Applying knowledge to improve water quality
Volunteer Water Quality Monitoring
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Volunteer Monitoring of Bacteria in Surface Waters

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Introduction

"Is it safe to swim in the water?" That question often motivates many volunteers' initial interest in monitoring. Researchers and regulatory agencies have determined that conducting fecal bacteria monitoring can help to identify human health risks associated with drinking and recreational water contact. Developing an effective volunteer bacterial water quality monitoring program has many benefits. It helps answer the question "is it safe?" It can also establish baseline data, help local communities target water quality protection or restoration activities, educate citizens about land use impacts, and non-point sources of pollution, provide essential data for Total Maximum Data Load (TMDL) development and implementation and ensure compliance with local, state and federal regulations.

This factsheet is a brief primer on bacteria. It provides an overview of what bacteria are, why we monitor fecal indicator bacteria, which bacteria are monitored, and highlights some emerging indicators used to identify human sources of contamination. A second factsheet, *Monitoring Bacteria – Methods*, focuses on how to monitor bacteria in surface waters, and a third, *Communicating Bacteria Data Effectively*, on presenting bacteria data.

What are Bacteria?

(Adapted from Michigan Water Science Center – Fecal Indicator Bacteria and Sanitary Water Quality http://mi.water.usgs.gov/h2oqual/BactHOWeb.html).

Microorganisms are found everywhere in our environment, including within our bodies. Many microorganisms do no harm, and in fact we depend on them to maintain soil fertility, decompose wastes, including pollutants, and to help create foods such as cheese, beer and bread. Microorganisms are often beneficial because they assist with bodily functions such as aiding our digestion and out competing or eliminating disease causing microorganisms. Fecal indicator bacteria are such microorganisms; they are normal inhabitants of the gastrointestinal tract of humans and most other warm-blooded animals. Not only do fecal indicator bacteria cause no harm, but we rely upon them for proper metabolic functioning.

A few microorganisms (called pathogens) can cause disease in humans; they may be viruses, bacteria or protozoa. Some pathogens found in contaminated water can cause minor illnesses such as gastroenteritis (characterized by vomiting, diarrhea, abdominal pain or fever) or upper respiratory (ear, nose and throat) infections due to exposure through ingestion, inhalation, or skin contact (table 1). Occasionally contamination can cause more serious diseases such as typhoid fever, dysentery, hepatitis and cholera.

This is the thirteenth in a series of factsheet modules which comprise the **Guide for Growing Extension Volunteer Monitoring Programs,** part of the *National Facilitation of Extension Volunteer Monitoring Efforts* project. Funded through the USDA National Institute of Food and Agriculture (NIFA), the purpose of this project is to build a comprehensive support system for Extension volunteer water quality monitoring efforts nationally. The goal is to expand and strengthen the capacity of existing Extension volunteer monitoring programs and support development of new groups. Please see http://www.volunteermonitoring.org/ for more information.

Table 1. Common Waterborne Pathogens

Microorganisms	Illnesses	Symptoms
Bacteria	Gastroenteritis, salmonellosis (food poisoning), cholera	diarrhea, abdominal pain, vomiting, fever
Viruses	Respiratory infection, common colds, gastroenteritis, hepatitis	fever, diarrhea, coughing, sore throat
Protozoa	Gastroenteritis, cryptosporidiosis, giardiasis, dysentery	diarrhea, abdominal pain, vomiting, fever

(Adapted from Bacteria Fact Sheet for the Maine Healthy (Coastal) Beaches Program http://www.mainehealthybeaches.org/documents/Bacteria_Fact_Sheet.pdf

In order to cause disease, a pathogen must successfully invade some part of the body and either produce more of itself or produce a chemical (usually called a toxin) which interferes with normal body processes. Whether or not a pathogen is successful in causing disease is related to the health of the individual and the state of his or her immune system, as well as to the number of pathogen cells required to cause symptoms of illness. Some pathogens can cause disease when only a few cells are present. In other cases, many cells are required to make a person ill. Young children and elderly persons are more susceptible to many pathogens than are teens, or young and middle-aged adults.

