste/grease spillage entering the storm drain.
Illicit connections to MS4s	Identification and removal of illicit connections through municipal stormwater programs.
Leaking Sanitary Sewer Lines	"TVing" sanitary sewer lines to identify leaks or breaks that may cause seepage of untreated sanitary wastewater to streams or storm sewers.
Illegal dumping	Enforcement related to illegal dumping by municipal stormwater programs.
Runoff from urban areas	Encouraging low impact development and development designs that minimize directly connected impervious areas, allowing stormwater to seep into the ground rather than run off into storm sewers. Implementing BMPs found in local or regional criteria manuals such as Volume 3 of UDFCD Storm Drainage Criteria Manual.
Dry weather irrigation flows	Dry weather flows from storm sewers can be reduced through better controlled lawn/park irrigation practices.
Transient Populations	Support of city shelters and services to reduce homelessness.
Open Space	
Waterfowl/ Canada Geese	Population controls (e.g., egg oiling, addling, dog harassment). See www.geesepeace.org for more information. Habitat modification is another potential BMP.
Wildlife: Beavers, deer, raccoons, coyotes, mice	Consult with Colorado Division of Wildlife (CDOW); consider controls to make storm drains less desirable homes; beaver trapping and relocation may be a consideration.
Domestic Pets	See description above. Also, strategic trail design incorporating vegetative buffers and grading away from the stream.

Also see "Removing Bacteria from Runoff," *Nonpoint Source News-Notes*, August, 2004: Issue #73 for more detail on some of these practices, selected excerpts from EPA (2004) regarding several practices in Table 14 include:

- *Riparian buffering—Vegetated or forested riparian zones can be used to provide buffers between impacted land uses and water resources in both urban and agricultural areas. The riparian zones help in two ways. First, they physically separate high concentrations of humans and domesticated animals from waterways. Second, the riparian zones serve as overland filters for treating animal waste to the extent that these zones are directly downslope of the impacted land use.*

- *Street sweeping—Research to quantify a bacteria load reduction benefit from street sweepers is lacking. A 1993 study by Roger Bannerman with the Wisconsin Department of Natural Resources identified streets and parking lots as significant sources or carriers for bacteria and other urban pollutants. Bacteria have an affinity for attaching themselves to fine sediments, and can form biofilms on gutters, both of which can be swept away. It is important to use sweepers that have good efficiencies for removing the tiniest particles. A new generation of high efficiency vacuum street sweepers has reversed the criticisms that earlier types of sweepers performed poorly in the Nationwide Urban Runoff Program studies of the early 1980s (see News-Notes Issue #56, February 1999, "State-of-the-art Street Sweepers Could Reduce Suspended Solids in Receiving Waters").*

- *Pooper scooper enforcement, public campaigns, and the free market—While many localities have some form of legal code banning pet waste in public areas, most localities put little or no effort into enforcement. A combination of ratcheting up enforcement and public education campaigns has been effective from New York to Texas.*

- *Dog parks as BMPs—An environmentally friendly dog park is one that is sited away from environmentally sensitive developed features, such as floodplains, and provides a safe off-leash fenced area, public education signage, free pooper scooper bags, and sanitary trash receptacles.*

6.2 Non-structural BMPs for Agricultural Areas

The EPA Pathogen TMDL Guidance (EPA 2001) identifies a variety of agricultural BMP source control practices in the general order of minimizing sources, minimizing movement (transport) and treating water, as summarized in Table 15. Other considerations in agricultural areas include enforcement of existing regulations related to Onsite Wastewater Treatment Systems (e.g., septic systems) and repair of failing systems.

Table 15. EPA Recommended Agricultural Source Control BMPs for Bacteria
(Source: Novotny and Olem, as cited in EPA 2001)

	Types of Controls		
Methods of Control	**Structural**	**Vegetative**	**Management**
Minimize source	Fences (livestock exclusion)		Animal waste management, especially proper application rate and timing
Minimize movement	Animal waste storage; detention pond	Filter strips; riparian buffer zones	Proper site selection for animal feeding facility; proper waste application rate
Treat water	Waste treatment lagoon; filtration	Artificial wetland; rock reed microbial filter	Recycle and reuse

Source: Novotny and Olem, 1994.

With regard to cattle and horse management, the U.S. Department of Agriculture (USDA) and others provide a variety of alternatives related to source controls that provide alternatives to fencing such as grazing management strategies; off-site water sources; controlled access points; fencing; vegetative barriers. Given the prevalence of cattle grazing on both public and private lands through the West, many studies and guidance documents have been developed for BMPs that can help minimize cattle impacts (e.g., Northwest Resource Information Center 1993; USBLM and USFS 1997; Ehrhart and Hanson 1997; EPA 2006a). Although fencing is often the first thought that comes to mind, it is noteworthy that fencing is not considered to be "the optimum solution in most cases" (Erhart and Hanson 1997). A "menu" of practices to proactively manage grazing areas, including managing cattle access to riparian areas, is described in *Effective Cattle Management in Riparian Zones: A Field Survey and Literature Review* (Ehrhart and Hansen 1997). A typical site would pick and choose practices that are practical for their specific site conditions, not necessarily implement all of these. A brief list of these practices includes:

- Off-stream water (e.g., troughs).
- Stable access points.
- Salt and mineral block placement (e.g., away from streams).
- Improved upland forage.
- "Riding" the herd (e.g., to redirect it away from the stream).
- Home ranges (e.g., culling cattle that tend to loiter in a riparian area so the practice isn't passed to offspring).
- Fenceless fences (e.g., ear tags that function like shock collars).
- Drift fence (e.g., obstacles to deter cattle from certain areas).

- Turn-in location (e.g., releasing the cattle into the pasture further away from the riparian area).

- Riparian pastures (e.g., controlling how riparian areas are grazed).

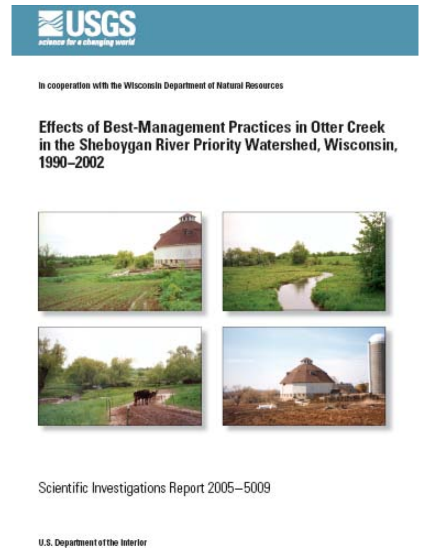
- Smaller pastures (e.g., using more small pastures with short-duration grazing).

- Fencing.

