UNDERSTANDING MICROBIAL RISK & IMPLICATIONS FOR WATER, WASTEWATER & STORMWATER MANAGEMENT

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10102 E. 116th St. N. Owasso, OK 74055

E. coli or Enterococci?

- “In this review we examine 73 papers generated over 40 years that reported the relationship between at least one indicator and one pathogen group or species.”
- For fresh water, “*E. coli* was the FIB with the greatest number of significant relationships, followed by enterococci, fecal and total coliforms (table 1).” (Asja Korajkic et al. 2018)
- For marine and brackish water, “The most significant relationships with pathogens were reported for enterococci (n=11), followed by *E. coli* (n=40), and fecal coliforms (n=2). (Asja korajkic et al. 2018)

E. coli or Enterococci?

- However, “The majority of the studies either did not report a relationship, or they reported a statistically non-significant relationship.” (Asja Korajkic et al. 2018)
- “General FIB tended to form statistically significant relationships more commonly with bacterial and protozoan pathogens, (compared to viral pathogens) and this difference was statistically significant. (Asja Korajkic et al. 2018)

Texas Regulations

Title 30, Part 1 (Texas Commission On Environmental Quality),
Chapter 307 (Texas Surface Water Quality Standards)
Rule §307.7 (Site-specific Uses and Criteria)
(A) Freshwater. (vi)

"E. coli is the applicable recreational indicator for instream bacteria sampling at all times for unclassified water bodies where conductivity values indicate that water bodies are not high saline." (Texas Administrative Code, Title 30, Chapter 307, Rule §,307.7)

E. coli or Enterococci?

The "Guidelines For Canadian Recreational Water Quality, Third Edition, 2012" states:

"Recreational waters should be routinely monitored for the presence of faecal contamination, using the following primary indicators of faecal contamination:

- Fresh water: *E. coli*;
- Marine water: Enterococci. (Guidelines for Canadian Recreational Water Quality, Third Edition. 2012)

E. coli or Enterococci?

- “In the New Zealand context where human wastewater, and consequently virus contamination, are not the drivers of faecal contamination in many areas, *E. coli* is likely to be a better indicator. The die-off of *E. coli* in the environment reflects the behavior of the most common bacterial pathogens associated with GI from water recreation in New Zealand, *Campylobacter* and *Salmonella*, and also shiga toxin-producing *E. coli* (US EPA 2018) which is less common.” (Leonard and Eaton. 2021)

E. coli or Enterococci?

- "… WHO still recommends enterococci as the FIB for freshwater, as it considers that there is no significant dose-response relationship for *E. coli* that can support a guideline value." (Leonard and Eaton. 2021)
- "No statistical relationship has been established for *Escherichia coli* that can support a dose-response guideline value." (World Health Organization. 2021)

Primary Body Contact Recreation Criteria in Oklahoma

(C) “compliance with OAC 252:730-5-16 shall be based upon meeting the requirements of one of the options specified in (1) or (2) of this subsection (c) for bacteria. Upon selection of one (1) group or test method, said method shall be used exclusively over the time period prescribed therefore.” (Okla. Admin. Code § 252:730-5-16)

In Oklahoma, *E. coli* or enterococcus can be used.

EPA Comparison of *E. coli* and Enterococci Recommendations from the 2012 RWQC

Criteria Elements	Recommendation 1 Estimated Illness Rate 36/1,000		Recommendation 2 Estimated Illness Rate 32/1,000	
Indicator	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
Enterococci	35	130	30	110
E. coli	126	410	100	320

"The STV approximates the 90th percentile of the water quality distribution and is intended to be a value that should not be exceeded by more than 10 percent of the samples taken." (EPA. 820-F-12-061. 2012)

32 or 36 Illnesses Per 1,000 Swimmers?

“Criteria values were provided for culture- and quantitative polymerase chain reaction (qPCR)-enumerated FIB at two illness rates, 32 and 36 illnesses per 1,000 swimmers (NGI illness rate). Based on the EPA’s analysis of the available information, either set of thresholds protects the designated use of primary contact recreation and, therefore, protects the public from the risk of exposure to harmful levels of pathogens from fecal contamination.” (EPA. 823 R 18 001. 2018)

32 or 36 Illnesses Per 1,000 Swimmers?

“2012 RWQC provides two sets of recommended criteria, each of which corresponds to a different illness rate.

- Either can be adopted in state/tribal WQS
- Both are protective
- Allows for risk management decision”

(Recreational Water Quality Criteria For Primary Contact Recreation. EPA. 2023)

Primary Body Contact Recreation

(B) "In waters designated for primary body contact recreation the following limits for bacteria set forth in (c) of this section shall apply only during the recreation period of May 1 to September 30. The criteria for secondary body contact recreation will apply during the remainder of the year."

(Okla. Admin. Code § 151:730-5-16)

Primary Body Contact Recreation Beneficial Use

(1) "*Escherichia coli* (*E. coli*): the E. coli geometric mean criterion is 126/100 ml. For swimming advisory and permitting purposes, E. coli shall not exceed a monthly geometric mean of 126/100 ml based upon a minimum of not less than five (5) samples collected over a period of not more than thirty (30) days. " (*E. coli* standard)

(Okla. Admin. Code § 252:730-5-16)

Primary Body Contact Recreation Beneficial Use

(1) "For swimming advisory and permitting purposes, no sample shall exceed a 75% one-sided confidence level of 235/100 ml in lakes and high use waterbodies and the 90% one-sided confidence level of 406/100 ml in all other primary body contact recreation beneficial use areas. These values are based upon all samples collected over the recreation period. For purposes of sections 303(d) and 305(b) of the federal clean water act as amended, beneficial use support status shall be assessed using only the geometric mean criterion of 126/100 milliliters compared to the geometric mean of all samples collected over the recreation period."   (*E. coli* standard)

(Okla. Admin. Code § 252:730-5-16)

Caution

- I am not a medical doctor.
- If you have questions about the possibility of infection, concerns regarding risk avoidance measures, or confirmation of infection, consult your physician.
- If you have questions about immunizations, vaccinations, or treatment options, consult your physician.

When to Use Italics for Bacteria and Viruses

Genus, and Species Are *Italicized*.

Example: *Escherichia coli* (*E. coli*)

Example: *Salmonella*, *S. enterica* and *S. bongori*. Salmonella consists of only two species which can be divided into 6 subspecies.

When speaking about a genus or species in general, don't italicize.

Example: When discussing "staphylococcus," "streptococci," or "salmonella" in general, don't use italics.

OSHA Regulations

- The Occupational Safety and Health Administration (OSHA) has numerous regulations regarding microbial safety in health care, laboratories, emergency response situations, and for individuals potentially exposed to pathogens like *Legionella*.
- For occupations and specific settings not specifically listed in OSHA regulations, OSHA falls back on the general duty clause.

OSHA General Duty Clause

- Section 5a1 of the OSH act is known as the general duty clause and states:
- Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.
- The general duty clause, by definition, means that employers must protect employees from any serious hazard once they're aware of it – whether OSHA's rules specifically address it or not.

Modes of Microbial Exposure

- Direct water contact
- Contaminated food
- Skin contact with objects that have been exposed to waterborne organisms
- Contact with soils, sediments, and sludges
- Ingestion
- Bioaerosols (skin and inhalation)
- Contact with infected people or other animals

Personal Protective Equipment (PPE)

The situation and conditions will dictate the appropriate PPE. Understand the risk and prepare accordingly.

Personal Protective Equipment (PPE)

- Gloves keep microbes off your skin and protect you from entry through abrasions (cuts, blisters, and open wounds) which are highly susceptible to infection.
- Boots protect your feet and lower legs from contact with microbes and leaving your boots at work helps prevent the spread of dangerous microbes to your home.

Personal Protective Equipment (PPE)

- Safety glasses or face shields can protect your eyes, nose, and face from contact with splashes and sprays that may contain microbes.
- Masks and respirators filter out airborne toxins as well as splashes and sprays.
- Coveralls protect the body and clothing from contact with biohazards.

Additional Safety Measures

- Wash hands thoroughly and frequently before eating, drinking, and smoking.
- Wash hands before and after using the bathroom and contacting contaminants.
- Wear PPE when it is required.
- Use barriers between skin and potentially contaminated surfaces.

Additional Safety Measures

- Keep wounds covered with clean, dry, bandages.
- If contaminated water or sludge gets on your skin or in your eyes, nose, or mouth, flush with safe water.
- Wear clean work clothes daily.
- Sanitize or change footwear before leaving work and before entering vehicles or buildings if practical.
- Clean equipment as necessary.

Additional Safety Measures

- Eat in designated areas away from biohazards.
- Avoid inhalation of infectious agents and aerosols.
- Don’t touch any part of your face, genitalia, or open sores and cuts with contaminated hands or gloves.
- Don’t smoke or chew tobacco or gum while working.
- Don’t wear work clothes at home or outside the work area.

Symptoms to Watch For

Symptoms	
Stomach cramps	Yellowing of the skin
Fever	Redness and pain in the eyes
Nausea	Skin rash, pain, infection
Diarrhea	Symptoms of breathlessness, chest tightness, and wheezing
Vomiting	

In The Beginning

- In the 1960s, the U.S. Public Health Service recommended using fecal coliform as the FIB.
- EPA recommended using fecal coliforms in 1976.
- Fecal coliforms *as a group* tend to be poor indicators of digestive or gastrointestinal illness.
- In 1986 EPA published *Ambient Water Quality Criteria for Bacteria* and recommended using *E. coli* for fresh water and enterococci for marine water.

Earl FIBs

- Along the way, regulatory agencies have used total coliforms, fecal coliforms, fecal streptococci, and ratios of fecal coliforms and fecal streptococci to try and predict recreational risk. These indicators are no longer used for recreational risk.
- However, some of these indicators are still used to assess shellfish-growing water risk, groundwaters, wastewater, and drinking waters.

Ambient Water Quality Criteria (AWQC)

"The EPA is charged with the development of criteria and regulations to protect the public from exposure to microbiological contaminants of fecal origin in recreational water. The overall goal of the current ambient water quality criteria (AWQC) for bacteria in the united states is to provide public health protection from gastroenteritis (GI illness) associated with exposure to fecal contamination during water-contact recreation." (EPA 823-B-14-001. 2022)

Ambient Water Quality Criteria (AWQC)

"The overall goal of the current clean water act (CWA) §304(a) ambient water quality criteria (AWQC) for bacteria in the united states is to provide public health protection from gastrointestinal (GI) illness (gastroenteritis) associated with exposure to fecal contamination during recreational water contact. Water quality criteria are specified throughout the world in terms of concentrations of fecal indicator…" (EPA 822-R-09-002. 2009) (continued)

Ambient Water Quality Criteria (AWQC)

“organisms 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. For decades, these fecal indicator organisms have served as surrogates for potential pathogens and subsequent health risks in both recreational and drinking waters.” (EPA 822-R-09-002. 2009)

Ambient Water Quality Criteria (AWQC)

"The U.S. Environmental Protection Agency (EPA) currently recommends AWQC for recreational water that encompass all fecal sources that contain the relevant indicator species (enterococci and *E. coli*). This approach assumes that animal fecal material is as hazardous as human fecal material. There is limited evidence, however, that recreational water contaminated with animal fecal material is less risky to swimmers than recreational water contaminated with human fecal material." (EPA 822-R-09-002. 2009)

Fecal Contamination And Pathogens

“When developing its 2012 RWQC, EPA identified the hazard of concern as pathogenic microorganisms in fecally-contaminated surface waters. Pathogens often co-occur with bacterial indicators of fecal contamination. Therefore, EPA relied on fecal indicator bacteria (FIB) to serve as pathogen indicators. A pathogen indicator, as defined in §502(23) of the CWA, as amended by the BEACH act, is defined as: ‘a substance that indicates the potential for human infectious disease’.” (EPA 823-b-14-001. 2022)

Fecal Contamination And Pathogens

- “Fecal indicator bacteria (FIB) serve as surrogates for enteric pathogens and are used to monitor the presence of fecal contamination of environmental waters worldwide.” (Brian D. Badgley, Florence I.M. Thomas and Valerie J. Harwood. 2011)
- “Elevated numbers of these indicator bacteria in the aquatic environment are indicative of faecal contamination and therefore suggest the possible presence of enteric pathogens.” (Guidelines for Canadian Recreational Water Quality. 2012)

Escherichia coli (E. coli)

- *Escherichia coli* (*E. coli*) is a type of bacteria that lives in the intestines of people and other animals and is commonly found in human and animal feces. (EPA 841 F 21007 F. 2021)
- Most strains of *E. coli* are harmless, but some can make people sick. (EPA 841 F 21007 F. 2021)

Escherichia coli

- *Escherichia coli* (*E. coli*) is a single species in the fecal coliform group. *Escherichia* is the genus, *coli* is the species.
- *E. coli* is known as a prokaryotic organism as it does not possess most of the membrane-bound organelles which are a characteristic feature of eukaryotes.

Escherichia coli

E. coli is gram-negative, non-sporulating, rod-shaped, facultative anaerobic coliform bacterium pertaining to the genus Escherichia that commonly inhabits the environment, foods, and warm-blooded animals' lower gut. It can live for long periods of time in feces, soil, and water, and is frequently used as a FIB. Most are motile and use flagella.

Are FIBs Pathogenic?

- "The FIB, enterococci and *Escherichia coli* (*E. coli*), are not pathogenic under usual circumstances, but their presence in water above specified levels can indicate the presence of viral, bacterial, or protozoan pathogens associated with an elevated risk of illness." (EPA. 823 R 18 001. 2018)
- "FIB densities have long served as the surrogate measure of fecal contamination and, by inference, the presence of pathogens commonly associated with fecal material." (EPA. 823 R 18 001. 2018)

What Is A Pathogen Indicator?

