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Six-Year Review 4 Technical Support Document for Microbial Contaminant Regulations

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List of Exhibits

Acronyms

ACRP	Airport Cooperative Research Program
ADWR	Aircraft Drinking Water Rule
AGI	Acute gastrointestinal illness
AIDS	Acquired immunodeficiency syndrome
ANSI	American National Standards Institute
AOC	Administrative Orders on Consent
ARCS	Aircraft Reporting and Compliance System
ASDWA	Association of State Drinking Water Administrators
AWWA	American Water Works Association
BF	Bank Filtration
CCR	Consumer Confidence Report
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
cfu/mL	Colony forming unit per milliliter
CT	Concentration x Time
CWS	Community Water System
DBP	Disinfection by-product
DC	District of Columbia
DCTS	Data Collection and Tracking System
DNA	Deoxyribonucleic acid
DWSRF	Drinking Water State Revolving Fund
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
FAA	Federal Aviation Administration
FBRR	Filter Backwash Recycling Rule
FDA	Food and Drug Administration
FLA	Free-living amoebae
FR	Federal Register
GLUMRB	Great Lakes- Upper Mississippi River Board

GW	Ground Water
GWR	Ground Water Rule
GWUDI	Ground Water Under the Direct Influence of Surface Water
HPC	Heterotrophic plate count
HUS	Hemolytic uremic syndrome
IBS	Irritable bowel syndrome
ICR	Information Collection Request
IESWTR	Interim Enhanced Surface Water Treatment Rule
LED	Light-emitting diode
LF – EMF	Low-frequency electromagnetic field
LRV	Log reduction values
LT1	Long Term 1 Enhanced Surface Water Treatment Rule
LT2	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
MCMC	Markov Chain Monte Carlo
MD	Maryland
MDBP	Microbial and Disinfection Byproducts
MF	Microfiltration
mg/L	Milligrams per liter
MLE	Maximum Likelihood Estimate
MRDL	Maximum residual disinfectant levels
MRDLG	Maximum residual disinfectant level goal
MS2	Male-Specific-2 Bacteriophage
MT	Montana
MUG	4-methylumbelliferyl-ß-D-glucuronide
NCWS	Non-community water system
NDWAC	National Drinking Water Advisory Council
NF	Nanofiltration
nm	Nanometer
NORS	National Outbreak Reporting System

NPDWR	National Primary Drinking Water Regulation
NTNCWS	Non-transient non-community water system
NTU	Nephelometric Turbidity Unit
PAC	Powdered Activated Carbon
PBS	Phosphate buffered saline
PCR	Polymerase chain reaction
PN	Public notification
PWSID	Public Water System Identification Number
QA	Quality Assurance
QC	Quality Control
QMRA	Quantitative microbial risk assessment
qPCR	Quantitative polymerase chain reaction
RO	Reverse Osmosis
RPEC	Repeat *E. coli* Samples
RPTC	Repeat Total Coliform Samples
RED	Reduction Equivalent Dose
RTCR	Revised Total Coliform Rule
RTEC	Routine *E. coli* Samples
RTTC	Routine Total Coliform Samples
SCADA	Supervisory control and data acquisition
SDWA	State Drinking Water Act
SDWIS	Safe Drinking Water Information System
SDWIS/FED	Federal Safe Drinking Water Information System database
SOP	Standard operating procedure
SW	Surface Water
SWAT	Surface Water Analytical Tool
SWTR	Surface Water Treatment Rules
SYR	Six-Year Review
TCR	Total Coliform Rule
TG	Triggered
TN	Tennessee

TNCWS	Transient Non-Community Water System
TOC	Total Organic Carbon
TT	Treatment technique
TX	Texas
UCFWR	Uncovered finished water reservoir
UDF	Unidirectional Flushing
UK	United Kingdom
US	United States
UV	Ultraviolet
UVA	Ultraviolet A
UVB	Ultraviolet B
UVC	Ultraviolet C
UVT	Ultraviolet Transmittance
WBDOSS	Waterborne Disease and Outbreak Surveillance System
WCP	Watershed Control Program
WSV	Water service vehicles

1 Introduction

The Safe Drinking Water Act (SDWA) requires the United States Environmental Protection Agency (EPA) to review each National Primary Drinking Water Regulation (NPDWR) at least once every six years and revise them, if appropriate. The purpose of the review, called the Six-Year Review (SYR), is to evaluate current information for regulated contaminants to determine if there is new information on health effects, treatment technologies, analytical methods, occurrence and exposure, implementation and/or other factors that provides a health or technical basis to support a regulatory revision that will improve or strengthen public health protection. EPA completed and published the results of its first Six-Year Review ("Six-Year Review 1"), on July 18, 2003 (USEPA, 2003) and the second Six-Year Review ("Six-Year Review 2"), on March 29, 2010 (USEPA, 2010a), after developing a systematic approach, or protocol, for the review of NPDWRs. During Six-Year Review 1, EPA identified the Total Coliform Rule (TCR) as a candidate for revision. Four additional NPDWRs (acrylamide, epichlorohydrin, tetrachloroethylene and trichloroethylene) were identified as candidates for revision during the Six-Year Review 2.

EPA completed and published the results of its third Six-Year Review ("Six-Year Review 3"), on January 11, 2017. Under the Six-Year Review 3, EPA concluded that eight NPDWRs are candidates for regulatory revision. These eight NPDWRs are included in the Stage 1 and the Stage 2 Disinfectants and Disinfection Byproducts Rules, the Surface Water Treatment Rule (SWTR), the Interim Enhanced Surface Water Treatment Rule (IESWTR) and the Long Term 1 Enhanced Surface Water Treatment Rule (LT1). The eight candidates are Chlorite, *Cryptosporidium* (under the SWTR, IESWTR and LT1), Haloacetic Acids, Heterotrophic Bacteria, *Giardia lamblia*, *Legionella*, Total Trihalomethanes, and viruses (under the SWTR). As of 2024, EPA is conducting analyses to further evaluate these eight NPDWRs for potential regulatory revisions; therefore these eight NPDWRs are not subject for review under SYR4.

Under the fourth (and current) Six-Year Review ("Six-Year Review 4"), EPA reviewed the regulated chemical, radiological and microbiological contaminants included in previous reviews. However, this is the first time EPA has conducted a comprehensive Six-Year Review of the following microbial contaminant regulations:

- Revised Total Coliform Rule (RTCR)
- Aircraft Drinking Water Rule (ADWR)

This document provides a summary of available information and data relevant to determining which, if any, of the microbial contaminant regulations are candidates for revision under this Six-Year Review. The information cutoff date for Six-Year Review 4 was December 2021. That is, information published during or before December 2021 was considered as part of the Six-Year Review 4. The Agency recognizes that scientists and other stakeholders are continuing to investigate microbial contaminants and publish information subsequent to this cutoff date. While not considered as part of the Six-Year Review 4, the Agency anticipates providing consideration for that additional information in future six-year reviews.

Chapter 2 of this document provides an overview of the protocol that EPA used in this review. Chapter 3 provides an overview of the specific regulations addressed in this support document, along with historical information about their development. Available information and data relevant to the Six-Year Review 4 are provided in Chapter 4 (health effects), Chapter 5 (analytical methods), Chapter 6 (occurrence and exposure) and Chapter 7 (treatment).

2 EPA's Protocol for the Six-Year Review 4

This chapter provides an overview of the process the Agency used to review the microbial National Primary Drinking Water Regulations (NPDWRs) discussed in the Six-Year Review 4 (SYR4). The protocol document, "EPA Protocol for the Fourth Review of Existing National Primary Drinking Water Regulations," contains a detailed description of the process the Agency used to review all the NPDWRs (USEPA, 2024a). The foundation of this protocol was developed for the Six-Year Review 1 based on the recommendations of the National Drinking Water Advisory Council (NDWAC, 2000). The process undertaken for SYR4 was very similar to the process implemented during the prior rounds of the Six-Year Review.

The review elements that the Environmental Protection Agency (EPA) considered for each NPDWR include the following: initial review, health effects, analytical feasibility, occurrence and exposure, treatment feasibility, and other regulatory revisions. Risk balancing is also a review element considered in the Six-Year Review process, however, was not applicable to the NPDWRs reviewed for SYR4. Further information about these review elements are described in the protocol document (USEPA, 2024a).

Exhibit 2-1 presents an overview of the Six-Year Review protocol and major categories of review outcomes. The protocol is broken down into a series of questions about whether there is new information for a contaminant that suggests it is appropriate to revise one or more of the NPDWRs. The two major outcomes of the detailed review are:

(1) the NPDWR is not appropriate for revision and no action is necessary at this time, or

(2) the NPDWR is a candidate for revision.

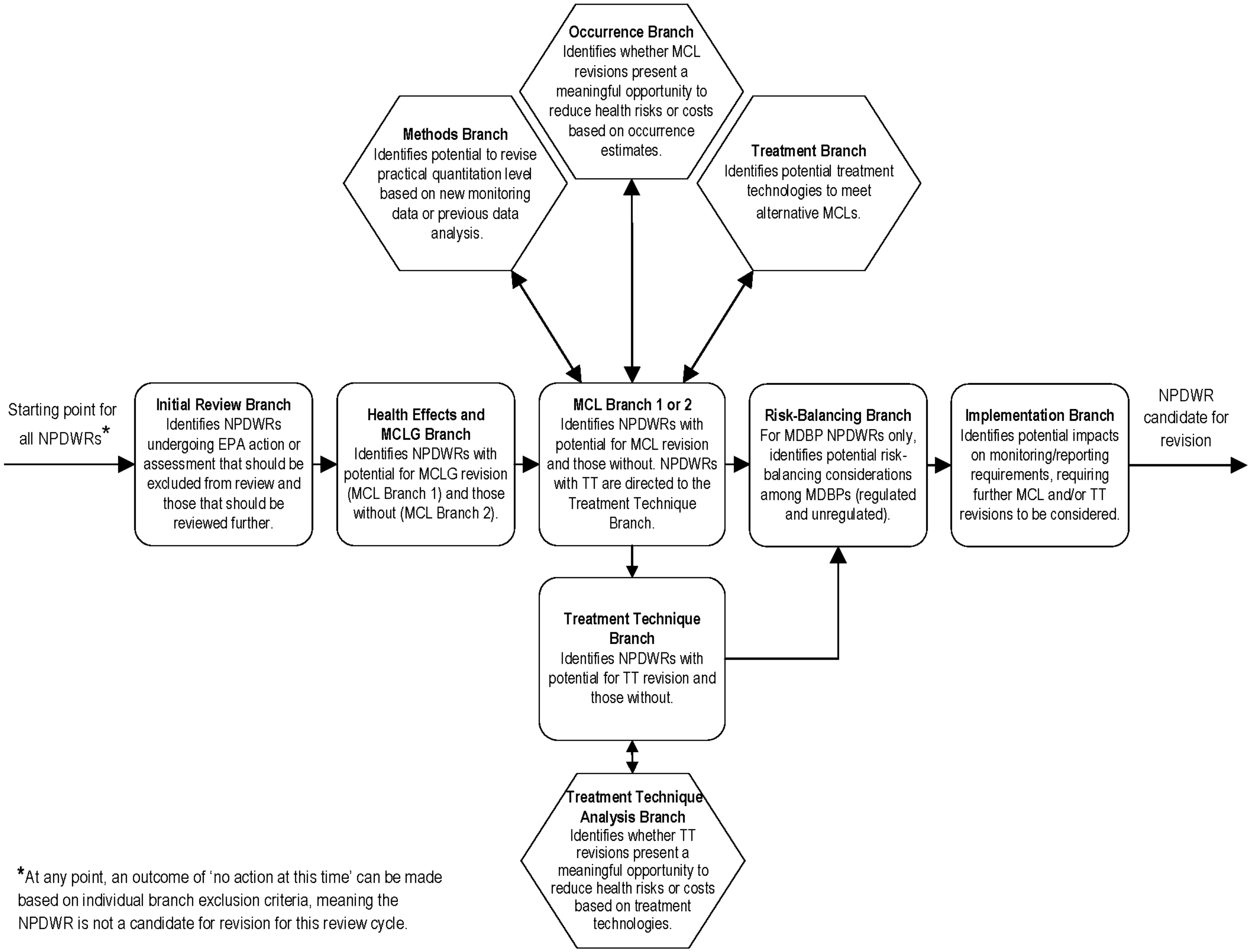
Individual regulatory provisions of NPDWRs that are evaluated as part of the Six-Year Review are: maximum contaminant level goals (MCLGs), maximum contaminant levels (MCLs), maximum residual disinfectant level goals (MRDLGs), maximum residual disinfectant levels (MRDLs), treatment techniques (TTs), and other treatment technologies and regulatory requirements (e.g., monitoring). The MCL provisions of the protocol are not applicable for evaluation of the microbial contaminants regulations which establish TT requirements in lieu of MCLs. Because mostly all the microbial regulations use TT in lieu of an MCL, the TT branch of the protocol is a tailored review of the microbial regulations used to guide the review of the SYR4 microbial regulations. The MRDLG and MRDL provisions are only applicable for evaluation of the Disinfectants and Disinfection Byproducts Rules (D/DBP) rules as part of the Six-Year Review.

The Initial Review branch or element of the protocol identifies NPDWRs with recent or ongoing actions and excludes them from the review process to prevent duplicative Agency efforts (USEPA, 2024a). The cutoff date for the NPDWRs reviewed under the Six-Year Review 4 was December 2021. Based on the Initial Review for microbial regulations, for the first time EPA included the Aircraft Drinking Water Rule (ADWR), which was promulgated in 2009, and the Revised Total Coliform Rule (RTCR) (the revision of the 1989 Total Coliform Rule (TCR)), which was promulgated in 2013. Since most of the 1989 TCR requirements were replaced by the

2013 RTCR, the 1989 TCR was excluded from the Six-Year Review 4. In addition, the Filter Backwash Recycling Rule (FBRR), the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2) and the Ground Water Rule (GWR) were included as in previous reviews.

During the previous round of Six-Year Review (the third Six-Year Review, or SYR3), EPA determined that eight NPDWRs were candidates for regulatory revision. The eight NPDWRs were included in the Stage 1 and the Stage 2 Disinfectants and Disinfection Byproducts Rules, the Surface Water Treatment Rule, the Interim Enhanced Surface Water Treatment Rule, and the Long Term 1 Enhanced Surface Water Treatment Rule. EPA has initiated the process to decide whether a rulemaking to revise the regulations should be initiated. Since these actions, initiated under SYR3, are still underway, these rules were not reviewed for SYR4.

Exhibit 2-1. Process for Identifying NPDWRs that are Candidates for Revision



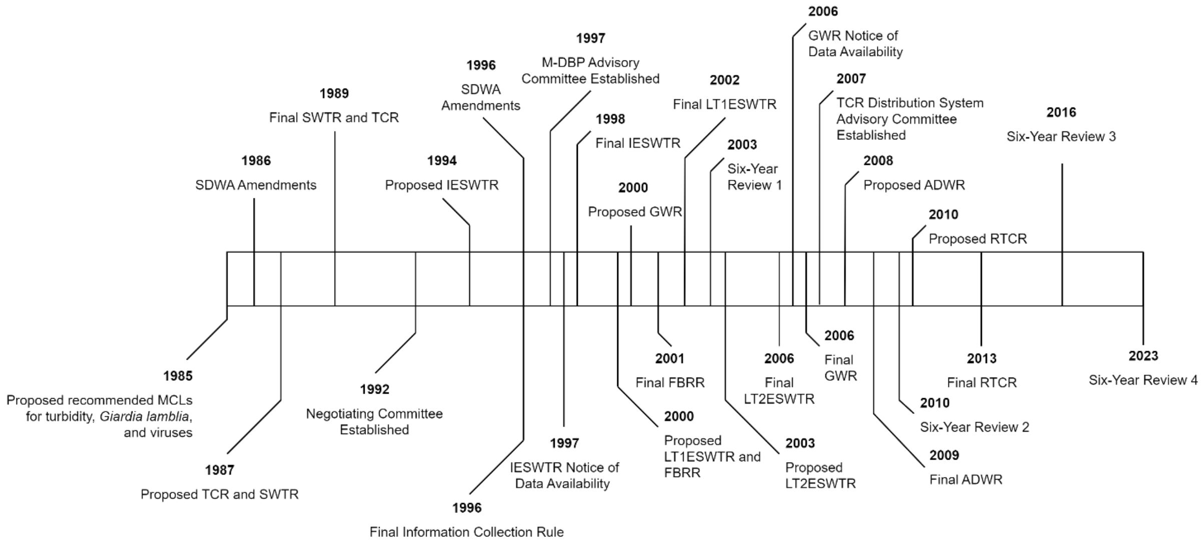
*At any point, an outcome of 'no action at this time' can be made based on individual branch exclusion criteria, meaning the NPDWR is not a candidate for revision for this review cycle.

3 History of Microbial Regulations

This chapter provides a brief history of the microbial contaminant regulations reviewed under Six-Year Review 4 (SYR4). The microbial contaminants regulations covered in SYR4 include: the Filter Backwash Recycling Rule (FBRR), the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2), the Revised Total Coliform Rule (RTCR), the Ground Water Rule (GWR), and the Aircraft Drinking Water Rule (ADWR).

A timeline of selected events in the statutory and regulatory history and regulatory review processes is shown in Exhibit 3-1.

Exhibit 3-1. Timeline for Selected Activities Associated with Microbial Regulations for Drinking Water



3.1 Filter Backwash Recycling Rule

The purpose of the Filter Backwash Recycling Rule (FBRR), promulgated June 8, 2001 (66 FR 31086), is to further protect public health by requiring public water systems (PWSs), where needed, to institute changes to the return of recycle flows to a plant's treatment process that may otherwise compromise microbial control. The rule addresses a statutory requirement of the 1996 SDWA amendments to promulgate a regulation that governs the recycling of filter backwash water within the treatment process of PWSs. It applies to all surface water and ground water under the direct influence of surface water (GWUDI) systems using direct or conventional filtration.

The FBRR requires that recycled filter backwash water, sludge thickener supernatant, and liquids from dewatering processes be returned through the processes of a system's conventional or direct filtration system or at an alternate location approved by the state. This requirement is codified in 40 CFR 141.76(i).

3.2 Long-Term 2 Enhanced Surface Water Treatment Rule

The Long-Term 2 Enhanced Surface Water Treatment Rule (LT2), promulgated on January 5, 2006 (71 FR 654, USEPA, 2006a), requires 2- to 3-log inactivation of *Cryptosporidium* in unfiltered systems and additional treatment for *Cryptosporidium* in filtered systems based on the results of source water monitoring. The rule includes a screening procedure to reduce monitoring costs for small systems. The rule also requires covering of all uncovered finished water reservoirs (UCFWR), unless systems treat reservoir effluent to provide at least 99.99 percent (4-log) inactivation or removal of viruses, 99.9 percent (3-log) inactivation or removal of *Giardia lamblia* and 99 percent (2-log) inactivation or removal of *Cryptosporidium*.

For the purposes of the LT2, filtered water systems are classified in one of four treatment categories (bins) based on their monitoring results. The majority of systems are classified in the lowest treatment bin, which carries no additional treatment requirements. Systems classified in higher treatment bins must provide 90 to 99.7 percent (1.0- to 2.5-log) of additional treatment for *Cryptosporidium.* Systems select from a wide range of treatment technologies, process optimization techniques, and management techniques from what is known as the "microbial toolbox" to meet their additional treatment requirements. Any system that fails to achieve treatment credit in any month that is at least equal to the level of treatment required under LT2 is considered in violation of the treatment technique (TT) requirement. All unfiltered water systems must provide at least 99 or 99.9 percent (2- or 3-log) inactivation of *Cryptosporidium,* depending on the results of their monitoring. All unfiltered systems must report to the state the arithmetic mean of all *Cryptosporidium* reported from the completion of the initial and second round of source water monitoring within six months. Additionally, if the monthly *Cryptosporidium* sampling frequency varies, systems must first calculate a monthly average for each month of monitoring. Then, systems must use these monthly average concentrations, rather than individual sample concentrations from the initial and secondary reports, in the calculation of the mean *Cryptosporidium* level. Lastly, unfiltered systems must supply a summary of the source water monitoring data used for the calculation to the State. Unfiltered systems that fail to comply with the aforementioned requirements are considered to be in violation of the TT requirement of LT2.

3.3 Ground Water Rule

EPA promulgated the Ground Water Rule (GWR) on November 8, 2006 (71 FR 65573, USEPA, 2006b) to provide for increased protection against microbial pathogens, specifically viral and bacterial pathogens, in PWSs that use ground water sources. EPA was particularly concerned about ground water systems that are susceptible to fecal contamination because these systems may be at risk of supplying water that contains harmful microbial pathogens. Viral pathogens found in ground water systems may include enteric viruses such as echovirus, coxsackieviruses, hepatitis A and E, rotavirus, and noroviruses. Enteric bacterial pathogens may include *E. coli* (most *E. coli* is harmless but a few strains are pathogenic, including *E. coli* O157:H7), *Salmonella* species, *Shigella* species and *Vibrio cholerae*.

The GWR established a risk-targeted approach to identify ground water systems susceptible to fecal contamination and requires action to correct significant deficiencies and source water fecal contamination in ground water systems (USEPA, 2006b). This risk-targeting strategy includes the following:

- Regular ground water system sanitary surveys
- A program for identifying higher risk systems through RTCR monitoring and state determinations
- Ground water source monitoring to detect fecal contamination at certain ground water systems that do not provide 4-log treatment of viruses or as part of state assessment of a ground water source
- Measures to protect public health:
  - TT requirements to address significant deficiencies and fecal contamination in ground water and
  - In systems providing treatment, compliance monitoring to ensure that 4-log treatment of viruses is maintained

TT requirements consist of implementation of one or more of the following corrective action options: correct all significant deficiencies; provide an alternate source of water; eliminate the source of contamination; or provide treatment that reliably achieves at least 99.99 percent (4-log) treatment of viruses (using inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal) for each ground water source (USEPA, 2006b). In addition, ground water systems must inform their customers of any fecal indicator-positive ground water source samples.

There are approximately 45,000 undisinfected (or "non-disinfecting") ground water systems in the U.S., judging by SYR4 ICR data for systems with total coliform records. Most serve small permanent populations or larger transient populations.