In another reference, *Managed Grazing in Riparian Areas* (Bellows 2003), published by the National Center for Appropriate Technology (NCAT), Appropriate Technology Transfer to Rural Areas (ATTRA), similar types of recommendations are made. Bellows (2003) provides this additional guidance:

> Farmers and ranchers use managed grazing practices in various areas of the country to improve pasture productivity, increase livestock growth, and protect riparian areas (Lyons et al. 2000; Clark 1998; Skinner and Hiller 1996). The term "managed grazing" encompasses a range of strategies and philosophies. But the most critical component is management. Most riparian grazing results suggest that the specific grazing system used is not of dominant importance, but good management is, with control of use in riparian areas a key item (Clary and Webster, 1989). Other critical components of riparian grazing practices include (Leonard et al. 1997; Clary and Webster 1989):
>
> - Combining managed upland grazing practices with good riparian grazing management.
>
> - Installing alternative watering systems and controlling grazing to minimize deposition of manure in or near streams.
>
> - Adapting grazing management practices to local conditions and to the species being grazed.
>
> - Employing long-term rest from grazing when riparian areas are highly degraded.
>
> - Employing short-term or seasonal rest to protect wet streambanks and riparian vegetation that is emerging, regenerating, or setting seed.
>
> - Maintaining streambank structure and function by maintaining a healthy cover of riparian vegetation.
>
> - Using a flexible approach that involves documenting mistakes so that they are not repeated.

Decision-makers should be aware that implementation of non-structural BMPs in agricultural areas may not necessarily reduce fecal indicator bacteria below stream standards. As one



example, the USGS (Corsi et al. 2005) released a study of the effects of BMPs in a priority watershed in Wisconsin that included these BMPs: streambank protection and fencing, stream crossings, grade stabilization, buffer strips, various barnyard-runoff controls, nutrient management, and a low degree of upland BMPs. Although the BMPs were beneficial in reducing a variety of pollutants, the fecal coliform concentrations in base-flow samples increased sharply over the study period. The cause of the increase was not determined.

6.3 Structural BMPs[24]

When properly designed, constructed and maintained, structural stormwater BMPs have been shown to reduce pollutant concentrations and loads for multiple constituents. For indicator bacteria, however, performance is variable—some BMPs may hold potential for reducing bacteria loading, whereas other BMPs appear to have minimal or even negative effects. These findings are based primarily on data compiled in the International Stormwater BMP Database (www.bmpdatbase.org), along with several other studies recently completed by researchers. The *E. coli* Work Group members were aware of only one publically-available structural BMP study in Colorado involving bacteria. This study was sponsored by Urban Drainage and Flood Control District and is discussed in Section 6.3.2.

6.3.1 International Stormwater BMP Database Performance Summary

The International Stormwater BMP Database contains over 100 paired *E. coli* monitoring events at 12 sites (Table 16) and nearly 500 paired fecal coliform monitoring events at 61 sites (Table 17. The majority of the *E. coli* data sets are in Portland, Oregon and are from sites with Low Impact Development BMPs such as bioswales and green roofs. The fecal coliform data set is more geographically diverse with studies in California, Florida, Virginia, Ontario, New York, Texas, Georgia, North Carolina and Oregon.

A few caveats related to this data set include:

- The number of events sampled for studies presented in Tables 16 and 17 varies. For the *E. coli* data set, an average of 10 storms per BMP was monitored. For fecal coliform, an average of eight storms per BMP was monitored; however, six of the studies (10 percent of the studies) had fewer than three sampling events, resulting in their exclusion from subsequent analysis.
- Although a few event mean concentration (EMC) data sets for bacteria exist in the Database, the majority of samples are grab samples, typically because a six hour maximum holding

[24] The majority of the text is this section has been extracted directly from papers by Clary, Jones and Urbonas (2009) and Clary, Jones, Urbonas and Wagoner (2008). The underlying data set forming the basis of this analysis can be obtained from www.bmpdatabase.org.

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

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

Table 16. Summary of *E. coli* Data for 114 Monitoring Events in the International Stormwater BMP Database

Summary of *E. coli* Data for 114 Monitoring Events in the International Stormwater BMP Database 2009					
BMP Name	**City**	**State**	**# of Events**	**Geometric Mean Inflow (#/100 mL)**	**Geometric Mean Outflow (#/100 mL)**
Bioswale					
Bureau of Environmental Services (BES) Bioswale Native[1] East	Portland	OR	6	1,079	3,035
BES Bioswale Non-Native West	Portland	OR	6	1,079	2,529
Russell Pond Bioswale	Portland	OR	7	780	575
WPCL Bioswale East	Portland	OR	10	2,121	3,789
WPCL Bioswale West	Portland	OR	10	2,121	3,286
Bioretention					
Hal Marshall Bioretention Cell	Charlotte	NC	13	275	17
BES Water Garden	Portland	OR	6	5,024	184
Green Roof					
Hamilton Ecoroof East Roof 2001 & 2002	Portland	OR	8	NA	27
Hamilton Ecoroof West Roof 2001 & 2002	Portland	OR	8	NA	25
Ponds and Sand Filters					
Heritage Estates Stormwater Manag. Pond	Richmond Hill	ON	25	1,271	109
Lexington Hills - Detention Pond	Portland	OR	10	399	272
Parkrose Sand Filter	Portland	OR	5	2,099	79

[1] Refers to vegetation types planted in bioswales.

Table 17. Summary of Fecal Coliform Data in Stormwater BMP Database

Summary of Fecal Coliform Data for 485 Monitoring Events in the International Stormwater BMP Database 2009[1]					
BMP	**City**	**State**	**# of Events**	**Geometric Mean Inflow (#/100 mL)**	**Geometric Mean Outflow (#/100 mL)**
Bioswales					
Altadena (strip)	Altadena	CA	3	386	459
Carlsbad Biofiltration Strip[2]	Carlsbad	CA	2	84,853	47
I-605/SR-91 Strip[2]	Cerritos	CA	2	490	1,122
US 183 at MoPac Grass Filter Strip	Austin	TX	10	59,606	37,321
Cerritos MS[2]	Cerritos	CA	2	20,199	2,915
I-605/SR-91 Swale[2]	Cerritos	CA	1	5,000	900
I-5/I-605 Swale[2]	Downey	CA	2	65	105
I-605 / Del Amo	Lakewood	CA	4	9,460	9,168
SR-78 / Melrose Dr	Vista	CA	3	1,366	239
Key Colony Swale	Key Colony Beach	FL	6	355	380
BES Bioswales - East Swale	Portland	OR	6	1,116	3,176
BES Bioswales - West Swale	Portland	OR	6	1,116	2,852
Russell Pond Bioswale	Portland	OR	4	677	795
WPCL Bioswale East	Portland	OR	10	2,924	4,724
WPCL Bioswale West	Portland	OR	10	2,924	4,134
Alta Vista PUD w/ swales	Austin	TX	19	36,193	25,428
Monticello High School Bioretention Area	Charlottesville	VA	3	5	1
Dayton Biofilter - Grass Swale	Seattle	WA	5	2,628	7,336
Detention Basins					
I-605 / SR-91 EDB	Cerritos	CA	7	654	813
I-5/Manchester (east)	Encinitas	CA	4	978	6,708
I-15/SR-78 EDB	Escondido	CA	9	438	766
I-5 / SR-56	San Diego	CA	9	NA	1,103
The Reserve at DeBary	DeBary	FL	48	682	45
Key Colony Detention Pond	Key Colony Beach	FL	10	95	68
Mountain Park	Lilburn	GA	9	168	1,839
BMP 13, West Lake Drive	Valhalla	NY	13	14,184	5,454
Lexington Hills - Detention Pond	Portland	OR	7	529	289
I-5 / I-605 EDB	Downey	CA	5	2,237	325
Green Roof					
Hamilton Ecoroof East Roof 2001	Portland	OR	4	NA	34
Hamilton Ecoroof East Roof 2002	Portland	OR	3	NA	11
Hamilton Ecoroof West Roof 2001	Portland	OR	4	NA	13
Hamilton Ecoroof West Roof 2002	Portland	OR	3	NA	28
Media Filter					
BMP 57, Nannyhagen Road	Mt. Pleasant	NY	6	NA	765