- "A pathogen indicator, as defined in §502(23) of the CWA, as amended by the BEACH act, is defined as follows: 'a substance that indicates the potential for human infectious disease.' Most strains of enterococci and *E. coli* do not cause human illness (that is, they are not human pathogens); rather, they indicate the presence of fecal contamination. The basis for recommending criteria that use bacterial indicators of fecal contamination is that pathogens often co-occur with indicators of fecal contamination." (EPA 820-F-12-058. 2012)

Developing Water Quality Standards

- "In the 2012 RWQC, EPA recommends using the fecal indicator bacteria (FIB) enterococci and *Escherichia coli* (*E. coli*) as indicators of fecal contamination for fresh water and enterococci for marine water." (EPA 820-F-12-058. 2012)
- You do not have to test for both enterococci and *E. coli*. You can use either one but must be consistent in usage. Both are used as indicators of the same thing; the presence of fecal material and the potential for pathogens.

Developing Water Quality Standards

"Fecal contamination in recreational waters is associated with an increased risk of gastrointestinal (GI) illness and less often identified respiratory illness. As such, fecal contamination and its indicators are considered 'pathogen indicators,' as defined by §502(23) of the CWA." (EPA 820-F-12-058. 2012)

Fecal Contamination And Pathogens

“While measurements of various FIB have shown good correlation with risks of waterborne illness in certain studies (Wade et al., 2003; Zmirou et al., 2003), other studies have indicated little or no correlation with pathogens, including those on *Salmonella*, *Campylobacter*, *Cryptosporidium*, *Giardia* or enteroviruses (Lund, 1996; Bonadonna et al., 2002; Lemarchand and Lebaron, 2003; Harwood et al., 2005).” (Brian D. Badgley, Florence I.M. Thomas and Valerie J. Harwood. 2011)

Are FIBs A Good Indicator of Fecal Contamination?

"However, increasing numbers of scientific studies have demonstrated the existence of non-fecal sources of FIB in environmental matrices (Fujioka and Byappanahalli, 2003; Stewart et al., 2008; Byappanahalli et al., 2011; Yan et al., 2011)." (EPA-820-R-010. 2014)

Are FIBs a Good Indicator of Fecal Contamination?

"Collectively, these studies suggest that under particular conditions, fecal indicator organisms from a variety of point and especially nonpoint sources (e.g., stormwater runoff, domestic pets, birds) can colonize and proliferate in ambient waters and associated sand and sediment. As a consequence, routine monitoring of fecal indicator bacteria may detect fecal indicator concentrations in excess of federal or state water quality standards-possibly resulting in unnecessary action being taken, such as beach advisories and closing (and also listings of ambient waters on the clean water act (CWA) 303(d) list of impaired waters)." (EPA 4305T. 2010)

Are Fibs a Good Indicator of Fecal Contamination?

“Another limitation of FIB is that they do not often correlate well with the presence of pathogens in environmental waters. The appropriateness of using FIB to indicate the presence of pathogens especially viruses and protozoa in stormwater has been questioned (Jiang et al., 2001; Schroeder et al., 2002; Jiang, 2004; Robertson and Nicholson, 2005; Signor et al., 2005; AWQC, 2008).” (Warish Ahmed et.al,. 2019)

Are Fibs a Good Indicator of Fecal Contamination?

"In addition, the decay rates of FIB may be significantly different than those of viruses (Ahmed et al., 2014b). Hence, monitoring of FIB and interpreting their concentrations in terms of human health risks may not yield any meaningful outcomes." (Warish Ahmed et.al,. 2019)

Are FIBs a Good Indicator of Fecal Contamination?

"As demonstrated by the regional studies discussed previously in this section, under favorable environmental conditions, fecal indicator organisms can persist and (re)grow outside of the gastrointestinal tracts of humans and other warm-blooded animals. The literature presented is consistent in demonstrating that these microorganisms are endemic to tropical, subtropical, and temperate regions and thus, their presence in water is not necessarily an indication of recent fecal contamination." (EPA 4305T. 2010)

Are Fibs a Good Indicator of Fecal Contamination?

Independent survival and growth of FIBs decouples the fecal indicator bacteria from the fecal pollution they are intended to represent.

Are Fibs a Good Indicator of Fecal Contamination?

“Therefore, use of bacterial indicators is predicated on the presumption that there are no significant environmental sources of these microorganisms (i.e., nonenteric sources). However, this presumption is not entirely valid; fecal indicator organisms have been demonstrated to have natural reservoirs in the aquatic environment where they can survive for extended periods and even proliferate (e.g., fecal indicator bacteria in U.S. Coastal [Yamahara et al., 2007] and great lake waters and sand [Whitman et al., 2006].” (EPA 822-R-09-002. 2009)

Why Not Test For All Potential Pathogens?

"Because widespread monitoring of recreational waters directly for all disease-causing microorganisms remain infeasible, public health and environmental protection agencies have relied on the detection of fecal indicator organisms to indicate the presence and magnitude of fecal material. This approach assumes that waterborne pathogens co-occur with the fecal material and that greater quantities of fecal contamination yield greater quantities of pathogens (NRC 2004)." (EPA. 4305T. 2010)

Fecal Indicator Bacteria (FIB) Sources

"Furthermore, fecal contamination from human and animal sources contribute different pathogens to ambient waters resulting in variable relationships between FIB, pathogens, and illness outcomes (Soller et al., 2010b; Mclellan and Eren, 2014). For example, human fecal contamination, such as untreated sewage and even disinfected effluent, is associated with the highest potential risk of GI illness (Soller et al., 2010b, Schoen et al., 2011)." (EPA. 823 R 18 001. 2018)

Coliform Bacteria

Source	Bacterial Pathway
Parking Lots, Roadways	Runoff
Sanitary Sewers (and WWTP Processes)	Overflows, Leaks, and Breaks
Onsite Septic Systems	Failures and Improper Maintenance
Shores and Beaches	Bathers and Wildlife
Wildlife (deer, birds, raccoons, etc.)	Runoff and Direct Deposition
Urban Pets	Runoff and Direct Deposition
Animal Agriculture	Runoff and Direct Deposition
Stormwater	Runoff
Sediments	Runoff and a Reservoir
Vegetation (aquatic primarily)	Runoff and a Reservoir
Soil and Sediment	Runoff and a Reservoir
Recreational Parks, Dog Parks, and Residential Lawns	Runoff

What Do We Test For?

- "*E. coli* most closely fits the requirements of an ideal indicator of faecal contamination for fresh waters." (Guidelines for Canadian Recreational Water Quality. Third Edition. 2012)
- "For several decades now, recreational water quality experts in Canada have recognized *E. coli* as the indicator of choice for faecal contamination." (Guidelines for Canadian Recreational Water Quality. Third Edition. 2012)

Bacteria

- Bacteria – “Bacteria are single-celled prokaryotes that range in size from 0.15 and 700 μm. [14] While the vast majority are either harmless or beneficial to their hosts, such as members of the human gut microbiome that support digestion, a small percentage are pathogenic and can cause infectious diseases.” [15] (Wikipedia. 2023)
- Bacterial infections may be treated with antibiotics.

Bacteria

Bacteria can be found virtually everywhere. They are in the soil, air, water, vegetation, on animals, and on food sources.

Response to Environmental Stressors

"When enterococci are released from the gastrointestinal tract of warm-blooded animals into secondary habitats such as environmental waters, aquatic vegetation, or sediment, they are subjected to a host of biotic and abiotic stressors that generally lead to a decline in population over time." (Muruleedhara N. Byappanahalli et all. 2012)

Exotoxin & Endotoxin Bacteria

Bacteria – “Some bacteria produce toxins, which cause diseases.[220] These are endotoxins, which come from broken bacterial cells, and exotoxins, which are produced by bacteria and released into the environment.[221]. The bacterium *Clostridium botulinum* for example, produces a powerful exotoxin that cause respiratory paralysis, and *Salmonellae* produce an endotoxin that causes gastroenteritis.[221]” [15] (Wikipedia. 2023)

Viability

- Some types of bacteria can form highly resistant, dormant structures called endospores which develop within the cytoplasm of the cell. Each endospore contains a core of DNA and ribosomes surrounded and protected by a multilayer rigid membrane.
- "Endospores show no detectable metabolism and can survive extreme physical and chemical stresses, such as high levels of uv light, gamma radiation, detergents, disinfectants, heat, freezing, pressure, and desiccation.[92] (Wikipedia, 2023)

Viability (Continued)

“In this dormant state, these organisms may remain viable for millions of years.[93] [94] [95] endospore-forming bacteria can cause disease; for example, anthrax can be contracted by the inhalation of *Bacillus anthracis* endospores, and contamination of deep puncture wounds with *Clostridium tetani* endospores causes tetanus, which, like botulism, is caused by a toxin released by the bacteria that grow from the spores.[98] (Wikipedia, 2023)

Viability

“The studies regarding the fate of enterococci in the environment refer to evaluations made by counting colony forming units (CFU/ml) and are thus based on the ability of bacteria to divide and form colonies on culture media. However, it is now clear that in the environment bacteria find adverse conditions, which do not allow their division but do not necessarily cause their death.” (Maria Del Mar Lleò et al. 2005)

E. coli Viability (Slide 2)

"These studies suggest that fecal indicator bacteria such as *E. coli* can persist in sand in low and freezing temperatures during winter months in temperate regions and then regrow when temperatures increase." (EPA 4305T. 2010)

E. coli Viability (Slide 3)

"Samples from a Lake Michigan beach were sterilized and inoculated with *E. coli*, which was then allowed to dry under natural conditions. Upon desiccation (humidity of <5 percent), *E. coli* entered a metabolically inert state but remained viable. The bacteria resumed active growth after rehydration. Byappanhalli et al. (2006) demonstrated that higher humidity encouraged growth of *E. coli* in soils of the Dunes Creek watershed on the southern shore of Lake Michigan." (EPA 4305T. 2010)

E. coli Viability (Slide 4)

- “The sand acted as a nonpoint source of *E. coli* and could support an indigenous population of *E. coli* for extended periods of time, regardless of additional input from humans, animals, or lake waters.” (EPA 4305T. 2010)
- Therefore, soils, sediments, and sand can act as a reservoir for fecal indicator microorganisms that are not associated with point source fecal contamination events.” (EPA 4305T. 2010)

E. coli Viability (Slide 5)

"Whitman et al. (2003) investigated 10 Lake Michigan beaches in Wisconsin, Illinois, Indiana, and Michigan and found that *E. coli* and enterococci were present in up to 97% of *Cladophora* samples. *Cladophora* is considered to be a nuisance macrophytic, green alga commonly found in the great lakes during the summer months." (EPA 4305T. 2010)

E. coli Viability (Slide 6)

“To investigate the survival ability of *E. coli* and enterococci in these algae, *Cladophora* mats were harvested, sun-dried, and kept at 4˚C for 6 months. Samples from the mats were then rehydrated and incubated and 35˚C - a temperature similar to exposed beach or shallow waters in summer months. Regrowth of *E. coli* and enterococci occurred within 24 hours of rehydration, and stable populations were established within 72 hours.” (EPA 4305T. 2010)

Viability Enterococci

“Bacterial species in general and *Enterococcus faecalis* specifically, can activate several survival strategies including starvation and the viable but nonculturable (VBNC) state [7-10] thus conserving their viability. The VBNC state is defined as a survival mechanism activated by bacteria in response to multiple environmental stresses and allowing microorganisms to conserve their viability despite the loss of their own culturability.” (Maria Del Mar Lleò et al. 2005)

Viability Enterococci

“When division-allowing conditions are restored in microcosms containing nonconculturable cells, at least a part of the VBNC cells of *E. faecalis* population is capable of recovering culturability as demonstrated elsewhere [13]. On the contrary, nonculturable cells of *E. faecium* cannot resume division either because they are dead or dying [13].” (Maria Del Mar Lleò et al. 2005) (VBNC is viable but nonculturable)

Viability Enterococci

"Although it is currently (2016) unknown whether this persistence of enterococci demonstrates growth or viability, the data indicate that enterococci can exist in channel bed-sediment environments outside of a host for a long time. This observation confirms previous reports that challenge the use of *Enterococcus* concentrations as an indicator of the recent introduction of fecal-related material and the associated acute risk to other pathogens." (James E. Landmeyer et al. 2016)

Survival Strategies of *Clostridium Botulinum* (Bacteria)

"When bacteria are under stress, they develop spores, which are inert. Their natural habitats are in the soil, in the silt that comprises the bottom sediment of streams, lakes, and coastal waters and ocean, while some types are natural inhabitants of the intestinal tracts of mammals (e.g., horse, cattle, humans), and are present in their excreta. The spores can survive in their inert form for many years. [26]" (Wikipedia. 2023)

Survival Strategies Of *Clostridium Botulinum* (Bacteria) (Continued)

"Toxin is produced by the bacteria when environmental conditions are favorable for the spores to replicate and grow, but the gene that encodes for the toxin protein is actually carried by a virus or phage that infects the bacteria. Little is known about the natural factors that control phage infection and replication within the bacteria.[27]" (Wikipedia. 2023)

Survival Strategies of *Clostridium Botulinum* (Bacteria) (Continued)

"The spores require warm temperatures, a protein source, an anaerobic environment, and moisture in order to become active and produce toxin. In the wild, decomposing vegetation and invertebrates combined with warm temperatures can provide ideal conditions for the botulism bacteria to activate and produce toxin that may affect feeding birds and other animals. Spores are not killed by boiling, but botulism is uncommon because special, rarely obtained conditions are necessary for botulinum toxin production from *C. botulinum* spores, including an anaerobic, low-salt, low-acid, low-sugar environment at ambient temperatures.[28]" (Wikipedia. 2023)

Campylobacter jejuni (Bacteria)

Campylobacter jejuni is a pathogenic bacteria and one of the most common causes of human gastroenteritis in the world. Symptoms (abdominal pain, diarrhea, fever) usually develop within two to five days from exposure and illness typically lasts seven days following onset.