3.4 Revised Total Coliform Rule

EPA published the RTCR in the Federal Register (FR) on February 13, 2013 (78 FR 10269, USEPA, 2013) and minor corrections on February 26, 2014 (79 FR 10665, USEPA, 2014a).

The RTCR upholds the purpose of the 1989 Total Coliform Rule (TCR) to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. The RTCR, which replaced the TCR, is the only current microbial drinking water regulation that applies to all PWSs. EPA anticipated greater public health protection under the RTCR, because it required PWSs that are vulnerable to microbial contamination to identify and fix problems, and it established criteria necessary for PWSs to qualify for and stay on reduced monitoring, thereby providing incentives for improved water system operation.

All PWSs, except aircraft water systems which are subject to ADWR, are required to collect total coliform samples to comply with the RTCR. If a sample is total coliform positive, it must be further analyzed for *E. coli*. If any total coliform positive sample is also *E. coli* positive, then the *E. coli* positive sample result must be reported to the state by the end of the day that the PWS is notified. Total coliform positive and *E. coli* positive samples initiate a find-and-fix approach to prevent fecal contamination and other microbial pathogens from entering the distribution system. Additionally, if any routine sample is total coliform positive, repeat samples are required. PWSs on a quarterly or annual monitoring schedule must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a total coliform positive routine or repeat sample. Another provision of the RTCR is that reduced monitoring may be available for PWSs using only ground water and serving 1,000 or fewer persons that meet certain additional PWS criteria.

Key provisions of the RTCR included:

- Setting a Maximum Contaminant Level Goal (MCLG) and Maximum Containment Level (MCL) for *E. coli* for protection against potential fecal contamination
- Setting a total coliform TT requirement
- Requirements for monitoring total coliforms and *E. coli* according to a sample siting plan and schedule specific to the PWS
- Provisions allowing PWSs to transition to the RTCR using their existing TCR monitoring frequency, including PWSs on reduced monitoring
- Requirements for seasonal systems (i.e., non-community water systems (NCWSs) not operated on a year-round basis that start up and shut down at the beginning and end of each operating season) to monitor and certify the completion of a state-approved start-up procedures
- Requirements for assessments and corrective action when monitoring results show that PWSs may be vulnerable to contamination. Assessments can be triggered by total coliform positive samples, *E. coli* MCL violations, and performance failures; the assessments are graded (“Level 1” and “Level 2”) depending on the severity or frequency of the problem. Assessment results must be reported, and sanitary defects discovered during an assessment must be corrected, within 30 days of the assessment being triggered
- Public notification (PN) requirements for violations
- Specific language for community water systems (CWSs) to include in their Consumer Confidence Reports (CCRs) when they must conduct an assessment or if they incur an *E. coli* MCL violation.

3.5 Aircraft Drinking Water Rule

Drinking water safety on aircraft is jointly regulated by EPA, the Food and Drug Administration (FDA), and the Federal Aviation Administration (FAA). EPA’s responsibility is to regulate systems that supply water to airports and onboard aircraft. Aircraft PWSs are considered transient non-community water systems (TNCWSs) and are subject to NPDWRs that apply to TNCWSs. In 2004, EPA found all aircraft water systems to be out of compliance with NPDWRs.

Subsequently EPA tested 327 aircraft and found that 15 percent of them were positive for total coliforms. Since the existing NPDWRs were designed for traditional stationary PWSs and not for mobile aircraft water systems that are operationally very different, EPA determined that an aircraft-specific rule would provide a clearer and more implementable regulatory framework for aircraft water systems. The final Aircraft Drinking Water Rule (ADWR) was promulgated on October 19, 2009 (74 FR 53590, USEPA, 2009). The ADWR establishes barriers of protection from disease-causing organisms targeted to the air carrier industry.

ADWR combines coliform sampling, best management practices, corrective action, PN, operator training, and reporting and recordkeeping to improve public health protection. Air carriers are required to develop a coliform sampling plan covering each aircraft they own or operate. The frequency of coliform monitoring is tied to the frequency of disinfection and flushing. Two coliform samples are required per monitoring period. One water sample to be tested for total coliforms must be taken from a lavatory, and one sample from a galley. Any total coliform positive sample must be further analyzed for the presence of *E. coli*. A positive finding of *E. coli* triggers PN, corrective action, and flushing. Also, routine disinfection and flushing are required at least once per year.

The ADWR applies only to aircraft with onboard water systems that provide water for human consumption through pipes and regularly serve an average of at least twenty-five individuals daily, at least 60 days out of the year, and that board finished water for human consumption. Human consumption includes water for drinking, hand washing, food preparation, and oral hygiene. Aircraft water systems include the water service panel, the filler neck of the aircraft finished water storage tank, and all finished water storage tanks, piping, treatment equipment, and plumbing fixtures within the aircraft that supply water to passengers or crew.

3.6 Summary of the Microbial Rules

Exhibit 3-2 provides a summary of the NPDWRs for the microbial rules. For each contaminant or indicator, the table lists the MCLG, whether the NPDWR involves an MCL or TT, and the rule(s) where it is referenced. The final column indicates whether the NPDWR is being reviewed in SYR4.

Exhibit 3-2. NPDWRs for Microbial Rules

Microorganism/Indicator	MCLG	MCL or TT	Rule(s)	Reviewed in SYR4?
Giardia lamblia	Zero	TT	SWTR	No
Viruses	Zero	TT	SWTR, GWR	Yes
Legionella	Zero	TT	SWTR	No
Total coliforms	Zero	TT	RTCR, ADWR	Yes
E. coli	Zero	MCL	RTCR, ADWR	Yes
Cryptosporidium	Zero	TT	IESWTR, FBRR, LT1, LT2	Yes
Heterotrophic bacteria (by the HPC method)	N/A	TT	SWTR	No

Microorganism/Indicator	MCLG	MCL or TT	Rule(s)	Reviewed in SYR4?
Turbidity	N/A	TT	SWTR, IESWTR, LT1	No

4 Health Effects

This chapter summarizes the results of EPA's review of information related to human health risks from drinking water exposure to the microbial contaminants reviewed in the Fourth Six-Year Review. The review examined human health risks from microbial contaminants regulated under the Revised Total Coliform Rule (RTCR), the Ground Water Rule (GWR), the Long Term 2 Enhanced Surface Water Treatment Rule (LT2), and the Aircraft Drinking Water Rule (ADWR).

EPA performed a systematic review of literature that was published no later than December 2021, however, EPA did also include a few recently published findings pertinent to this chapter. EPA evaluated whether any new (and older relevant) health effects information would suggest that it is appropriate to revise the Maximum Contaminant Level Goal (MCLG), the Maximum Containment Level (MCL), or the treatment technique (TT) associated with the microbial contaminant regulation. An MCLG is a health goal set at a level at which no known or anticipated adverse health effects occur, allowing an adequate margin of safety. An MCL is the maximum level of a contaminant allowed in public drinking water systems. MCLs are set as close to MCLGs as feasible using the best available treatment technology, and taking cost into consideration. MCLs are enforceable standards. When there is no reliable analytical method that is economically and technically feasible to measure a contaminant at concentrations to indicate there is not a health concern, EPA sets a TT requirement instead of an MCL. The TT is an enforceable procedure or level of technological performance that public water systems (PWSs) must follow to ensure control of a contaminant. EPA's review of existing TT requirements for SYR4 microbial contaminants is discussed in the occurrence and treatment chapters.

EPA's review of human health risks from exposure to microbial contaminants in drinking water encompassed endemic disease and outbreaks. The scope of the review varied by Rule: the RTCR review focused on general trends in outbreaks and endemic disease caused by fecal pathogens (versus opportunistic pathogens), the GWR focused on viruses, the LT2 review focused on *Cryptosporidium*, and the ADWR review focused on pathogens known or suspected to be of concern in aircraft drinking water.

4.1 Summary of Health Effects Review Outcome and Information Evaluated – Revised Total Coliform Rule and Ground Water Rule

Reduced rates of endemic disease, notably acute gastrointestinal illness (AGI), was an anticipated benefit of RTCR and GWR. A number of papers were published in and around 2006 attempting to calculate rates of endemic AGI (and/or total AGI) attributable to drinking water exposure in the United States. Using data from published randomized trials of drinking water (surface water) interventions, Colford et al. (2006) estimated AGI attributable to public drinking water systems in the United States to be in the range of 4.26 to 11.69 million cases annually. Messner et al. (2006) used data from epidemiological studies to estimate the incidence of AGI from drinking water in the U.S. at 0.06 cases per person per year, which translates to 16.4 million AGI cases per year or 8.5 percent of annual AGI cases from all sources. Both Colford et al. (2006) and Messner et al. (2006) studies used Canadian data to estimate AGI cases. Calderon and Craun (2006) reviewed available data from community intervention studies that could be used to help develop a national estimate of endemic AGI incidence, but did not perform new calculations. Reynolds et al. (2008) estimated that community ground water systems in the U.S. are responsible for 10.7 million infections and 5.4 million illnesses annually, that non-community ground water systems are responsible for 2.2 million infections and 1.1 million illnesses annually, and that surface water systems are responsible for 26.0 million infections and 13.0 million illnesses annually, for a grand total of 19.5 million illnesses per year attributed to drinking water. These illnesses include but are not limited to AGI. Colford et al. (2009) addressed ground water and is discussed in the SYR3 technical support document. See the SYR3 technical support document for more discussion on Colford et al.'s (2009) study.

Applicable to RTCR, Collier et al. (2021) conducted a systematic study using structured expert judgment to estimate the likely collective U.S. disease burden attributable to over a dozen waterborne illnesses (vibriosis, campylobacteriosis, cryptosporidiosis, giardiasis, Legionnaires' disease, otitis externa, pneumonia, septicemia, salmonellosis, and shigellosis, and norovirus) from infectious pathogens.

Collier et al. (2021) estimated the total disease burden of waterborne illnesses domestically acquired is approximately 7.15 million cases annually, and responsible for an estimated 118,000 hospitalizations and 6,630 deaths. In Collier et al.'s analysis, waterborne disease is understood to include gastrointestinal, respiratory, and systemic disease attributable to both drinking-water and non-drinking water exposure. Of the estimated 7.15 million infectious waterborne illnesses in 2014 in the United States, drinking water exposure caused 40 percent of hospitalizations and 50 percent of deaths. From further evaluation of this study's cases, Gerdes et al. (2023) determined that 1.13 million (95% credible interval 255,000-3.54 million) of these illnesses were attributable to drinking water. Among the 17 waterborne infectious diseases included in the Collier et al. (2021) study, those caused by opportunistic pathogens (i.e., Legionairres' disease, non-tuberculous mycobacterial infections, *Pseudomonas* pneumonia, *Pseudomonas* septicemia, and the two-thirds of otitis externa attributed by the authors to *Pseudomonas*) account for a large share of the diseases' public health burden, accounting for 34 percent of domestically acquired waterborne cases, 80 percent of associated hospitalizations, and 95 percent of associated deaths. When the calculations are limited to cases associated with drinking water exposure, per Gerdes et al. (2023), the diseases caused by opportunistic pathogens account for only 10 percent of cases, but fully 89 percent of associated hospitalizations and 98 percent of associated deaths. The structured expert judgement approach used in these studies is employed when primary data are not available, and therefore is subject to limitations, such as expert bias. Only those waterborne infectious diseases for which data were available to quantify associated health outcomes were included in the studies.

Ashbolt (2015) reviewed trends for viral, bacterial, protozoan, and fungal threats in drinking water, including the emergence of opportunistic pathogens, and suggested that emerging Polymerase chain reaction (PCR) and genome-sequencing techniques will over time enhance our ability to detect and quantify pathogens that are currently not susceptible (at all, or in the life stage present in water) to monitoring using culture-based techniques.

In some studies, waterborne pathogens such as adenovirus, enteroviruses, hepatitis A, norovirus, rotavirus, *Salmonella*, *Giardia*, *Cryptosporidium*, and *Shigella* have been found in untreated ground water samples (Borchardt et al. 2012; Wallender et al. 2014; Stokdyk et al. 2020). Infections from these pathogens can cause mild to severe illnesses. Illnesses may include AGI with diarrhea, abdominal discomfort, nausea, vomiting, conjunctivitis, aseptic meningitis, and hand-foot-and-mouth disease. Other more severe illnesses include hemolytic uremic syndrome (HUS) (kidney failure), hepatitis, and bloody diarrhea (WHO, 2004). Infections from some waterborne pathogens (e.g., *Campylobacter*) may cause sequelae with long-term implications, such as reactive arthritis, Guillain-Barré syndrome, and irritable bowel syndrome (IBS) (Keithlin et al. 2014).

Borchardt et al. (2023) reports the results of a community intervention human health study (randomized controlled trial) to measure the proportion of AGI caused by undisinfected ground water provided by 14 community PWS systems. Ultraviolet (UV) disinfection was installed on supply wells of intervention communities, and in control communities, residents continued to drink undisinfected ground water. Intervention and control communities switched treatments by moving UV disinfection units at midpoint of the study (crossover design). Study participants completed health diaries weekly during four 12-week periods and water supply wells were analyzed monthly for pathogenic enteric viruses. The researchers compared AGI incidence between intervention and control communities within the same period of time. They observed that with norovirus contaminated wells, AGI attributable risk from well water was 19% (95% confidence interval of −4% to 36%) for children less than 5 years old and 15% (95% confidence interval of −9% to 33%) for adults. They also observed when echovirus 11 contaminated wells that UV disinfection slightly reduced AGI in adults. Researchers found highly variable estimates of AGI attributable risks from drinking undisinfected ground water due to exposure of various types and quantity of viruses in supply wells changing through the study. However, AGI attributable risks appeared greatest during times when supply wells were contaminated with specific AGI etiologic viruses.

In Wallender et al.'s (2014) analysis of the reported waterborne outbreaks from the Centers of Disease Control's (CDC) waterborne disease outbreak surveillance system, the researchers found that among the 172 outbreaks associated with untreated ground water sources where contributing factor data were available, the leading contamination sources associated with outbreaks with ground water sources included human sewage (*n* = 57, 33.1%), animal contamination (*n* = 16, 9.3%), and contamination entering via the distribution system (*n* = 12, 7.0%). Improper design, maintenance, or location of the water system or a nearby septic tank was a contributing factor in many cases (*n* = 116, 67.4%). Other contributing factors included rapid pathogen transport through hydrogeologic formations (e.g., karst limestone; *n* = 45, 26.2%) and preceding heavy rainfall or flooding (*n* = 36, 20.9%). Similarly, the Mattioli et al. (2021) study of a waterborne norovirus outbreak at an inadequately disinfected campground identified high discharge septic pollution, high yield well water demand, and unfavorable hydrogeology as factors. The Wallender et al. (2014) and Mattoli et al. (2021) findings stress the importance of identifying vulnerabilities of undisinfected and/or inadequately disinfected PWSs through frequent inspection and routine maintenance, as recommended by protective regulations such as GWR, and the need for consideration of the local hydrogeology. GWR allows, but does not require, states to perform hydrogeological sensitivity assessments for ground water systems to identify those most susceptible to contamination.

Campylobacter is an example of a fecal bacterial pathogen that can cause outbreaks in undisinfected ground water systems under conditions favorable to growth. A survey conducted by Pitkanen (2013) found that 28 waterborne *Campylobacter* outbreaks were reported in 11 countries between 1978 and 2010. Most occurred in small ground water systems without adequate disinfection. The probable causes of the outbreaks were cross contamination and breaks in water treatment due to heavy rainfall or contamination by sewage. Two recent case studies are described by Gilpin et al. (2020) and Pedati et al. (2019). Gilpin et al. (2020) reported on a 2016 outbreak of campylobacteriosis caused after heavy rain contaminated an untreated drinking water supply in New Zealand. This was the largest outbreak of *Campylobacter* ever reported with approximately 7,570 cases of diarrheal illness and four deaths. According to Gilpin et (2020), the probable cause was sheep feces that contaminated a stream adjacent to the drinking water source. This outbreak resulted in a recommendation that in New Zealand, all drinking water supplies, including ground water, should be treated and that residual disinfection should be required. Pedati et al. (2019) reported on an investigation of 39 cases of campylobacteriosis in Nebraska in 2017. Analysis showed a significant association between illness and consumption of untreated municipal tap water from wells (odds ratio = 7.84, 95% confidence interval = 1.69-36.36). According to Pedati et al. (2019), *Campylobacter jejuni* was determined to be the cause of the illness, with six confirmed cases (either a stool culture or PCR-positive result for *Campylobacter*) and 33 probable cases (a laboratory-confirmed probable illness in a nonresident who worked, dined, or shopped in the city). The source was determined to be wastewater runoff from an adjacent animal feeding operation after an irrigation system malfunctioned. The wastewater runoff collected in a road ditch adjacent to two wells that supplied tap water to the city. After the wells were permanently removed from service, no additional cases of illness were reported.

The Economic Analysis for the GWR relied on a static factor or multiplier to account for secondary transmission (person-to-person transmittal of illness initially caused by contaminated drinking water). Soller (2009) demonstrated the application of a dynamic model for secondary transmission. The author reports that “depending on the assumptions employed, the predicted number of additional illnesses due to secondary transmission could be greater than that predicted by the GWR base analysis by approximately an order of magnitude or could be as low as effectively zero.”

Although fecal indicator bacteria are useful for detecting fecal contamination, indicator bacteria do not necessarily correlate with the presence of human pathogens (NRC, 2004). Studies by Fout et al. (2017) and Stokdyk et al. (2020) found that total coliforms (and other indicators like *E. coli*, somatic phage, HF183, and *Bacteroidales*-like HumM2) tend to have high *specificity*, meaning that absence of the indicator provides relatively strong assurance that ground water is free of viral and other pathogens, but low *sensitivity*, meaning that presence of the indicator does not necessarily predict presence of pathogens.

Fout et al. (2017) found that hydrogeology affects the strength of the association between the presence of indicators and the presence of pathogenic viruses. Specifically, sensitivities and positive predictive values were higher for indicators measured in wells in hydrogeologically susceptible areas (karst, fractured bedrock, and gravel/cobble settings) than in other wells. As a methodological point, the authors also note that it can be particularly challenging to assign wells to the right category of hydrogeological susceptibility.

Noncommunity public water systems, which are systems that provide water to locations outside consumers' residences (e.g., schools, restaurants), are subject to less stringent monitoring requirements than community systems. Burch et al. (2022) found that noncommunity wells had higher infection risk than community wells. Burch et al. (2022) along with Mattioli et al. (2021) study show that PWSs served by ground water remain susceptible to contamination by viruses and other pathogens.

The studies described above indicate that there could be opportunity to further protect public health from microbial contamination of untreated ground water. However, these studies are limited in number and the prevalence of endemic disease from microbial contamination of untreated ground water is not well characterized. More studies are needed to further understand the magnitude of the issue.

4.2 Long-Term 2 Enhanced Surface Water Treatment Rule

The purpose of LT2 (71 FR 654, USEPA, 2006a) is to reduce illness linked to *Cryptosporidium* and other pathogenic microorganisms in drinking water. Under the Interim Enhanced Surface Water Treatment Rule (IESWTR) (63 FR 69477, USEPA, 1998) and LT1 (67 FR 1812, USEPA, 2002), EPA established an NPDWR for *Cryptosporidium* and set an MCLG of zero. These regulations established TT requirements for *Cryptosporidium* removal/inactivation rather than an MCL. LT2 supplements these regulations by establishing additional *Cryptosporidium* treatment requirements at higher risk systems. LT2 also contains provisions to reduce risks from uncovered finished water reservoirs (UCFWR) and provisions to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection byproducts that result from chemical water treatment.

4.2.1 Summary of Health Effects Review Outcome and Information Evaluated – Long Term 2 Enhanced Surface Water Treatment Rule

Cryptosporidium is a protozoan parasite that can be found in surface waters used as drinking water sources by PWSs. Cryptosporidiosis, the illness caused by the ingestion of infectious *Cryptosporidium* oocysts, is excreted in the feces of infected humans or animals, can cause seven to 14 days of diarrhea, and possibly be accompanied by low-grade fever, nausea, and abdominal cramps in individuals with healthy immune systems (CDC, 2017; Juranek, 1995). Though the illness is typically self-limiting, there have been cases where it recurs after initial clearance. In the 1993 cryptosporidiosis outbreak in Milwaukee, Wisconsin, 39 percent of those with laboratory-confirmed cryptosporidiosis experienced recurrences, which lasted for an average of two days (Mac Kenzie et al., 1994). Longer-term effects have also been recently documented. After a foodborne outbreak of cryptosporidiosis in the United Kingdom, those with confirmed cases reported symptoms such as fatigue, diarrhea, IBS, joint pain, and eye pain at six months to 12 months following illness (Stiff et al., 2017).

People with acquired immunodeficiency syndrome (AIDS) are more likely to experience atypical presentations of cryptosporidiosis, such as infections of the bile duct (cholecystitis), stomach (enteritis), pancreas, or respiratory system (Hunter and Nichols, 2002). Severe cases of cryptosporidiosis have also been reported in cancer patients undergoing chemotherapy and in a few cases in patients being immunosuppressed following organ transplantation (Hunter and

Nichols, 2002). The elderly are also at increased risk (Naumova et al., 2003), particularly those older than 85 years of age (Mor et al., 2009). Children may also be at increased risk. In the developing world, cryptosporidiosis was found to be twice as likely to cause death in toddlers one to two years old compared to other pathogenic diarrheal diseases (Kotloff et al., 2013).