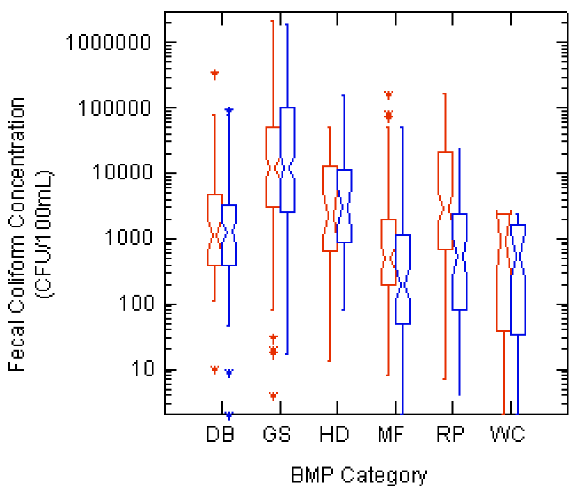
Summary of Fecal Coliform Data for 485 Monitoring Events in the International Stormwater BMP Database 2009[1]					
BMP	**City**	**State**	**# of Events**	**Geometric Mean Inflow (#/100 mL)**	**Geometric Mean Outflow (#/100 mL)**
Kearny Mesa MS	San Diego	CA	7	200	170
Clear Lake Packed Bed Filter	Orlando	FL	11	2,653	1,012
Lake Olive VVRS	Orlando	FL	5	4,710	859
Hal Marshall Bioretention Cell	Charlotte	NC	14	1,278	172
Lakewood P&R	Downey	CA	6	122	175
Via Verde P&R	San Dimas	CA	6	393	232
La Costa P&R	Carlsbad	CA	7	538	33
Escondido MS	Escondido	CA	8	377	182
Foothill MS (Sand Filter)	Monrovia	CA	4	8,284	1,531
I-5/SR-78 P&R	Vista	CA	7	510	1,254
Eastern Regional MS SF	Whittier	CA	6	627	200
Parkrose Sand Filter	Portland	OR	4	1,602	83
Manufactured Device					
I-210 / Filmore Street	Lake View Terrace	CA	18	1,972	2,676
I-210 / Orcas Ave	Lake View Terrace	CA	13	2,681	4,187
Retention Pond					
I-5 / La Costa (east)	Encinitas	CA	6	4,619	42
DUST Marsh Debris Basin	Fremont	CA	9	1,929	515
Indialantic Project H Pond[2]	Indialantic	FL	2	387	77
Largo Regional STF	Largo	FL	24	58	5
FL Blvd Detention Pond	Merrit Island	FL	5	8,746	530
Jungle Lake (1993)	St. Petersburg	FL	4	2,320	241
Jungle Lake (1995+)	St. Petersburg	FL	7	2,247	411
Shawnee Ridge Retention Pond	Suwanee	GA	5	946	35
BMP 12, Malcolm Brook	Valhalla	NY	16	4,231	2,475
Heritage Estates Stormwater Manag. Pond	Richmond Hill	ON	22	1,446	133
Wetland					
BES Water Garden	Portland	OR	5	7,087	108
DUST Marsh System A	Fremont	CA	8	455	223
DUST Marsh System B	Fremont	CA	8	566	291
DUST Marsh System C	Fremont	CA	9	280	405

[1]Two porous pavement studies and one vegetated buffer strip were excluded from the analysis due to data limitations.
[2]BMPs with less than three studies have been excluded from subsequent analysis due to small sample size, but have been retained in this table for general information. The geometric mean is not a meaningful statistic for these studies.
NA = not available.

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

In addition to review of the tabulated data, graphical presentation of the data is useful in identifying potential trends. The International Stormwater BMP Database analysis protocols (Geosyntec and WWE 2007) used for conventional water chemistry analysis focus on the effluent concentrations achieved by various BMPs (e.g., is the BMP helping to protect receiving water quality?) and whether there is a statistically significant reduction between influent and effluent concentrations (e.g., is the reduction in reported means real?). Several other factors such as changes in runoff volumes are also considered. In keeping with this approach, Figure 18 provides notched box and whisker plots of the fecal coliform data according to BMP type for several categories of BMPs. The geometric mean is used as a benchmark in these plots because attainment of stream standards is based on the geometric mean of the bacteria data. The EPA promulgated instream standard for primary contact recreation is currently 126/100 mL for *E. coli* and was 200/100 mL for fecal coliform prior to EPA's adoption of *E. coli* as a pathogen indicator. Figure 18 indicates that swales (GS) and detention basins (DB) do not appear to effectively reduce bacteria in effluent concentrations and may possibly increase bacteria concentrations. Although the effluent values are still above primary contact recreation standards, media filters and retention ponds show potential promise in reducing bacteria counts, based on statistically significant differences between the influent and effluent medians (i.e., the 95th percentile confidence limits for the medians of the influent and effluent data sets do not overlap). Data sets for wetlands and manufactured devices are not of adequate size to draw meaningful conclusions.

Figure 18. Notched Box and Whisker Plots Summarizing Paired Fecal Coliform BMP Monitoring Results (Source: International Stormwater BMP Database 2007)



Key:
Inflow (Red)
Outflow (Blue)

DB= Detention Basin
GS= Grass Swales
HD=Manufactured Devices
MF= Media Filters
RP= Retention Ponds
WC=Wetland Channels

It is also worthwhile to evaluate the performance of individual BMPs. Bar charts presenting the geometric mean concentrations for the influent and effluent for each study were prepared. Figure 19 provides the geometric mean influent and effluent concentrations for *E. coli* studies in the database. A series of similar plots for fecal coliform were also prepared according to BMP type (Clary et al. 2008) based on the data summarized in Table 17, but are not reproduced in this paper due to space limitations. A representative plot for grass swales is provided in Figure 18.

Figure 19. Bioswale (Grass Strips/Swales) Fecal Coliform Data for 13 Studies in the International Stormwater BMP Database