CAMPYLOBACTERIOSIS

“Campylobacteriosis is the most common diarrheal illness in the united states. The infection is caused by the bacterium *Campylobacter*. While some people exhibit no symptoms, clinical manifestations include bloody diarrhea, cramping, abdominal pain, nausea, vomiting, and fever within 2 to 5 days after exposure to the organism. In the immunocompromised, *Campylobacter* occasionally spreads to the bloodstream and causes a life-threatening infection.” (Diseases Involving Sewage)

Campylobacter (Bacteria)

Common sources: fecal matter from people or animals.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), polluted stormwater runoff, and agricultural runoff.

Symptoms of infection: the most common symptoms are diarrhea, fever, and stomach cramps.

CAMPYLOBACTERIOSIS (BACTERIA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Campylobacteriosis	*Campylobacter jejuni* (most common)	Drinking water contaminated with feces	Produces dysentery-like symptoms along with a high fever. Usually lasts 2-10 days.

Campylobacteriosis is among the most common infections caused by a bacteria in humans, often as a foodborne illness. Produces bloody diarrhea or dysentery. Infectious routes include fecal-oral and contaminated food and water. The CDC estimates a total of 1.5 million infections every year. *C. jejuni* is commonly associated with poultry and cattle and is also commonly found in animal feces.

Wikipedia

Cholera (Bacteria)

"Cholera is an infection of the small intestine by some strains of the bacterium *Vibrio cholerae*.[4][3] Symptoms may range from none, to mild, to severe. [3] Symptoms start two hours to five days after exposure. [3] It is spread mostly by unsafe water and unsafe food that has been contaminated with human feces containing the bacteria. [2] Humans are the only known host for the bacteria.[2] Transmission is usually through the fecal-oral route of contaminated food or water caused by poor sanitation.[2]" (Wikipedia. 2023)

Cholera

- "*V. cholerae* also exists outside the human body in natural water sources, either by itself or through interacting with phytoplankton, zooplankton, or biotic and abiotic detritus.[26] Drinking such water can also result in the disease, even without prior contamination through fecal matter.[3] Selective pressures exist however in the aquatic environment that may reduce the virulence of *V. cholerae*.[26] Specifically, animal models indicate that the transcriptional profile of the pathogen changes as it prepares to enter an aquatic environment. [26]" (Wikipedia. 2023)

Cholera (Bacteria)

"This transcriptional change results in a loss of ability of *V. cholerae* to be cultured on standard media, a phenotype referred to as 'viable but non-culturable' (VBNC) or more conservatively 'active but non-culturable' (ABNC).[26] One study indicates that the culturability of *V. cholerae* drops 90% within 24 hours of entering the water, and furthermore that this loss in culturability is associated with a loss in virulence.[26][27]" (Wikipedia. 2023)

Cholera (Bacteria)

- “Both toxic and non-toxic strains exist. Non-toxic strains can acquire toxicity through a temperate bacteriophage.[28]” (Wikipedia. 2023)
- Cholera poses a much greater risk in developing nations. In the U.S. and other developed nations people have access to safer drinking water, better hygiene, and better medical care.

Survival Strategies of Cholera (Bacteria)

“When consumed, most bacteria do not survive the acidic conditions of the human stomach.[31] The few surviving bacteria conserve their energy and stored nutrients during the passage through the stomach by shutting down protein production. When the surviving bacteria exit the stomach and reach the small intestine, they must propel themselves through the thick mucus that lines the small intestine to reach the intestinal walls where they can attach and thrive. [31] ” (Wikipedia. 2023)

Survival Strategies of Cholera (Bacteria) (Continued)

“Once the cholera bacteria reach the intestinal wall, they no longer need the flagella to move. The bacteria stop producing the protein flagellin to conserve energy and nutrients by changing the mix of proteins that they express in response to the changed chemical surroundings. On reaching the intestinal wall *V. cholerae* start producing the toxic proteins that give the infected person a watery diarrhea. This carries the multiplying new generations of *V. cholerae* bacteria out into the drinking water of the next host if proper sanitation measures are not in place. [32] ” (Wikipedia. 2023)

Coliform Bacteria

Coliform bacteria are generally found within the digestive systems of warm-blooded animals. Coliforms are often broken down into groups like: total coliforms, fecal coliforms, enterococcus, and *Escherichia coli* (*E. coli*).

All of these groups can *indicate* the presence of fecal material and therefore the possibility that other harmful bacteria, viruses, and protozoa may be present. The coliforms are often called indicator organisms.

Enterococcus faecalis (Bacteria)

- *Enterococcus faecalis* (also called *E. faecalis*) is one of the most common species of *enterococci* and is the leading cause of enterococcal infections.
- The cell wall of this species is very thick and can make up as much as 40% of the cell's mass. This thick cell wall can help protect against various stressors.

Escherichia coli O157 (Bacteria)

Common sources: fecal matter from people or animals.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), polluted stormwater runoff, and agricultural runoff.

Symptoms of infection: the most common symptoms are bloody diarrhea, severe stomach cramps, and throwing up.

E. coli O157:H7 Viability (Slide 1)

"Wang and Doyle (1998) found that the pathogen *E. coli* O157:H7 can survive up to 91 days at 8˚ C. Under these cooler temperatures, the bacteria entered a viable but nonculturable (VBNC) state until temperatures warmed again, when the bacteria regained metabolic activity. Whitman and Nevers (2003) determined that *E. coli* can survive winter temperatures, including freezes, in the sands on a Lake Michigan beach." (EPA 4305T. 2010)

Escherichia coli O157:H7 (Bacteria)

"*E. coli* O157:H7 can survive for at least several weeks in animal feces and slurries (Avery et al., 2005) and has been demonstrated to survive at least 500 days at -20˚ C in frozen soil (Gagliardi and Karns, 2002)." (EPA. 822-R-09-002. 2009)

-20˚C = -4˚F

Escherichia coli (BACTERIA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
E. coli infection	Certain strains of *Escherichia coli* (commonly *E. coli*)	Water contaminated with the bacteria	Mostly diarrhea. Can cause death in immunocompromised individuals, the very young, and the elderly due to dehydration from prolonged illness.

Wikipedia

Escherichia coli (PATHOGENIC BACTERIA)

"*Escherichia coli* can be transmitted by contaminated water or by person-to-person via the fecal-oral route. While some people exhibit no symptoms, most experience watery or bloody diarrhea, abdominal cramps, nausea, vomiting, and fever. In 2-7% of those who acquire *E. coli O157:H7* infection, hemolytic uremic syndrome may develop, causing kidney failure and sometimes death. This syndrome occurs particularly in children under the age of 5, the elderly, and those with weakened immune systems." (Diseases Involving Sewage)

Legionella Bacteria

- Common sources: Legionella bacteria are found naturally in freshwater environments like lakes and streams.

  Means of entry: this bacteria can become a health risk when they grow and spread in building water systems (such as faucets or hot water heaters), and devices that create small drops of water (such as cooling towers, hot tubs, or decorative fountains).

Legionella Bacteria

Symptoms of infection: cough, fever, headaches, muscle aches, and shortness of breath.

Leptospira (Bacteria)

“More than ten genetic types of *Leptospira* cause disease in humans.[12] Both wild and domestic animals can spread the disease, most commonly rodents.[8] The bacteria are spread to humans through animal urine, or water or soil contaminated with animal urine, coming into contact with the eyes, mouth, nose or breaks in the skin.[8] The bacteria can be found in ponds, rivers, puddles, sewers, agricultural fields and moist soil.[7] Pathogenic *Leptospira* have been found in the form of aquatic biofilms, which may aid survival in the environment. [28] ” (Wikipedia. 2023)

Leptospira (Bacteria)

- “In developed countries, it occurs during heavy downpours and is a risk to pest controllers, sewage workers[13] and those involved in outdoor activities in warm and wet areas. [5]” (Wikipedia. 2023)
- “The symptoms of leptospirosis usually appear one to two weeks after infection,[7] but the incubation period can be as long as a month. [20] (Wikipedia. 2023)

Leptospira (Bacteria)

- “The bacteria enter through cuts, abrasions,[7] ingestion of contaminated food, or contact with mucous membrane of the body (e.g. mouth, nose, and eyes).[31]” (Wikipedia. 2023)
- “It is common among water-sports enthusiasts in specific areas, including triathlons, water rafting, canoeing and swimming, as prolonged immersion in water promotes the entry of the bacteria.[5] However, *Leptospira* are unlikely to penetrate intact skin.[8] Once humans are infected, bacterial shedding from the kidneys usually persist for up to 60 days. [27] (Wikipedia. 2023)

LEPTOSPIROSIS (BACTERIA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Leptospirosis	Caused by bacterium of genus *Leptospira*	Water contaminated by the animal urine carrying the bacteria	Begins with flu-like symptoms then resolves. The second phase then occurs involving meningitis, liver damage (causes jaundice), and kidney failure

Wikipedia

Salmonella (Bacteria)

- "Typhoid fever, also known as typhoid, is a disease caused by salmonella serotype typhi bacteria.[2] Symptoms vary from mild to severe, and usually begin six to 30 days after exposure. [3][4] *S. enterica* typhi is believed to infect and replicate only within humans.[7] Unlike other strains of salmonella, no animal carriers of typhoid are known.[25] "
- Typhoid is spread by eating or drinking food or water contaminated with the feces of an infected person.[6] (Wikipedia. 2023)

Salmonella (Bacteria)

Common sources: fecal matter from people and animals.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), polluted stormwater runoff, and agricultural runoff.

Symptoms of infection: diarrhea (that can be bloody), fever, stomach cramps.

These viruses are too small to be removed by most filters.

SALMONELLOSIS (BACTERIA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Salmonellosis	Caused by many bacteria of genus *Salmonella*	Drinking water contaminated with the bacteria. More common as a food borne illness.	Symptoms include diarrhea, fever, vomiting, and abdominal cramps

Wikipedia

TYPHOID FEVER (BACTERIA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Typhoid fever	Caused by many bacteria of genus *Salmonella*	Ingestion of water contaminated with feces of an infected person	Characterized by sustained fever up to 40˚C (104˚F), profuse sweating; diarrhea, muscle aches, fatigue, and constipation may occur. Symptoms progress to delirium, and the spleen and liver enlarge is untreated. In this case, it can last up to four weeks and cause death. Some people with typhoid fever develop a rash called "rose spots", small red spots on te abdomen and chest.

Wikipedia

SHIGELLOSIS

"Shigellosis (also known as 'Bacillary Dysentery') is caused by a group of bacteria called *Shigella*. *Shigella sonnei* and *Shigella flexneri* account for most of the Shigellosis in the United States. While some people experience no symptoms, most develop bloody diarrhea, fever, and stomach cramps starting a day or two after exposure. Shigellosis usually resolves in 5 to 7 days, but it can be severe for infants, young children, and those who are disabled, elderly, or immunocompromised, if they cannot drink enough fluids to replace what they lose through diarrhea. A severe infection with high fever may lead to seizures in children less than 2 years old." (Diseases Involving Sewage)

Shigella (Bacteria)

Common sources: fecal matter from people.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), and polluted stormwater runoff.

Symptoms of infection: diarrhea (that can be bloody), fever, stomach pain, and feeling the need to poop even when your bowels are empty.

Virus

- The word virus is derived from Latin and Greek root words meaning poison and viruses are found wherever there is life.
- They don’t have their own metabolism or produce their own energy and are dependent upon a host to reproduce.
- In general viruses are much smaller than bacteria.

Enteric Viruses

- “Human enteric viruses are excreted in the feces of an infected person and are mainly transmitted through the fecal-oral route by ingestion of contaminated food and/or water.” (Kattareeya Kumthip et al. 2022.)
- “Enteric viruses are shed in extremely high numbers in the feces of infected individuals, typically between 10^5 and 10^{11} virus particles per gram of stool (45).” (Theng-Theng Fong and Erin K. Lipp. 2005)

Virus Infections

- Viral infections usually result in the death of the host cell. They generally rupture the host’s cell wall or alter the host’s normal cellular functions too much.
- Some viruses can infect a host cell without disrupting normal cellular functions. This latent virus may remain dormant for months or years and cause persistent infections.

Are Viruses Alive?

"In contrast, viruses, including coliphage, are defined as bordering on the living and non-living. Like all viruses, coliphage require a specific host for reproduction, are non-motile and are not as easily inactivated by common wastewater treatment processes as are FIB." (EPA. 822-R-17-003. 2016)

How Do Viruses Work?

- Virus – “viruses are generally between 20-200 nm in diameter. [27] For survival and replication, viruses infect their genome into host cells, insert those genes into the host genome, and hijack the host's machinery to produce hundreds of new viruses until the cell bursts open to release them for additional infections.[28]”(Wikipedia. 2023)
- This process upsets normal cellular functions and kills host cells. (A nanometer is 1,000 times smaller than a micrometer.)

Bacteriophage

- Bacteriophage means “bacteria eater” and is a virus that infects and replicates only in bacterial cells. They are also sometimes called phages. Phages are the most abundant biological agent on earth.
- A complete virus particle is called a virion.

Coliphages

Coliphages are a subset of bacteriophages that infect *E. coli*. Other types of bacteriophages [i.e., those that infect enterococcus and various Bacteroides species (spp.)] have also been evaluated for their use as indicators of fecal contamination.