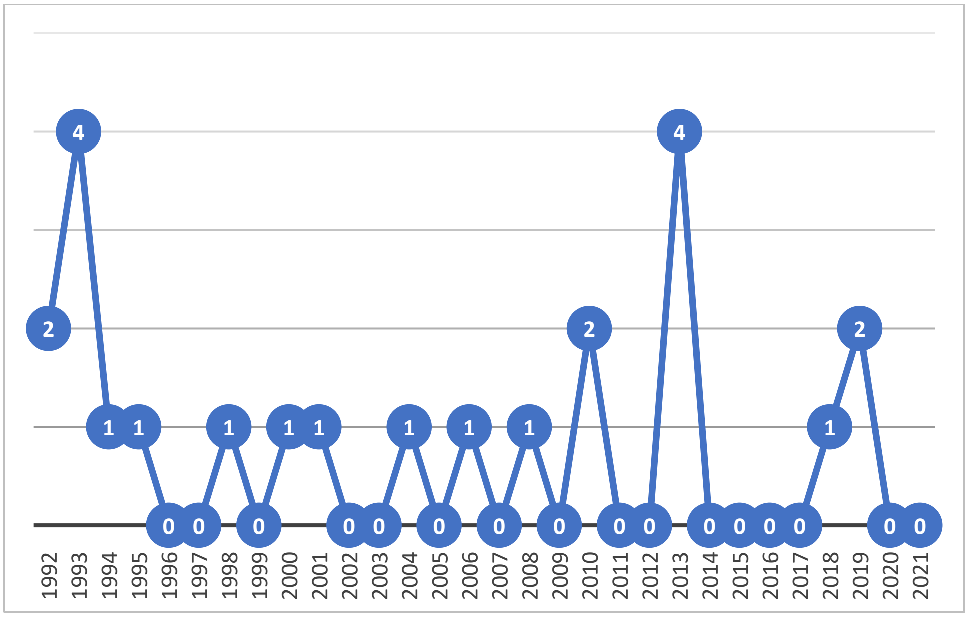
Several species of *Cryptosporidium* can infect and cause illness in humans, including *C. parvum*, *C. hominis*, *C. canis*, *C. felis*, and *C. meleagridis* and *C. cuniculus* (Chalmers et al., 2011; Koehler et al., 2014). *C. parvum* and *C. hominis* are thought to be responsible for most cases of infection in humans (Chappell et al., 2011). Audebert et al. (2020) researched virulence differences in *C. parvum* isolates. Comparing phenotypic differences between four different *C. parvum* isolates (IOWA, DID, TUM1, and CHR), Audebert et al. found that *C. parvum* DID, TUM1, and CHR isolates had higher virulence than the IOWA isolates. The researchers inoculated mice with the four different isolates obtained from fecal samples of naturally infected animals or humans and found that mice inoculated with the three more virulent isolates exhibited a higher mortality rate, more severe clinical manifestations, and earlier onset of neoplastic lesions, and only these mice showed extra gastrointestinal lesions.

A study by Messner and Berger (2016) investigated six different *Cryptosporidium* infectivity dose-response models using human challenge data from earlier studies. The authors found that three models that allowed for variability in human susceptibility (fractional Poisson, exponential with immunity, and beta Poisson) fit the data better than earlier models that explicitly accounted for virulence differences among the *Cryptosporidium* isolates rather than human susceptibility differences. The authors reported that the three human-focused models predicted significantly higher risk of infection from low-dose exposures than earlier models had predicted: for example, a 72 percent probability of infection from a single ingested oocyst as opposed to a previous estimate of 4 percent probability of infection.

However, Schmidt and Chappell (2016) disagreed with Messner and Berger's assumption that all *Cryptosporidium* isolates share a single dose-response relationship and are equally infectious. Their criticism was that Messner and Berger chose to analyze only the studies where subjects had no serological evidence of prior infection and therefore did not include data that could have provided a more representative depiction of the general population. Ethical considerations prevent the gathering of experimental data on infective doses in immunocompromised persons. An experiment comparing healthy mice and immunosuppressed mice, however, found that *Cryptosporidium* infectivity rates were no higher in immunosuppressed mice than in healthy mice, though illness was more severe and sometimes fatal in the immunosuppressed group (Miller et al., 2007).

Exhibit 4-1 shows annual waterborne cryptosporidiosis outbreaks recorded in CDC's National Outbreak Reporting System (NORS) as attributable to drinking water exposure (1992-2021). Some of these outbreaks have been associated with private water wells, and others have occurred at public water systems. Since 2012, there have been four reported outbreaks of cryptosporidiosis from public water systems. One of the four outbreaks involved both *Cryptosporidium* and shiga-toxin-producing *E. coli*. The four outbreaks together resulted in a total of 201 recorded illnesses, two hospitalizations, and no deaths. Note that additional outbreaks may have gone unreported by NORS or may have been recorded as of uncertain etiology. In addition, since NORS is specifically focused on outbreaks it does not capture rates of endemic disease.

Exhibit 4-1. Outbreaks per year of waterborne disease caused by *Cryptosporidium* in drinking water (1992-2021)



Starting with CDC data on foodborne illnesses and factoring in estimated rates of underreporting and underdiagnosis, Collier et al. (2021) calculated that in 2014 there were approximately 823,000 cases of cryptosporidiosis in the U.S., of which 322,000, were domestically acquired waterborne cases. Of the approximately 322,000 cases, the authors estimate that 1,120 resulted in hospitalizations and 24 in death.

4.3 Aircraft Drinking Water Rule

EPA promulgated the ADWR in 2009 (74 FR 53590; USEPA, 2009) to ensure that drinking water provided to aircraft passengers and crew is protected from microbial contaminants. ADWR requires aircraft carriers to develop operation and maintenance plans (O&M plans) and coliform sampling plans and to conduct routine disinfection and flushing. Positive total coliform samples are further analyzed for *E. coli*. If positive *E. coli* samples result, public notification and corrective measures are required.

4.3.1 Summary of Health Effects Review Outcome and Information Evaluated

There is limited new literature available on the presence of microbial pathogens in aircraft drinking water. Handschuh et al. (2015) found that long-haul flights were significantly poorer in terms of microbial water quality than short haul flights, and that water service vehicles were a significant source of increased microbial load in aircraft.

A follow-up study by Handschuh et al. (2017) demonstrated that there is a diversity of microorganisms within the aircraft drinking water supply chain. The researchers sourced water samples from long-haul and short-haul aircraft, the aircraft water source, and a water service vehicle. In total, 308 isolates were characterized and their identity was determined. Many of the bacteria found were identified as known or potential human pathogens. *Burkholderia pseudomallei*, for example, which was isolated from a water service vehicle, is highly pathogenic and can be transmitted by skin contact with contaminated water. Opportunistic pathogens capable of causing infections in vulnerable individuals were also found, such as the *Burkholderia cepacian* complex, *Pseudomonas aeruginosa*, *Stenotrophomonas maltophilia*, *Acinetobacter baumannii*, *Ralstonia pickettii*, *Pseudomonas fluorescens,* and *Sphingomonas paucimobilis*.

Other studies have also found microbial contaminants present in aircraft drinking water, including *Pseudomonas aeruginosa*, enterococci, clostridia, and *Salmonella* (WHO, 2009; Schaeffer et al. 2012).

Tracking an illness back to contaminated water served on an aircraft presents a technical challenge. Most disease incubation periods are longer than the duration of a flight, and even if it is possible to determine that a disease was incurred in air travel, it may be difficult to determine if the route of transmission was from beverages, food, or close proximity of people, and to determine whether transmission occurred on board the aircraft or at an air terminal. Possibly for these reasons, there was no new health effects information identified that indicated increased health risk compared to when ADWR was developed.

5 Analytical Methods

This chapter summarizes the analytical methods approved for contaminant monitoring or treatment technique (TT) requirements included under the Revised Total Coliform Rule (RTCR), Ground Water Rule (GWR), Long-Term 2 Enhanced Surface Water Treatment Rule (LT2) Round 2 and Aircraft Drinking Water Rule (ADWR). The Six-Year Review 4 (SYR4) also includes the Filter Backwash Recycling Rule (FBRR), but because there are no monitoring requirements under this rule, there are no analytical methods described for this rule in this section.

5.1 Revised Total Coliform Rule Monitoring Requirements

Under the RTCR, samples are routinely collected by systems at sites which are representative of water quality throughout the distribution system. These samples, also called routine samples, are analyzed for the presence of total coliform bacteria. The number and frequency of samples required by RTCR depend on the size of the system. If a sample tests positive for total coliform bacteria, the sample is further analyzed for the presence of *E. coli*. The rule requires that the presence of total coliform bacteria in any routine samples require the water system to collect additional samples (called "repeat" samples) confirming evidence of fecal contamination. Samples positive for total coliforms and *E. coli* will trigger the need for the system to take corrective actions referred to as Level 1 and Level 2 assessments to identify sanitary defects that could provide pathways for entry of microbial contamination into the distribution system.

For the RTCR, there have been new methods approved as well as revisions to existing methods since SYR3. The Modified Colitag and Tecta methods were revised with one new method approved. Other revised methods of RTCR can be identified by referencing updated versions listed in the 23rd and 24th editions of "Standard Methods for the Examination of Water and Wastewater."

A new method, Membrane Filtration procedure using REC2, was approved in 2021 and is a newly approved method for RTCR. This method is similar to the other methods in terms of providing microbial density values but this method uses a different media.

For all revised and new methods for RTCR, there are no new technologies or significant changes to the detection methodology. Approved methods are specified in 40 CFR 141.852(a)(5). Additional methods are listed in Appendix A to Subpart C of Part 141.

5.2 Ground Water Rule Monitoring Requirements

Under the GWR, ground water systems that do not provide 4-log treatment of viruses must monitor their source water for a fecal indicator if there is a positive total coliform sample in the distribution system. This positive total coliform sample triggers the source water monitoring requirement of the GWR. The system must monitor their source water for either *E. coli*, enterococci, or coliphage. Approved methods are specified in 40 CFR 141.402(i).

Since the SYR3, there have been revisions to approved methods, with the Modified Colitag and Tecta methods having been revised along with those from “Standard Methods for the Examination of Water and Wastewater.” In addition, there was one new method approved, Rapid’ *E. coli* 2 (REC2). The REC2 method is similar to other methods in terms of the technique used and was shown to be equally effective in the recovery of total coliform bacteria and *E. coli*.

There have been no new technologies or significant changes to the detection methodologies used to detect total coliforms or *E. coli*, which are detected under the RTCR. The Membrane Filtration procedure using REC2 method, as with RTCR, is a newly approved method for the GWR.

5.3 Methods for Measuring Disinfectant Residuals in Ground Water

Ground water systems that provide 4-log inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal, must continue to conduct compliance monitoring to show that they are providing 4-log treatment. The GWR requires that a system using a chemical disinfectant to achieve the 4-log inactivation of viruses must use the analytical methods under the SWTR in 40 CFR 141.74(a)(2).

5.4 Long-term 2 Enhanced Treatment rule Analytical Methods Approved

The purpose of LT2 is to reduce illness linked to *Cryptosporidium* and other pathogenic microorganisms in drinking water. Under the Interim Enhanced Surface Water Treatment Rule (IESWTR) (63 FR 69477, USEPA, 1998) and LT1 (67 FR 1812, USEPA, 2002), EPA established an NPDWR for *Cryptosporidium* and set an MCLG of zero. The LT2 supplements these existing regulations through additional treatment requirements in systems at higher risk for *Cryptosporidium*. The LT2 also contains provisions to reduce risks from uncovered finished water reservoirs and provisions to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection byproducts that result from water treatment.

The analytical methods for *Cryptosporidium*, *E. coli*, and turbidity have not changed, nor have any new methods been approved for these analytes since LT2 was promulgated. The LT2 requires systems and/or laboratories to use either “Method 1622: *Cryptosporidium* in Water by Filtration/IMS/FA” (USEPA, 2005a) or “Method 1623: *Cryptosporidium* and *Giardia* in Water by Filtration/IMS/FA” (USEPA, 2005b). EPA Methods 1622, 1623, or 1623.1 can be used to characterize *Cryptosporidium* levels in the source water of PWSs for the purposes of risk-targeted treatment requirements under the LT2. Approved methods are specified in 40 CFR 141.704-707.

5.5 Aircraft Drinking Water Rule

ADWR was developed to protect against disease-causing microbiological contaminants through the required development and implementation of aircraft water system operations and maintenance plans. This includes routine disinfection and flushing of the water system, and periodic sampling of the onboard drinking water. All aircraft water systems collect samples for analysis of total coliform bacteria according to the frequency and procedures described in the coliform sampling plan. Each routine, repeat, or follow-up sample that is positive for total coliforms is tested for the presence of *E. coli*. If any sample is positive for *E. coli*, public notification and corrective disinfection and flushing are triggered. Approved methods are specified in 40 CFR 141.852.

6 Occurrence and Exposure

This chapter summarizes the results of EPA's occurrence analyses of regulated microbial pathogens and indicators. The objectives of the occurrence analyses are to characterize national occurrence baselines of the relevant microbial contaminants and related indicators and changes to these baselines under the microbial rules covered during the SYR4. First, the chapter presents occurrence analyses for total coliforms and *E. coli* relative to the Ground Water Rule (GWR) and the Revised Total Coliform Rule (RTCR), using compliance monitoring data from the Fourth Six-Year Review Information Collection Request (ICR) database (referred to as the "SYR4 ICR microbial dataset" in this document, see USEPA, 2019a), and other sources, including the SYR3 ICR microbial dataset.

The SYR4 also includes the Filter Backwash Recycling Rule (FBRR), but because there are no monitoring requirements under this rule, there is no occurrence analysis presented for this rule in this chapter.

Next, the chapter presents and discusses the analytical results of the source water monitoring data, related to the Long Term 2 Enhanced Surface Water Treatment Rule (LT2), primarily for *Cryptosporidium*, that are contained in the SYR4 ICR microbial dataset. Third, EPA applies statistical modeling to quantify uncertainty in total coliform occurrence at undisinfected ground water systems (which mostly serve small populations), and also conducts a brief analysis of triggered source water monitoring for *E. coli* at undisinfected ground water systems. Both of these analyses depend on decision trees used to identify undisinfected systems. EPA presents the systematic approach used to identify disinfection status in SYR4, and explains how this definition differs from the definition used in SYR3.

Finally, the chapter presents the results of occurrence analysis for the Aircraft Drinking Water Rule (ADWR) using the Aircraft Reporting and Compliance System (ARCS) database. Overall, the analytical results presented and discussed in this chapter are intended to be helpful for addressing one of the questions prescribed in the *EPA Protocol for the Fourth Review of Existing National Primary Drinking Water Regulations* (USEPA, 2024a): Is there a significant increase in health risk estimated from exposure to the contaminant?

EPA notes that (1) as presented below, the majority of the sampling records in both the SYR4 and SYR3 ICR microbial datasets are related to total coliforms and *E. coli* in distribution systems in the context of the GWR and RTCR; (2) data on *Cryptosporidium* in source water (from round 2 monitoring under LT2) are also included in the SYR4 ICR dataset but are not present in the SYR3 ICR dataset; (3) disinfectant residuals in distribution systems, which enable the evaluation of paired records of total coliforms / *E. coli* and residuals, are being analyzed under a separate effort to support potential revision of Microbial and Disinfection Byproducts (MDBP) rules, so they are not discussed in this document; and (4) the compliance monitoring data presented for ADWR show results for total coliform / *E. coli* sampling. Thus, the analytical results presented and discussed in this chapter include total coliform / *E. coli* occurrence in distribution systems and aircraft systems, *E. coli* in source ground water, and *Cryptosporidium* in source surface water.

Some of the goals of SYR4 are: to evaluate the possible differences in total coliform occurrence between disinfected and undisinfected ground water systems, to suggest potential impacts of the combined GWR and RTCR on the occurrence of total coliform and E. coli*,* and to identify the sizes and types of undisinfected systems with the highest potential for public health improvements, informed by robust statistical methods that identify total coliform detection rates with low uncertainty. Here are some considerations that go into the analyses:

Identifying Disinfecting vs. Undisinfecting Systems

In SYR3, EPA identified and grouped disinfecting ground water systems based, in part, on the level of disinfection for the purpose of assessing the impact of different levels of disinfectant residuals on microbial contamination as indicated by total coliforms and *E. coli*. For SYR4, the definition of disinfecting ground water systems (for community and non-transient non-community water systems) was revised so that it was not based on disinfection residual levels but focused instead on the inclusion of DBP data as an indicator of disinfection. A more detailed justification for the change in definition is provided in section 6.4.1. For most analyses performed in this document, systems from the SYR3 and SYR4 ICR were categorized as either "disinfecting" or "undisinfecting" based on the SYR4 definition. There are a few instances where SYR3 and SYR4 data are categorized using the SYR3 definition to enable comparison, to see what difference the selected definition makes.

Evaluating Changes Attributable to the GWR and RTCR

To evaluate impacts of the GWR and RTCR on the occurrence of microbial indicators, it was necessary to identify a subset of systems with data that span the timeline from before GWR, after GWR, and after RTCR. To achieve this, a subset of systems that reported their routine total coliform / *E. coli* monitoring samples for all years from 2007 to 2019 was identified. All data were evaluated using the SYR4 definition of "undisinfected" (see above). Trends over time are calculated using simple summary statistics of the total coliform / *E. coli* sampling results. EPA did not attempt to investigate any combined GWR/RTCR attributable changes over time using the statistical models applied to undisinfected systems. However, the years 2011 and 2019 are compared using both definitions for undisinfected systems in Exhibit 6-24 and Exhibit 6-25.

Eliminating Outliers in Positivity Rate

To keep the size of the working data set manageable, all total coliform / *E. coli* occurrence data (number of samples taken and the number of positive results) were aggregated by system, month, and year. With this "reduced dataset," the percentage of positive samples for each system in any given year could be calculated. The results were summarized using simple statistics. Note that the number of systems in the data set varied year to year.

An important detail of the SYR3 and SYR4 ICR is that systems may not have collected or reported all their required routine monitoring samples. This can lead to a misrepresentation of the positivity rate (e.g., the 100% positivity rate of a system on quarterly monitoring that only reported one sample for the year instead of four, and had a single positive result, might not be representative of actual conditions at the system). To avoid including false representations of the total coliform / *E. coli* positivity rate without overly excluding valuable data, a threshold of 90%

completeness was created for certain analyses. In these cases, only data from the subset of systems that reported a minimum of 90% of their routine monitoring samples were included. In contrast to this 90% completion criterion, the statistical models used to assess the undisinfected systems (Exhibit 6-24 and Exhibit 6-25) did not exclude data and presented the results with a suitable display that captured the uncertainty associated with using all data.

Characterizing Systems that Have Highest Percentage of Total Coliform Positive Samples

Under SYR3, routine total coliform and *E. coli* sample data from undisinfected small ground water systems were analyzed (Messner et al., 2017). For the year 2011, Messner et al. divided the undisinfected systems into three types: (community, non-community transient, and non-community non-transient. Each type was then further sub-divided into three population-served size bins. When focusing the analysis on specific groups of systems (i.e., based on system size or system type), the sample sizes become smaller, and this makes it challenging to generate reliable estimates. For SYR3, a Bayesian Markov Chain Monte-Carlo (MCMC) model was implemented to quantify the distribution of positive total coliform / *E. coli* samples and derive a mean positivity rate with quantified uncertainty. This analysis was repeated using the SYR4 2019 data and the SY4 definition of undisinfected systems for 2011 and 2019 (Exhibit 6-24 and Exhibit 6-25). EPA chose not to evaluate every SYR4 year (2012-2018) using the Bayesian MCMC model. EPA reasoned that the common systems with 90% completeness summary statistics were adequate to evaluate putative GWR/RTCR effects.

This chapter is organized as follows:

- Section 6.1 describes the data sources used in the microbial occurrence analysis;
- Section 6.2 presents a summary of the analysis related to the microbial contaminants in distribution systems relative to the GWR and RTCR, focusing on total coliforms and *E. coli*;
- Section 6.3 presents a summary of the analysis to support the evaluation of LT2, , focusing on *Cryptosporidium* in source water;
- Section 6.4 presents EPA's methodology for identifying undisinfected ground water systems, along with two sets of analyses involving these undisinfected ground water systems: modeling of total coliform detection rates and characterization of triggered E. *coli* source water monitoring results; and
- Section 6.5 presents a summary of the analysis related to the ADWR.

6.1 Data Sources for Microbial Occurrence Analyses

Data sources used in EPA's analyses of national-level microbial occurrence include national datasets compiled by EPA such as the third and fourth Six-Year Review Information Collection Request datasets (SYR3 ICR and SYR4 ICR, respectively), the Aircraft Reporting and Compliance System (ARCS), and Safe Drinking Water Information System (SDWIS). Each of those sources are described below along with how they were used in the microbial occurrence analyses. See USEPA (2024b) for more information on the data files that were used for the analyses summarized in this chapter.

6.1.1 Six-Year Review 4 Information Collection Request Data

This section provides a description of the SYR4 ICR database, which is the primary source of data used in the SYR4 microbial analysis, and describes subsets of the database that were used for the various analyses in this chapter. It is important to note that analyses described in this report were conducted to inform the Six-Year Review and were not meant to assess compliance with regulatory standards.

The 1996 SDWA Amendments require EPA to review each National Primary Drinking Water Regulation (NPDWR) at least once every six years and revise it, if appropriate. As part of the Six-Year Review, EPA evaluates any newly available data, information, and technologies to determine if any regulatory revisions are needed. There is no national database that receives and stores all relevant data on the occurrence of regulated contaminants in public drinking water systems. To help support each Six-Year Review of NPDWRs, EPA conducts a voluntary data call-in from the states and primacy entities (territories and tribes) to obtain compliance monitoring data. EPA works with the states and other primacy agencies to receive their complete records of compliance monitoring data (i.e., public drinking water system regulated contaminant occurrence data). The compliance monitoring data are obtained through an ICR process. Under the SYR4 ICR (EPA ICR No. 2574.01, USEPA, 2018), EPA requested compliance monitoring data for the time period from 2012 through 2019 for the following microbial contaminants and indicators: total coliforms, *E. coli*, fecal coliforms, enterococci, coliphage, *Cryptosporidium,* and *Giardia lamblia*. In addition, the SYR4 ICR included treatment and disinfectant residual information, sample-specific and system-specific information such as system type and source water type, and corrective action information. In all, 46 states and thirteen other primacy agencies provided compliance monitoring data records (USEPA, 2024b).

6.1.1.1 Description of Data Collected Under Six-Year Review 4 Information Collection Request

EPA conducted data management and quality assurance (QA) evaluations on the data received for contaminants evaluated for the SYR4 to establish a high quality, national compliance monitoring and treatment technique (TT) dataset consisting of data from 59 states / primacy entities (46 states plus territories, Washington, D.C., and tribes). The compliance monitoring data for these 59 states / primacy agencies comprise more than 71 million analytical records from approximately 140,000 public water systems (PWSs), which collectively serve more than 301 million people nationally.[1] This dataset is the largest and most comprehensive compliance monitoring and TT dataset ever compiled and analyzed by EPA's Drinking Water Program. The final SYR4 ICR dataset includes more than 25 million analytical records for microbial contaminants and indicators (total coliforms, *E. coli*, fecal coliforms, heterotrophic bacteria (as measured by heterotrophic plate count [HPC]), *Giardia lamblia*, *Cryptosporidium*, coliphage, and enterococci). By comparison, the final SYR3 ICR dataset included almost 12 million analytical records for microbial contaminants and indicators. For more details on the SYR4 ICR Dataset, including descriptions of reviews for completeness, representativeness, and data management and quality assurance / quality control (QA / QC), refer to USEPA (2024b).