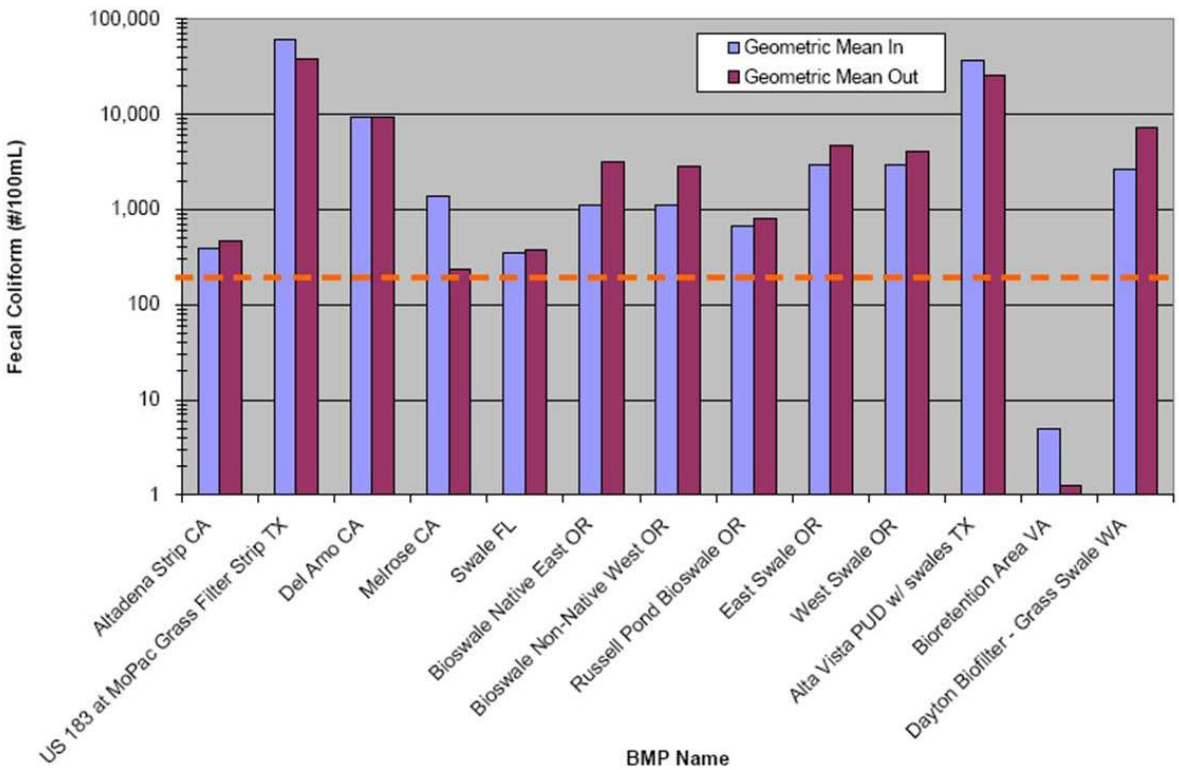
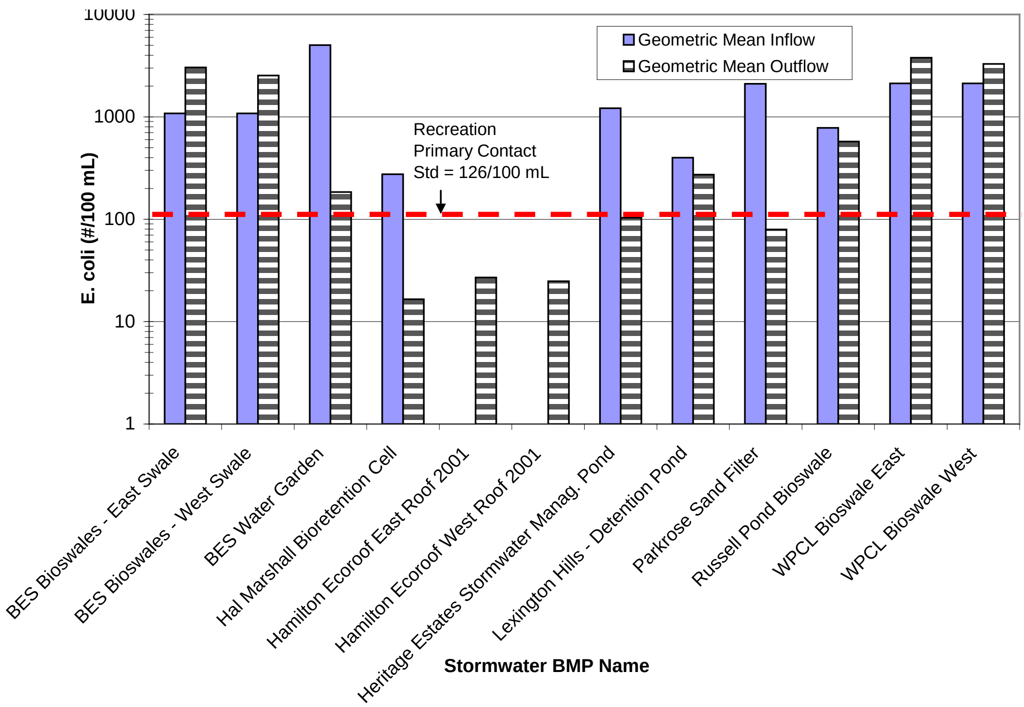


Figure 20. Comparison of Geometric Mean *E. coli* Data for Stormwater BMPs in the International Stormwater BMP Database



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

- Bacteria concentrations in untreated runoff were consistently high for the majority of the BMP study sites, with the influent concentrations varying substantially. The variation may be due to both site-specific conditions as well as the upper quantitation limit for the study.

- The ability of structural BMPs to reduce bacteria varies widely within BMP categories. No single BMP type appears to be able to consistently reduce bacteria in surface effluent to levels below instream primary contact recreation standards. As a result, stormwater managers, permit writers and TMDL participants should not assume that structural BMPs can meet numeric effluent limits for bacteria for all storms and under all conditions. This is consistent with 2006 findings from a Stormwater Panel Recommendations to the California State Water Resources Control Board regarding the feasibility of numeric effluent limits for stormwater in general (CSWRCB 2006).

- Computer modeling of bacteria in stormwater should incorporate significant variability in both untreated runoff (influent) and BMP effluent and should be undertaken with caution. Feedback from some environmental engineers and consultants who apply common models to pathogen and fecal indicator transport suggests that the models provide highly uncertain predictions for pathogen and indicator concentrations and fluxes (EPA 2007, based on input from Ali Boehm, Stanford University). Additionally, modeling assumptions related to microbe association with particles are typically not well developed (Characklis and Camper 2009). Models should be kept simple, with results not reported in unrealistically precise terms. TMDLs should acknowledge this variability and incorporate terms of compliance based on real-world monitoring data.

- BMP categories that appear to have potential for bacteria reduction in effluent include retention ponds, media filters, and bioretention practices, with these considerations:

  - Retention ponds may be well suited for development with significant land area and adequate water rights (typically a challenge in semi-arid and arid states such as Colorado) or abundant rainfall. In ultra-urban areas, infill development, and arid/semi-arid climates, retention ponds are often impractical. Another potential disadvantage with retention ponds if bacteria removal is an objective is that they can attract waterfowl and wildlife, which can increase bacterial levels. Research related to unit treatment processes that are potentially effective for retention ponds is needed. For example, Characklis and Camper (2009) are conducting ongoing research related to microbe association with particles. This is important because the degree to which microbes in the water column associate with settleable particles has important implications for microbial removal via sedimentation-based BMPs.

  - Media filters and bioretention cells show promise in removing bacteria at the site-level. These findings are consistent with recent research by Hathaway and Hunt (2008) in North Carolina. For new developments based on Low Impact Development techniques, the use of bioretention cells or rain gardens is becoming more common in some parts of United States. The key unit treatment process (filtration) associated with media filters is well proven in the drinking water arena, so it is not surprising that these BMPs would reduce bacteria, provided that the facilities are properly maintained. For existing developments, some targeted retrofitting in bacteria "hot spot" areas could be possible, but costs of watershed-wide retrofits with many media filters will likely be cost prohibitive. One of the important aspects of long-term functioning of distributed controls such as bioretention cells is ensuring that these facilities are maintained and continue to function as designed in perpetuity. In many cases, local governments are already stretched to ensure maintenance of regional stormwater facilities, so although these practices may hold promise, "ensuring" their continued function may be administratively challenging.