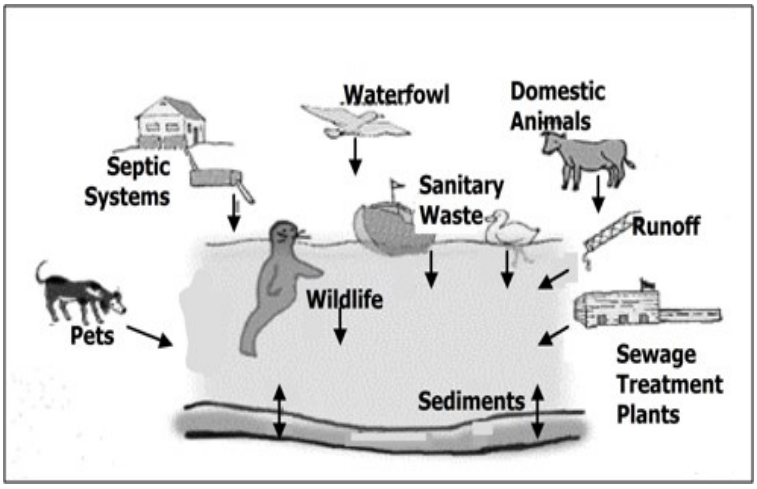
Why Monitor Fecal Indicator Bacteria?

Bacterial monitoring is a practical method to determine the potential health risk of water exposure. While the fecal indicator bacteria are usually not harmful themselves, there are many pathogens that can also be found in the intestines of warm-blooded animals Thus the presence of these bacteria ***indicates*** that fecal contamination ***may*** have occurred, increasing the risk that pathogens may be present in the water. Fecal indicator bacteria in a waterway come from many sources (figure 1), e.g., animal droppings (from wild-life, particularly waterfowl, pets and livestock), faulty or leaking septic or sewage systems, combined sewage overflows, stormwater runoff, boat sanitary waste and disturbed sediments. To protect public health by reducing exposure to potential pathogens, beaches must be closed or an advisory posted, when the potential for fecal contamination is too high. Direct measurement of these pathogens, such as *Giardia*, cryptosporidium and Norwalk virus, is expensive and impractical because:

- There are innumerable types of pathogens that may be in water bodies; it would be impossible to check for all these pathogens.
- The presence of one pathogen may not indicate the presence of others.
- Generally, simple laboratory techniques do not currently exist to measure pathogens.
- Current tests for pathogens can be very expensive and time consuming.

Characteristics of good bacterial indicators of fecal contamination are listed in the box on page 3.

Figure 1. Sources of fecal contamination



(Courtesy of *The Volunteer Monitor*)

***Homo sapiens* -**
More microbe than human
Microorganisms make up a small percentage of a human's body weight (between 2 and 5 pounds of live bacteria), in terms of cell numbers, a human is around 10% human and 90% bacterial cells or genetically 1% human and 99% bacterial (Wexler 2007).

Why Monitor Bacteria (continued)

Some fecal indicator bacteria and pathogens are naturally found in the environment. For example the protozoa *Giardia lamblia* is found in the gastrointestinal system of some wild mammals, and may enter water through the feces of these mammals. *Giardia* causes severe diarrhea in humans who ingest it, even if water comes from a seemingly pristine, clear, cold mountain stream. In addition, both pathogenic and non-pathogenic strains of *E. coli*, are present in the guts of all warm-blooded animals and are found naturally in water and soil. Thus, the risk of disease is not uniquely a result of the presence of human wastes in the environment.

When fecal wastes, and especially human wastes and the human-host specific pathogens associated with those wastes, are concentrated in the environment, we assume for our own protection, that the risk of transmission of those pathogens may increase, even though we may have no direct evidence of the presence of a specific pathogen. It is for this reason that we monitor the quality of our food and water, and establish personal hygiene and public policies that attempt to prevent contamination in the first place.

Criteria for a good bacterial indicator (adapted from Ohrel and Register, 2001).
Good bacterial indicators are:

- Present whenever intestinal pathogens are present
- Useful in fresh and marine waters
- Alive as long as the hardiest intestinal pathogen
- Of human or animal origin
- Analyzed with an easy testing method
- Present in densities correlated with the degree of fecal contamination

Photo credits: Eleanor Ely for *The Volunteer Monitor* article on the Morro Beach Monitoring program

Which Bacteria Should You Monitor?