Quality Assurance Activities

After the individual state datasets received under the SYR4 ICR were converted into a consistent format, a significant effort was undertaken to ensure the quality of the data submitted. An important objective regarding the data to be used for the SYR4 contaminant occurrence analyses is development of a consistent and repeatable data management approach. Consistent data editing and QA/QC assessments allow the individual state datasets to be aggregated and jointly evaluated, to provide an overview of national occurrence patterns for individual contaminants.

Uniform, detailed QA/QC assessments conducted on the state compliance monitoring datasets included comparisons of the number of systems with compliance monitoring data in each state against total system inventory numbers from the Federal Safe Drinking Water Information System database (SDWIS/Fed), and examination of the number of analytical records per system (or per contaminant) to evaluate the completeness of the submitted analytical records. These comparisons helped to understand the representativeness of the data provided by each state. Identified errors or questionable results that did not have straight-forward explanations were addressed through consultations with state data management staff to ensure consistent and appropriate interpretations.

As described in the QA/QC document (USEPA, 2024b), the following QC measures were applied to the Microbial Rule contaminants, including total coliforms, fecal coliforms, *E. coli, Cryptosporidium, Giardia lamblia,* enterococci, and coliphage:

- Removal of records from non-public water systems
- Removal of records from systems with missing source water type or population served data
- Removal of records from outside the SYR4 ICR date range
- Removal of records marked as being "not for compliance"
- Removal of records marked with a sample type code other than routine, repeat, or triggered

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[1] These statistics reflect the portion of the dataset representing compliance monitoring samples collected for requested regulated contaminants. The full dataset (including data not specifically requested by EPA but submitted voluntarily by some states) was comprised of over 83 million records from approximately 142,000 water systems.

- Removal of records with no data/results
- Removal of records with irregular system type codes

The number of microbial records excluded per each of the steps described above is summarized in Exhibit 6-1. Overall, 99 percent of microbial records are retained after these QA steps. Note that very limited data were submitted for enterococci (8 records) and coliphage (3 records). For the purpose of SYR4 occurrence analysis, EPA focused on total coliforms, *E. coli* (in distribution systems and source water, examined separately), and *Cryptosporidium* in source water. Although EPA requested data under SYR4 for *Giardia lamblia*, enterococci, and coliphage, those contaminants were not included as part of the analysis due to low number of records received for enterococci and coliphage and the fact that *Giardia lamblia* is part of an on-going potential revision action. See Exhibit A-1 in Appendix A for a state-level breakdown of the number of records included in the analysis for total coliforms, *E. coli*, fecal coliforms, and *Cryptosporidium*.

Exhibit 6-1. SYR4 Data Summary of the Count of Records Removed via the Quality Assurance Measures Applied to Microbial Rule Contaminants

QA Step	Count of Records[1]	
	Included	**Excluded**
Original number of records	28,329,039	
Step1: Removal of data from non-public water systems.	28,315,533	13,506
Step 2: Removal of data from systems with missing source water type and/or population served information.	28,236,298	79,235
Step 3: Removal of data with a sample collection date outside of the Six Year 4 ICR date range of 2012 - 2019.	28,114,841	121,457
Step 4: Removal of data marked as being "not for compliance."	27,985,027	129,814
Step 5: Removal of microbial data with sample type code other than "RT" (routine), "RP" (repeat), or "TG" (triggered).	27,981,035	3,992
Step 6: Removal of records with no data/results	27,964,042	16,993
Step 7: Removal of records with irregular system type codes (specific to State of PA where unknown system type codes were included)	27,962,474	1,568
Final number of records	27,962,474	
Percent Included	99%	

[1] The following analytes are included in the counts: total coliforms, fecal coliforms, *E. coli, Cryptosporidium, Giardia lamblia,* enterococci, and coliphage.

6.1.1.2 Limitations of the Six-Year Review 4 Data

The SYR4 ICR microbial dataset consists of data from 57 primacy agencies (including 44 states and 13 tribes and other entities). The SYR4 ICR does not include any data from four states (Georgia, Michigan, Mississippi, and New Mexico) and three other entities (Guam, Puerto Rico, and U.S. Virgin Islands). The SYR4 ICR microbial dataset includes data from approximately 127,000 PWSs, representing over 85 percent of the public water systems in the U.S. and 67 percent of the population served by public water systems in the U.S. In addition to the four states that did not provide any SYR4 ICR data, two states did not provide microbial data that could be utilized in the analysis. EPA recognizes a large degree of variability in the number of records provided by water systems from state to state. Furthermore, the dataset is limited to the period of 2012 to 2019 and the number of samples and number of systems included in the SYR4 ICR dataset from each state varies from year to year. There may also be varying levels of completeness of data records for some compliance monitoring periods at some systems.

6.1.1.3 SYR4 "Reduced" Total Coliform / *E. coli* Dataset to Support Analysis of Ground Water Rule and Revised Total Coliform Rule

As described above, the total coliform / *E. coli* / fecal coliform data received as part of the SYR4 ICR included records for individual samples. After EPA performed the QA/QC steps described in Exhibit 6-1, the resulting dataset contained nearly 28 million individual monitoring records. Such a large number of records poses great challenges for data management and analysis. To better facilitate the analysis of how total coliform and fecal indicator (either *E. coli* or fecal coliform) positivity rates varied by system size, system type, source water type, and disinfection status over time, EPA created a "reduced total coliform / *E. coli* dataset." The "reduced dataset" was formed by data aggregation. In this case, the individual sampling records were reduced to summary counts for each month, year, and water system for the following measures: (a) the total number of routine (RT) samples provided for total coliforms, (b) the number and percent of RT samples testing positive for total coliforms, (c) the total number of RT samples provided for *E.* coli, and (d) the number and percent of RT samples testing positive for *E. coli* / fecal coliforms. Similar counts were generated for repeat (RP) samples of total coliforms and *E. coli* / fecal coliforms as well. In other words, the reduced dataset includes, for each water system and month, counts of the number of routine and repeat samples assayed and the number found to be positive for total coliforms and for *E. coli* / fecal coliforms.

Note that because of the small count of fecal coliform monitoring results (as indicated in Exhibit 6-2 below), findings for fecal coliforms are not presented and discussed in this chapter. Also, some additional QA steps beyond what are described in Section 6.1.1.1 were applied to the individual sample results prior to the creation of the reduced dataset. These steps involved considering the monitoring and reporting requirements for total coliforms / *E. coli* prescribed under the RTCR. Exhibit 6-2 summarizes the number of records removed via each QA step before generating the SYR4 reduced total coliform / *E. coli* dataset. EPA notes, in contrast to the SYR3 QA steps, the SYR4 QA steps do not include this step. *E. coli* records that did not have a corresponding total coliform positive record were not excluded from the reduced dataset.

Exhibit 6-2. Summary of the Count of Records Removed via the Quality Assurance Measures for Six-Year Review 4 Reduced Total Coliform / *E. coli* Dataset

QA Steps Applied	Total Coliforms		*E. coli*		Fecal Coliforms	
	Included	**Excluded**	**Included**	**Excluded**	**Included**	**Excluded**
Starting number of records	21,010,733		7,277,177		16,920	
Number of records after QA measures applied	20,746,119	264,614	7,175,363	101,814	16,818	102
Removal of records with sample type code other than "RT" or "RP"	17,539,775	3,206,344	6,527,234	648,129	16,416	402
Removal of records with presence indicator code other than "A" or "P"	17,533,540	6,235	6,525,739	1,495	16,416	0
Removal of non-distribution system samples. (I.e., include only the records with sample point type of "DS", "FC", "FN", "LD", "MD", or "MR" or records with water facility type of "CC", "DS", "TP", or "TM" and sample point type of "WS" or null.)	16,538,009	995,531	5,852,233	673,506	11,193	5,223
Removal of records with a greater free chlorine concentration than total chlorine concentration (Note: Kept records with <0.1 mg/L of absolute difference or <30% of relative difference between free and total chlorine concentrations.)	16,462,870	75,139	5,846,138	6,095	11,192	1
Removal of records from states who confirmed that their microbial data are not recorded as individual samples	16,454,914	7,956	5,839,855	6,283	11,190	2
Final Number of Records	**16,454,914**		**5,839,855**		**11,190**	

In the final “reduced” dataset, there are data for a total of 109,155 water systems located in 48 states/entities. Exhibit 6-3 provides an excerpt of the information included in the final “reduced” dataset. Note that not all included systems have results for all 12 months of each year and not all included system months have complete monitoring records relative to the regulatory monitoring requirements of RTCR. Furthermore, there were some repeat samples that occurred in a different month than their corresponding routine sample; thus, some system/month/year combinations have repeat samples but no routine samples. Overall, the data “reduction” process reduced the number of records from 22,305,959 individual sampling results to 5,327,984 records at the system monthly level. This enabled EPA to more easily manage the data file and more effectively conduct analyses on personal computers. See Appendix A for a table that includes the field names and definitions for the reduced dataset.

Exhibit 6-3. Excerpt of Data from Six-Year Review 4 Reduced Total Coliform / *E. coli* Dataset

PWSID	State	Population Served	Pop Cat	System Type	Source Water Type	Year	Month	Disinfecting Status	Number of RTTC Samples Required	Percent Completeness of RTTC Records	Number of RTTC	Number of RTTC Positive	Percent RTTC Positive	Number of RTEC	Number of RTEC Positive	Percent RTEC Positive	Number of RPTC	Number of RPTC Positive	Number of RPEC	Number of RPEC Positive
OR4100601	OR	172	2	C	GW	2018	12	Disinfecting	1	100%	1	100%	1	1	0	0%	3	0	0	0
OR4100601	OR	172	2	C	GW	2018	6	Disinfecting	1	100%	1	100%	1	1	1	100%	3	3	3	3
OR4100601	OR	172	2	C	GW	2018	2	Disinfecting	1	100%	1	100%	1	1	0	0%	3	0	0	0
OR4100601	OR	172	2	C	GW	2018	11	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	10	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	9	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	8	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	7	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	5	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	4	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	3	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0
OR4100601	OR	172	2	C	GW	2018	1	Disinfecting	1	100%	1	0%	0	0	0	0%	0	0	0	0

Notes: PopCat = system's population size category; RTTC = number of routine total coliform samples; RTEC = number of routine *E. coli* samples; RPTC = number of repeat total coliform samples; RPEC = number of repeat *E. coli* samples; Percent Completeness = percent of routine total coliform samples taken by the system as compared to the total number of required routine total coliform samples based on system size.

6.1.1.4 Additional Six-Year Review 4 Information Collection Request Data Records to Support Review of the Long Term 2 Enhanced Surface Water Treatment Rule

The LT2 provides for source water monitoring for *Cryptosporidium* and associated water quality parameters. Under this provision, monitoring data from the Round 1 monitoring period (2006 to 2012) were analyzed by EPA and the results were presented in the *Six-Year Review 3 Technical Support Document for the Long-Term 2 Enhanced Surface Water Treatment Rule* (USEPA, 2016b). Primacy agencies provided more than 19,000 monitoring records (sample analytical results) for *Cryptosporidium* over the 8-year period of the SYR4 ICR (2012 – 2019). More than 99 percent of the *Cryptosporidium* records were from CWSs, with about 95 percent of those records from surface water sources. Fewer than 0.3 percent of the 19,000 *Cryptosporidium* monitoring records provided concentration levels.

In addition to these occurrence data, primacy agencies provided binning information for PWSs based on monitoring conducted in response to LT2. Filtered systems serving at least 10,000 people were classified into a “bin” based on the results of their initial source water monitoring. (See Exhibit 6-18 for more details on systems’ bin classifications.) Bin classification determines whether further treatment for *Cryptosporidium* is required. A second round of source water monitoring was required six years after the initial bin classification per Round 1 monitoring results and bin classifications were revised for some systems based on Round 2 monitoring results.

6.1.2 Aircraft Drinking Water Rule Data

The Aircraft Reporting and Compliance System (ARCS) is a centralized web-based data collection and management system that is used to facilitate the reporting of aircraft water system data under the ADWR, for accountability and regulatory oversight. Air carriers subject to the ADWR must report to EPA the following information in ARCS, unless an alternative reporting method has been approved (see https://www.epa.gov/dwreginfo/aircraft-drinking-water-rule):

- A complete inventory of aircraft water system fleet,
- The date the Operations and Maintenance plan was developed,
- The date the Coliform Sampling plan was developed,
- The date the aircraft water system sampling plan(s) was/were incorporated into the aircraft water system Operations and Maintenance plan,
- The date the Operations and Maintenance plan(s) was/were incorporated into FAA-accepted air carrier Operation and Maintenance program,
- The frequency of routine disinfection and flushing, the corresponding routine total coliform sampling frequency, and
- The dates of routine disinfection and flushing, routine coliform sampling dates and results, and corrective actions (when applicable).

For SYR4, EPA downloaded and reviewed compliance monitoring data available in ARCS as of May 2021. Approximately 140,000 records of aircraft water system compliance monitoring data for total coliform and *E. coli* samples were available in ARCS from February 2011 through May

2021, including results reported for more than 70 different makes/models of aircraft. These results were used to characterize the positivity rates of total coliforms and *E. coli* in aircraft water system on an annual basis, as well as for all the years that data were available (2011-2021) and for the subset of years 2012 through 2019. The evaluation of data for years 2012 through 2019 was performed to allow for a comparison with similar data for stationary PWSs as described in Section 6.2. In addition, this approach removes potentially confounding considerations associated with evaluating data for calendar year 2020, when a large number of aircraft water systems were inactive due to COVID-19, as well as years 2011 and 2021, for which the ARCS data evaluated at this time only represent partial years.

Aircraft inventory data, including manufacturer, model, and disinfection and flushing frequency, were linked to the monitoring results by public water system identification number (PWSID). Aircraft PWSs were categorized as small, medium, or large based on the seat capacity (small = 130 or fewer seats; medium = 131 – 250 seats; large = over 250 seats). Note that these categories were developed specifically for this analysis, based on the dataset, and do not represent regulatory categories. ADWR does not categorize aircraft water systems based on size. In addition, the first three digits of the model number were used to summarize the make/model of each aircraft.

A number of QA steps were applied to the ADWR dataset to identify the total coliform and *E. coli* records suitable for analysis. Data were excluded via the following QA steps:

- Records where [Location] was "-" were excluded.
- Records where [Total Coliform] was "-" or "from" were excluded.
- Records where the [Sample Taken On] date was incorrectly entered were excluded. These incorrectly entered dates were as follows: 12/08/0014 00:00", "09/26/0201 03:52", "09/13/0019 03:59", "09/09/0201 03:35", "07/22/0204 05:17", "07/16/0018 01:35", "06/21/0018 01:40", and "02/02/0017 16:10."
- Records where a [Total Coliform] result was entered as "absent" but [*E. coli*] was positive.

The ADWR analyses were stratified in a variety of ways to summarize results, including the number of total coliform samples and public water systems, by aircraft size, manufacturer, model, air carrier, sample type, and more. It is important to note that all *E. coli* positivity rates were calculated twice, under two different sets of assumptions:

1. An *E. coli* sample was included in the analysis only if the *E. coli* result was listed as "Present" or "Absent."

2. An *E. coli* sample was included if the *E. coli* result was listed as "Present" or "Absent" (i.e., the same as the first set of assumptions), but with an added assumption that an *E. coli* sample could be considered "Absent" and included in the analysis as such if the associated total coliform result was reported as "Absent" and there was no *E. coli* result provided. These results are labeled in the file as "*E. coli* (Alternative Approach)."

After the QA steps were applied, there were 140,502 total coliform results used in this evaluation, provided by 8,093 PWSs and covering the full range of years for which ARCS data were collected (i.e., February 2011 – May 2021). Under the first set of assumptions listed above, there were 92,994 *E. coli* results provided by 7,091 PWSs (i.e., 66 percent of the number of total coliform results and 88 percent of the number of aircraft water systems providing total coliform results), with a total of 241 results (0.26 percent) positive for *E. coli*. Under the second set of assumptions listed above for the *E. coli* analysis, there were 140,485 *E. coli* results provided by 8,093 aircraft water systems, with 241 results (0.17 percent) positive for *E. coli*.

6.1.3 Safe Drinking Water Information System Data

EPA used inventory information from SDWIS/Fed to identify the number of systems and the population served by systems nationally, as well as the breakdown by source water type, system type, and system size. SDWIS inventory tables were filtered to include all active water systems in 2019 (USEPA, 2019b). In addition, SDWIS data were used in the process for identifying the undisinfected ground water systems as discussed in Section 6.4.1.

6.1.4 Other Data Sources

6.1.4.1 Six-Year Review 3 "Reduced" Total Coliform / *E. coli* Dataset for Analysis of Ground Water Rule

A SYR3 reduced total coliform / *E. coli* dataset was also generated using the same method and the same QA steps described above for the SYR4 reduced dataset. As described above, the data for each system and month / year were reduced to a small number of summary counts: (a) the total number of routine (RT) samples provided for total coliforms, (b) the number and percent of RT samples testing positive for total coliforms, (c) the total number of RT samples provided for *E. coli* and (d) the number and percent of RT samples testing positive for *E. coli*. Similar counts were generated for repeat (RP) samples of total coliforms and *E. coli* as well. In other words, the reduced dataset includes, for each water system and month, counts of the routine and repeat samples assayed for and found to be positive for total coliforms, *E.* coli, and fecal coliforms. Note that at the time of the SYR3 analyses (USEPA, 2016a), a separate "reduced total coliform / *E. coli*" dataset had been created using some different QA steps. A new SYR3 reduced total coliform / *E. coli* dataset was created here for use in direct comparisons with the SYR4 reduced total coliform / *E. coli* dataset. Exhibit 6-4 summarizes the number of records removed via each QA steps in order to generate the SYR3 reduced dataset.

Exhibit 6-4. Summary of the Count of Records Removed via the Quality Assurance Measures for Six-Year Review 3 Reduced Total Coliform / *E. coli* Dataset

QA Steps Applied	Total Coliforms		*E. coli*		Fecal Coliforms	
	Included	**Excluded**	**Included**	**Excluded**	**Included**	**Excluded**
Starting number of records	9,953,551		1,833,281		281,642	
Number of records after QA measures applied under the SYR3 effort (Note: Used text files posted on SYR3 website.)	9,766,686	186,865	1,804,329	28,952	264,090	17,552
Removal of non-distribution system samples. (i.e., include only the records with sample point type of "DS", "FC", "FN", "LD", "MD", or "MR" or records with water facility type of "CC", "DS", "TP", or "TM" and sample point type of "WS" or null.)	9,018,655	748,031	1,545,146	259,183	111,059	153,031
Removal of records with a greater free chlorine concentration than total chlorine concentration (Note: Kept records with <0.1 mg/L of absolute difference or <30% of relative difference between free and total chlorine concentrations.)	8,869,163	149,492	1,544,418	728	111,034	25
Removal of records from one state (South Carolina) as the data are not representative of the full state monitoring results.	8,864,250	4,913	1,543,025	1,393	110,067	967
Removal of records with sample type code other than "RT" or "RP"	8,850,363	13,887	1,543,025	0	110,067	0
Removal of records with presence indicator code other than "A" or "P"	8,526,333	324,030	1,543,025	0	110,067	0
Final Number of Records	**8,526,333**		**1,543,025**		**110,067**	

In the final “reduced” dataset, there are data for a total of 84,389 water systems located in 39 states/entities. Note that not all included systems have results for all 12 months of each year and not all included system months have complete monitoring records relative to the regulatory monitoring requirements of RTCR. Furthermore, there were some repeat samples that occurred in a different month than their corresponding routine sample; thus, some system/month/year combinations have repeat samples but no routine samples. Overall, the data “reduction” process reduced the number of records from 10,179,425 individual sampling results to 3,024,834 records at the system monthly level.

6.2 Analytical Results of Samples Taken from the Distribution System

This section presents and discusses results of EPA’s analysis of total coliform and *E. coli* contamination in source water and distribution systems based on samples measured in distribution systems. In the smallest systems with little or no distribution system, distribution system samples can be used to infer source water contamination. It is important to note that a total coliform or *E. coli* positive sample collected in the distribution system should not be viewed solely as a distribution system contamination event because there is an unknown source water contamination component. To evaluate the occurrence of total coliforms and *E. coli* in the distribution system, EPA used a statistical summary approach.