- Swale and extended detention (dry) pond BMPs appear to have low effectiveness in reducing bacteria and in some cases have the potential for exporting bacteria. The authors hypothesize that potential causes could include that fact that these types of BMPs tend to attract geese, wildlife and domestic pets, which may contribute to bacteria loading. Regardless, these BMPs can still be effective at reducing pollutant concentrations such as total suspended solids (TSS), total metals, and other constituents, as demonstrated in the 2007 analysis of the International Stormwater BMP Database (Geosyntec and Wright Water Engineers 2007), and are valuable components of stormwater management programs. Some infiltration may also occur in these facilities, as well, which potentially concentrates *E. coli* concentrations.

- Several BMP categories have data sets too small to warrant interpretation; these include the wetland, porous pavement and manufactured device categories. However, one could anticipate how some of these BMPs may perform by evaluating BMPs with similar unit processes. For example, properly designed porous pavements, such as those with a sand layer above the sub-surface underdrains, could potentially perform similarly to media filters.

- In addition to the ability of a BMP to reduce concentrations of bacteria, it is also important to consider whether the BMP reduces the volume of stormwater runoff and the frequency of discharges.(In addition to the pollutant itself, volume helps determine the magnitude of the pollutant loading and its relative importance in terms of impacts to the receiving water.) BMPs such as bioretention, vegetated biofilters, and, in some cases, dry-extended detention basins have shown the ability to reduce runoff volumes via infiltration and/or evapotranspiration losses. These factors should also be considered in BMP selection.

As part of the data analysis, Clary et al. (2009) compared the conclusions based on International Stormwater BMP Database to previous findings reported by others such as Pitt (2004) and Schueler and Holland (2000). A few representative excerpts from previous findings include:

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

- *Concentrations of bacteria in urban stormwater are notoriously variable on a site-specific basis, even for similar land use types and even at the same sampling location. Due to the wide variability of bacterial data, it is difficult to make accurate estimates of expected pollutant loading and pollutant removal that are transferable from site-to-site with any degree of confidence. Even with the significant variability, all of the databases and literature sources agree that bacteria concentrations in untreated urban stormwater are very high (estimates range from 15,000/100 mL to over 50,000/100 mL for fecal coliform) and difficult to reduce to instream standards* (Schueler and Holland 2000).

- *Currently stormwater, buffer and source control practices do not appear capable of removing enough fecal coliform bacteria to meet the 200 MPN/100 mL water contact recreation standard…Considering that the outflow concentration from stormwater practices is on the order of 2,500 to 5,000 MPN/100 mL, it is probable that bacterial concentrations will always exceed pre-development conditions in most urban watersheds, even if stormwater* *treatment and buffer practices are fully implemented and all wastewater discharges are eliminated.* (Schueler 2000).

- Schueler suggests some potential design practices that *might* provide greater bacteria reduction. These are factors like greater light penetration in shallow stormwater facilities, providing additional retention/detention time, implementing practices that reduce resuspension of sediment, reducing turf and open water areas around stormwater ponds to help control waterfowl, promoting infiltration and other measures. Schueler emphasizes that additional research is needed in these areas.

Conclusions and Recommendations

In conclusion, the International Stormwater BMP Database provides a relatively large and growing bacterial data set that is useful in evaluating the effectiveness of various structural BMPs with regard to bacteria removal. Media filters and retention ponds were most effective based on the current data set; however, effluent concentrations for these BMPs remained above primary contact recreation standards in many cases. Although several BMP types such as extended detention basins and grass swales did not appear to be effective at reducing bacteria concentrations, these BMPs can be effective at removing other pollutants such as TSS and total metals and may help to reduce runoff volumes and frequencies (thereby reducing bacteria loading). The bacteria-related findings reinforce earlier research by investigators such as Pitt (2004) and Schueler and Holland (2000). Recommendations for additional research include:

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

- Continued submittal of bacteria monitoring data for BMPs to the International Stormwater BMP Database is needed to continue to refine these findings and enable more statistically robust conclusions. Even though the overall number of paired storm events is fairly large, the number of studies per BMP category remains relatively small, as does the number of storm events monitored for some BMP studies. It is essential that evaluation of BMP performance related to bacteria include geometric mean effluent concentrations due to the fact that even when large percentage removals are present (and the BMP appears to be "doing something"), the effluent concentrations still typically exceed primary contact stream standards. This is critical for realistic expectations in BMP-based stormwater permits.

6.3.2 Colorado BMP Performance Data

Although stormwater BMPs have been monitored in multiple locations throughout the metro Denver area by UDFCD, local governments and some industries, relatively little data for bacteria are known to be available. This is believed to relate in part to the inherent challenges in sample collection for bacteria, which have a holding time of 6 hours and typically require manual grab sample collection. Nonetheless, UDFCD has monitored the Orchard Pond Extended Detention

Basin in Littleton, CO since 2002, with approximately 20 storms reporting *E. coli* results. Although this BMP has performed well with regard to multiple conventional pollutants such as total suspended solids (e.g., median effluent concentrations of 9 mg/L), the pond has not been capable of reducing *E. coli* concentrations down to primary contact recreation standards for *E. coli*. Approximately half of the sample pairs showed effluent concentrations lower than influent concentrations, but approximately one-third of the samples showed elevated effluent concentrations relative to influent concentrations. The Colorado data set is consistent with the national data, with the following noteworthy observations based on the five-year data set summarized in Figure 20.

- Influent and effluent concentrations of *E. coli* were highly variable, with both several orders of magnitude above primary contact stream standards. The extreme variation in effluent concentrations (e.g., 230/100 mL to >240,000/100 mL) emphasizes the importance of a large data set for drawing any conclusions regarding BMP performance with regard to bacteria.

- Available data indicate that although extended detention basins provide water quality benefits, meaningful reductions in bacteria concentrations are not expected.

- "Percent removal" is not a meaningful statistical measure to assess BMP performance with regard to bacteria removal. Percent removal varied from -1,550% to 99.9% for the paired storms monitored. This highlights problems associated with computer models that "plug in" BMPs to predict improvements in water quality. Additionally, high percent pollutant removal may occur without the effluent concentrations attaining the stream standard.