The type of bacteria monitored depends on what questions you are asking, what types of water you are monitoring, what the designated uses of those waters are, and how you plan to use the data. The most commonly tested fecal indicator bacteria are: total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*) and enterococci.

Total coliforms are a group of closely related genera of rod-shaped bacteria that are widespread in nature. All members of this group can occur in human and animal feces, but some can also be present naturally in soil, submerged wood, and in other places not associated with the presence of warm-blooded animals. Thus, the usefulness of total coliforms as an indicator of fecal contamination is limited and they are no longer recommended for use with recreational waters. However, because their presence indicates contamination of a water supply by an outside source, total coliforms are still the standard for drinking water.

Fecal coliforms, a subset of total coliform bacteria that can grow at 44.5 °C, are generally from fecal sources. However, even this group contains a genus, *Klebsiella*, with species that are not necessarily fecal in origin. *Klebsiella* are commonly associated with textile, pulp and paper mill wastes, and even leaf litter. While fecal coliforms are still the required indicator for shellfish waters and for recreational waters in some states, the United States Environmental Protection Agency (USEPA) now recommends *E. coli* and enterococci be used as the primary indicators of human health risk from water contact (USEPA 1986). (See Bacteria Rule for Coastal and Great Lakes Recreation Waters http://www2.epa.gov/beach-tech/final-water-quality-standards-bacteria-rule-coastal-and-great-lakes-recreation-waters for more information including links to state standards and the BEACH Act Standards. Table 2 lists the BEACH Act recommended criteria.)

Table 2. US EPA Bacteria Criteria for the BEACH Act

Test	Geomean	Single sample maximum, CFU/100 mL			
		Designated Beach area	Moderate, full body contact	Lightly-used, full body contact	Infrequently used, full body contact
Enterococci, marine	35	104	158	276	501
Enterococci, fresh	33	62	78	107	151
E. coli	126	235	298	410	576

***Escherichia coli* (*E. coli*)** is a specific type of fecal coliform bacteria commonly found in the intestines of warm blooded animals and humans. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination. *E. coli* and enterococci have been shown to be better predictors of swimming-related gastrointestinal illnesses than either total or fecal coliforms, so the USEPA now recommends the use of either for monitoring fresh water (USEPA 1986).

Enterococci are a subgroup within the fecal streptococcus group. Enterococci are distinguished by their ability to survive in saltwater, better than *E. coli*. They are typically more human-specific than the larger fecal streptococcus group, thus USEPA recommends enterococci be used as the indicator of human health risk in salt water used for recreation, and they can be used for fresh water as well (USEPA 1986).

The type of indicator bacteria you choose to assess fecal contamination depends on regulations associated with the type of water being tested, which is classified according to its use (Table 3). State regulations can differ from federal criteria, so it is important that you consult with your state agencies to ensure that you are monitoring the correct bacteria based on your state's standards.

Microbial Source Tracking

The difficulty with determining the sources of fecal contamination is that the indicator bacteria that are currently measured are present in the gut of all warm-blooded animals. The methods approved for bacteria monitoring do not differentiate between bacteria from an animal source, such as cow manure or pet waste, and those from human-based sources such as leaking sewer systems. Most watersheds are stressed by multiple sources of fecal pollution, making it difficult to take action to clean up our waterways without knowing where to focus our attention.

To address this, researchers are working to develop advanced technologies to differentiate fecal sources. Currently these microbial source tracking (MST) methods tend to be too expensive or complicated for use by volunteers. But often volunteers are involved in the sample collection component of MST efforts, so we will briefly highlight some of the methods being developed. Many MST methods are based on identifying unique characteristics of fecal contamination in order to link it to specific sources. It may involve comparing the DNA of fecal organisms or isolating species unique to humans or other warm blooded animals. Many of the DNA based techniques require a "library" to compare samples to, which can be very expensive and difficult to build, and may need to be supplemented for each project due to localized differences. Building a library requires collecting samples from known sources (i.e., from feces that are recognizable as coming from various animals, including human sewage) to build a reference list. After DNA is extracted from fecal indicators found in water samples, the results are compared to a DNA reference list to hopefully identify the sources of fecal indicators.