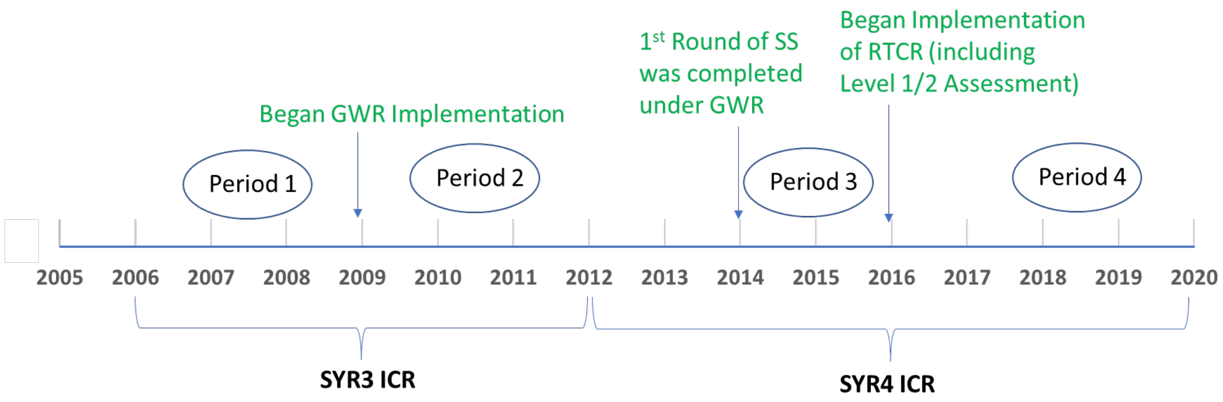
6.2.1 Total Coliform / *E. coli* Occurrence in Context of Ground Water Rule and Revised Total Coliform Rule

To evaluate the potential impact of the GWR and the RTCR on the occurrence of microbial indicators throughout the United States and whether there is an opportunity to make further improvements in public health, EPA conducted an analysis focused on the occurrence of total coliforms and *E. coli* using compliance monitoring data from the SYR4 and SYR3 ICRs. The SYR3 ICR dataset included total coliform and *E. coli* compliance monitoring from 2006 to 2011 and the SYR4 ICR dataset included total coliform and *E. coli* compliance monitoring data from 2012 to 2019. As indicated in Exhibit 6-5, three regulatory milestones fell within the SYR3 and SYR4 periods of record:

- Beginning of GWR implementation (2009)
- First round of Sanitary Surveys completed under the GWR (2014)
- Beginning of the implementation of the RTCR, including Level 1 and Level 2 assessments (2016)

E. coli source water monitoring under the GWR is triggered by RTCR monitoring positive total coliform results for undisinfected ground water systems or ground water systems with less than 4 log inactivation/removal of viruses. EPA notes that in addition to *E. coli* results, the routine distribution system monitoring from TCR/RTCR itself (for total coliforms) can also be used as a potential indicator of risk, e.g. Messner et al, 2017. The results of triggered source water monitoring for *E. coli* under GWR are discussed in section 6.4.2.3.

Exhibit 6-5. GWR and RTCR Implementation Milestones in the Context of the Six-Year Review 3 and Six-Year Review 4 Information Collection Request Timeframes



The GWR and the RTCR apply in combination to protect public health. All systems are required to take routine total coliform samples under the RTCR. If an undisinfected system's RTCR sample is also positive for *E. coli* then the GWR and the RTCR require additional samples and actions. Given the overlapping requirements, it is difficult to assess the protections of each individual rule based on total coliform detections.

To start, EPA examined yearly total coliform detections (using the SYR4 disinfection definition--see Section 6.4.1, below) by including all monitoring records from all PWSs (including both ground water and surface water systems) contained in the SYR4 ICR and SYR3 ICR databases to ensure the maximum representation of all PWSs (all of which are subject to the RTCR requirements) by the datasets. This analysis focused on results from eight separate years, two from each of the four periods identified in Exhibit 6-5 (viz., 2007/2008, 2010/2011, 2014/2015, and 2018/2019). EPA used two-year averages from each of the periods to reduce the effect of background yearly variation. Exhibit 6-6 shows the result of this analysis. The number of systems and the associated number of routine total coliform records varied substantially from year to year but there was an overall apparent decreasing trend in total coliform occurrence from 2006 to 2019, and particularly after the implementation of RTCR (i.e., after 2016). Inspection of the underlying data indicates that the apparent observed decreasing trend among all PWSs is mainly driven by an apparent decreasing trend among ground water systems, which constitute a majority of PWSs in the nation. This is explored further with a more focused analysis of common systems that also has reduced bias, described below.

Exhibit 6-6. Yearly Trend of Percent Total Coliform Positive Results for Routine Sampling at All Public Water Systems (GW and SW Systems)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems (GW + SW)	70,685	70,278	74,953	74,691	86,237	85,415	95,516	95,099
#RTTC	1,226,098	1,327,476	1,589,336	1,647,311	1,861,738	1,883,681	2,231,731	2,304,040
#RTTC+	19,589	20,364	20,056	19,474	21,787	21,804	20,455	19,058
%RTTC+	1.60%	1.53%	1.26%	1.18%	1.17%	1.16%	0.92%	0.83%

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
Ave @ 2 years	1.57% (Right Before GWR)		1.22% (Right after GWR)		1.16% (Right after completing SS)		0.87% (Few years after RTCR)	
Relative difference			-21.96%		-4.76%		-25.09%	
Overall Difference	-44.32%							

As noted above and as indicated by Exhibit 6-6, the number of systems with total coliform records in the SYR3 and SYR4 ICR datasets varied from year to year (e.g., the number of systems in 2007 and 2019 was 70,685 and 95,099, respectively). In addition, the included systems may have different degrees of completeness of total coliform records (relative to the number of routine total coliform samples that need to be taken for the given population served under TCR/RTCR) in different years. These differences can contribute to the background yearly variability of the percent total coliform positive findings.

To reduce the background yearly variability due to these factors, EPA took some additional steps. EPA analyzed the yearly trends using only common systems (i.e., systems with data for all eight of the years between 2007 and 2019 included in the analysis) with at least 90 percent of completeness of routine total coliform monitoring records for a given system month (i.e., those system months with less than 90 percent of completeness were excluded for yearly trend analysis). (See Appendix A for further explanation on the use of the 90 percent completeness threshold, and a sensitivity analysis on the difference between requiring 100 percent and 90 percent completeness and on the decision to use common systems only.)

EPA notes that the smallest systems take either quarterly or monthly total coliform samples, so they are more likely to be excluded from the common systems analysis.

After applying these additional screening criteria, EPA focused the analysis on ground water systems. Because the small systems are usually undisinfected ground water systems, this focus may preferentially exclude these small ground water systems. EPA determined which systems are disinfecting using the systematic method described in Section 6.4.1. Results are shown in Exhibit 6-7. Overall, an apparent increase in the percentage of disinfecting systems was observed over time (i.e., steadily increasing from 45.3 percent in 2007/2008 to 53.1 percent in 2018/2019). Although it is difficult to associate this apparent trend with regulatory actions, it appears to confirm improved public health protections over time, at least for the larger undisinfected systems.

See Appendix A for similar tables that present results separately for the following size categories: systems serving fewer than 1,000 people; systems serving 1,000 people or more but less than 10,000 people; and systems serving 10,000 people or more (Exhibit A-3, Exhibit A-4, and Exhibit A-5, respectively). Note that in Section 6.4, EPA describes the use of a Bayesian MCMC statistical approach for analysis of undisinfected ground water systems.

Exhibit 6-7. Changes in Percent of GW Systems with Disinfection (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
#Common Systems	42.822	42.822	42.822	42.822	42.822	42.822	42.822	42.822
#Disinfecting Systems	20,067	18,740	21,494	20,091	21,384	20,789	22,729	22,769
#Non-disinfecting Systems	22,755	24,082	21,328	22,731	21,438	22,033	20,093	20,053
%disinfecting Systems	46.9%	43.8%	50.2%	46.9%	49.9%	48.6%	53.1%	53.2%
%disinfecting Systems (Ave @ 2 years)	**45.3% (Before GWR)**		**48.6% (Right after GWR)**		**49.2% (Right after SS)**		**53.1% (After few years of RTCR)**	
Relative Change	**7.2% (Right after GWR)**			**1.4% (Right after SS)**		**7.9% (Ater few years of RTCR)**		
Overall Change	**17.24%**							

EPA then evaluated the total coliform positive rate and the *E. coli* positive rate (as a percentage of total coliform samples) for the common ground water systems. As shown in Exhibit 6-8 and Exhibit 6-9, the percent of total coliform positives and *E. coli* positives consistently decreased over the years.

Exhibit 6-8. Changes of Percent RTTC+ Rates among All Ground Water Systems (“Common Systems” with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
All Systems	42,822	42,822	42,822	42,822	42,822	42,822	42,822	42,822
#RTTC	524,701	568,901	565,792	573,023	568,412	572,193	566,225	566,448
#RTTC+	10,915	11,212	10,751	10,414	9,243	9,660	7,868	7,691
%RTTC+	2.1%	2.0%	1.9%	1.8%	1.6%	1.7%	1.4%	1.4%
Periods	Period 1: Right before GWR		Period 2: Right after GWR		Period 3: Right after completion of Sanitary Survey under GWR		Period 4: Few years after RTCR	
Ave @ 2 years	2.0%		1.9%		1.7%		1.4%	
Relative difference		-8.2% (Right after GWR)		-10.9% (Right after Completion of Sanitary Survey)		-17.1% (After RTCR)		
Overall Difference	-32.2%							

Exhibit 6-9. Changes of Percent RTEC+ Rates among All Ground Water Systems (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	42,822	42,822	42,822	42,822	42,822	42,822	42,822	42,822
#RTTC	524,701	568,901	565,792	573,023	568,412	572,193	566,225	566,448
#RTEC+	492	485	441	409	360	316	341	294
%RTEC+	0.09%	0.09%	0.08%	0.07%	0.06%	0.06%	0.06%	0.05%
Ave @ 2 years	0.09%		0.07%		0.06%		0.06%	
Relative difference		-16.6%		-20.6%		-5.4%		
Overall Difference	-37.4%							

EPA also broke out the assessed total coliform and *E. coli* detection rates for disinfecting and undisinfected ground water systems. As indicated in Exhibit 6-10 and Exhibit 6-11, both total coliform detection rates and *E. coli* detection rates are apparently 2-3 times higher among undisinfected systems than among disinfecting systems. Messner et al, 2017 reported that, for small undisinfected ground water systems, five percent of total coliform detections were *E. coli* positive in all system sizes and types.

At disinfecting ground water systems, total coliform detection rates decreased after the GWR rule implementation and in the periods that followed. A small apparent increase (5 percent) in total coliform detection rates was observed in undisinfected ground water systems after the initial implementation of the GWR (which to some extent could be attributable to background yearly variation) and then there was an apparent decreasing trend after the Sanitary Survey completion and the RTCR implementation. Overall, Exhibit 6-10 shows an apparent decrease of total coliform detection rates.

Exhibit 6-10. Changes of Percent RTTC+ Rates among Disinfecting and Undisinfected Systems (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
#Disinfecting Systems	20,067	18,740	21,494	20,091	21,384	20,789	22,729	22,769
#RTTC	355,296	374,135	411,575	399,646	417,688	415,336	421,189	421,961
#RTTC+	4,656	4,591	4,817	4,167	3,999	4,322	3,971	3,885
%RTTC+	1.31%	1.23%	1.17%	1.04%	0.96%	1.04%	0.94%	0.92%
Ave @ 2 years	1.27%		1.11%		1.00%		0.93%	
Relative difference		-12.79%		-9.72%		-6.73%		
Overall Difference	-26.56%							
Year	2007	2008	2010	2011	2014	2015	2018	2019
#Undisinfected Systems	22,755	24,082	21,328	22,731	21,438	22,033	20,093	20,053
#RTTC	169,405	194,766	154,217	173,377	150,724	156,857	145,036	144,487
#RTTC+	6,259	6,621	5,934	6,247	5,244	5,338	3,897	3,806
%RTTC+	3.69%	3.40%	3.85%	3.60%	3.48%	3.40%	2.69%	2.63%

Year	2007	2008	2010	2011	2014	2015	2018	2019
Ave @ 2 years	3.55% (Right before GWR)		3.73% (Right after GWR)		3.44% (Right after completing SS)		2.66% (Few years after RTCR)	
Relative difference		5.03%		-7.63%		-22.68%		
Overall Difference	-24.99%							

Exhibit 6-11 presents changes to *E. coli* positive rates among disinfecting and undisinfected systems. At disinfecting systems, *E. coli* detection rates apparently decreased after GWR implementation and in the period that followed, and then apparently increased a few years after RTCR implementation. An apparent decrease of *E. coli* detection rate was observed in undisinfected systems across the four periods. As noted earlier, *E. coli* records that did not have a corresponding total coliform positive record were not excluded from the reduced dataset. The total number of *E. coli* samples at common systems across the 8 years where there was no corresponding total coliform positive record was approximately 0.20 percent of the total. Thus, not excluding these *E. coli* records will probably not have a significant effect on the observed trends.

Exhibit 6-11. Changes of Percent RTEC+ Rates among Disinfecting and Undisinfected Systems ("Common Systems" with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
#Disinfecting Systems	20,067	18,740	21,494	20,091	21,384	20,789	22,729	22,769
#RTTC	355,296	374,135	411,575	399,646	417,688	415,336	421,189	421,961
#RTEC+	217	217	221	186	158	148	181	172
%RTEC+	0.06%	0.06%	0.05%	0.05%	0.04%	0.04%	0.04%	0.04%
Ave @ 2 years	0.06%		0.05%		0.04%		0.04%	
Relative difference		-15.82%		-26.71%		13.99%		
Overall Difference	-29.68%							
Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Non Disinfecting Systems	22,755	24,082	21,328	22,731	21,438	22,033	20,093	20,053
#RTTC	169,405	194,766	154,217	173,377	150,724	156,857	145,036	144,487
#RTEC+	275	268	220	223	202	168	160	122
%RTEC+	0.16%	0.14%	0.14%	0.13%	0.13%	0.11%	0.11%	0.08%
Ave @ 2 years	0.15%		0.14%		0.12%		0.10%	
Relative difference		-9.55%		-11.12%		-19.23%		
Overall Difference	-35.07%							

EPA assessed the annual average percent of total coliform positives and *E. coli* positives for three groups of systems: all PWSs, all disinfecting ground water systems, and all undisinfected ground water systems. Exhibit 6-12 presents a summary of the results for total coliforms. Similar to the findings in Exhibit 6-8 and Exhibit 6-10 above, there is generally an apparent declining trend after each regulatory milestone, with the exception of the undisinfected ground water systems from 2007-2010. Overall, there was an apparent reduction of the percent total coliform positive rate after the collective implementation of the GWR and RTCR. For *E. coli* positives, as shown in Exhibit 6-13 (in part summarizing results presented in Exhibit 6-11), EPA observed an apparent declining trend after each of regulatory milestones except the last. Overall, there was more than an apparent 35 percent reduction in *E. coli* positives in undisinfected ground water systems after implementation of GWR and RTCR. Because the total number of *E. coli* detections is small, there is high uncertainty associated with apparent changes over time. These apparent changes will be examined further, using 95 percent confidence intervals, in the subsection that follows, titled "Assessing the Changes in Total Coliform and *E. coli* Occurrence with All Available Records."

Exhibit 6-12. Summary of Changes of Percent RTTC+ Rates by System Categories (All Public Water Systems, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-8.8%		-8.5%		-16.3%		
	Overall Change	-30.2%							
Disinfecting GW systems	Relative Change		-12.8%		-9.7%		-6.7%		
	Overall Change	-26.6%							
Undisinfected GW Systems	Relative Change		5.0%		-7.6%		-22.7%		
	Overall Change	-25.0%							

Exhibit 6-13. Summary of Changes of Percent RTEC+ Rates by System Categories (All Public Water Systems, Disinfecting Ground Water Systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-19.2%		-10.1%		2.8%		
	Overall Change	-25.3%							
Disinfecting	Relative Change		-15.8%		-26.7%		14.0%		
	Overall Change	-29.7%							
Undisinfected GW Systems	Relative Change		-9.6%		-11.1%		-19.2%		
	Overall Change	-35.1%							

Assessing the Changes in Total Coliform and E. coli Occurrence with All Available Records

To evaluate the degree to which the occurrence of total coliform positives and *E. coli* positives may have changed from year to year using undisinfected ground water systems, EPA utilized 95 percent confidence intervals[2]. If the confidence interval for one year and the confidence interval for another year do not overlap, one can conclude with 95 percent certainty that there was an actual decline (or increase) between the two years (i.e., the difference is "statistically

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[2] Upon considering various uncertainties in the underlying data such as weather, state policies, changes made by systems, incomplete census of systems, etc. EPA utilized a 95 percent confidence interval analysis.

significant”). EPA notes the following caveats about this analysis: Unlike analyses presented earlier in the document that involved a “90% completeness” filter, all data from undisinfected ground water systems were included in this analysis without any exclusions. The number of systems with total coliform / *E. coli* records and, thus, the number of routine total coliform and *E. coli* records, varied from year to year. The number of states included in each year also varied. Furthermore, systems may have different degrees of completeness with respect to rule requirements from one month to the next.

Exhibit 6-14 presents the annual total coliform positive rates for undisinfected ground water systems from 2012 through 2019. There is a confidence interval overlap between each pair of consecutive years, so the analysis does not show a statistically significant change from year to year. But over the entire period (comparing 2012 figures to 2019 figures), there is a statistically significant decline in total coliform positive results. The period of the statistically significant decline in total coliform positives encompasses the period of GWR implementation (2012-2016) and RTCR implementation (2014-2019).

Exhibit 6-24 and Exhibit 6-25 compare 2011 and 2019 total coliform detections in undisinfected systems using Bayesian MCMC statistical models. In contrast to the statistical test described above, the statistical model results (using the maximum likelihood estimate) do not support the apparent conclusions from the summary statistics. Rather, the model results show that in general, depending on system size and type, the smallest systems (large numbers of systems with maximum likelihood estimates that have low uncertainty) have small increases or decreases between the two years analyzed. Observing results using the two differing definitions for undisinfected systems, it appears that the definition of an undisinfected system has a greater effect on the maximum likelihood estimate than the comparison between years.

Exhibit 6-15 presents the annual *E. coli* positive rates for undisinfected ground water systems from 2012 through 2019. As with the total coliform results, there is a confidence interval overlap between each pair of consecutive years, so the analysis does not show a statistically significant change from year to year. Furthermore, even the first and last year of the *E. coli* positive rates data have overlapping confidence intervals, so no conclusions can be drawn with statistical significance about trends in *E. coli* positive rates over the span of years from 2012 to 2019.

Exhibit 6-14. Total Coliform Positive Rates for Undisinfected Ground Water Systems (2012-2019)

Year	RTTC+	RTTC	%RTTC+	STD	CI Lower	CI Upper
2012	2,568	73,859	3.48%	0.000674	3.345%	3.609%
2013	2,619	74,610	3.51%	0.000674	3.378%	3.642%
2014	2,672	74,527	3.59%	0.000681	3.452%	3.719%
2015	2,688	75,389	3.57%	0.000675	3.433%	3.698%
2016	2,347	75,386	3.11%	0.000633	2.989%	3.237%
2017	2,298	76,560	3.00%	0.000617	2.881%	3.122%

Year	RTTC+	RTTC	%RTTC+	STD	CI Lower	CI Upper
2018	2,321	78,860	2.94%	0.000602	2.825%	3.061%
2019	2,285	78,970	2.89%	0.000596	2.777%	3.010%

Notes:
RTTC+ = Number of systems reporting positive total coliform
RTTC = Number of systems reporting routine total coliform samples
%RTTC+ = Percent of systems reporting positive total coliform
STD = Standard deviation
CI Lower Bound = Confidence interval lower bound
CI Upper Bound = Confidence interval upper bound

Exhibit 6-15. *E. coli* Positive Rates for Undisinfected Ground Water Systems (2012-2019)

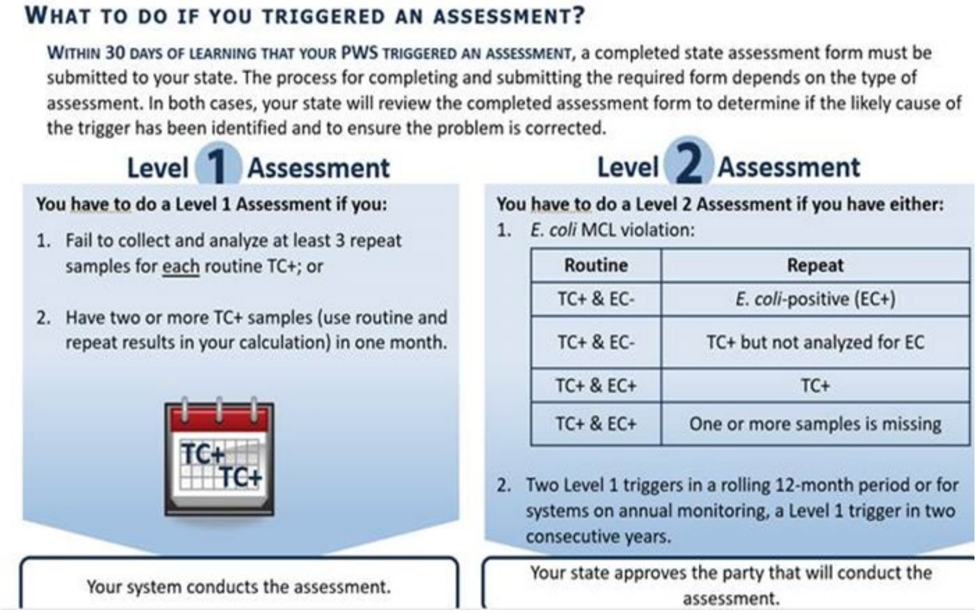
Year	RTEC+	RTTC	%RTEC+	STD	CI Lower	CI Upper
2012	75	73,859	0.10%	0.000117	0.079%	0.125%
2013	75	74,610	0.10%	0.000116	0.078%	0.123%
2014	112	74,527	0.15%	0.000142	0.122%	0.178%
2015	99	75,389	0.13%	0.000132	0.105%	0.157%
2016	81	75,386	0.11%	0.000119	0.084%	0.131%
2017	75	76,560	0.10%	0.000113	0.076%	0.120%
2018	108	78,860	0.14%	0.000132	0.111%	0.163%
2019	83	78,970	0.11%	0.000115	0.083%	0.128%

Notes:
RTTC+ = Number of systems reporting positive total coliform
RTTC = Number of systems reporting routine total coliform samples
%RTTC+ = Percent of systems reporting positive total coliform
STD = Standard deviation
CI Lower Bound = Confidence interval lower bound
CI Upper Bound = Confidence interval upper bound

6.2.2 Analytical Results of Level 1 and Level 2 Assessments Under Revised Total Coliform Rule

Under the RTCR, a PWS whose sampling results show that it is vulnerable to microbial contamination is required to conduct an assessment and take corrective action. They must identify and correct any sanitary defects in the distribution system or treatment processes. Under the RTCR, EPA uses total coliform occurrence as an indicator of the microbial integrity of the distribution system, and *E. coli* as an indicator of the presence of fecal contamination. Exhibit 6-16 presents a summary of the assessment process if a Level 1 or Level 2 Assessment is triggered.

Exhibit 6-16. Summary of Level 1 and Level 2 Assessment Processes



WHAT TO DO IF YOU TRIGGERED AN ASSESSMENT?