Figure 21. Colorado BMP Case Study

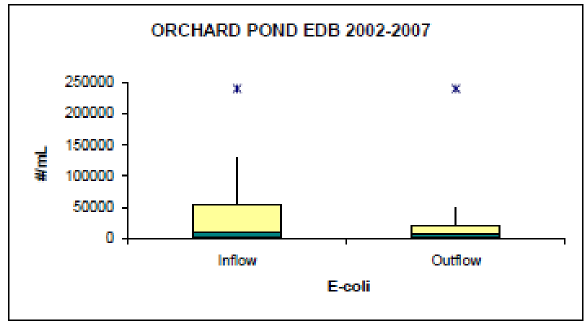
Colorado Case Study:
Orchard Pond Extended Detention Basin, Littleton, CO
Data Source: UDFCD 2009

Sample Date	E-coli (#/mL) In	Out	% Difference
5/13/2002	1,100	7,000	-536%
6/4/2002	4,900	11,000	-124%
6/17/2002	54,000	160,000	-196%
7/3/2002	24,000	13,000	46%
5/16/2003	7,900	N/A	N/A
6/18/2003	110,000	19,000	83%
7/28/2003	240,000	240,000	0%
8/4/2005	240,000	22,000	91%
8/5/2005	3,300	11,000	-233%
9/15/2005	17,000	N/A	N/A
4/7/2006	230	N/A	N/A
5/5/2006	20	330	-1550%
5/10/2006	170	460	-171%
6/22/2006	N/A	790	N/A
8/14/2006	N/A	35,000	N/A
9/12/2006	3,300	130	96%
9/21/2006	3,300	3,300	0%
4/17/2007	310	N/A	N/A
5/2/2007	240,000	92,000	62%
5/25/2007	N/A	3,500	N/A
5/31/2007	49,000	N/A	N/A
6/6/2007	240,000	230	99.9%
8/15/2007	9,400	1,700	82%
8/23/2007	11,000	3,300	70%
Geometric Mean	8,190	5,536	-136%
# Samples	21	19	16
Maximum	>240,000	>240,000	99.9%
Minimum	20	130	-1550%

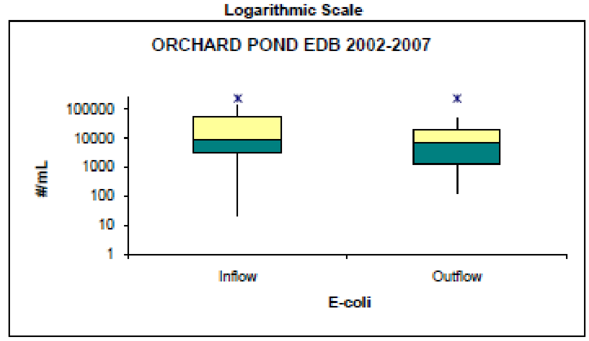
Notes:
6 out of 17 paired monitoring events (35%) showed increases in E. coli.
9 out of 17 paired monitoring events (53%) showed decreases in E. coli.
2 out of 17 paired monitoring events (12%) showed no chage in E. coli.

Range of difference between inflow and outflow E. coli: -1,550% to 99.9%
No outflow samples meet the primary contact recreation standard of 126/100mL.

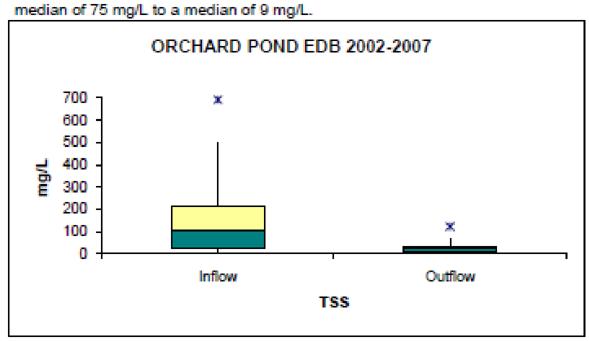
Arithmetic Scale



Logarithmic Scale



In contrast, the pond performs consistently well in removing TSS from a median of 75 mg/L to a median of 9 mg/L.



6.3.3 Disinfection

At this time, disinfection methods such as UV radiation, ozonation and chlorination, have not been recommended for use at stormwater outfalls in Colorado. Nonetheless, it is important for Colorado MS4 permit holders to be aware that some communities in California (e.g., Encinitas, Orange County and Santa Barbara) have implemented disinfection technology at swim beaches affected by frequent beach closures due to elevated fecal indicator bacteria. Many of the implemented treatment projects demonstrate that although disinfection is successful at the facilities themselves, bacteria loads often increase downstream after discharge due to regrowth, regeneration, and animal inputs (Murray and Streets 2009).

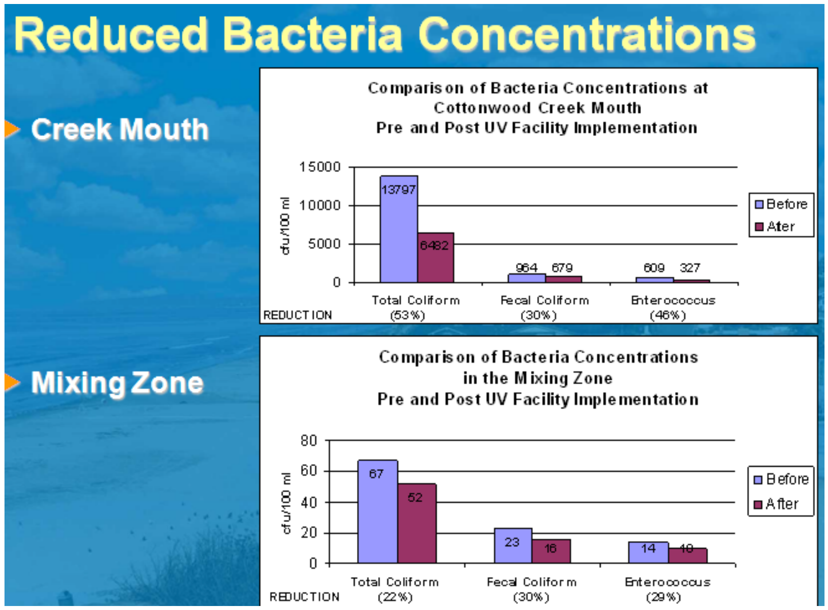
A representative application is documented in the Moonlight Beach study in Encinitas, California. The Southern California Water Resources control Board (SCWRCB) provides a fact sheet under its Clean Beaches Initiative Urban Runoff/Water Quality Improvement Projects regarding the Moonlight Beach UV project (http://www.swrcb.ca.gov/water_issues/programs/beaches/cbi_projects/docs/summaries/026_encinitas_moonlight_beach.pdf. The beach is reported to have a $47 million economic value to the City with over 1,200,000 visitors a year. The project cost was approximately $936,000, with additional supporting information including:

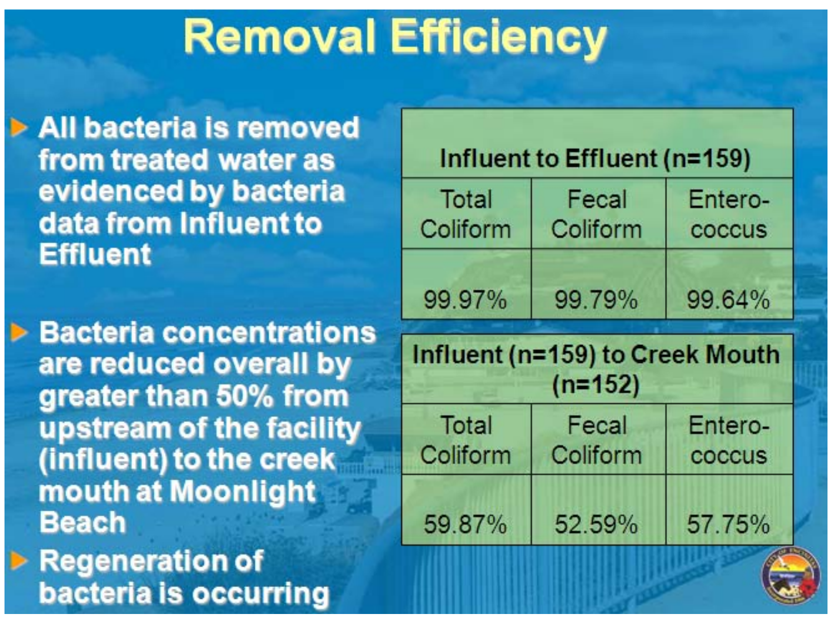
- *Project Description/Purpose: Moonlight State Beach is the most popular coastal feature in the City of Encinitas and is one of North San Diego County's most famous recreation areas with over 2.5 million visitors in the year 2000. Unfortunately, in the same year, there were over 90 days of beach postings/closures, in addition to the year-round postings at the Cottonwood Creek outfall, which discharges onto the north shore of the beach. These postings were attributed to urban runoff in Cottonwood Creek. Although the City's aggressive urban runoff management program has reduced pollutants throughout the watershed, it was determined that a structural treatment was needed, to protect the public health at the beach. An ultra-violet treatment process was selected and funding provided through the Clean Beaches Initiatives grant program. The treatment facility was designed in the Fall of 2001 and constructed between June 2002 and August 2002. The treatment facility consists of a wet well and pumping station, a series of filters, including a two dual media (sand and anthracite) pressure filters, and a disinfection unit. The disinfection unit consists of two UV disinfection chambers approximately 48 inches in length and 8 inches in diameter. Each chamber has four low-pressure, high intensity UV lamps. The chambers are mounted horizontally. The system is operated from a programmable logic controller (PLC). System controls are set to shut the entire system down on three operating conditions: high level in the wet well, high pump discharge pressure, and high effluent turbidity. Treated flow is returned to Cottonwood Creek. The entire treatment facility is housed in a 24 feet long, 10 X 10 foot prefabricated steel enclosure. The system is designed to operate during dry weather conditions.*

- *Project Outcomes/Effectiveness/Benefit: The overall project has been a true success; the City has reduced the bacteria levels entering the Pacific Ocean at Moonlight State Beach and bacteria levels through the facility are consistently reduced by 99%. Beach postings have been reduced by an average of 90% per year for the two years that facility has been in operation.*

The City reported the project to be a success in terms of treatment efficiency (i.e., >99% reduction) and reduction of beach closures; however, they also noted that increases in indicator bacteria occurred downstream of the treated effluent, as shown in Figure 22.

Figure 22. Performance of Moonlight Beach UV Disinfection Project
(Source: Weldon and Hartman 2006; Moonlight Beach Urban Runoff Ultraviolet Treatment Facility Effectiveness Assessment, Stormwater Committee Meeting Nov. 16, 2006)





Special studies to evaluate the increases in indicator bacteria following treatment have suggested the following:

- Rise (~180%) in fecal coliform concentrations immediately after treatment in open "natural" channel, likely due to animals.
- Nearly 200% rise in all three indicators in 72" pipes downstream of open channel thought to be due to ideal conditions for bacterial growth in pipes, dark, wet, with organic matter

- Continued 57% rise in enterococcus concentrations only (on beach) thought to be due to birds and typical wrackline on beach.

Selected recommendations, among others, included regular cleaning of system piping to reduce media for bacterial growth and locating the system as close to the receiving water as possible to limit opportunity for regrowth after treatment.

6.4 BMPs in MS4 Permits

One of the primary reasons that the Colorado Stormwater Council has sponsored the *E. coli* Work Group project is that TMDLs potentially have significant impacts on the cities' stormwater municipal separate storm sewer (MS4) permits. Under the Phase I and Phase II stormwater permits, permit holders must reduce pollutant loadings in municipal storm sewer discharges to the maximum extent practicable (MEP). Under the CDPS Stormwater MS4 General Permit (CDPHE 2008)[25], activities required to achieve this objective include establishment of measurable goals in these areas:

1. Public outreach and education on stormwater impacts
2. Public involvement/participation
3. Illicit discharge detection and elimination program on the hazards associated with illicit discharges.
4. Construction site stormwater runoff control
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operation.

Several of these are relevant to bacteria reduction. One key item is illicit discharge detection, which requires: 1) development of a storm sewer system map; 2) an ordinance prohibiting illicit discharges; 3) a plan to detect and address illicit discharges; and 4) an education program on the hazards of illicit discharges. Illicit discharge detection guidance is provided in Section 5.2.1.

The CWQCD has provided letters to MS4 permit holders discharging to listed streams scheduled for TMDLs in the next year with a variety of information in preparation of forthcoming TMDLs along several Front Range streams. Representative language (Moore 2009) includes:

> *…the [CWQCD] must determine whether discharges from the permittee's MS4 are contributing E. coli to [listed] segments. If it is determined that there is a discharge from the permittee's MS4 to [the listed segment] and a contribution of E. coli, a Waste Load Allocation (WLA) will be included in the final TMDL for discharges from the permittee's MS4. The WLA would assign a limit on*

[25] Phase I permit requirements vary somewhat from the general permit.

> *discharges of E. coli for the MS4. …the MS4 permit addresses the process that will then be followed to ensure the permit includes adequate effluent limits to require discharges meet the WLA. In accordance with [the permit], if the [CWQCD] determines that the conditions of the current permit are not adequate to bring about compliance with the WLA, the [CWQCD] may modify the existing MS4 permit conditions, or require an individual permit or alternative general permit. Effluent limits in stormwater permits are often practice based, such as the permittee's current six minimum control measures, but could also be numeric limits.*
>
> *The permittee should evaluate its current practices/discharges to proactively address any known sources of E. coli to possibly avoid the need for additional effluent limits. Specifically, any illicit discharges containing E. coli, such as cross connection or sanitary sewer seepage, must be addressed in accordance with the current requirements in [the permit].*

6.5 Recommended Multi-tiered Management Approach

Based on data available to date, the following BMP strategy is recommended for 303(d) listed streams for bacteria in urban areas:

1. Dry weather survey to identify illicit connections and discharges to the storm sewer system.
2. Remove or control illicit connections/discharges.
3. Provide public education and enforcement of pet waste ordinances and leash laws. Provide pet waste disposal cans in open space areas.
4. Preserve natural riparian buffers.
5. Work with local wildlife managers to assess the need for population controls or active management of urban wildlife.
6. Where contributing drainage area, depth to groundwater and soil conditions are appropriate for infiltration-oriented BMPs, consider use of such practices. As ongoing research continues to refine the state of the science regarding structural BMP performance, more robust guidance regarding selection of appropriate structural BMPs for treatment of bacteria may also continue to emerge.

Effectiveness of control measures will vary depending on a variety of factors, beginning with the degree to which understanding of bacteria sources has been correctly identified. Assuming that sources are correctly targeted, the expected effectiveness of controls will also vary and many unknowns remain. In 1983, Pitt prepared a summary of practices recommended for the Rideau River area of Ottawa, based on extensive local testing and analyses. Although an old evaluation, Pitt (2004) suggest that it is likely still reasonably valid. Table 18 contains these recommendations.