Microbial Source Tracking Resources

Beachapedia - Bacterial Pollution, Tracking the Sources - http://www.beachapedia.org/index.php?title=Bacterial_Pollution,_Tracking_the_Sources&oldid=1635

California Microbial Source Identification Manual: A Tiered Approach to Identifying Fecal Pollution Sources to Beaches http://www.waterboards.ca.gov/water_issues/programs/beaches/cbi_projects/docs/sipp_manual.pdfhttp://www.waterboards.ca.gov/water_issues/programs/beaches/cbi_projects/docs/

Table 3. Types of Indicator Bacteria Used to Assess Fecal Contamination – Federal Criteria

Type of water	Description of water type and its use	Federally required indicator bacteria
Ambient water	Any water body encountered in the environment, regardless of use designation.	(Depends on use.)
Recreational water	Water bodies where people engage in, or are likely to engage in, activities that could lead to ingestion of the water or immersion in the water. Recreational water is designated as such in State and Tribal water quality standards.	Enterococci or *E coli* required for Great Lakes and coastal (marine) beaches. Requirements for inland beaches are subject to State regulations.
Shellfish growing water	Any site that supports or could support the propagation and harvesting of shellfish, such as oysters, clams, mussels, and scallops in the natural environment or at fish farms.	Total coliform and fecal coliform (National Shellfish Sanitation Program – Food & Drug Administration)
Potable (drinking) water	A water supply that meets the requirements of the Safe Drinking Water Act, as administered by the U.S. Environmental Protection Agency and any applicable State or local jurisdictions.	Total coliform. Detection requires follow-up testing for fecal coliform and *E. coli*.
Treated drinking water	Potable water from a public water supply that has been treated by physical or chemical means to improve water quality.	The U.S. Environmental Protection Agency Ground Water Rule for public supply systems includes testing for
Public water system	A water system that serves 25 or more people or that has 15 or more service connections and operates at least 60 days per year.	total coliform, *E. coli*, enterococci, and coliphage viruses.

(Table from the USGS National Field Manual for the Collection of Water-Quality Data – Chapter)

MST Resources: (Continued)

Bacterial Source Tracking (BST) - A Review (2006): http://www.chebucto.ns.ca/ccn/info/Science/SWCS/H-2/bst.html

USGS Water-Quality Information - Microbial Source-Tracking and Detection Techniques: list with links http://water.usgs.gov/owq/microbial.html

USGS report - Selection and Application of Microbial Source Tracking Tools For Water-Quality Investigations http://www.water.rutgers.edu/Source_Tracking/MicrobialSourceTracking/SelectionandApplicationofMicrobialSourceTrackingToolsForWater-QualityInvestigations.pdf

Evaluation of microbiological water quality in the Pettaquamscutt River (Rhode Island, USA) using chemical, molecular and culture-dependent methods http://www.ncbi.nlm.nih.gov/pubmed/21570698

USEPA - Microbial Source Tracking Guide http://twri.tamu.edu/docs/bacteria-tmdl/epa%20mstguide%206-05.pdf

Rutgers University - Microbial Source Tracking http://www.water.rutgers.edu/Source_Tracking/MicrobialSourceTracking/MicrobialSourceTrackingEPApresentation.pdf - Powerpoint presentation

Microbial Source Tracking: Watershed Characterization and Source Identification AZ CE (AZ1547) http://cals.arizona.edu/pubs/water/az1547.pdf

Development and Implementation of Rapid Microbiological Methods for Measuring Recreational Water Quality http://www.cws.msu.edu/documents/Griffith_RapidIndWhitepaper.pdf

Evaluation of microbial source tracking methods using mixed fecal sources in aqueous test samples http://www.environmental-expert.com/files/19961/articles/4579/4579.pdf

Microbial Source Tracking: Current Methodology and Future Directions http://aem.asm.org/content/68/12/5796