WITHIN 30 DAYS OF LEARNING THAT YOUR PWS TRIGGERED AN ASSESSMENT, a completed state assessment form must be submitted to your state. The process for completing and submitting the required form depends on the type of assessment. In both cases, your state will review the completed assessment form to determine if the likely cause of the trigger has been identified and to ensure the problem is corrected.

Level 1 Assessment

You have to do a Level 1 Assessment if you:

1. Fail to collect and analyze at least 3 repeat samples for each routine TC+; or
2. Have two or more TC+ samples (use routine and repeat results in your calculation) in one month.

Your system conducts the assessment.

Level 2 Assessment

You have to do a Level 2 Assessment if you have either:

1. *E. coli* MCL violation:

Routine	Repeat
TC+ & EC-	*E. coli*-positive (EC+)
TC+ & EC-	TC+ but not analyzed for EC
TC+ & EC+	TC+
TC+ & EC+	One or more samples is missing

2. Two Level 1 triggers in a rolling 12-month period or for systems on annual monitoring, a Level 1 trigger in two consecutive years.

Your state approves the party that will conduct the assessment.

Further details about Level 1 and Level 2 assessments are found in Section 7.3.1 and Appendix C.

To evaluate the impact of Level 1 and Level 2 assessments on total coliform positive / *E. coli* positive rates, EPA compared total coliform positive rates before the completion of Level 1 and Level 2 assessments and after the completion of corrective actions. EPA utilized RTCR Level 1 and Level 2 Assessment “event milestone” information available from SDWIS for the years 2016 through 2019 (i.e., after RTCR became effective) for systems with available total coliform and *E. coli* data from the SYR4 ICR dataset. EPA recognized that systems’ RTCR compliance monitoring schedules may be monthly, quarterly, biannual, or yearly, and that most of the systems with the relevant data records in SYR4 ICR are systems with monthly compliance monitoring schedules. Thus, the analysis described here was focused on these systems. Exhibit 6-17 presents counts of routine total coliform and *E. coli* samples from systems with Level 1 or Level 2 Assessments, counts of total coliform positive and *E. coli* positive routine samples, and the total coliform and *E. coli* positivity rates, for the months before and after a Level 1 or 2 assessment. Exhibit 6-17 also presents the percent reduction in the total coliform positive rate from the two months before the Level 1 or Level 2 Assessment to the two months after the Level 1 or Level 2 Assessment. The analysis makes use of 2-month averages, to reduce the effect of month-to-month background variability.

The analysis shows a remarkable drop in total coliform and *E. coli* levels after corrective actions were implemented. Overall, there was more than an 80 percent decrease in both total coliform positives and *E. coli* positives after completion of RTCR assessments at systems having a monthly monitoring schedule. It may be noted that some systems in some states could take longer than two months to complete the corrective actions, and in such situations the positivity rates two months after the assessment would represent the period before corrective actions were fully completed. Thus, the findings could be different from state to state.

Exhibit 6-17. Total Coliform and *E. coli* Positivity Rate for Months Before and After Level 1 or 2 Assessment (90% Completeness Applied[1])

Two months before L1 or L2 (e.g., April & May for the Assessment month of June)			Two months after L1 or L2 (e.g., August & Sept.)			%Reduction in %total coliform positives (based on 2-month averages)
#RTTC	**#RTTC+**	**%RTTC+**	**#RTTC**	**#RTTC+**	**%RTTC+**	
69,333	15,023	21.67%	63,064	2,175	3.45%	84.08%
#RTTC	**#RTEC+**	**%RTEC+**	**#RTTC**	**#RTEC+**	**%RTEC+**	**%Reduction in %*E. coli* positives (based on 2-month averages)**
69,333	656	0.95%	63,064	77	0.12%	87.10%

[1] For this analysis, EPA only included systems with at least 90% completeness in their total coliform sampling results for the "months before" and the "months after," meaning included systems must have collected at least 90% of their required monthly total coliform samples.

Notes:
L1 = Level 1 Assessment
L2 = Level 2 Assessment
#RTTC = number of systems reporting routine total coliform samples
#RTTC+ / #RTEC+ = number of systems reporting positive total coliform / *E. coli* samples
%RTTC+ / %RTEC+ = percent of systems reporting positive total coliform / *E. coli* samples

6.3 Microbial Contaminants in Raw Water under Long-Term 2 Enhanced Surface Water Treatment Rule

Under the LT2, systems monitored their water sources to determine whether additional treatment is needed for further removal of *Cryptosporidium*. This monitoring included an initial two years of monthly sampling for *Cryptosporidium* in source water. To reduce monitoring costs, small, filtered water systems (serving fewer than 10,000 people) first monitored for *E. coli*—a bacterium that is less expensive to analyze for than *Cryptosporidium*—and then monitored for *Cryptosporidium* if their *E. coli* results exceeded specified concentration levels. For more information on source water monitoring provision, refer to USEPA (2006c).

6.3.1 Occurrence of *Cryptosporidium* in Source Water

EPA conducted an analysis of *Cryptosporidium* occurrence using compliance monitoring data from SYR4 that reflect Round 2 monitoring results under LT2. Among records of raw water samples (routine only) from surface water CWSs, about 9 percent reported that *Cryptosporidium* was present. However, none of those 9 percent of records that reported the presence of *Cryptosporidium* provided a concentration value. In the SYR4 dataset more broadly, fewer than 0.3 percent of the 19,000 *Cryptosporidium* monitoring records provided concentration levels with units of oocysts/L.

EPA examined available data to assess the accuracy of predictions for binning changes for a group of systems from LT2 Round 1 to Round 2 monitoring. Under SYR3, Round 1 monitoring data were available from the Data Collection and Tracking System (DCTS); these data are described in the *Six-Year Review 3 Technical Support Document for Long-Term 2 Enhanced Surface Water Treatment Rule* (USEPA, 2016b). EPA conducted a comparison of data from systems with SYR4 *Cryptosporidium* binning information to data from systems with SYR3 *Cryptosporidium* binning information from the DCTS. Note that the DCTS data were limited to systems identified as being in Bin 2. The bin classifications are described in Exhibit 6-18.

Exhibit 6-18. Bin Classification for Filtered Systems

Mean *Cryptosporidium* Concentration (oocysts/L)	**Bin Classification**	**Additional *Cryptosporidium* Treatment Required**			**Alternative Filtration**
		Conventional Filtration	**Direct Filtration**	**Slow Sand or Diatomaceous Earth**	
< 0.075 oocysts/L	Bin 1	No additional treatment	No additional treatment	No additional treatment	No additional treatment
≥ 0.075 to < 1.0 oocysts/L	Bin 2	1-log treatment	1.5-log treatment	1-log treatment	(1)
≥1.0 to < 3.0 oocysts/L	Bin 3	2-log treatment	2.5-log treatment	2-log treatment	(2)
≥ 3.0 oocysts/L	Bin 4	2.5-log treatment	3-log treatment	2.5-log treatment	(3)

[1] As determined by the state (or other primacy agency) such that the removal/inactivation > 4.0-log.
[2] As determined by the state (or other primacy agency) such that the removal/inactivation > 5.0-log.
[3] As determined by the state (or other primacy agency) such that the removal/inactivation > 5.5-log.

Data provided in response to the SYR4 ICR showed that there were 309 systems serving >10,000 people that provided binning results based on *Cryptosporidium* monitoring (presumed Round 2 monitoring). Thirty-two (32) of those systems had at least some records in Bin 2. Only one of those 32 systems appeared in the SYR3 “DCTS Binning Report” file. EPA determined that approximately 10 percent of the systems serving >10,000 people (i.e., 31 out of 309 systems) would potentially move to an action bin (i.e., Bin 2, Bin 3, or Bin 4) based on Round 2 data. Under this analysis, EPA determined that the percentage of PWSs moving to an action bin based on *Cryptosporidium* monitoring in Round 2 was not significantly higher than the 8 percent of systems predicted to have moved to an action bin during the previous LT2 review.

Note that EPA did not examine *E. coli* co-occurrence with *Cryptosporidium* because of low positive rates.

6.4 Analyses Involving Undisinfected Ground Water Systems

Similar to SYR3, EPA conducted an analysis to evaluate the possible differences in coliform occurrence between disinfecting and undisinfected ground water systems as part of SYR4.

6.4.1 Approaches to Identify Undisinfected Ground Water Systems

For the SYR3 data analysis, disinfecting systems were defined in the following manner: Of systems with SYR3 total coliform data that were evaluated, any of those systems with an indication of disinfecting per the SYR3 treatment data were considered to be disinfecting. Remaining systems with free or total chlorine residual concentrations greater than 0.1 mg/L were also considered to be disinfecting. Remaining systems were considered to be undisinfected. This classification approach to differentiate systems can be called the "SYR3 definition of disinfecting." See Appendix D of USEPA (2016a) for more details.

For the SYR4 ICR data analysis, a revised classification method was used to identify disinfecting and undisinfected systems, as described in this section. This classification approach to differentiate systems can be called the "SYR4 definition of disinfecting."

In SYR3, the focus was on distinguishing different levels of disinfection rather than specifically identifying undisinfected systems. The purpose of the SYR3 approach was to understand if there was an opportunity to balance disinfection byproduct risk with pathogen control with respect to disinfectant residual level changes.

During the SYR4 process, EPA attempted to maximize the use of the available SYR4 ICR data records for determining the disinfection status of systems included in the SYR4 ICR datasets by making logical inferences from information pertaining to regulatory requirements. Exhibit 6-19 and Exhibit 6-20 illustrate the steps taken to achieve this purpose, using as an example the final year (2019) of data records. The considerations involved are explained in the paragraphs that follow.

Since the routine disinfectant by-product monitoring provisions under the Stage 1 and Stage 2 DBPRs apply to all of CWSs and NTNCWSs (including both GW and SW systems) that use chemical disinfectants, two major steps were taken (See Exhibit 6-19): First, EPA considered all of those GW CWSs and NTNCWSs reported any monitoring records of DBPs (i.e., TTHM/HAA5) in 2019 as disinfecting GW systems (assuming that the sole use of non-chemical disinfectants such UV is rare). Second, among systems without any DBP records, EPA considered any with disinfectant residual records to be disinfecting GW systems as well. With this systematic approach, EPA was able to quantify the number of disinfecting versus undisinfected GW systems in the SYR3 and SYR4 ICR datasets for the individual years[3] shown in Exhibit 6-10 and evaluate their yearly trends. (Note: Systems with no SYR3 or SYR4 data could not be used in any of the analyses to evaluate trends in total coliform / *E. coli* occurrence; however, systems could be classified as disinfecting or undisinfected based on SDWIS treatment information (or lack thereof) for overall national counts of disinfecting systems, as shown in the lower branch of the flowchart.)

Exhibit 6-20 shows how the process was adapted for transient non-community water systems (TNCWSs). Since the routine disinfectant by-product monitoring provisions of the Stage 1 and Stage 2 DBPRs do not apply to all TNCWSs (including both GW and SW systems) that use chemical disinfectants (only TNCWSs using chlorine dioxide are required to monitor DBPs), the step 1 described above was skipped.

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[3] The disinfection status of systems was identified separately for each year of data to enable year-to-year trends. Exhibit 6-19 and Exhibit 6-20 show the process using the calendar year 2019 as an example.

There were differences in the two definitions of undisinfected ground water systems considered for use by EPA at different times. The SYR3 approach was included to enable a comparison with the analytical results presented on the Messner et al. (2017) paper. The SYR4 approach focuses on the inclusion of DBP data as a primary indicator of disinfection, incorporates disinfectant residual records, and treatment information from SDWIS. Additionally, the data used for SYR4 ICR data analysis contained non-SDWIS state data while the SYR3 assessment in Messner et al. (2017) did not. These differences may account for why the SYR4 approach identifies more undisinfected ground water systems overall than are identified when using the SYR3 approach.

Exhibit 6-19. Process to Identify Community Water Systems and Non-Transient Non-Community Water Systems that are Undisinfected Ground Water Systems (Using Year 2019 as Example)

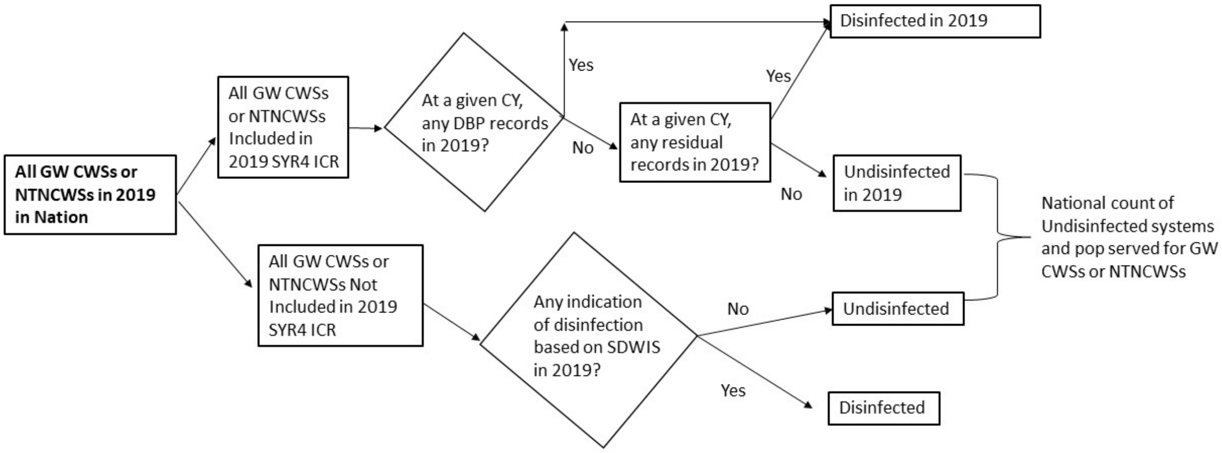
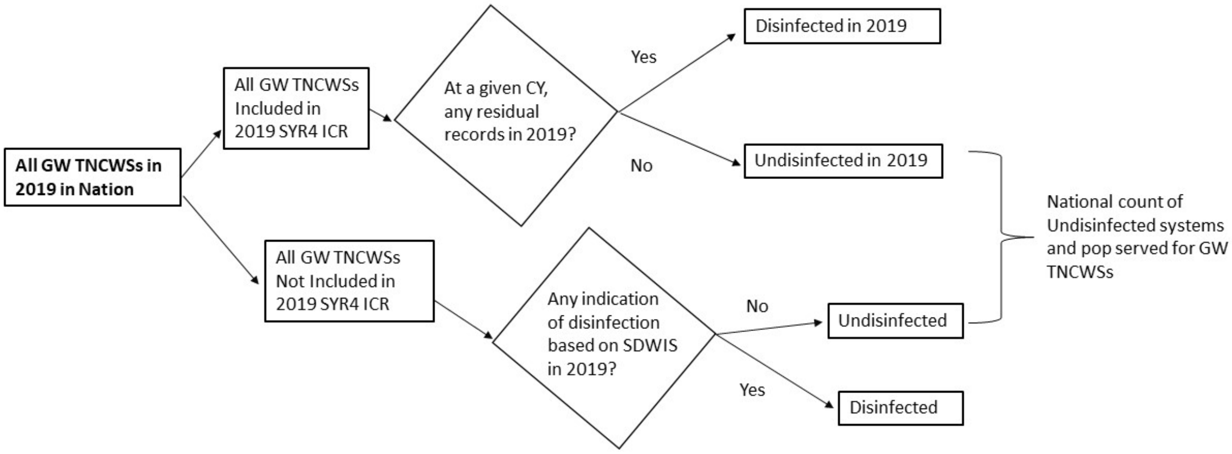


Exhibit 6-20. Process to Identify Transient Non-Community Water Systems that are Undisinfected Ground Water Systems (Using Year 2019 as Example)



6.4.2 Modeling Total Coliform Positivity Rates

6.4.2.1 Statistical Techniques

The analyses of total coliform / *E. coli* data presented above involved the use of summary statistics to compute positivity rates. This approach (which is generally referred to as the "frequentist" or "classical" statistical approach) has the advantage of being relatively straightforward computationally. That is, the positivity rate is simply a proportion calculated as the number of positives samples observed divided by the total number of samples taken. While some characterization of uncertainty around that proportion can be obtained by computing confidence intervals, the correct interpretation of those confidence intervals can be confusing in that they do not conform to the common sense interpretation of confidence intervals, namely that the "true" value of the proportion has a specified likelihood (e.g., 95%) of falling within the confidence interval.[4]

An alternative statistical approach for obtaining estimates of positivity rates from data such as the SYR4 data set is a Bayesian analysis using Markov Chain Monte Carlo (MCMC) simulation methods. While computationally more involved than the summary statistics approach, the Bayesian MCMC approach has the advantage of providing multiple estimates of the proportion of positive samples, from which one can compute an overall mean estimate and also "credible intervals" around that mean estimate to characterize uncertainty. The Bayesian credible intervals also have an advantage over the frequentist confidence intervals in that they can be interpreted to infer that the "true" value does have a specified likelihood (e.g., 95%) of falling within the range of the interval.

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[4] The correct interpretation of a frequentist confidence interval is that if one were to perform multiple sampling of the same number of samples from that population, then 95% of those confidence intervals would include the true value.

A Bayesian analysis was conducted by Messner et al. (2017) using data from SYR3; this work serves as a model of how such an analysis could be performed to better inform the goals of the SYR4 microbial data analysis (i.e., to evaluate the possible differences in total coliform occurrence between disinfecting and undisinfected ground water systems, to assess the potential impact of the GWR and RTCR on the occurrence of microbial indicators, and to characterize the systems with the highest potential for public health improvements).

Messner et al. (2017) used the Bayesian MCMC method to estimate the positivity rate of total coliform detections in routine sampling at small (serving $\leq$4,100 people) undisinfected ground water systems for the year 2011, using data from SYR3. That Bayesian MCMC analysis involved the estimation of parameters for beta distributions from which the mean positivity rates could be derived. Uncertainty around those mean estimates was also obtained and displayed graphically as scatter plots around those mean estimates (see Exhibits F.2 – F.5 in Appendix F from USEPA (2016a)). Similarly, an expanded Bayesian MCMC analysis could be conducted using SYR4 data to more specifically address the three goals of SYR4 microbial data analysis stated in the preceding paragraph.

6.4.2.2 Markov Chain Monte Carlo Modeling Results

Systems that use undisinfected ground water may benefit the most from public health improvements due to the lack of any disinfection barrier. As part of the data analysis conducted under SYR3, routine total coliform / *E. coli* sample data from undisinfected small ground water systems were analyzed to characterize the PWSs with high total coliform detection rates (Messner et al., 2017). For SYR4, this analysis was repeated using data from the SYR4 ICR. The goal was to investigate patterns and differences in the total coliform / *E. coli* positivity rates of undisinfected small ground water systems in the SYR3 and SYR4 ICR datasets. The results section below first presents the modeling output from the SYR3 analysis as an introduction to the format of the output and then describes the results gathered from the analysis performed under the SYR4 effort as well as a comparison of results using differing definitions (flow charts) for identifying undisinfected systems in 2011 and 2019 data

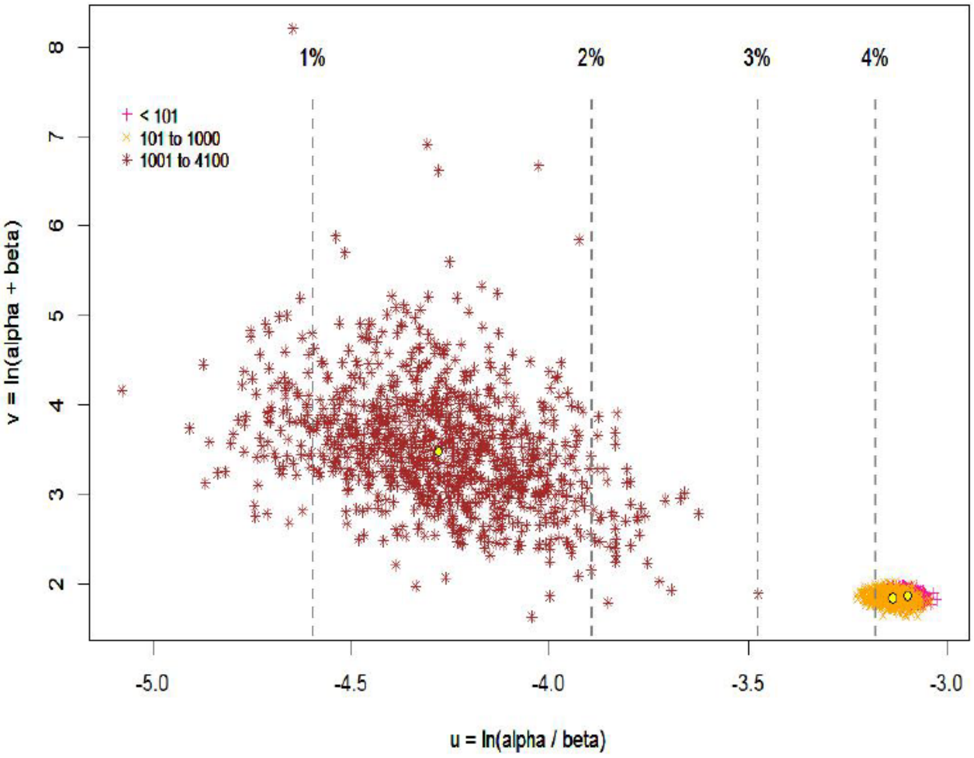
Data Analysis

Limited total coliform data for the large number of small PWSs taking monthly or quarterly total coliform samples are available from the SYR4 ICR. This makes it challenging to precisely estimate the detection rate at a given system. Under SYR3, EPA used a Bayesian statistical analysis approach to estimate mean total coliform detection rates. The probability distribution was estimated using a likelihood function of the available data. One advantage of using the Bayesian approach to determine the mean total coliform detection rate with Markov Chain Monte Carlo (MCMC) simulations based on the available data is that the mean total coliform positive detection rates of the different PWS groups being modeled can be compared without the necessity of having identical sample sizes or common systems when comparing between different years of the same system population served sizes and types. A more detailed explanation of the MCMC modeling approach is outlined in Appendix F of USEPA (2016a).