Coliphage

"Coliphages are generally found in the gut and are excreted in the feces of humans and other warm-blooded animals. Coliphages are present in large numbers in sewage (approximately 10^7 plaque forming units [PFU] per milliliter [ml] (Ewert and Paynter, 1980; Lucena et al., 2004; Lodder and De Roda Husman, 2005)." (EPA. 820-R-15-098. 2015)

Coliphage

- Coliphage – viruses that infect bacteria and often have a low potential to multiply in the environment once discharged.
- “The review showed coliphages are a better indicator of viruses than bacteria and that the fate and transport of coliphages is more similar to viruses than FIB.” (Leonard and Eaton. 2021)
- “Coliphage expert workshop 15 in 2016 concluded that it was a good potential indicator and both types should be included in future epidemiological studies.” (Leonard and Eaton. 2021)

Bacteriophages

"Bacteriophages are considered the most abundant form of 'life' on earth and can be found in all environments where bacteria grow, including in soil, water, and inside other larger organisms (e.g., humans) harboring host bacteria (e.g., *E. coli*) (Clokie et al., 2011; Dutilh et al., 2014; Díaz-muñoz and Koskella, 2014)." (EPA.820-R-15-098. 2015)

Bacteriophages

“For replication to occur in a given environment, such as in recreational waters, their host must be both viable in that environment (Grabow, 2001; Bitton, 2005; Jofre, 2009) and susceptible to bacteriophage infection (Wiggins and Alexander, 1985; Woody and Cliver, 1995, 1997). (EPA. 820-R-15-098. 2015)

How Does a Virus Replicate?

Once a virus enters a host cell, the virus inserts its genetic material into its host, literally taking over the host's functions. An infected host cell then produces more viral protein and genetic material instead of the host cell’s usual products. The host cell no longer does what it is supposed to do. It is now a replicating machine for the virus.

Bacteriophages

“Bacteriophages use the host cell’s ribosomes, protein-synthesizing machinery, amino acids, and energy generating systems to replicate. Some bacteriophage species possess fewer than 10 genes and use essentially all of the host’s cellular functions to replicate. In contrast, other bacteriophages have 30 to 100 genes and are less dependent on the host. For example, larger bacteriophage may not require host genes for DNA replication because their own genomes contain the necessary genes (Grabow, 2001).” (EPA. 820-R-15-098. 2015)

Virus Mutation

“High genetic diversity also can occur when pathogens have high mutation rates. This latter phenomenon, referred to as ‘quasispecies,’ occurs mainly in RNA viruses because viral RNA replicase enzymes lack proofreading functions during replication, which leads to high mutation rates (Domingo et al., 1998; Morse, 1997).” (EPA. 822-R-09-002. 2009)

Viruses

"Historically, bacterial pathogens caused the most serious disease outbreaks (e.g., cholera and typhoid), and wastewater treatment improvements and discharge permits based on FIB effectively control such bacterial pathogens. More recently, quantitative microbial risk assessment (QMRA), epidemiology, and microbial water quality studies indicate that viruses may be a more significant cause of swimming-associated illnesses in human-impacted waters." (EPA. 822-R-17-003. 2016)

Viruses and FIBs

"The die off and survival characteristics of viruses and protozoa would not be accurately reflected by FIB. While viruses have been shown to be the key etiological agent (US EPA 2018), they are usually only present intermittently and likely to be present at low concentrations, unless there was a local outbreak. Even if a suitable virus was identified, a standard methodology would need to be developed to ensure consistency of results. While viruses are the highest risk factor, there is insufficient epidemiology to support viral regulations." (Leonard and Raton. 2021)

Coliphage as an Indicator

"Coliphage as an indicator. Because evidence strongly suggests most illnesses in recreational waters are due to enteric viruses, development and implementation of viral indicators, such as coliphage, may yield advances in public health protection." (EPA. 823-R-18 001. 2018)

Why Not Just Test For Viruses?

"Perhaps the biggest advantage of coliphage as an water quality indicator versus traditional FIB is that they are more likely to mimic the fate and transport mechanisms of human enteric viruses in the environment than are bacteria. This is important because viruses, not bacteria, are posited to cause >90% of waterborne illnesses (Soller et al., 2015)." (EPA 822-R-17-003. 2016.)

Why Not Just Test for Viruses?

- "Currently, there are limitations associated with using individual pathogenic viruses as indicators. For one, the measurement of densities of individual pathogenic viruses in water is expensive and time consuming, as culture-based techniques to propagate them can take over a week." (EPA 820-R-15-098. 2015.)
- Not many commercial labs have this ability.
- Testing for numerous viruses is very costly.

Viruses

“Current wastewater treatment processes, however, do not specifically target enteric virus removal/inactivation. Thus, viruses can enter surface waters from both treated and untreated human sources.” (EPA. 822-R-17-003. 2016)

Viruses and Wastewater

“Traditional wastewater treatment processes are not designed to reduce enteric viral loads in human sewage but do reduce culturable fecal indicator bacteria.” (Recreational Water Quality Criteria for Primary Contact Recreation. EPA. 2023)

Virus Survival

(1)“pathogenic viruses are generally more resistant than bacterial indicators during conventional wastewater treatment such as chlorination and filtration and are able to withstand lipid solvents (51, 79, 152). In the environment, enteric viruses can survive under a wide pH range (pH 3 to 10) and for extended periods at low temperatures (90).” (Theng-Theng Fong and Erin K Lipp. 2005.)

Virus Survival (Continued)

(2)"viruses have been reported to survive and remain infective for up to 130 days in seawater, for up to 120 days in freshwater and sewage, and for up to 100 days in soil at 20 to 30˚C (79, 159). These survival periods surpass those reported for fecal coliform and other indicator bacteria in similar environments (109). Finally, because viruses have an obligate host requirement, there is no potential for regrowth in the environment." (Theng-Theng Fong and Erin K Lipp. 2005.)

Viruses and Wastewater

“Other results indicate that enteric viruses can be highly infectious even at low doses (Teunis et al., 2008, Wade, et al., 2001) and are relatively resistant to standard sewage treatment processes (Laverick et al., 2004; Lodder and De Roda Husman, 2005; Pusch et al., 2005; Van Den Berg et al., 2005; Haramoto et al., 2006). These studies collectively highlight the potential importance of human enteric viruses as etiological agents of concern in recreational waters contaminated by human fecal sources and, in particular, treated and disinfected effluent.” (EPA. 823-R-18-001. 2018)

Viruses and Wastewater

"During these discussions, individual experts had common views that viruses are a source of illness in recreational water exposures and that those viruses enter surface waters via wastewater treatment plant (WWTP) effluent, especially during wet weather events and when WWTPs exceed design flows. Additionally, experts noted that coliphages are more similar to human pathogenic viruses than traditional FIB and they more closely mimic the persistence of human pathogenic viruses." (EPA. 823-R-18-001. 2018)

Viruses and Wastewater Effluent

"QMRA analysis confirmed that viruses were the most likely etiological agent in waters affected by human faecal contamination (Soller et al 2010). Disinfected effluent was likely to have lower FIB while still potentially containing significant concentrations of viruses." (Leonard and Eaton. 2021)

Viruses and GI

“Viruses are considered the main etiological agent of GI (US EPA 2018) and are human specific. Therefore, the risk from faecal contamination from animal sources is likely to be lower. The exception is where there is direct bovine faecal deposition, where *Campylobacter* is the likely pathogen of concern (Soller et al 2014).” (Leonard and Eaton. 2021)

Viruses and Illnesses

“Health studies indicate enteric viruses cause majority of swimming-associated illnesses in waters affected by human fecal contamination.” (Recreational Water Quality Criteria for Primary Contact Recreation. EPA. 2023)

Nonzoonotic vs. Zoonotic

"Although the most common waterborne recreational illnesses are probably due to nonzoonotic human viruses, which typically cause short-term gastroenteritis, the waterborne zoonotic pathogens discussed in this report have the potential to cause serious health effects – especially in immunocompromised persons and subpopulations." (EPA. 822-R-09-002. 2009)

Virus Survival

- "Viruses are more stable at lower temperatures; however, different viruses have different stabilities under similar environmental conditions." (EPA 822-R-09-002. 2009)
- "The authors conclude that viruses contained in manure may persist for prolonged periods of time if stored under nonaerated conditions and this may lead to environmental contamination with viruses." (EPA 822-R-09-002. 2009)

Viral Symptoms

"Infection by human enteric viruses is often asymptomatic in healthy people but may cause clinical symptoms ranging from mild diarrhea to chronic or severe symptoms in young children, the elderly, and immunocompromised individuals (4)." (Kattareeya Kumthip et al. 2022.)

Viral Symptoms

"Vomiting and diarrhea can result in dehydration and death if untreated. Despite abundant growth *in vivo*, they initially proved difficult or impossible to grow *in vitro*. Most are genetically diverse, species specific, highly infectious within species and transmitted by the fecal-oral route. Severe symptoms are most commonly associated with primary infections of young animals, and are followed by short-lived immunity." (R.F Bishop and C.D Kirkwood. 2014)

Viral Symptoms

- "The main symptoms of viral gastroenteritis are watery diarrhea and vomiting. The person may also have headache, fever, and abdominal cramps ("stomach ache"). In general, the symptoms begin 1 to 2 days following infection with the virus and may last for 1 to 10 days, depending on which virus causes the illness. Dehydration is the most common complication, especially among the young and elderly, and may require medical attention. The viruses that cause gastroenteritis are spread through close contact with infected persons. Individuals may also become infected by eating or drinking contaminated foods or beverages." (West Virginia Department of Health & Human Resources, Bureau for Public Health)

Enterovirus

Enterovirus infections usually start in your digestive tract ("entero" means related to the intestines) or throat, they can cause digestive symptoms, but often times they do not. They can spread to other parts of your body.

All enteroviruses are contagious. They spread through mucus, spit (saliva), poop, and contaminated water.

Enterovirus

Common sources: fecal matter from people.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), and polluted stormwater runoff.

Symptoms of infection: symptoms are often mild and commonly include fever, runny nose, sneezing, cough, skin rash, mouth blisters, and body and muscle aches.

Enterovirus

- Disinfectants do **not** work well to kill enteroviruses and enteroviruses are too small to be removed by most water filters.

Enterovirus is a group of viruses that can make you sick in lots of different ways. Some of them cause respiratory illnesses similar to a cold. Others cause hand, foot and mouth disease, pink eye, or polio. They can cause severe complications like pneumonia and paralysis.

Hepatitis A Virus

- Common sources: fecal matter from people.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), and polluted stormwater runoff.

Symptoms of infection: dark urine or clay-colored poop, diarrhea, feeling tired, fever, joint pain, loss of appetite, nausea, stomach pain, throwing up, and yellow skin or eyes (jaundice).

Hepatitis A Virus

- Hepatitis A virus is too small to be removed by most water filters.
- “Humans are the only natural reservoir of the virus. No known insect or other animal vectors can transmit the virus. (Wikipedia. 2023)

Hepatovirus A

- "Hepatitis A is an infectious disease of the liver caused by *hepatovirus A* (HAV);[6] it is a type of viral hepatitis. [7] The time between infection and symptoms, in those who develop them, is 2-6 weeks. [2]" (Wikipedia. 2023)
- "It is usually spread by eating food or drinking water contaminated with infected feces.[1] Undercooked or raw shellfish are relatively common sources.[8] It may also be spread through close contact with an infectious person.[1] While children often do not have symptoms when infected, they are still able to infect others.[1]" (Wikipedia. 2023)

Hepatovirus A (Continued)

- “Following ingestion, HAV enters the bloodstream through the epithelium of the oropharynx or intestine.[32] The blood carries the virus to its target, the liver, where it multiples within hepatocytes and Kupffer cells (liver macrophages).” (Wikipedia. 2023)
- “HAV is excreted in large numbers about 11 days prior to the appearance of symptoms or anti-HAV IgM antibodies in the blood” (Wikipedia. 2023)

HEPATITIS A (VIRUS)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Hepatitis A	Hepatitis A virus (HAV)	Can manifest itself in water (and food)	Symptoms are only acute (no chronic stage to the virus) and include fatigue, fever, malaise, abdominal pain, nausea, diarrhea, weight loss, itching, jaundice, and depression.

Wikipedia

Hepatovirus A (Virus)

"The virus is resistant to detergent, acid (pH 1), solvents (e.g., ether, chloroform), drying, and temperatures up to 60˚C. It can survive for months in fresh and salt water." (Wikipedia. 2023)

Norovirus

Common sources: fecal matter from people.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), and polluted stormwater runoff.

Symptoms of infection: diarrhea, throwing up, nausea, stomach pain.

Noroviruses are somewhat resistant to chlorine and are too small to be removed by most filters.

Norovirus

The family *Caliciviridae* contains the genus *Norovirus* (NOV).

"Human noroviruses (NOV) are the leading causes of 'non-bacterial gastroenteritis' outbreaks in all age groups worldwide. Outbreaks frequently occur in communities such as nursing homes, hospitals, schools, and cruise ships. No consistent seasonal variation has been observed. Infection involves transmission via person-to-person contact or ingestion of contaminated food and water." (R.F Bishop and C.D Kirkwood. 2014)

Norovirus

- “In addition, culturable indicator densities might not reflect potentially high-risk scenarios when disinfected effluents affect a waterbody (Wade et al., 2008; Wong et al., 2009; Soller et al., 2010b; Schoen et al., 2011).” (EPA. 823-R-18-001. 2018)
- “In general, norovirus is likely to be the most important pathogen for humans in waters affected by discharges of treated sewage (Soller et al., 2010a). (EPA. 823-R-18-001. 2018)

Virus Spread

- Viruses are spread by vectors (i.e., plant to plant by aphids, animal to animal by mosquitoes and ticks), through the air (coughing and sneezing for influenza, Sars-CoV-2, chickenpox, smallpox, measles), fecal-oral route, and through contaminated food and water.
- "Norovirus and rotavirus, common causes of viral gastroenteritis, are transmitted by the faecal-oral route, passed by hand-to-mouth contact or in food or water. The infectious dose of norovirus required to produce infection in humans is fewer than 100 particles.[12]" (Wikipedia. 2023)

Rotavirus

Common sources: fecal matter from people.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), and polluted stormwater runoff.