Identification Methods in Surface Waters: http://www.ecy.wa.gov/pubs/99345.pdf

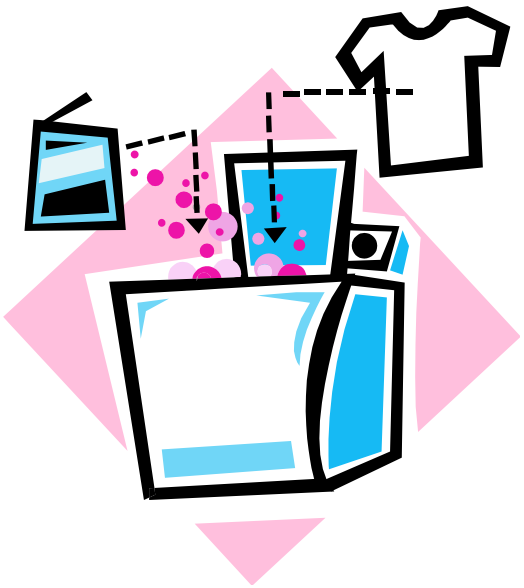
Emerging Indicators

All of the commonly monitored fecal indicator bacteria have animal and human sources. Management activities needed to deal with human sources are usually different than those used to reduce animal sources. Thus developing screening tests for uniquely human-associated compounds such as optical brighteners or caffeine is being researched. As with fecal indicators, ideally these constituents should be present in nearly all human wastes at levels correlated to the amount of waste, survive only as long in the environment as the wastes are present, and be easy to monitor. While we have not yet identified a perfect indicator, several show promise in their utility to successfully identify human sources of bacteria.

These emerging indicators can be difficult to monitor for many volunteer monitoring programs. However, these indicators can be very useful particularly in conjunction with other chemical or microbiological tests to better identify potential fecal sources. Partnering with local researchers or pursuing funding to enable you to work with commercial labs can be a logical "next step" if your monitoring data suggest a human source which can't be verified through observation or other volunteer-based methods.

Optical brighteners are chemical dyes that are added to laundry detergents, soaps, shampoos, conditioners and even toilet paper to enhance appearance, causing a 'whitening' effect. These chemicals will fluoresce under ultraviolet light, and so are being used to help track wastewater or sewage contamination. Monitoring optical brighteners is done by either leaving an unbleached cotton pad in a waterway for a designated time period and analyzing the fluorescence of the pad, or by measuring fluorescence of a water sample. The analyses are typically done in a lab using a fluorometer, which some volunteer monitoring programs may already use for chlorophyll analysis. By correlating high fecal indicator values with sites that also have high levels of optical brighteners, sites with potential human sources of contamination can be targeted for additional source tracking.

Caffeine is found not only in coffee and tea, but also in a wide range of sodas, energy drinks and many foods, making it widely consumed by people of all ages and most cultures. However caffeine is seldom used in animal feeds and has few natural sources in temperate environments. Since caffeine degrades within a few days to several months in the environment, it has been shown to be a good marker for human sewage contamination (http://www.sciencedaily.com/releases/2011/11/111122112023.htm).



Currently solid-phase extraction, a process which concentrates or purifies compounds that are dissolved or suspended in a liquid mixture, along with either liquid chromatography or gas chromatograph-mass spectrometry methods are used to quantify caffeine concentrations. This requires the use of research or commercial labs for sample processing that typically exceeds the resources of may volunteer programs. However, volunteers can be helpful in water sample collection efforts. The Massachusetts Volunteer Coastal Monitoring General Quality Assurance Project Plan (QAPP) includes criteria for caffeine monitoring http://www.mass.gov/eea/docs/czm/cwq/general-qapp.doc. Also see *Use of Caffeine and Human Pharmaceutical Compounds to Identify Sewage Contamination* http://waset.org/publications/8464/use-of-caffeine-and-human-pharmaceutical-compounds-to-identify-sewage-contamination. To assess well or ground water fecal contamination sources try *Caffeine and Pharmaceuticals as Indicators of Waste Water Contamination in Wells* http://info.ngwa.org/gwol/pdf/991565002.PDF.

Optical Brightener Resources:

Measuring Optical Brighteners in Ambient Water Samples Using a Fluorometer (Standard Operating Procedure) http://www.swrcb.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/3414.pdf