Messner et al. (2017) analyzed 2011 data from approximately 38,000 small (serving fewer than 4,101 individuals) undisinfected public water systems. Their statistical modeling results showed that the smallest undisinfected systems have significantly higher total coliform detection rates, with low uncertainty in the estimate. Exhibit 6-22 shows, from Messner et al. 2017, the total coliform detection rates for the three types of undisinfected systems. For the system type with the greatest numbers of undisinfected systems (transient, non-community), the graph is annotated with values to illustrate the total coliform detection magnitude. This annotated curve reports 25% of undisinfected systems had total coliform detection rates of at least 5% (8% of transient systems had total coliform detection rates greater than 15%) (Exhibit 6-22). In this document, EPA calculates that these percentages translate to about 7000 systems having detection rates of 5% or more (Exhibit 6-26 and Exhibit 6-27).

Total coliform positivity rates modeled in Messner et al. (2017) for TNCWSs serving populations of 25-100, 101-1,000, and 1,001-4,100 are shown in Exhibit 6-21. Similar modeling was performed for CWSs and NTNCWSs. Exhibit 6-21 shows results of 10,000 simulations, each providing an estimate of the total coliform detection rate for each of the three population served groups. The maximum likelihood estimate for the total coliform detection rate is shown as a small circle in the center of each of three “clouds” of “star” points. The spread in the “cloud” displays the uncertainty in the maximum likelihood estimate of the total coliform detection rate. Tightly grouped clouds have low uncertainty. The total coliform detection rate fields (e.g. 2%, 3%, 4%) is shown by the vertical dashed lines. Note that the tight clouds almost completely overlap so that the two population size clouds have very similar, low uncertainty, total coliform detection rates.

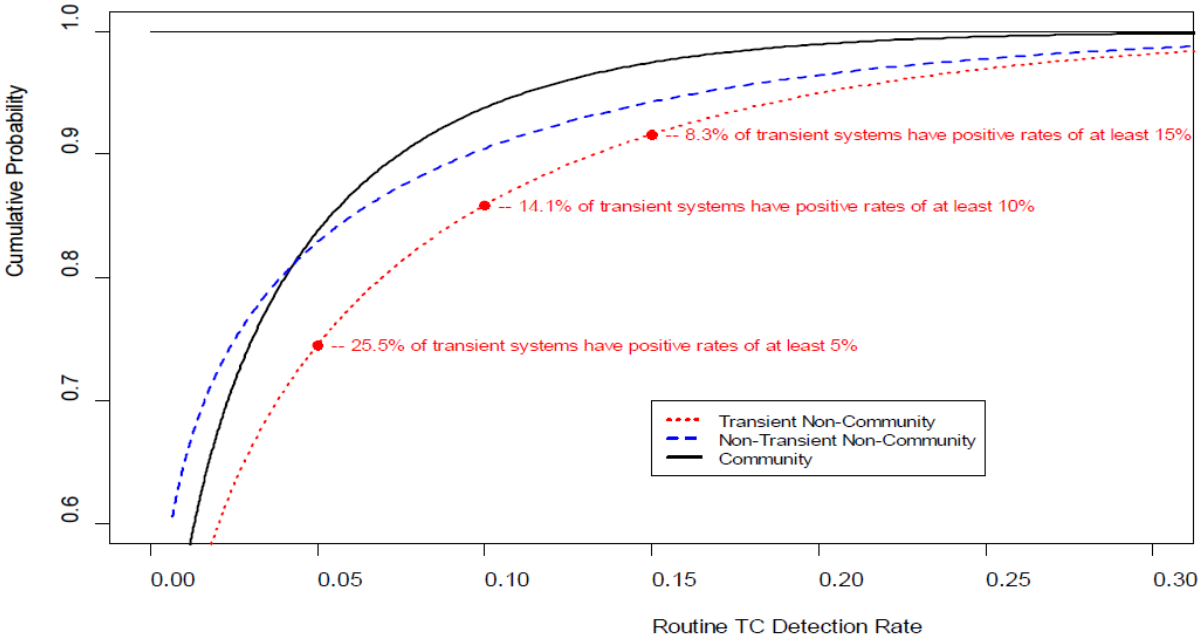
Exhibit 6-21. Markov Chain Monte Carlo Samples Predicting Total Coliform Detection Rates in Small Undisinfected Transient Non-Community Water Systems (2011 Data, Six-Year Review 3 Definition of Disinfecting)



Source: USEPA (2016a)

Using the resulting scatter plot output, EPA determined the mean total coliform positivity rate and the parameters (u and v) that describe the beta distribution associated with the mean. With the mean and beta distribution parameters, EPA derived the probability distribution curve for the detection rates within the beta distribution and thus counts of systems with specific total coliform positive sample rates in routine sampling, as shown for systems in the smallest size category (25-100) in Exhibit 6-22.

Exhibit 6-22. Detection Rate Distribution Functions for Small Public Water Systems (serving 25-100) based on Markov Chain Monte Carlo Sample Mean Parameter Values (2011 Data, Six-Year Review 3 Definition of Disinfecting)



Source: USEPA (2016a)

Definitions of "Disinfecting" Systems

As discussed at the beginning of Chapter 6 and in Section 6.4.1, two definitions of disinfection status have been developed. The process used for determining disinfection status in SYR4 (shown in the flowcharts in Exhibit 6-19 and Exhibit 6-20) is not the same as the process used in SYR3 (USEPA, 2016a).

An example of the difference made by the choice of definition is displayed in Exhibit 6-25, which offers a comparison of 2011 and 2019 total coliform maximum likelihood estimate (MLE) detection rates using the two processes for identifying undisinfected NTNCWS systems. Using 2019 data (i.e., the graphs on the right-hand side of the exhibit), the total coliform MLE for the smallest systems (serving 25-100 people), at the center of the green "cloud," was about 3.2% using the SYR3 definition (the upper graph) and about 2.7% using the SYR4 definition (the lower graph). The differences produced by choice of definition is less marked for other undisinfected PWS categories. The horizontally tight statistical model results in the cloud around the MLE show that there was low uncertainty associated with determining these specific MLE values. Uncertainty is low because the available data included results from a very large number of systems.

To confirm that the SYR4 definition of disinfecting applied to the SYR3 data yields the same results and maintains the conclusions drawn in the Messner et al. (2017) paper, the SYR4 and

SYR3 datasets were classified using both the SYR3 and SYR4 definitions of disinfecting to create four different datasets: SYR3 data using the SYR3 definition of disinfecting, SYR3 data using the SYR4 definition of disinfecting, SYR4 ICR data using the SYR3 definition of disinfecting, and SYR4 ICR data using the SYR4 definition of disinfecting. MCMC modeling was performed on all four variations of the data.

Average Total Coliform Detection Rate Comparison for Different System Sizes

The MCMC modeling was conducted by using as inputs the count of routine total coliform samples and the count of these that were positive. These sample counts were generated separately for several groupings, based on system population size category (systems serving 25-100, 101-1,000, and 1,001-4,100 people), system type (CWSs, TNCWSs, and NTNCWSs), and year (2011-2019). The output of the MCMC simulation modeling is a scatter plot of the simulated mean total coliform positivity rates of the PWS subsets, with the sample mean total coliform positivity rate in the center of the cluster.

Two different versions of the routine total coliform sampling data from 2011 and 2019 were created: one using data from undisinfected systems that conform to the SYR3 definition of disinfecting, and the other using data from undisinfected systems that conform to the SYR4 definition of disinfecting. These results were then compared to confirm that the conclusions drawn in SYR3 do not need to be changed as a result of the additional analyses performed in SYR4.

Accounting for the two different definitions of disinfecting systems and the data available for each year, the MCMC total coliform results shown in Exhibit 6-23 are available.

Exhibit 6-23. List of Data Sources and Disinfection Definition for Markov Chain Monte Carlo Model Runs

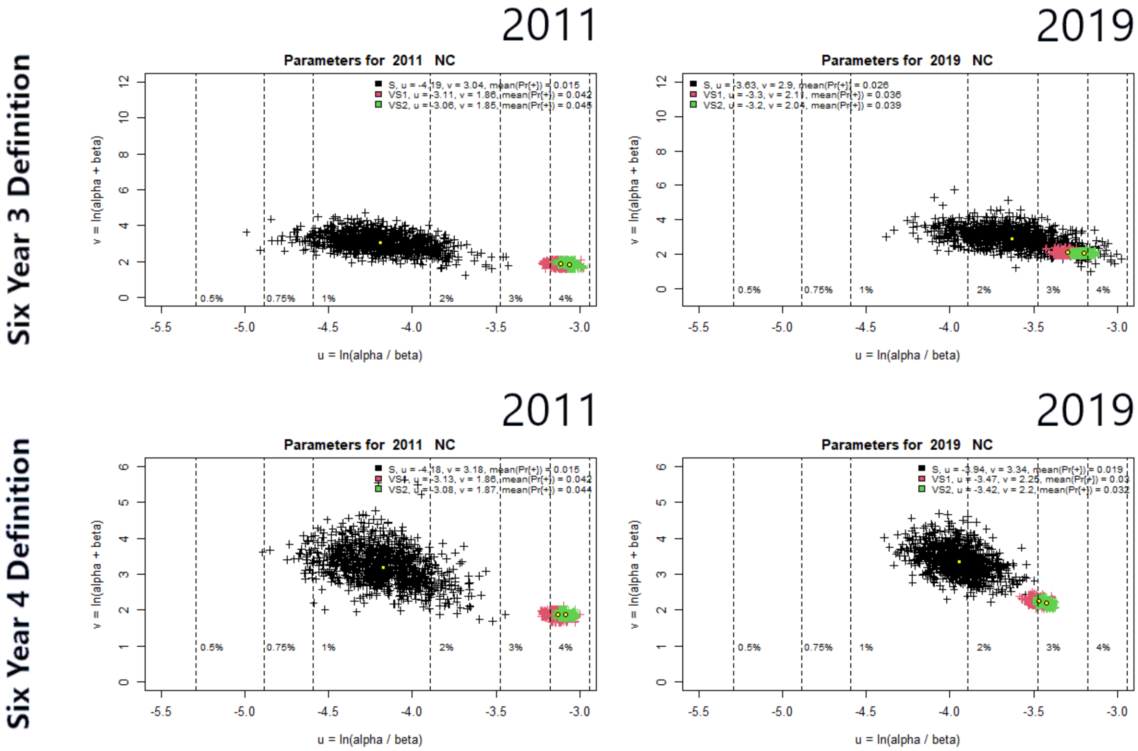
MCMC TC Results for Non-Disinfecting PWSs			
Year(s)	**Definition**	**PWSs**	**Data Source**
2005	RTCR	60,000	EPA RTCR EA, 2012
2011	SYR3	38,000	Messner et al, 2017
2019	SYR3	28,000	Six Year 4, 2023 based on Messner et al, 2017
2011-2019	SYR4	45,000	Six Year 4, 2023

In the scatter plots that follow (Exhibit 6-24 for small undisinfected TNCWs and Exhibit 6-25 for small undisinfected NTNCWSs), the size categories are color-coded: “small” systems (serving 1,001-4,100) are represented by black points, “very small” systems (serving 101-1,000) are represented by pink points, and “very, very small” systems (serving 25-100) are represented by green points. These system sizes are also abbreviated as “S,” “VS1,” and “VS2,” respectively.

Each point shown in the scatter plots is the results from one iteration of the model. The clouds of points show the distribution of the MCMC modeled samples; the larger the spread of the points, the greater the uncertainty. The black clouds are more spread out than the others because there aren’t many systems that fall into this category, so the uncertainty is relatively high. The “S” (black) plots represent a few hundred systems while the “VS1” (pink) and “VS2” (green) plots represent approximately 30,000 systems. The Maximum Likelihood Estimate (MLE) of all simulations for a system group is represented by a yellow dot in the center of the respective cloud of points. The value of the MLE (interpreted as a projected total coliform detection rate) is indicated by the vertical lines in the plot area.

For undisinfected transient-non-community systems (Exhibit 6-24), the modeling projects that “VS2” and “VS1” systems had more than two times higher MLE total coliform positivity rates than the “S” systems in 2011, regardless of definition of “undisinfected” used. Using 2019 data, the MLEs for “S” and for “VS2” and “VS1” are closer together, using both definitions. Under both definitions, the MLE for the “S” systems increased from 2011 to 2019 and the MLEs for the “VS2” and “VS1” systems decreased.

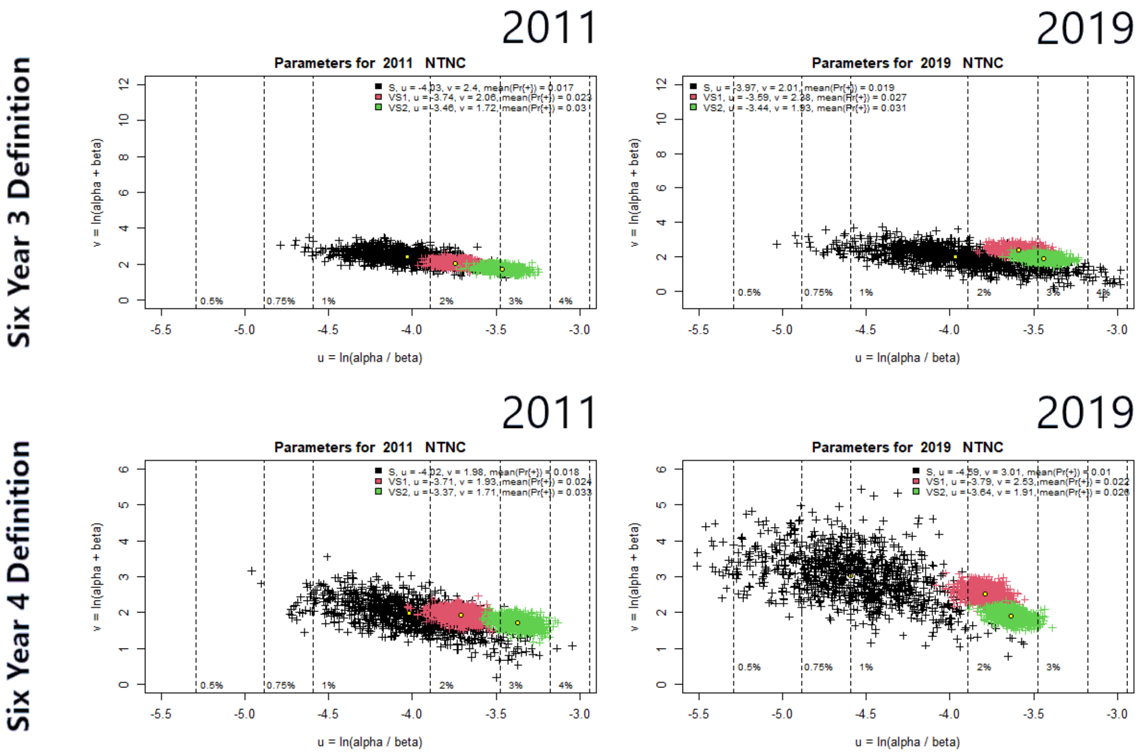
Exhibit 6-24. Maximum Likelihood Estimates of National Total Coliform Occurrence using Six-Year Review 3 and Six-Year Review 4 Definitions for Small Undisinfected Transient Non Community Water Systems



The plots in the top row represent data that were analyzed using the SYR3 definition of "disinfecting" and the plots in the bottom row represent data that were modeled using the SYR4 definition of "disinfecting." The plots on the left use data from 2011 and the plots on the right use data from 2019.

For undisinfected non-transient-non-community systems (Exhibit 6-25), the modeling projects that in 2011 the MLE total coliform positivity rates ranged from slightly under 2% (for "S" systems) to slightly over 3% (for "VS2" systems), with "VS1" systems in between, regardless of the definition of "undisinfected" used. Using 2019 data, "VS2" and "VS1" systems have more than two times higher MLE projected total coliform positivity rates than the "S" systems under the SYR4 definition of disinfecting. Under the SYR3 definition of disinfecting, the 2019 MLEs are closer together, without much change from 2011.

Exhibit 6-25. Maximum Likelihood Estimates of National Total Coliform Occurrence using for Small Undisinfected Non-Transient Non-Community Water Systems



The plots in the top row represent data that were analyzed using the SYR3 definition of "disinfecting" and the plots in the bottom row represent data that were modeled using the SYR4 definition of "disinfecting." The plots on the left use data from 2011 and the plots on the right use data from 2019.

Comparing the MCMC cloud plot outputs using the SYR3 definition of disinfecting (the top row in Exhibit 6-24 and Exhibit 6-25) to the MCMC cloud plot outputs using the SYR4 definition of disinfecting (the bottom row in Exhibit 6-24 and Exhibit 6-25) shows that MLE projected total coliform positivity rates are, on the whole, very similar. EPA finds that the conclusions drawn in the SYR3 analysis (Messner et al., 2017) do not need to be changed as a result of the adoption of a new process for identifying undisinfecting systems developed in SYR4.

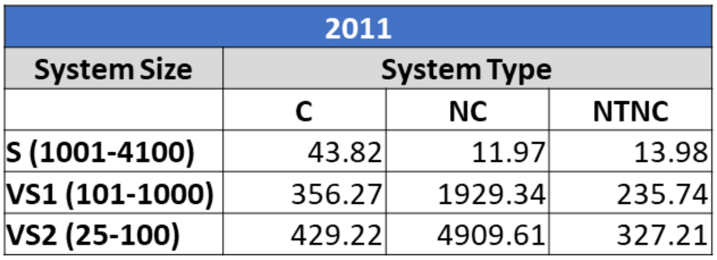
Average total coliform positive rates, as well as high total coliform positive rates in approximately 7,000 vs1 and vs2 undisinfected systems show an imbalance between small and vs1/vs2 systems (Exhibit 6-24 and Exhibit 6-25). In one study, low average total coliform positive rates (e.g., 2.5 percent) in small CWSs are thought to result in a 22 percent acute gastrointestinal illness (AGI) attributable risk to drinking water from norovirus and enterovirus (Borchardt et al., 2012). QMRA based on pathogens in undisinfected Minnesota drinking waters show populations with high infection rates (Stokdyk et al., 2019; Stokdyk et al., 2020; Burch et al., 2022). Note that these Wisconsin and Minnesota papers are representative of national disease burden in so far as undisinfected ground water systems in these two states constitute about 23 percent of undisinfected ground water systems nationally.

High Detection Rate Systems

From the MCMC modeling, the number of systems with total coliform positive sample rates above a given percentage can be estimated. EPA developed counts of systems with total coliform positive rates greater than 5 percent using the beta distributions for each of nine groups, based on system size (“S,” “VS1,” and “VS2”) and system type (abbreviated below as “C” for CWS, “NC” for TNCWS, and “NTNC” for NTNCWS). Comparing results using the 2011 data (Exhibit 6-26) to results using the 2019 data (Exhibit 6-27), EPA finds that there has not been a significant change in the count of systems with total coliform positive rates greater than 5 percent; the projected number of the TNCWSs and NTNCWSs serving less than 1001 persons with total coliform positive rates greater than 5 percent is over 7000 in 2019, only slightly higher than in 2011. The MCMC modeling projects no detection rates higher than 30 percent. These findings were generated using the SYR4 definition of undisinfected systems.

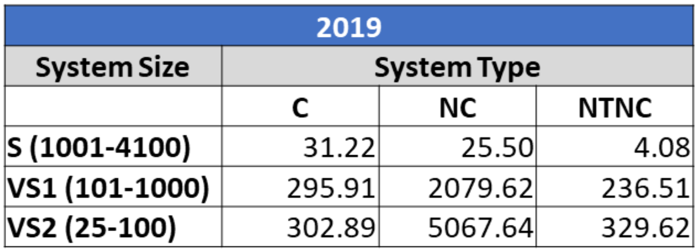
Using the SYR4 ICR dataset, applying the SYR3 definition of undisinfected systems, EPA finds that the counts of systems with total coliform positive rates greater than 5 percent do not change significantly, though increase marginally, between 2011 and 2019.

Exhibit 6-26 Count of Systems by Size and Type with Total Coliform Positive Rates >5% (2011 Data; SYR4 Definition of Disinfecting)



2011			
System Size	**System Type**		
	C	**NC**	**NTNC**
S (1001-4100)	43.82	11.97	13.98
VS1 (101-1000)	356.27	1929.34	235.74
VS2 (25-100)	429.22	4909.61	327.21

Exhibit 6-27. Count of Systems by Size and Type with Total Coliform Positive Rates >5% (2019 Data; SYR4 Definition of Disinfecting)



2019			
System Size	**System Type**		
	C	**NC**	**NTNC**
S (1001-4100)	31.22	25.50	4.08
VS1 (101-1000)	295.91	2079.62	236.51
VS2 (25-100)	302.89	5067.64	329.62

Based on the findings from Messner et al. (2017) and the more recent findings presented in this section, it appears that smaller PWSs (those serving less than 1,000 people) have significantly higher average total coliform detection rates than the larger systems (serving 1,001-4,100). While up to about 7,000 small (VS1 and VS2) undisinfected PWSs (non-transient and transient systems serving less than 1,001 people) have detection rates above 5 percent per year (5 percent total coliform positive rates in a month triggers a Level 1 assessment per the RTCR), the total coliform positive rates of these undisinfected PWSs do not exceed 30 percent per year. Average total coliform positive rates in undisinfected PWSs have remained static or changed slightly (increased or decreased) since 2011.

Caveats

The MCMC modeling was only conducted to evaluate the occurrence of total coliforms. There were insufficient detection data for *E. coli* to support MCMC modeling of that contaminant. In addition, EPA used the SYR4 definition of undisinfected ground water systems rather than the SYR3 definition of undisinfected ground water systems for this recent modeling effort.

6.4.3 Analytical Results of Triggered Source Water Monitoring under Ground Water Rule

Under the Ground Water Rule, if ground water systems that do not provide at least 4-log treatment of viruses are notified of a routine total coliform positive sample collected in compliance with the Revised Total Coliform Rule (RTCR) they must collect at least one source water sample for *E. coli* from each ground water source (well) within 24 hours. This source (well) sample is referred to as a "triggered source water sample." Results in the SYR4 ICR database with a sample type code of "TG" (triggered) were evaluated for their *E. coli* positive rate. Results are shown in Exhibit 6-28 for undisinfected ground water systems. Note that the method used to identify undisinfected ground water systems is described in Section 6.4.1.