Symptoms of infection: severe watery diarrhea, throwing up, fever, stomach pain.

These viruses are too small to be removed by most filters.

Protozoans and FIB

"While lack of relationship between FIB and pathogenic viruses is not surprising given the enormous differences between the two groups in terms of persistence in the environment and low levels of viral pathogens typically found in ambient waters, correlations between FIB and protozoan pathogens are more difficult to understand." (Asja Korajkic et al. 2018)

Protozoa

- Protozoa –single-celled eukaryotes that feed on microorganisms and organic matter. Many protozoans are pathogenic parasites and can cause diseases like malaria (plasmodium), amebiasis (entamoeba histolytica), giardiasis (giardia duodenales), toxoplasmosis (toxoplasma gondii), cryptosporidiosis (cryptosporidium spp.), etc. Many protozoa have flagella, cilia, or move by the temporary extensions of cytoplasm called pseudopodia and are mobile.

Giardia and *Cryptosporidium*

"Two protozoans that are common pathogens in surface waters are *Giardia* and *Cryptosporidium*. To infect new hosts, these protozoans create hard casings known as cysts (*Giardia*) or oocysts (*Cryptosporidium*) that are shed in feces, and travel through surface waters in search of a new host. The cysts or oocysts are very durable and can remain viable for many months. The protozoan emerges from its hard casing if and when a suitable host is found." (Microbes and Urban Watersheds: Concentrations, Sources, & Pathways)

Protozoa Survival Strategies

Some protozoa can form microbial cysts to endure harsh environmental conditions. These resilient capsules enclose a single cell, and the organism may enter an encysted state when faced with food scarcity, overcrowding, desiccation, temperature extremes, etc. When conditions improve, the organism will emerge from the cyst and resume its activities.

Cryptosporidium (Crypto)

Common sources: fecal matter from people or animals.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), polluted stormwater runoff, and agricultural runoff.

Symptoms of infection: the most common symptom is watery diarrhea.

CRYPTOSPORIDIOSIS

- "A disease caused by the microscopic parasite *cryptosporidium parvum*. It is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine disinfection. Cryptosporidiosis (also known as "crypto") is the most common waterborne disease in the united states." "While some people exhibit no symptoms, most experience diarrhea, loose or water stools, stomach cramps, upset stomach, and a slight fever." (Diseases Involving Sewage)

CRYPTOSPORIDIOSIS (PROTOZOA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Cryptosporidiosis	*Cryptosporidium parvum*	Collects on water filters and membranes that cannot be disinfected, animal manure, seasonal runoff of water	Flu-like symptoms, watery diarrhea, loss of appetite, substantial loss of weight, bloating, increased gas, nausea

Some zoonotic reservoirs include cattle, sheep, and goats. C. parvum is a very common waterborne disease in the developed world and has caused some of the largest waterborne disease outbreaks in the U.S. The oocysts are very resilient.

Wikipedia

Giardia

Common sources: fecal matter from people and animals.

Means of entry: sewage overflows, sewage systems that are not working properly (on-site and off-site), polluted stormwater runoff, and agricultural runoff.

Symptoms of infection: diarrhea is the most common symptom.

GIARDIASIS (PROTOZOA)

Disease & Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Giardiasis (fecal-oral) (hand-to-mouth)	*Giardia lamblia* (most common intestinal parasite)	Untreated water, poor disinfection, pipe breaks, leaks, groundwater contamination, campgrounds where humans and wildlife use same source of water. Beavers and muskrats are Giardia carriers.	Diarrhea, abdominal discomfort, bloating, and flatulence

Also *G. duodenalis* and *G. intestinalis*. Cysts may survive for nearly 3 months in cold water. Also known as beaver fever. Can also occur in rodents, cows, sheep, dogs, and cats. Ingestion of only a few cysts can cause infection.

Wikipedia. 2023.

Protozoa (*Naegleria Fowleri*)

- "Naegleriasis (also known as primary amoebic meningoencephalitis: PAM) is an almost invariably fatal infection of the brain by the free-living unicellular eukaryote *Naegleria Fowleri*." This is also known as the "brain-eating amoeba".
- *N. fowleri* is typically found in warm stagnant bodies of fresh water, and could be in ponds, lakes, rivers, hot springs, near warm water discharges from industrial plants, in soil, water heaters, poorly chlorinated or unchlorinated swimming pools, etc. The disease is rare and not always considered during diagnosis. (Wikipedia. 2023)

Protozoa (*Naegleria Fowleri*) (Continued)

- These amoeba thrive under moderately elevated temperatures (up to 115 ˚F) in water that has an ample supply of bacteria for food. As a result, the summer months are of greatest concern.
- *N. fowleri* enters through the nasal cavity and works it way to the brain where it replicates and feeds on nervous tissue in the brain. Swallowing *N. fowleri* is not believed to be a route of serious infection and it is not infectious from person to person.

Parasites

- “Parasites may be present in food or in water, but cause waterborne illness much more often than foodborne illness in the United States. Parasites range in size, from tiny single-celled organisms to worms visible to the naked eye. They may be transmitted through consumption or accidental ingestion of contaminated water/food, or by putting anything into your mouth that has touched the stool (feces) of an infected person or animal.” (West Virginia Department of Health & Human Resources, Bureau for Public Health.)

Parasites

- “An intestinal parasite infection is a condition in which a parasite infects the gastro-intestinal tract of humans and other animals. Such parasites can live anywhere in the body, but most prefer the intestinal wall.”
- “Routes of exposure and infection include ingestion of undercooked meat, drinking infected water, fecal-oral transmission and skin absorption.”
- “Some types of helminths and protozoa are classified as intestinal parasites that cause infection-those that reside in the intestines.” (Wikipedia, 2023)

Parasites

"The illnesses they can cause range from mild discomfort to debilitating illness and possible death. Typically, the symptoms are watery diarrhea, abdominal cramping, bloating and alternating periods of constipation. Symptoms generally begin a week or so after ingestion of the contaminated item and typically last for several weeks." (West Virginia Department of Health & Human Resources, Bureau for Public Health.)

Parasitic Worms

- Parasitic worms – "parasitic worms (helminths) are macroparasites that can be seen by the naked eye. Worms live and feed in their living host, acquiring nutrients and shelter in the digestive tract or bloodstream of their host. They manipulate the host's immune system by secreting immunomodulatory products which allows them to live in their host for years.[31]"(Wikipedia. 2023)
- Categories: roundworms, tapeworms, and flatworms.

Streamflow and Bacteria Concentrations

- Precipitation and corresponding runoff typically washes land-based bacteria into waterways along with the runoff.
- The 'first flush' during a runoff event generally mobilizes the most bacteria. Bacteria concentrations in the runoff decrease as the duration of the runoff increases.
- Antecedent rain events wash bacteria accumulations from land prior to closely following rain events. Bacteria does not have time to accumulate between close rain events.

High Flow and Bacteria Concentrations

"Numerous studies previously have demonstrated that both external loading from catchments, in addition to internal resuspension of FIB within waterways during high-flow events, can lead to increased FIB concentrations (Jamieson et al. 2005; Cho et al. 2010a; Walters et al 2014; Ribolzi et al. 2016)." (Kathryn Vincent et al. 2022)

Streamflow and Bacteria Concentrations

"Research has demonstrated normal and high streamflow induced streambed bacteria releases. In southeast Texas, up to 90% of observed instream *E. coli* load was derived from sediment under baseflow conditions (Brinkmeyer et al. 2015). This deviates from conventional thought that resuspension only occurs during high-flow events (Jamieson et al. 2005)." (Lucas F. Gregory et al. 2022)

Waves

- "The authors concluded that turbulence generated by boats that resuspend sediments that are laden with fecal indicator bacteria, resulted in elevated counts in the water column." (EPA 4305T. 2010)
- Since sediments are known to frequently be a sink or storage reservoir for bacteria, anything that stirs and resuspends the sediments can increase bacteria counts in the water column above.

Light Exposure and Microbial Fate

"Sunlight influences indicator organism survival directly through inactivation and direct damage to DNA and RNA in the cells, and indirectly through changes in the microbial population." (EPA 4305T. 2010)

Light Exposure and Microbial Fate

"In all studies, sunlight was seen to dramatically decrease fecal indicator bacteria concentrations as a function of applied dose. Significant decreases in survival were noted for fecal coliforms (Bordalo et al. 2002, Fujioka et al. 1981, Sinton et al. 1999, šolić and Krstulović 1992), enterococci (Boehm et al 2002, Noble et al. 2004, Rosenfeld et al. 2006), and *E. coli* (Alkan et al. 1995, Davies and Evison 1991, McCambridge and McMeekin 1981, Noble et al. 2004, Rosenfeld et al. 2006, Whitman et al. 2004)." (EPA 4305T. 2010)

Light Exposure and Microbial Fate

"Light exposure causes inactivation of FIB and associated pathogens (Evison, 1988; Sinton et al., 2002; Kay et al., 2005), making photoinactivation rates critical to FIB models. Light-induced FIB inactivation rates can be modified by suspended solids or turbidity (Whitman et al., 2004; Kay et al., 2005; Gitiérrez-Cacciabue et al., 2016), water column depth, and time of day (Davies-Colley et al., 1994; Sinton et al., 2002)." (Elise M. Myers and Andrew R. Juhl. 2020)

Light Exposure and Microbial Fate

- "After temperature, UV radiation is the most common factor leading to virus inactivation. Sinton et al. (142) found that bacteriophage inactivation rates in sunlight are 10 times higher than their inactivation rates in the dark." (Theng-Theng Fong and Erin K. Lipp. 2005)
- Some types of bacteria can produce internal gas vacuoles, which they use to regulate their buoyancy, allowing them to move up or down into water layers with different light intensities and nutrient levels.

Light Exposure and Microbial Fate

"Despite their susceptibility to UV radiation, viruses are more resilient than many other pathogens and indicator bacteria to that effect because of their low molecular weight (i.e., lower target density) (51, 81). Furthermore, viruses with double-stranded DNA or RNA (e.g., double-stranded DNA adenoviruses) are extremely stable when exposed to UV because their undamaged DNA or RNA strand may serve as a template for repair by host enzymes (56, 152)." (Theng-Theng Fong and Erin K. Lipp. 2005)

Temperature and Microbial Fate

"Generally, increasing temperatures are linked to higher FIB inactivation (Auer and Niehaus, 1993; Schulz and Childers, 2011; Boehm et al., 2018) while lower temperatures tend to increase FIB persistence (Bordalo et al., 2002; Lleodel et al., 2005)." (Elise M. Myers and Andrew R. Juhl. 2020)

Temperature and Microbial Fate

"Salmonella bacteria are not destroyed by freezing,[33] [34] but UV light and heat accelerated their destruction. They perish after being heated to 55 ˚C (131˚F) for 90 min, or to 60 ˚C (140˚F) for 12 min…[35]" (Wikipedia. 2023)

Temperature and Microbial Fate

"In several studies, enteric viruses have been reported to survive longer and occur more frequently at lower temperatures in natural environments (i.e., seawater, river, and groundwater) (57, 99, 100, 165). High temperatures can damage the virus capsid or nucleic acids, which might prevent adsorption of the virus to its host and may inactivate enzymes required for replication (8)." (Theng-Theng Fong and Erin K. Lipp. 2005)

Temperature and Microbial Fate

"In summary, optimal survival or growth conditions for fecal coliforms, *E. coli*, and enterococci in the water column appear to be at a temperature around 10˚ C, though several contradictory observations were found in the literature. Growth and survival in soils appears to favor higher temperatures (>30˚C, though limited data were available to make this determination." (EPA 4305T. 2010)

(10˚C is 50˚F and 30˚C is 86˚F)

Temperature and Microbial Fate

"Fecal coliform levels are about 90% lower in runoff that occurs in winter than during the summer months, although bacteria levels can increase sharply during snowmelt events (USEPA, 1983 and figure 4)." (Microbes and Urban Watersheds: Concentrations, Sources, & Pathways)

Nutrients and Microbial Fate

"Influx of nutrients (in the form of organic carbon, nitrogen and phosphorus) can result in extended persistence [158-160], and potentially mitigate the effects of biotic interactions [161] but this assertion was not tested in detail for organisms other than culturable FIB." (Asja Korajkic et al. 2018)

Nutrients and Microbial Fate

- “Increased nutrients (e.g. phosphate) have been shown to enhance FIB persistence (Bordalo et al., 2002; Lleodel et al., 2005).” (Elise M. Myers and Andrew R. Juhl. 2020)
- “The transition from the animal gastrointestinal tract, a nutrient-rich environment, to oligotrophic environmental waters exposes enterococci to nutrient starvation, one of the abiotic factors detrimental to their survival.” (Muruleedhara et. al. 2012)

Nutrients And Microbial Fate

- "Positive extra-enteric growth of enterococci has been observed in sediments (e.g. Jeng et al., 2005; yamahara et al., 2009), in association with organic rich substrates, such as algae and vegetation (e.g. Byappanahalli et al., 2003; Byappanahalli and Whitman, 2009; Imamura et al., 2011), and in treated wastewater with high dissolved nutrients (Surbeck et al., 2010). Therefore, our relatively high growth rates could be related to high levels of dissolved organic matter in the Hudson River (Findlay, 2005)." (Elise M. Myers and Andrew R. Juhl. 2020)