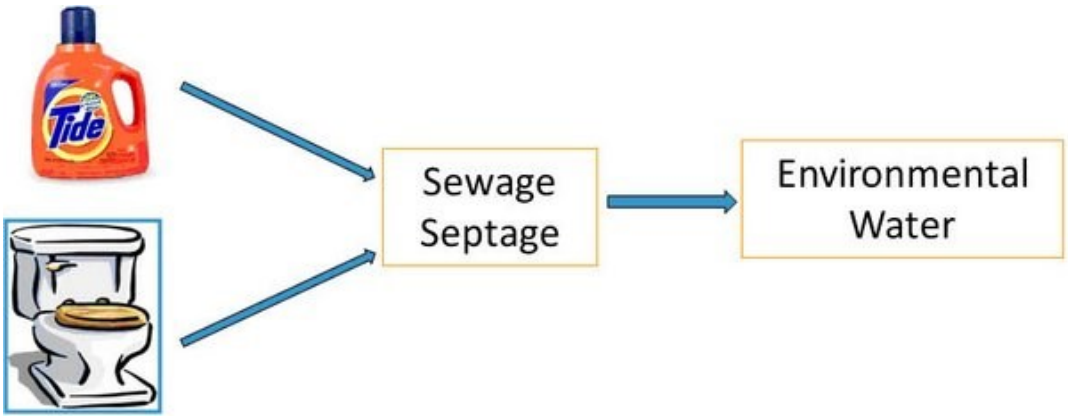
An Optical Brightener Handbook http://nature.thecompass.com/8tb/sampling/

Fluorometric Detection of Optical Brighteners as an Indicator of Human Sources of Water Pollution. Part I. Description and Detection of Optical Brighteners http://www.sites.ext.vt.edu/newsletter-archive/cses/2005-11/part1.html

Optical Brighteners and Source Tracking (ppt) NJDEP Water Monitoring and Standards http://www.nj.gov/dep/wms/Heddendorf%20-%20summit.pdf

Massachusetts Department of Environmental Protection – Bacteria Source Tracking Pilot Study Summary Report http://www.mass.gov/eea/docs/dep/water/priorities/bact2004.pdf (combines extensive watershed mapping and surveys, with sampling and OB monitoring to track sources).

Detecting Sewage Leaks with Optical Brightener Monitoring (including Low-Cost Homemade OB Trap) in *The Volunteer Monitor*, http://water.epa.gov/type/rsl/monitoring/upload/2004_10_13_monitoring_volunteer_newsletter_volmon15no2.pdf



(Image from the South California Coastal Water Research Project)

References and for further information on bacterial monitoring:

California Source Water Ambient Monitoring Program – Clean Water Team Citizen Monitoring Program – Compendium for Watershed Monitoring and Assessment (3.4. Bacteria Pathogen Indicators http://www.swrcb.ca.gov/water_issues/programs/swamp/cwt_guidance.shtml

E. coli Project. Building Capacity of E. coli Monitoring By Volunteers: A Multi-State Effort http://www.usawaterquality.org/volunteer/Ecoli/

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Pathogen Indicators of Recreational Water Quality (a PowerPoint Presentation) http://www.state.nj.us/dep/wms//Recreational%20Indicators%20Overview.pdf

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USEPA. Beaches Environmental Assessment and Coastal Health (BEACH) Program http://www2.epa.gov/beaches

USEPA. Water: Monitoring & Assessment 5.11 Fecal Bacteria http://water.epa.gov/type/rsl/monitoring/vms511.cfm.

USGS Field Manual – Fecal indicator bacteria: http://water.usgs.gov/owq/FieldManual/Chapter7/7.1_ver2.0.pdf.

Volunteer Monitoring of Bacteria

Summary

Regular monitoring of fecal indicator bacteria can help volunteers understand how water quality is changing over time or space and what activities might be affecting it. This information can also help to assess the risk of swimming in a particular area, or to target efforts to protect or restore a waterbody. However, since bacteria are found naturally in the environment, it is important to understand how and why bacteria are being monitored. This factsheet summarized the types of bacteria that are monitored and some emerging indicators that volunteer monitoring programs may get involved with. Two other factsheets in this series can help you develop and enhance your bacteria monitoring efforts. They provide information on the methods used to monitor bacteria, and how to present bacterial monitoring data most effectively for your intended audience.

Other *Guide for Growing Programs - Bacteria Modules*

See ***Monitoring Bacteria – Methods*** to learn more about:

- Sampling for Bacteria Analyses
- Bacteria Testing Laboratory Basics
- Laboratory Methods

See ***Presenting Bacteria Data Effectively*** to learn more about:

- Unique Characteristics of Bacteria Data
- Effective Charts and Graphs for Presenting Bacteria Data
- Cautions Regarding the Use of Bacteria Data

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