Table 18. Overview of Bacteria Control Measures and Expected Cost and Effectiveness
(Source: Pitt 2004, citing Pitt [1983] for the Rideau River)

	Control Effectiveness	Costs
Litter control	Low	Low/moderate
Bird control on river bridges	Moderate (to 50%)	Low/moderate
Catchbasin cleaning	Low (<10%)	Moderate/high
Street cleaning	Low/moderate (to 20%)	Very high
Dog feces control programs	Moderate (to 35%)	Very low
Inappropriate discharge detection and elimination program	High (if present)	Moderate/high
Runoff treatment and disinfection	Can be very high (>99%)	Very high

7 UNRESOLVED ISSUES RELATED TO *E. COLI* IN COLORADO

7.1 Inland Flowing Waters and Relation to 1986 Ambient Water Quality Criteria

Work Group members expressed concerns regarding the applicability of the epidemiological studies forming the basis of the 1986 Ambient Water Quality Criteria to inland flowing streams. Essentially, the studies used as the basis of the criteria were located in lake settings where sanitary sewage contamination was present. In contrast, many of the Colorado-listed streams are not in swim beach settings, have significantly different hydrologic conditions, and may not have sanitary sewage sources of contamination. Both EPA and WERF have acknowledged these types of concerns and are conducting additional research in this area in support of the recreational criteria update in 2012. Because Colorado stream standards and TMDLs must comply with the existing federal criteria, this is currently an unresolved issue.

7.2 Use of *E. coli* as Basis of Recreational Stream Standard

Concerns regarding *E. coli* as the basis of the recreational stream standards generally relate to its relationship with human illness and the widespread occurrence of *E. coli* in the environment from natural, non-human, largely uncontrollable sources. Specifically, recent research raises doubt as to the correlation of "indicator" bacteria such as *E. coli* with fecal contamination from humans. Ultimately, the questions and uncertainties in accurately assessing naturalized strains versus anthropogenic sources of fecal contamination create difficulties in determining human health risks associated with exposure (Monroe 2009). This issue was not considered to be resolvable within the context of the Work Group given efforts at the federal level to revisit existing national criteria. However, both the EPA (2007) and WERF (2009) Expert Panel reports validated many of the concerns expressed by Work Group participants and the participants look forward to the multi-faceted research currently being conducted as a result of the report.

7.3 Wildlife Contributions and Implications for TMDLs

A topic of discussion during several Work Group meetings related to the impact of wildlife on the attainability of recreational stream standards. Specifically, the concept of "wildlife off-ramps" was discussed, including a summary of provisions present in other states. Essentially, the group recognizes that open space and national forest areas may have elevated bacteria due to wildlife. Such sources are largely uncontrollable and/or wildlife removal conflicts with other community objectives (e.g., wildlife in urban open space areas is desirable). In order to enable regulatory flexibility for this issue, changes to the Colorado Basic Standards would be required. Given a number of high priority issues associated with the Basic Standards unrelated to bacteria and the expectation that the Basic Standards may change as a result of the 2012 EPA criteria update, this issue was left unresolved. An additional factor resulting in this issue being set aside is that EPA's current position on this issue is that non-human source exclusions to the criteria can only be allowed when both of the following criteria are met: 1) the sources are only from non-human sources (supported by sanitary surveys/watershed characterization studies) AND 2) Those non-human sources are shown to pose no risk to human health (i.e., through an epidemiological study) per the BEACH Act rule (69 FR 67226-67227; November 16, 2004). Although states may use existing epidemiological data in lieu of conducting their own study, the second component of this standard is difficult to meet.

7.4 Recreational Use Classifications

Multiple streams in Colorado are currently assigned primary contact or potential primary contact recreation standards due to actual or potential for water play by children. This standard is protectively applied to include streams where access to the stream is not restricted by a fence or other private property restrictions. Such streams may not have adequate flow for full-body immersion or primary contact water sports such as swimming, kayaking, tubing, etc.; however, primary contact standards are applied because of the potential for splashing and the hand-to-mouth pathway where children could potentially ingest small quantities of water. This use classification is intended to be applied in areas with frequent water play by children. In practice, the standard has been protectively applied in areas where unrestricted access to the stream exists.

The *E. coli* Work Group had much discussion regarding whether primary or secondary contact standards were better suited for streams where water play by children potentially occurs. Group consensus was not reached on this issue, but a variety of opinions were expressed that may warrant further dialogue in the future:

- The 1986 Ambient Water Quality Criteria were based on epidemiological data associated with full-body contact (swimming) in lakes; therefore, questions exist regarding using the resulting primary contact standards to shallow streams where immersion is unlikely. Although several states in addition to Colorado apply primary contact recreation to wading or water play by children, other states assign secondary contact standards to such uses.

- Given risk-based work in progress with regard to EPA's Ambient Water Quality Criteria, the group believed it was appropriate to await the outcome at the national level before exploring this issue further.

- A basic dilemma existed among work group participants with regard to balancing the desire to protect children from waterborne illness with the constraint that the natural environment poses certain inherent risks that cannot be eliminated.

7.5 TMDL "Endpoints"

The endpoint of a TMDL is the identification of pollutant sources and the differentiation and allocation between point and non-point source contributions. The outcome, or implementation, of the TMDL would be intended to result in the elimination of pollutant sources contributing to exceedances of the *E. coli* standard (e.g., removal of sanitary cross-connections, repair of leaking pipes or septic systems, etc.).

As it pertains to TMDL implementation, Work Group participants devoted considerable discussion to whether *E. coli* standards are realistically attainable, even after controllable sources of *E. coli* are addressed. If this is the case, implementation of the TMDL is a concern, particularly to MS4 permit holders. Based on Work Group discussions, one possible step in the regulatory process would be the proposal of a site-specific standard based on "natural or irreversible human induced conditions," or a Use Attainability Analysis (UAA) which would be addressed through the triennial review process on a segment-by-segment basis. A key issue in such cases would include determination of acceptable risk.

8 CONCLUSIONS

Nationally, the Clean Water Act serves as the regulatory driver establishing ambient water quality criteria for recreational use to protect human health. For freshwater streams, *E. coli* is used as an indicator of fecal contamination and the CWQCC has developed standards for recreational use in Colorado. Effectively addressing recreational use impairments is a significant state and national issue, as evidenced by nearly 10,500 streams listed as impaired for pathogens nationally and over 2,300 stream miles in Colorado listed as impaired due to elevated *E. coli*. While protection of swimmers, kayakers and other recreators from sewage-contaminated water is clearly a high priority and an unquestionable human health concern, the *E. coli* issue becomes more complex when natural and environmental sources of elevated *E. coli* are present, particularly from diffuse, non-point sources. Additionally, since establishment of the 1986 EPA criteria, scientific research has raised questions regarding various aspects of the recreational criteria with regard to indicator-pathogen relationships, human health risks associated with various types of recreational use, relative risks posed by human versus non-human sources of indicator bacteria/pathogens, and other issues. Nationally, EPA, WERF and researchers are working to address these questions in support of the 2012 EPA criteria.

Despite the transitional state of the national criteria, states must continue to meet their Clean Water Act responsibilities to protect human health, and the current stream standards remain applicable. Therefore, Colorado is required to move forward in addressing stream impairments due to elevated *E. coli*. The *E. coli* Work Group has served as a forum to discuss various approaches on how to address these impairments, incorporating a variety of viewpoints while working within the current regulatory framework. This white paper is intended to provide a common information base that can be used by a wide variety of entities to better understand *E. coli* issues in Colorado.

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