Nutrients and Microbial Fate

“In a study by Lopez-Torres et al. (1987), statistical analyses indicated a positive correlation between concentrations of fecal coliforms and increasing concentrations of phosphates, total phosphorus, and nitrates. This finding implies that fecal coliforms follow a familiar pattern of association with productive environments and high nutrients-conditions that are conducive to growth.” (EPA 4305T. 2010)

Nutrients and Microbial Fate

“The following two general conclusions can be drawn from these findings:

- Nutrient requirements for growth of indicators in soils and the water column are modest and have been shown to be present in sufficient quantities for growth in relatively unimpacted waters and soils.
- High nutrient levels are associated with relatively high counts of fecal coliforms in soils.” (EPA 4305T. 2010)

Predation and Microbial Fate

"Grazing by bacterivorous protozoa, bacteriophage infection followed by virus-mediated lysis, and predation by some bacteria are among the biotic effects that control the abundance of prokaryotic organisms in the environment." (Muruleedhara N. Byappanahalli et al. 2012)

Predation and Microbial Fate

“Bacteriophage infection affects a much wider range of bacteria, and viral infection was suggested to be a mechanism responsible for the elimination of up to 50% of autochthonous bacteria from aquatic habitats (109, 266, 327).” (Muruleedhara N. Byappanahalli et al. 2012)

Predation and Microbial Fate

“Protozoan grazing is an important top-down control of bacterial populations in aquatic environments (e.g., see references 18, 75,125, 224, and 229). Some estimates suggest that protozoan grazing is responsible for up to 90% of the overall mortality of both autochthonous and allochthonous microorganisms from freshwater and marine environments (8, 229)”. (Muruleedhara N. Byappanahalli et al. 2012)

Factors Affecting Predation Rates

"Digestion rates of both flagellated and ciliated protozoa increased exponentially at temperatures between 12˚C and 22˚C (294), and a direct correlation between rates of predation and temperature was found in a variety of environments, with more vigorous grazing and an increase in protozoan concentrations at higher temperatures (7, 9, 225, 294)." (Muruleedhara N. Byappanahalli et al. 2012)

Vegetation and Bacteria Concentrations

"Most recently, Badgley et al. (2010) and others (Byanppanahalli et al. 2003, Craig et al. 2004, Anderson et al. 2005, Ishii et al. 2007, Englebert et al. 2008) have shown that submerged aquatic vegetation are reservoirs allowing for the persistence of environmental populations of fecal indicator bacteria by providing secondary habitat, allowing for the formation of biofilms and protection from UV irradiation." (EPA. 4305T. 2010)

Vegetation and Bacteria Concentrations

"In studies in fresh waters in Lake Michigan, Byappanahalli (2003) determined that *Cladophora* (macro-alga) provides a suitable environment for indicator bacteria to persist for extended periods and to grow under natural conditions. Observed growth of *E. coli* and enterococci was directly related to the concentration of algal leachate." (EPA. 4305T. 2010)

The nutrients released by *Cladophora* seemed to be what was allowing the FIBs to persist.

Cladophora Densities and Vegetation

"*Cladophora*, a macrophytic green alga, is found in both fresh and marine waters. Until recently, the impact of *Cladophora* on beach water quality was unexamined, but in a seminal work, Whitman et al. (358) showed that the algal mats collected along shorelines of southern and northern Lake Michigan in the great lakes were a significant source of FIB (*E. coli* and enterococci), with densities often exceeding 100,000 CFU/g (dry weight)." (Muruleedhara N. Byappanahalli et al. 2012)

Cladophora Densities and Vegetation

"These findings have been confirmed by a number of studies of Lake Michigan and elsewhere (342). Aside from FIB, enteric pathogens, such as Shiga toxin-producing *E. coli* (STEC), *Shigella*, *Salmonella*, and *Campylobacter*, have also been isolated from these mats, indicating that *Cladophora* may serve as an environmental source of these pathogens in recreational water (41)." (Muruleedhara N. Byappanahalli et al. 2012)

Algal Mats and Enteroccocci

“Enterococci survived in sun-dried algal mats stored at 4˚C for over 6 months and displayed the ability to grow to high concentrations (~10^8 CFU/g upon rehydration (358).” (Muruleedhara N. Byappanahalli et al. 2012)

4˚C = 39.2˚F

10 to the power of 8 = 100,000,000 CFU/g

Seaweed and Enterococci

"Other aquatic macrophytes that have been identified as sources of enterococci include decaying seaweed (11, 131, 167). In New Zealand, Anderson et al. (11) observed that the densities of enterococci in drifting seaweed exceeded those in seawater by 2 to 4 orders of magnitude; Grant et al. (131) found densities of enterococci as high as a 450,000 most probable number (MPN)/100 g in a marsh in southern California." (Muruleedhara N. Byappanahalli et al. 2012)

Submerged Aquatic Vegetation and Enterococci

- “In addition to seaweed, recent studies have expanded the occurrence of enterococci to submerged aquatic vegetation (SAV) (mostly *hydrilla verticillata*) (15, 16). In laboratory studies, Badgley et al. (15) found that enterococci survived longer and at much higher densities in mesocosms containing SAV than in those without SAV. Furthermore, the recovery of a dominant *E. casseliflavus* strain indicated that this genotype was likely adapted to or naturalized on this vegetation.” (Muruleedhara N. Byappanahalli et al. 2012)

Submerged Aquatic Vegetation and Enterococci

"The presence of submerged aquatic vegetation provides conditions conducive to higher mean densities of enterococci than in sediment or water (Badgley et al. 2010), indicating another potential source of enterococci contamination and/or persistence during low-flow conditions." (Kathryn Vincent et al. 2022)

Enterococci and Terrestrial Vegetation

"Some of the earliest findings for the association of enterococci with terrestrial vegetation were demonstrated by Mundt (236), who recovered these bacteria from flowers and buds of different plant species." (Muruleedhara N. Byappanahalli et al. 2012)

Enterococci and Terrestrial Vegetation

"Recent studies have expanded these findings to forage and crop species (235, 261). Mundt (237) initially suggested that the occurrence of enterococci in plants was seasonal, with maximum recovery in late summer (September), and that these bacteria were transient populations most likely introduced by insects and wind (237)." (Muruleedhara N. Byappanahalli et al. 2012)

Enterococci and Terrestrial Vegetation

"Shortly thereafter, Mundt et al. Demonstrated the ability of *E. faecalis* to grow on plants (238), and many other studies have argued for the existence of epiphytic enterococci (204, 235, 261)." (Muruleedhara N. Byappanahalli et al. 2012)

Epiphytic refers to organisms, primarily plants, that grow on the surface of another plant for physical support without causing it harm.

*E. coli a*nd Particulates

"Turbidity and suspended solids influence indicator organism survival through reflection of sunlight (Davies et al. 1995), adsorption and sheltering of indicator organisms (particle-associated bacteria), and possibly other mechanisms (Characklis et al. 2005)." (EPA 4305T. July 2010)

*E. coli a*nd Particulates

"*E. coli* concentrations may be linked with other parameters such as high total suspended solids (TSS) and turbidity concentrations because the bacteria tend to be found with particles." (Factsheet on Water Quality Parameters. EPA. July 2021)

Turbidity and Bacteria Concentrations

"A study of the lower Hudson River estuary demonstrated that approximately 50 percent of water column FIB were particle-associated, and FIB concentrations were found to be correlated with turbidity (Suter et al. 2011)." (Smith-Krudener, A. et al. 2022)

Turbidity and Microbial Fate

- "Herrig et al. (2019) showed that global solar irradiance was inversely associated with the FIB concentrations." (Kathryn Vincent et al. 2022)
- "Increased turbidity may also limit the amount of solar radiation penetrating the water column, decreasing its potential to inactivate microbial contaminants (Williamson et al. 2017)." (Kathryn Vincent et al. 2022)

Particulates and Fecal Indicating Bacteria (FIB)

- "The two fractions also differed because particle-associated enterococci had measurable sinking rates, while the free-living fraction remained suspended.." (Elise M. Myers and Andrew R. Juhl. 2020)
- Much higher particle-associated FIB sinking rates have been estimated in streams where the particles are predominantly resuspended sediment (Jamieson et al., 2005a). (Elise M. Myers and Andrew R. Juhl. 2020)

Turbidity and Bacteria Concentrations

- “Indicator organism concentrations have correlated poorly with turbidity and suspended solids concentrations in most cases.” (EPA 4305T. 2010)
- “However, Mallin (2001) found significant correlation between turbidity and fecal coliforms across multiple sites in a tidally-influenced creek while Tunnicliff and Brickler (1984) noted that in the Colorado River, fecal coliforms were positively correlated with turbidity during storm conditions. (EPA 4305T. 2010)

Sediments and Bacteria Concentrations

"Research, however, has shown that many bacteria merely disappear from the water column and settle to bottom sediments, where they can persist for weeks or months in the warm, dark, moist and organic-rich conditions found there (Burton *et al*., 1987). Fecal coliform levels in stream and lake sediments are routinely three to four orders of magnitude higher than those in the overlying water column (Van Donsel and Geldrich, 1971)." (Microbes and Urban Watersheds: Concentrations, Sources, & Pathways)

Sediments and Bacteria Concentrations

"The same behavior has recently been noted in the bottom sediments of stormwater ponds and urban lakes (Pitt, 1998). Other researchers have documented that fecal coliform bacteria can survive and even multiply in the sediments in urban streams, ditches and drains (Burton *et al*., 1987; Marino and Gannon, 1991)." (Microbes and Urban Watersheds: Concentrations, Sources, & Pathways)

Sediments and Bacteria Concentrations

"Some evidence of fecal coliform survival has been observed in catch basins (Butler *et al*., 1995; Ellis and Yu, 1995) and also within roadway curb sediments (Sartor and Boyd, 1977; Bannerman *et al*., 1996). Coliform bacteria also have been found to survive and grow in moist soils and leaf piles (Oliveri et al., 1977). This may explain why grass swales and ditches frequently have high bacteria levels." (Microbes and Urban Watersheds: Concentrations, Sources, & Pathways)

Streamflow and Bacteria Concentrations

“Elevated concentrations of fecal indicator bacteria (FIB) in aquatic sediments and vegetation have prompted concern that environmental reservoirs of FIB disrupt the correlation between indicator organisms, pathogens and human health risks.” (Brian D. Badgley, Florence I.M Ihomas and Valerie J Harwood. 2011)

Streamflow and Bacteria Concentrations

"Using artificial floods, Muirhead et al. (2004) and Stocker et al. (2018) demonstrated roughly two order of magnitude increases in *E. coli* concentrations that directly resulted from flow rate induced sediment resuspension. This is not surprising, considering that a literature review by Pachepsky and Shelton (2011) noted that *E. coli* concentrations can be 1 to 2,200 times greater in sediments than in the water column." (Lucas F. Gregory et al. 2022)

Sediment

"Regardless of transport mechanism, sediment provides an environmental niche where *E. coli* can persist for extended periods of time (Garzio-Hadzick et al. 2010) and potentially grow (Solo-Gabriele et al. 2000; Stocker et al. 2018)." (Lucas F. Gregory et al. 2012)

Sediment

“This challenges water managers, as extended persistence and growth can yield *E. coli* populations that may not be associated with recent contamination events (Anderson et al. 2005), thus diminishing potential relationships between *E. coli* concentration and human health risk. It may also lead to impaired waterbody status and significant financial investments to correct perceived pollution issues (Wagner et al. 2016).” (Lucas F. Gregory et al. 2012)

Beaches

- “The sanitary quality of beach sand, i.e., the extent of contamination by FIB, has been a subject of public health concern in recent years (reviewed in reference 142). Numerous investigations across marine and freshwater beaches have repeatedly shown that enterococci and other FIB and pathogens (e.g., *E. coli, Salmonella*, and *Campylobacter*) are common microbial contaminants in beach sand, with potential implications for shoreline water quality (120, 278, 290, 355, 363).” (Muruleedhara N. Byappanahalli et al. 2012)

Beaches

"Other studies (Desmarais et al. 2002, Vigness et al. 2006) have demonstrated the ability of fecal indicator bacteria to regrow in soils after desiccation. Vigness and colleagues demonstrated tolerance of desiccation in sand plot experiments conducted near fresh waters. Specifically, they demonstrated that *E. coli* could tolerate low sand humidity conditions (<5 percent) and can resume active growth after rehydration." (EPA 4305T. 2012)

Sediment

- "*Sediments*; the experts indicated sand and sediments support the accumulation of microbes that affect water quality. FIB accumulate and grow in the environment and can have high concentrations in sediment and sand." (EPA. 822-R-17-003. 2016)
- However the fact that coliphage do not easily regrow in the environment, as compared to traditional FIB, is a benefit to the use of coliphage, though this has not been studied extensively. (EPA. 822-R-17-003. 2016)

Sediment

“Whether enterococci can grow under most environmental conditions remains speculative; however, Mundt et al. (238) demonstrated the growth of *E. faecalis* on germinating seeds and plants. High bacterial densities in sediments (85, 102, 205), in aquatic vegetation (15, 42, 358), and in detritus and planktonic communities (234) suggest that enterococci grow in these nonenteric habitats under certain conditions.” (Muruleedhara N. Byappanahalli et al. 2012)

Sediment as a Bacteria Reservoir

"Occurrence and persistence of fecal indicator bacteria in soils and sediments are consistently greater than those observed in the water column, regardless of media, climate, or water type. Important factors that enhance survival of indicator organisms in soils and sediments include the availability of nutrients and organic material, shelter from sunlight, and the presence of conditions more favorable to the survival of the indicator organisms than their predators." (EPA 4305T. 2010)

Sediment as a Bacteria Reservoir

"Enhanced persistence of fecal indicator bacteria in soils, sand, and sediments is significant because fecal indicator bacteria stored or growing in soils may be mobilized via washing of soils or resuspension. Thus, mobilized indicator organisms represent a potentially important source of fecal indicator bacteria that is not specific to a recent fecal contamination event, and may indicate decoupling of the fecal indicator bacteria population from pathogens of concern." (EPA 4305T. 2010)

Bacterial Resuspension

Boat wakes, shoreline wading, increases in stream velocities and currents, and breaking waves can agitate sediments resulting in resuspension of FIB thus increasing the bacteria concentration in a water column.

Microbial Risk to Water Plant Workers

Of the three categories (Water Treatment, Wastewater Treatment, and Stormwater Management), I believe water plant personnel have the lowest microbial risk. However, there is still some risk.

Source waters for drinking water treatment are generally cleaner, more tightly regulated, monitored, and protected than stormwater runoff and wastewater influents and effluents.

Source and Finished Water Treatment Concerns

- Water plant employees can be exposed to microbes in source water, and the community can be exposed to microbes in the finished water.
- Surface and groundwater can collect microorganisms from the environment, piping, tanks, and treatment processes as it moves through natural and manmade systems.

Are Microbes Present?

- We cannot see bacteria, viruses, and pathogens in source or finished water. However, these microorganisms can enter raw source waters like lakes, reservoirs, rivers, or wells through agricultural and municipal runoff, sewage leaks and spills, fecal matter, or decaying organic matter.
- Once present in a water supply, they can multiply rapidly if not properly managed.

Which Microbes Are Present?

Microbes that inhabit water supply sources:

- Viruses
- Bacteria
- Fungi
- Protozoa
- Parasites

Disinfection

- Chemical agents, like chlorine, chloramines, and hydrogen peroxide, work by penetrating and breaking down cell walls/membranes and effectively destroying microbes.
- For oxidizing agents to work properly, minimum contact times and correct concentrations must be present. Contact times and concentrations vary according to the specific microbes being treated.

Contact Time

- Insufficient contact time or concentration allows the microbes to survive.
- An oxidizing concentration too high can result in odor issues, damage system components, cause corrosion problems, and the formation of excess disinfection by products.

Ultraviolet Light (UV) and Ozone

- Alternative treatments like ultraviolet light (UV) and ozone disinfection can disrupt microbial DNA without the addition of chemicals and the problems they can present.
- Maintaining low particle concentrations in the water aids UV light and ozone disinfection and can allow reduced contact time and lower doses to effectively treat the microbes.

Filtration

- Filters can also remove microorganisms. Fine media or very small pores in semi-permeable membranes can capture microbes before the water reaches distribution.
- By its very nature, this media can have concentrated, living colonies of microbes.
- If these filters are not periodically removed and cleaned, sediment can accumulate promoting microbial growth and reducing the efficiency of disinfection.

Microbes That Can Contaminate Tap Water

Treated tap water can still contain microorganisms. The CDC, in an article titled "Germs That Can Contaminate Tap Water" on their website (4-13-26) says:

- Public tap water in the united States is regulated and usually safe to drink.
- However, sometimes tap water gets contaminated with germs that can make you sick.

Drinking Water Regulations Regarding Private Wells

Private water well water quality is essentially unregulated.

- It isn't practical to test private well water for every disease-causing microorganism.
- It is relatively easy to test well water for a group of indicator bacteria called total coliform bacteria.

Drinking Water Regulations Regarding Private Wells

Total coliform bacteria are good indicators of sanitary protection of the well and water system because they are everywhere on the surface of the ground, but do not usually occur past a few feet into the soil. If total coliform bacteria show up in a water test, they can indicate that surface contamination has gotten into the water and that disease-causing organisms may also be present.

Stormwater Risks

Microbes are often present in high concentrations in stormwater, but risk depends upon precautions individuals take, the activity, and the types of microbes present.

The method of exposure or transmission, pathogen concentration, and the age and health of the exposed individual play a role in determining individual risk.

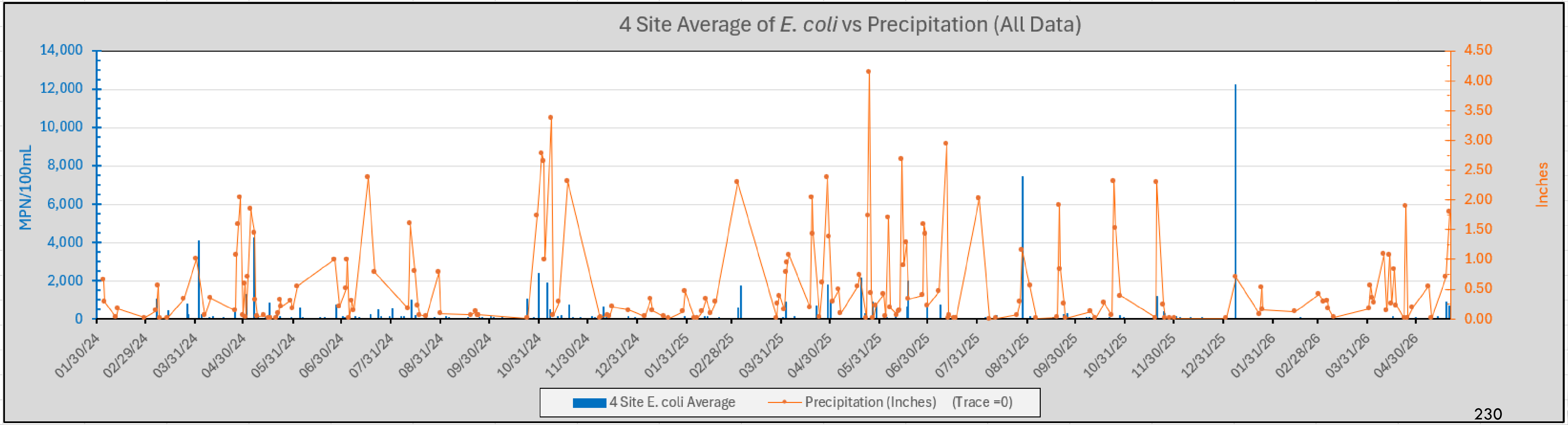
Infection Risks

Stormwater personnel frequently work with untreated surface water and runoff during and after precipitation events. This surface water typically contains a wide variety of microbes, especially during first flush events.

As a result, proper protective gear and safety measures should be utilized when in the field.

Runoff Impact

Rainfall results in bacteria runoff. The longer the dry spell before the rain event and the less antecedent rainfall the higher the bacteria counts.



Microbial Sources

- Wastewater/sewer overflows and releases
- Failing septic systems
- Human and animal fecal matter (pets, livestock, wildlife)
- Homeless encampments
- Illicit discharges
- Microbial regrowth
- Stormdrain system itself

Potential Stormwater Microbial Pathogens

Potential Stormwater Microbial Pathogen Examples	
Adenoviruses	*Shigella spp.*
Noroviruses	*Pseudonomas auerognosa* (swimmers itch)
Enteroviruses	*Leptospira*
Giardia	*Cryptosporidium*
Salmonella spp.	

Wastewater Treatment Infection Risks

Influents, effluents, sludges, and wastewater in general can contain bacteria, funguses, viruses, and parasites that can cause intestinal, lung, blood, skin, and other infections.

Work involved in the treatment, transport, or application of sewage and sludge can expose you to microorganisms that can cause disease.

Infection Risks

Working with sewage (plant operators, maintenance crews, collection system workers, laboratory personnel), including treated and untreated sewage, sludge, influent and effluent waters, grit, septic tank waste and biosolids, can expose workers to infections.

Learn how to recognize and manage the risks of infection to protect yourself and others.

Bioaerosols

Aerosols containing microbiological organisms are called bioaerosols. If these organisms are pathogens and a worker is exposed to a high enough concentration, they can cause illness. Inhalation and skin contact are the two principal pathways to exposure to airborne microbes.

Wastewater treatment operations can expose workers to a veritable cocktail of airborne pathogens. The study of bioaerosols is still relatively new, but we are learning and beginning to understand the risks.

Bioaerosols

The main emission sources of airborne bacteria are treatment facilities with aeration and mechanical agitation processes using screens and aerators.

Wastewater contains large numbers of microorganisms and if these processes are indoors, and a capable air circulation and filtration system is not in place, the potential to concentrate airborne bacteria is greater.

Bioaerosols (slide 1)

"Some opportunistic pathogenic species were found among these airborne bacteria. Strains of *Acinetobacter* sp., *Pseudomonas* sp., *Enterococcus* sp., *Bacillus* sp., and *Escherichia coli* were isolated from the air emissions of WWTPs (Fracchia et al., 2006; Uhrbrand et al., 2017)." (Airborne bacteria in a wastewater treatment plant: Emission characterization, source analysis and health risk assessment, Kaixiong Yanget al., 2019, Water Research, volume 149, pages 596-606)

Bioaerosols (slide 2)

"Additionally, an increased prevalence of respiratory and intestinal diseases induced by airborne bacteria was reported among WWTPs employees (Benami et al.,2016; Heinonen-Tanski et al., 2009; Li et al., 2016). Since airborne bacteria usually attach to the surface of small particles, they can be easily carried by the wind reaching significant distances (Jahne et al., 2015)." (Airborne bacteria in a wastewater treatment plant: Emission characterization, source analysis and health risk assessment, Kaixiong Yanget al., 2019, Water Research, volume 149, pages 596-606)

Bioaerosols

Whenever possible, avoid cleaning methods that can disperse aerosols such as high-pressure washing (power washers) and using compressed air.

At this time, some researchers believe the risk posed by bioaerosols is low while others believe it could be significant. With our limited knowledge about dose-response relationships, caution is warranted.

Vaccination

Get vaccinated

(Just a couple of examples, talk to your doctor.)

- Tetanus can be transmitted through cuts and can cause lockjaw and muscle spasms.
- Hepatitis A is transmitted through feces and body fluids, contaminated food and water, or an infected person, causing liver damage, jaundice, fever, and vomiting.

Cleaning Equipment and Work Areas

Keep your work areas and equipment as clean as possible.

- Wipe cables and hoses with an antibacterial solution when retracting them.
- Clean cameras, crawlers, and nozzles with an antibacterial solution.
- Sanitize door handles, controls, keyboards/mice, tables, work surfaces, etc. as often as possible.

Protect Your Family and Home Environment

The last thing anyone wants is for the people they love to get sick. To prevent that, shower and disinfect yourself before returning home, and don't take your work clothes and boots home if you can prevent doing so.

Clean clothes onsite or have them laundered professionally if possible and keep work contaminants far away from the home.

If you do get sick, always tell your doctor that you work in a wastewater treatment plant.

Categories of Wastewater Pathogens

- Bacteria
- Viruses
- Fungus
- Worms
- Protozoa

Examples of Wastewater Pathogens

- *E. coli*
- Salmonella
- Encephalitis
- Hepatitis A
- Cryptosporidium
- *Pseudomonas aeruginosa*
- *Legionella pneuomophila*
- *Giardia duodenalis*

Public Works Workforce Outlook

Clean water strikes at the core of growing communities, a healthy environment, and a high quality of life. To maintain essential water services, we must have trained and knowledgeable people that are dedicated to water treatment in all of its various forms

Diminishing Workforce

As the workforce in our water industry ages out, we need to figure out how to recruit and maintain the people and resources needed to keep this industry healthy and moving forward. Individuals involved in operations, maintenance, testing, management, and finance are all vital to the success of these programs.

Diminishing Workforce

"A strong water workforce is essential to protecting our waterways and public health. But in recent years, many clean water agencies have faced significant retirement rates and are having trouble finding and retaining workers," said National Association of Clean Water Agencies CEO Adam Krantz.

Why Are Workers Getting Harder To Find?

Water and Wastewater workers are often "out of sight and out of mind" or invisible. They frequently work in the shadows keeping their systems functioning and the general public doesn't see them in action. As long as clean water comes out of the faucet or shower head when they turn the knob or goes down the drain when it is supposed to, they don't think about the people that make this happen.

Bloomberg Report

Bloomberg's December 2024 article "*America's Next water Crisis? A Lack of Experienced Workers*" stated: "Nationwide, many of the roughly 1.7 million people employed in the water sector have hit or are nearing retirement age. In total, between 30% and 50% of the workforce will retire in the next decade and there aren't enough younger workers in the pipeline to replace them.

(Continued)

Brookings Institution

…A Brookings Institution analysis of 2021 data found that 88% of treatment plant operators were aged 45 or older, compared with 45% nationally.” (WaterOperator.org, The Impending Workforce Shortage in the Water Sector)

The National Rural Water Association (NRWA) has been surveying water workers and finds that succession planning hasn’t been happening like it should, especially in rural areas.

Black & Veatch 2024 Water Report

Black & Veatch's 2024 Water Report states: "Nearly half – 47 percent – of the nearly 630 U.S. water industry stakeholders who responded to the report's survey cited the aging workforce and hiring of qualified staff their top challenge. That's second only to aging water and wastewater infrastructure – a chronic issue for decades." (Black & Veatch 2024 Water Report)

Black & Veatch 2024 Water Report

"Eighty-six percent of respondents cited management or supervisors as the most impacted job category, up 9 percentage points over last year in overtaking last year's No. 1 answer – operators, at 82 percent. It seems in 2024, therefore, that water utilities are experiencing the most impact when it comes to the retirements or departures of their management or supervisory staff." (Black & Veatch 2024 Water Report)

Black & Veatch 2024 Water Report

"Another pain point was engineers. Sixty percent of respondents stated that engineer job functions are most impacted by retirements or people leaving, compared to 53 percent in 2023. This tracks with another survey question, in which six of 10 respondents said they are outsourcing engineering or technical work with outsourcing of information technology (IT) staff a distant second at 28 percent." (Black & Veatch 2024 Water Report)

Silver Tsunami

The impending rapid loss of experienced water utility workers is being called the "silver tsunami". It is the tide of aging, experienced workers, stepping into retirement and taking with them their vast operational, institutional, and facility knowledge. Knowledge that took years to acquire will walk out the door in a day.

Succession Planning

Many rural municipalities can’t afford to hire more than one plant operator which makes it difficult to have an apprentice or operator-in-training. The succession plan is, when the time comes, to hire a new, inexperienced worker that isn’t familiar with the facility, and hope he figures it out quickly.

Hope isn’t a good plan or strategy.

Succession Planning

Succession planning permits eager, younger workers to gain the knowledge they need to step up and fill the shoes of an older retiring worker.

Forward thinking municipalities are putting succession protocols in place and hiring young operators, billing clerks, and engineers and fast tracking them for the supervisory positions that will be opening soon.

Succession Planning

Retirements continue to outpace recruitment, leaving many utilities understaffed because of widespread shortages of qualified workers.

Forward thinkers are also encouraging high school and college students and graduates to apply for an apprenticeship, mentoring, or emerging leader program the municipality offers and helping them get the required licenses they will need.

What Should the Industry Do?

- The industry needs more licensed workers with real life experience. To have these individuals available for future positions, they need to be hired and trained now.
- To retain existing, trained and experienced personnel, incentives such as competitive pay, sign-on bonuses, competitive insurance plans, advancement possibilities, a good and safe work environment, and recognition must be provided.

What Should the Industry Do?

- Water and wastewater personnel should receive more recognition for the work they do. The general public needs to be educated and understand the vital role water workers play and how some of the things they take for granted only happen because of the work they do.
- Promote the water industries better in the future than we have in the past. Attending job fairs is a good way to start.

What Should the Industry Do?

- Upgrade plants with systems, controls, and automation to reduce the number of physical workers required. The younger generation has grown up with computers, automation, and has good digital technology skills, and can easily learn to operate these systems.
- Secure arrangements to outsource work when necessary.

Occupational Outlook Handbook, U.S. Bureau Of Labor Statistics

Quick Facts; Water and Wastewater Treatment Plant and System Operators	
2024 Median Pay	\$58,260 per year \$28.01 per hour
Typical Entry-Level Education	High School Diploma or Equivalent
Work Experience in a Related Occupation	None
On-the-job Training	Long-term on-the-job training
Job Outlook, 2024 - 2034	-7% Decline

Workforce Decline but Added Demand

The Bureau of Labor Statistics expects a drop in the number of water and wastewater workers nationwide over the next decade as automated systems take over more tasks. Despite this, an estimated 10,000 positions will need to be filled each year to make up for the people who retire, change fields, or return to school.

Positive Points to Promote Water Jobs

- As competition to fill vacant positions in the future increases, salaries will likely continue to rise.
- 53% of water workers have a H.S. Diploma. This means that many water jobs don't require higher, formal education in order to earn a living.
- Most positions are not traditional desk jobs. Some positions are office jobs, but many are outside, in the plant, or in a lab.

EPA's Water Workforce Initiative

EPA's Water Workforce Initiative was originally launched in 2020 with the goal of strengthening the water and wastewater industry through coordination of resources between the government, utilities, and industries.

Renewing this initiative was driven by the widespread staffing shortages caused by retirements and increasing operational complexity at many plants.

EPA's Water Workforce Initiative

In the spring of 2026, during a roundtable meeting with industry leaders in Washington, D.C. the EPA announced it is renewing its Water Workforce Initiative to tackle staffing shortages in the water sector by expanding training, apprenticeships, and public awareness efforts to help ensure a pipeline of skilled professional for the future.

EPA's Water Workforce Initiative

The program goal is to attract new workers, support skill development for existing staff, and address emerging needs such as cybersecurity. EPA is also talking about developing apprenticeship programs, setting labor standards, and assisting in training efforts for advanced treatment technologies. EPA believes these programs are necessary to ensure a strong pipeline of workers and high-quality jobs.

EPA's Innovative Water Workforce Development Grant Program

EPA also highlighted its Innovative Water Workforce Development Grant Program, which has invested more than $13 million since 2018 to expand awareness of water sector careers. Additional funding opportunities are expected later this year as part of the agency's broader push to address workforce gaps.

National Rural Water Association Efforts

The National Rural Water Association, through some state affiliations, has an apprenticeship program intended to help younger workers interested in the water industry secure a position.

Veolia North America, (Formerly Suez)

Veolia opened Veolia Academy, its in-house training program, to the public in 2023 to help water workers pass state certification exams.

Regulatory Update
Stormwater Deregulation?

Federal momentum to roll back stormwater regulations in the interest of creating more affordable housing is causing concern in some circles.

On March 13, 2026, President Trump signed an executive order titled “Removing Regulatory Barriers to Affordable Home Construction”.

Stormwater Deregulation?

One element of this executive order is "reducing regulatory barriers to housing development," with stormwater permits listed *first* among the regulatory programs targeted for review.

Stormwater Deregulation?

This comes shortly after the Senate passage of the 21st Century ROAD to Housing Act. Here again, regulations tied to housing development were targeted.

Both of these measures address the affordable housing crisis. The purpose is to review costs and delays in construction and ease up on regulatory hurdles.

Manhattan Institute Report

These actions were preceded by the release of a report from the Manhattan Institute titled “The High Cost of Stormwater Regulations” posted online Feb. 5, 2026.

On Feb. 4th, 2026 the Washington Post published an opinion piece titled “Building a New House? This Little-Known Rule Could Cost You Thousands”.

The Goal or Intent of This?

The intent seems to be to make the general public aware of the cost behind stormwater regulations thus gaining support for regulatory roll-back.

The opinion held by some is that the current stormwater regulations, although seemingly reasonable, are making nearly all housing and construction more expensive and slowing growth. The focus is on money savings.

The Goal or Intent of This?

Stormwater program benefits:

- ✓Water quality improvement
- ✓Reduced flood risk
- ✓Increased water supply
- ✓Urban greening improvements through LID

Remember these points when defending your stormwater program.

Stormwater Management Benefits

The failure to effectively promote the many benefits of stormwater management has left the sector vulnerable to campaigns that question the value of stormwater regulations.

The industry must do a better job of demonstrating the benefits of sound stormwater management and show that permitting authorities and municipalities are striving to ensure stormwater requirements are cost-effective.

Emerging Contaminants (ECs)

Emerging Contaminants consist of a group of chemicals and materials that are considered to have a negative effect on human health and the environment but aren't fully regulated. Some ECs are:

- ✓PFAS (per-and polyfluoroalkyl substances) and other industrial chemicals and pesticides
- ✓ Pharmaceuticals (medications)
- ✓Microplastics (small plastic particles)

PFAS

"PFAS, or per- and polyfluoroalkyl substances, are a group of synthetic chemicals that have been used in various industries since the 1940s. Their persistence in the environment and the human body has earned them the moniker "forever chemicals." Today, PFAS are found in the blood of an estimated 98 percent of Americans, raising significant health and environmental concerns."

(Why Government And Industry Must Address "Forever Chemicals" In The Food Supply, Center For Responsible Food Business)

PFAS

PFAS are man-made chemicals that have been used in non-stick cookware, food packaging (plastic wrap and styrofoam), cosmetics, firefighting foams, and stain and water repellent products.

The vary properties that make these chemicals useful (they degrade slowly), make them an environmental and health concern.

Pharmaceuticals and Antibiotics

Pharmaceuticals are compounds used in human and veterinary medicines. This group includes antibiotics, anti-inflammatories, hormones, and many more drug components which are appearing in water, soil and air. They are classified as emerging contaminants because they are largely unregulated, persist in aquatic environments, and enter water sources via human and animal excretions and improper disposal.

Microplastics

Microplastics are tiny pieces of plastic less than 5 millimeters (0.2”) in length. Microplastics can occur when larger pieces of plastic break down or can be manufactured as microbeads and synthetic fibers. These particles are ubiquitous in oceans, rivers, lakes, air, soil, and found in humans and animals of all types.

Nanoplastics

As microplastics continue to degrade they form nanoplastics. They range in size from 1 to 1,000 nanometers, roughly 100 times smaller than the width of a human hair. Nanoplastics are found throughout the environment and can enter a human or other animal's body via ingestion or inhalation and tend to bioaccumulate.

2025 Comprehensive Water Plan

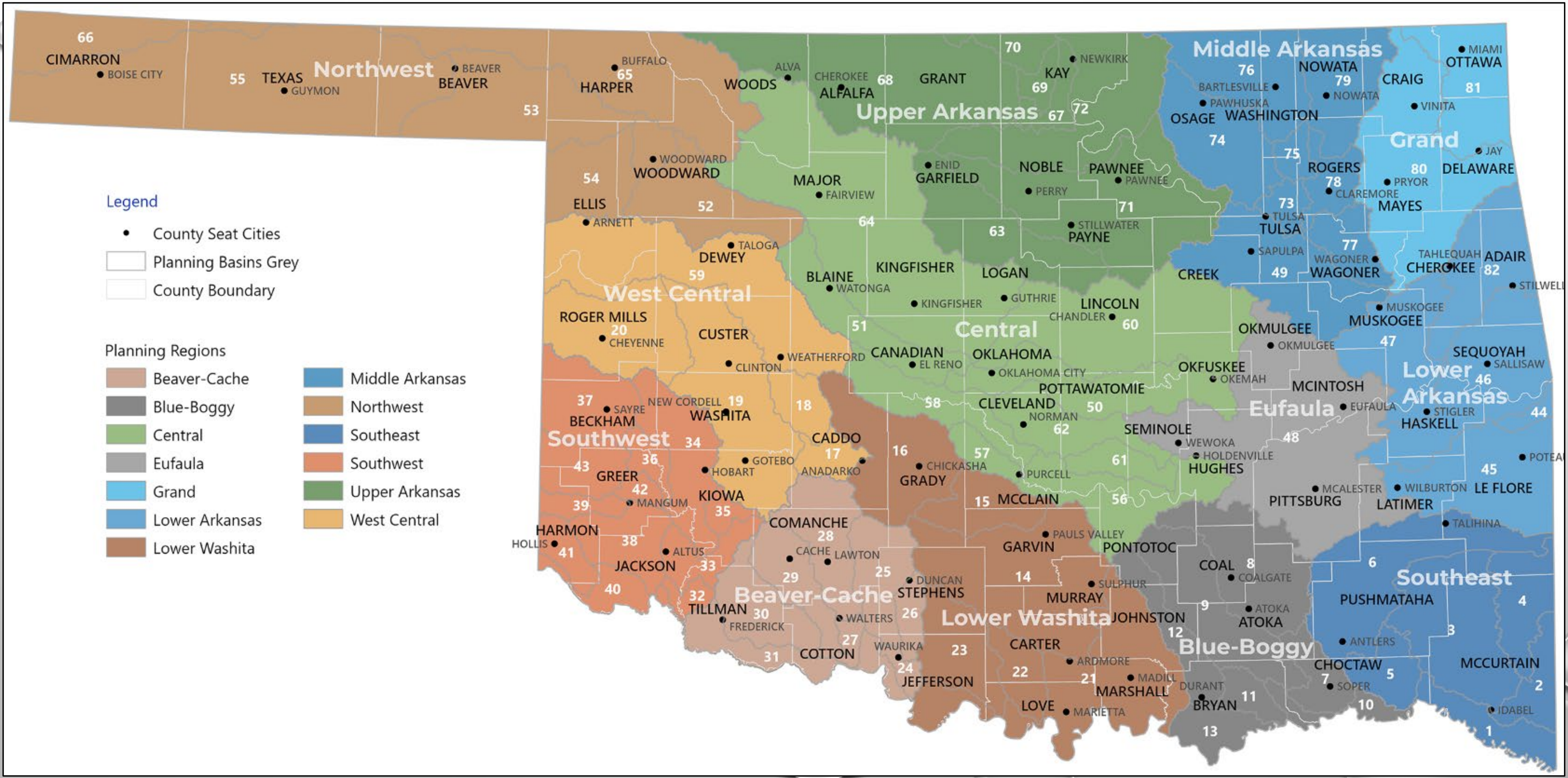
The 2025 Oklahoma Comprehensive Water Plan (OCWP) prepared by the Oklahoma Water Resources Board is now available on the OWRB website.

The OCWP provides water resource managers, public works personnel, developers, state agencies, and municipal managers with information regarding water availability and quality for future planning activities.

2025 Comprehensive Water Plan

- In the plan you will find statewide information regarding water supply, water demand, surface water gaps, and groundwater depletion.
- It evaluates infrastructure needs and offers strategies for each of the 82 planning basins across the 13 planning regions.
- These basin and region level insights provide a local perspective to guide water planning.

Oklahoma’s 13 Planning Regions



2025 Comprehensive Water Plan

General observations:

- Statewide water demand is projected to increase by approximately 13% between 2020 and 2075 due to population increases, growth in the agriculture sector, and expanding industrial water use.
- By 2075 surface water demand is expected to exceed supply in more than half of the 82 planning basins.

2025 Comprehensive Water Plan

- The largest gaps are expected in Central and Middle Arkansas planning regions due to population growth and competing demands.
- Groundwater depletions (withdrawals exceed recharge) are expected in most planning basins.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