Overall, 270 triggered source water samples (1.42 percent) collected from undisinfected ground water systems between 2012 and 2019 were *E. coli* positive. When evaluated by system type, the *E. coli* positive rate was highest in TNCWSs. The rates of *E. coli* positives in CWSs, NTNCWSs, and TNCWSs were 0.57 percent, 0.76 percent, and 1.82 percent, respectively.

EPA broke results down by system size, as shown in Exhibit 6-28. The highest *E. coli* positive rate, and also the highest absolute count of *E. coli* positive samples, were found in the smallest size category (i.e., systems serving ≤100 people). In this size category, 183 *E. coli* positive samples were reported (representing two thirds of *E. coli* positive samples in water source), or 1.57 percent of samples from all systems in that size category.

When the results are broken down by system size and type, they show that in all three system types (CWS, NTNCWS, TNCWS), the highest rate of *E. coli* positives was found in one of the three smallest size categories (≤100, 101-500, 501-1,000). Among all system categories, the highest rate of *E. coli* positives (3.33 percent) was found in TNCWSs serving between 501 and 1000 people.

Exhibit 6-28. Six-Year Review 4 Information Collection Request – Summary of *E. coli* Results in Undisinfected Ground Water Systems Collected as Triggered Source Water Samples (2012-2019)

System Type	Population Served Size Category	Undisinfected GW Systems			
		Number of Systems	Number of *E. coli* Samples	Number *E. coli* positive Samples	Percent *E. coli* positive Samples
Community Water Systems	≤100	614	1,724	13	0.75%
	101-500	458	1,723	14	0.81%
	501-1,000	83	396	0	0.00%
	1,001-4,100	95	693	0	0.00%
	4,101-33,000	14	163	0	0.00%
	33,001-100,000	0	0	0	0.00%
	>100,000	0	0	0	0.00%
	Total GW	**1,264**	**4,699**	**27**	**0.57%**
Non-Transient Non-Community Water Systems	≤100	355	812	7	0.86%
	101-500	283	657	4	0.61%
	501-1,000	58	167	2	1.20%
	1,001-4,100	21	68	0	0.00%
	4,101-33,000	0	0	0	0.00%
	33,001-100,000	0	0	0	0.00%
	>100,000	0	0	0	0.00%
	Total GW	**717**	**1,704**	**13**	**0.76%**
Transient Non-Community Water Systems	≤100	4,348	9,111	163	1.79%
	101-500	1,437	3,092	54	1.75%
	501-1,000	126	300	10	3.33%
	1,001-4,100	48	151	3	1.99%
	4,101-33,000	2	5	0	0.00%
	33,001-100,000	0	0	0	0.00%
	>100,000	0	0	0	0.00%
	Total GW	**5,961**	**12,659**	**230**	**1.82%**
All system types	≤100	5,317	11,647	183	1.57%
	101-500	2,178	5,472	72	1.32%
	501-1,000	267	863	12	1.39%
	1,001-4,100	164	912	3	0.33%
	4,101-33,000	16	168	0	0.00%
	33,001-100,000	0	0	0	0.00%
	>100,000	0	0	0	0.00%
	Total GW	**7,942**	**19,062**	**270**	**1.42%**

Regarding source water *E. coli* detections, there are three different ways to interpret the data: (1) raw *E. coli* detections can represent *E. coli* sampling at seasonal systems, (2) *E. coli* sampling following a total coliform positive from routine sampling under RTCR at systems that do not have distribution systems, or (3) *E. coli* detections that may be follow up samples under RTCR intended to be distribution system samples but are effectively source water samples because the system does not have a distribution system (as is the case at some small systems). Therefore, it is difficult to draw clear conclusions about the outcome of triggered source water monitoring other than to say that even if all the raw *E. coli* detections were a result of the GWR Triggered Source Water requirement, there is a small percent of positive detections and it appears that the vast majority of *E. coli* detections were associated with undisinfected systems serving less than 1,000 people.

6.5 Analyses of Aircraft Drinking Water Rule

The ADWR dataset contains samples from a variety of system sizes, types, and aircraft manufacturer/models. Exhibit 6-29 through Exhibit 6-31 provide a summary of the types of information contained in the ADWR data. (Note that here and throughout this document "system" is used in place of "aircraft public water system").

A count of total coliform samples broken down by system size for the years 2012-2019 is presented in Exhibit 6-29. Approximately 6 percent of the samples were collected from large systems, 53 percent from medium systems, and 41 percent from small systems. Large systems represent 5 percent of the total systems with data; medium and small systems represent 55 percent and 40 percent of the total systems, respectively.

Exhibit 6-29. Count of Total Coliform Samples and Aircraft Systems by Size; 2012-2019

Size	Seat Cap	Count of Samples	Percent of Total Samples	Count of Systems	Percent of Total Systems
Large	>250	7,003	5.93%	415	5.31%
Medium	>130 – 250	62,454	52.90%	4,323	55.31%
Small	<=130	48,613	41.17%	3,078	39.38%
Total		**118,070**	**100.00%**	**7,816**	**100.00%**

A breakdown of total coliform samples by size and aircraft manufacturer/model for the years 2012-2019 is presented in Exhibit 6-30. The average number of samples per size and manufacturer/model category was 1,663, with a median of 94 and a maximum of 28,282. The average number of systems per size and manufacturer/model category was 110, with a median of 13 and a maximum of 1,954.

Exhibit 6-30. Count of Total Coliform Samples and Systems by Size, Aircraft Manufacturer and Model; 2012-2019

Size	Manufacturer, Model	Count of Total Coliform Samples	Count of Systems
Large	AIRBUS, 330	10	1
Large	AIRBUS, A330	1,724	82
Large	AIRBUS, A350	58	13
Large	BOEING, 747	606	42
Large	BOEING, 767	1,271	58
Large	BOEING, 777	3,072	180
Large	BOEING, 787	222	34
Large	BOEING, B747	14	1
Large	DOUG, DC1030	0	0
Large	DOUG, MD11	14	3
Large	EMB, ERJ170	12	1
Medium	AIRBUS, 320	2,028	122
Medium	AIRBUS, 321	20	2
Medium	AIRBUS, A220	12	6
Medium	AIRBUS, A231	10	1
Medium	AIRBUS, A319	1,254	109
Medium	AIRBUS, A320	7,502	521
Medium	AIRBUS, A321	3,448	344
Medium	AIRBUS, A330	306	12
Medium	BOEING, 737	28,282	1,954
Medium	BOEING, 747	30	2
Medium	BOEING, 757	7,288	463
Medium	BOEING, 767	3,825	215
Medium	BOEING, 777	34	1
Medium	BOEING, 787	522	54
Medium	BOEING, B737	468	63
Medium	BOEING, B757	8	1
Medium	BOEING, DC982	4	1
Medium	BOEING, DC983	2	1
Medium	DOUG, DC950	6	1
Medium	DOUG, DC982	946	118
Medium	DOUG, DC983	1,515	131
Medium	DOUG, MD83	280	18
Medium	DOUG, MD88	3,066	118
Medium	DOUG, MD90	482	23
Medium	DOUG, MD9030	1,116	42
Small	ACE, 123	2	1
Small	ACE, 737	4	1
Small	ADAMS, 7897	16	1
Small	AIRBUS, 319	886	55
Small	AIRBUS, A220	48	22
Small	AIRBUS, A318	14	4
Small	AIRBUS, A319	3,934	212
Small	AIRBUS, A321	1,094	116
Small	BOEING, 707	4	1

Size	Manufacturer, Model	Count of Total Coliform Samples	Count of Systems
Small	BOEING, 717	2,601	111
Small	BOEING, 737	1,705	132
Small	BOEING, 757	94	12
Small	BOEING, 767	34	4
Small	BOEING, 777	16	1
Small	BOEING, B737	24	3
Small	BOMBDR, BD100	1,683	71
Small	BOMBDR, CL6002	17,070	933
Small	BOMBDR, CRJ900	0	0
Small	BOMBDR, DHC8402	356	33
Small	BOMBDR, Q400	2	1
Small	CNDAIR, CL6002	1,836	101
Small	DOUG, DC915	4	2
Small	DOUG, DC931	2	1
Small	DOUG, DC932	2	1
Small	DOUG, DC934	2	1
Small	DOUG, DC950	150	20
Small	DOUG, DC983	2	1
Small	DOUG, DC987	8	2
Small	DOUG, MD88	80	3
Small	EMB, 140	20	3
Small	EMB, EMB135	1,039	102
Small	EMB, EMB145	6,182	447
Small	EMB, EMB175	12	3
Small	EMB, ERJ170	8,203	584
Small	EMB, ERJ190	1,484	93
Total		**118,070**	**7,816**

A breakdown of total coliform samples by sample type (e.g., “Routine,” “Repeat”) for the years 2012-2019 is presented in Exhibit 6-31. Approximately 84 percent of the total coliform samples were identified as routine.

Exhibit 6-31. Count of Aircraft Total Coliform Samples by Sample Type; 2012-2019

Sample Type	Number of Total Coliform Samples	Percent of All Total Coliform Samples
Routine	99,677	84.42%
Repeat	94	0.08%
Follow-up	11,001	9.32%
Special	7,298	6.18%
Total	**118,070**	**100.00%**

6.5.1 Occurrence of Total Coliforms and *E. coli* in Aircraft Systems

Exhibit 6-32 through Exhibit 6-35 present summaries of total coliform and *E. coli* occurrence from the ADWR data. Additional tables and information are included in Appendix B.

A breakdown of total coliform and *E. coli* samples and positivity rates by year for the years 2012-2019 is presented in Exhibit 6-32. The overall total coliform positivity rate was 5.46 percent, with a median annual rate of 5.6 percent, a minimum annual rate of 3.8 percent, and a maximum annual rate of 7.0 percent. The annual total coliform positivity rate tended to decrease over the 2012-2019 period.

For *E. coli* samples, two approaches were used to evaluate the positivity rate. One approach used the *E. coli* samples present in the data set, while under the "alternative approach," additional inferred data were added to the analysis: when there was a total coliform "Absent" and no corresponding *E. coli* record, EPA assumed that the missing *E. coli* result was also "Absent." Under the first approach, the average *E. coli* positivity rate was 0.26 percent and the median annual *E. coli* positivity rate was also 0.26 percent, with a minimum of 0.17 percent and a maximum of 0.33 percent. Regardless of approach, the *E. coli* positivity rate generally decreased over the years, but this trend was less pronounced and less consistent than the decreasing trend observed for total coliform positivity rate.

Exhibit 6-32. Count of Aircraft Total Coliform and *E. coli* Samples, and Total Coliform and *E. coli* Positives by Year; 2012-2019

Year	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
	Total Samples	# Positive	%Positive	Total Samples	# Positive	%Positive	Total Samples	# Positive	%Positive
2012	14,707	1,034	7.03%	10,283	33	0.32%	14,702	33	0.22%
2013	14,996	892	5.95%	9,493	31	0.33%	14,996	31	0.21%
2014	15,658	890	5.68%	9,845	17	0.17%	15,656	17	0.11%
2015	15,436	861	5.58%	9,186	24	0.26%	15,433	24	0.16%
2016	15,823	933	5.90%	9,512	30	0.32%	15,823	30	0.19%
2017	13,648	651	4.77%	9,672	21	0.22%	13,647	21	0.15%
2018	13,903	665	4.78%	10,058	26	0.26%	13,900	26	0.19%
2019	13,899	522	3.76%	10,065	19	0.19%	13,899	19	0.14%
Total	**118,070**	**6,448**	**5.46%**	**78,114**	**201**	**0.26%**	**118,056**	**201**	**0.17%**

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

A breakdown of total coliform and *E. coli* sample counts and positivity rates by system size is presented in Exhibit 6-33. For total coliforms, small systems had a positivity rate nearly three times higher than for medium systems and more than four times higher than large systems. A comparison of total coliform positive rates for small aircraft with similar information for small stationary PWSs (transient non-community) shows that both aircraft and stationery PWSs had total coliform positive rates for small systems that were more than two times higher than for larger systems and that total coliform positive rates for both aircraft and stationary PWSs generally declined over the 8-year period (2012–2019) of SYR4 ICR data.

For *E. coli*, using the standard approach, small systems had a positivity rate more than two times higher than that of medium systems and more than four times higher than that of large systems. Using the alternative approach, small systems had a positivity rate more than three times higher than that of medium systems and more than nine times higher than that of large systems.

Exhibit 6-33. Aircraft Total Coliform and *E. coli* Sample Count and Positivity Rate, by Size; 2012-2019

Size	Seat Cap	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
		Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive
L	>250	7,003	138	1.97%	2,569	2	0.08%	7,002	2	0.03%
M	>130 – 250	62,454	1,897	3.04%	37,600	59	0.16%	62,450	59	0.09%
S	<=130	48,613	4,413	9.08%	37,945	140	0.37%	48,604	140	0.29%
Total		**118,070**	**6,448**	**5.46%**	**78,114**	**201**	**0.26%**	**118,056**	**201**	**0.17%**

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

A breakdown of total coliform and *E. coli* sample counts and positivity rates by sample location (galley vs. lavatory) is presented in Exhibit 6-34. Similar information is presented in Appendix B, Exhibit B-4, broken down by year. Note that Exhibit B-4 also includes data for the years 2011, 2020, and 2021. The total coliform positivity rate for lavatory samples was approximately eight times higher than for galley samples. Exhibit B-4 shows that annual total coliform positivity rates for lavatory samples tended to decrease during the period of interest. That trend was not as apparent for total coliform positivity rates in galley samples.

The *E. coli* positivity rate for lavatory samples was five times higher than for galley samples under the standard approach, and more than five times higher under the alternative approach. There was little to no observable decreasing trend in *E. coli* positivity rate in galley or lavatory samples for either set of *E. coli* assumptions during the period of interest.

The total coliform positivity rates for galley samples from small aircraft water systems (1-2 percent, varying by year) were slightly lower than the total coliform positivity rates for small stationary PWSs (2-3 percent in 2019, the most recent year of data on stationary small TNCWSs serving ≤1,000 people).

Exhibit 6-34. Aircraft Total Coliform and *E. coli* Sample Count and Positivity Rate, by Location; 2012-2019

Location	**Total Coliforms**			***E. coli***			***E. coli* (Alternative Approach)[1]**		
	# Samples	**# Total Coliform Positive**	**% Total Coliform Positive**	**# Samples**	**# *E. coli* positive**	**% *E. coli* positive**	**# Samples**	**# *E. coli* positive**	**% *E. coli* positive**
Galley	54,277	635	1.17%	34,512	27	0.08%	54,275	27	0.05%
Lavatory	63,793	5,813	9.11%	43,602	174	0.40%	63,781	174	0.27%
Total	**118,070**	**6,448**	**5.46%**	**78,114**	**201**	**0.26%**	**118,056**	**201**	**0.17%**

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

Exhibit 6-35 presents total coliform and *E. coli* sample counts and positivity rates for follow-up samples, broken down by air carrier. Note that only data for air carriers with at least one follow-up sample are presented. For total coliforms, the average carrier-specific positivity rate for follow-up samples was 9.2 percent. The median was 7.8 percent, with a minimum of 0 percent and a maximum of 34.6 percent. The 90th percentile rate was approximately 21 percent.

For *E. coli*, using the standard approach, the average carrier-specific positivity rate for follow-up samples was 0.28 percent. The median and minimum were both 0 percent, and the maximum was 7.9 percent. The 90th percentile rate was approximately 0.36 percent. Using the alternative approach, the average *E. coli* positivity rate for follow-up samples was 0.07 percent and the 90th percentile rate was approximately 0.34 percent.

Exhibit 6-35. Aircraft Total Coliform and *E. coli* Sample Counts and Positivity Rate for Follow-up Samples, by Air Carrier; 2012-2019

Carrier[1]	**Total Coliforms**			***E. coli***			***E. coli* (Alternative Approach)[2]**		
	# Follow-Up Samples	**# Positive Follow-Up Samples**	**% Positive**	**# Follow-Up Samples**	**# Positive Follow-Up Samples**	**% Positive**	**# Follow-Up Samples**	**# Positive Follow-Up Samples**	**% Positive**
AIR WISCONSIN AIRLINES CORPORATION	394	47	11.93%	393	1	0.25%	394	1	0.25%
AIRTRAN AIRWAYS INC	16	0	0.00%	16	0	0.00%	16	0	0.00%
ALASKA AIRLINES INC	142	11	7.75%	141	0	0.00%	142	0	0.00%
ALLEGIANT AIR LLC	76	5	6.58%	76	0	0.00%	76	0	0.00%
AMERICAN AIRLINES INC	1,412	102	7.22%	1,142	5	0.44%	1,412	5	0.35%
AMERISTAR AIR CARGO INC	8	2	25.00%	8	0	0.00%	8	0	0.00%
ATLAS AIR INC	16	1	6.25%	14	0	0.00%	16	0	0.00%
CHAUTAUQUA AIRLINES INC	158	40	25.32%	134	0	0.00%	158	0	0.00%
COLGAN AIR INC	2	0	0.00%	2	0	0.00%	2	0	0.00%

Carrier[1]	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[2]		
	# Follow-Up Samples	# Positive Follow-Up Samples	% Positive	# Follow-Up Samples	# Positive Follow-Up Samples	% Positive	# Follow-Up Samples	# Positive Follow-Up Samples	% Positive
COMAIR INC	26	9	34.62%	26	0	0.00%	26	0	0.00%
COMPASS AIRLINES LLC	142	34	23.94%	142	0	0.00%	142	0	0.00%
DELTA AIR LINES INC	730	37	5.07%	38	3	7.89%	730	3	0.41%
ENDEAVOR AIR INC	888	113	12.73%	888	3	0.34%	888	3	0.34%
ENVOY AIR INC	424	73	17.22%	366	0	0.00%	424	0	0.00%
EXPRESSJET AIRLINES INC	1,510	287	19.01%	1,510	2	0.13%	1,510	2	0.13%
FALCON AIR EXPRESS INC	2	0	0.00%	2	0	0.00%	2	0	0.00%
FRONTIER AIRLINES INC	30	0	0.00%	30	0	0.00%	30	0	0.00%
GOJET AIRLINES LLC	150	0	0.00%	150	0	0.00%	150	0	0.00%
HAWAIIAN AIRLINES INC	20	0	0.00%	14	0	0.00%	20	0	0.00%
JETBLUE AIRWAYS CORPORATION	290	21	7.24%	290	0	0.00%	290	0	0.00%
MESA AIRLINES INC	176	7	3.98%	167	1	0.60%	176	1	0.57%
MIAMI AIR INTERNATIONAL INC	18	2	11.11%	18	0	0.00%	18	0	0.00%
OMNI AIR INTERNATIONAL INC	8	1	12.50%	8	0	0.00%	8	0	0.00%
PIEDMONT AIRLINES INC	18	0	0.00%	18	0	0.00%	18	0	0.00%
PSA AIRLINES INC	222	26	11.71%	157	0	0.00%	222	0	0.00%
REPUBLIC AIRWAYS INC	294	31	10.54%	150	0	0.00%	294	0	0.00%
SHUTTLE AMERICA CORPORATION	102	14	13.73%	39	0	0.00%	102	0	0.00%
SKYWEST AIRLINES INC	2,407	366	15.21%	2,228	7	0.31%	2,406	7	0.29%
SOUTHWEST AIRLINES CO	234	6	2.56%	234	0	0.00%	234	0	0.00%
SPIRIT AIRLINES INC	96	7	7.29%	24	0	0.00%	96	0	0.00%
SUN COUNTRY AIRLINES	54	0	0.00%	54	0	0.00%	54	0	0.00%
SWIFT AIR LLC	4	0	0.00%	4	0	0.00%	4	0	0.00%
TEM ENTERPRISES INC	6	1	16.67%	6	0	0.00%	6	0	0.00%
TRANS STATES AIRLINES LLC	184	37	20.11%	184	0	0.00%	184	0	0.00%
UNITED AIRLINES, INC	412	34	8.25%	267	0	0.00%	412	0	0.00%
US AIRWAYS INC	290	25	8.62%	96	1	1.04%	290	1	0.34%
VIRGIN AMERICA INC	36	3	8.33%	36	0	0.00%	36	0	0.00%
VISION AIRLINES INC	2	0	0.00%	2	0	0.00%	2	0	0.00%
WORLD AIRWAYS INC	2	0	0.00%	2	0	0.00%	2	0	0.00%

[1] Only the counts for carriers with at least one follow-up sample are presented in this table

[2] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

7 Treatment

This chapter summarizes the results from Environmental Protection Agency's (EPA's) Six-Year Review 4 (SYR4) of new information related to the treatment of microbial contaminants in drinking water. For this SYR4, EPA conducted a scientific review of available information, published in or before December 2021, to determine if new information has the potential to present a meaningful opportunity to revise treatment technique (TT) requirements.

This chapter provides a brief overview of major TT requirements in the microbial contaminant regulations, provides a description of recent regulatory implementation impacts for rules covered by the scope of SYR4, and highlights new technical information that has become available since SYR3. Additional background about the technical basis of the Ground Water Rule (GWR) is provided in Chapters 3 and 7 of the *Six-Year Review 3 Technical Support Document for Microbial Contaminant Regulations* (USEPA, 2016a), while the basis of Long Term 2 Enhanced Surface Water Treatment Rule (LT2) is covered in Chapters 3 and 7 of the *Six-Year Review 3 Technical Support Document for Long-Term 2 Enhanced Surface Water Treatment Rule* (USEPA, 2016b).

Information in this chapter is organized as follows:

- Section 7.1 presents treatment information on the LT2
- Section 7.2 presents treatment information on the GWR
- Section 7.3 presents treatment information on the Revised Total Coliform Rule (RTCR)
- Section 7.4 presents treatment information on the Aircraft Drinking Water Rule (ADWR)

Overall, the treatment information presented and discussed in this chapter are intended to be helpful for addressing one of the questions prescribed in the *EPA Protocol for the Fourth Review of Existing National Primary Drinking Water Regulations* (USEPA, 2024a, see Section 2 for more detail as well): Is there a significant improvement in analytical or treatment feasibility?

7.1 Long Term 2 Enhanced Surface Water Treatment Rule

EPA promulgated the LT2 on January 5, 2006 to increase protection against microbial pathogens, specifically *Cryptosporidium*, in public water supplies that use surface water sources. This section presents a summary of literature that has become available since 2015 and key new information related to each LT2 microbial toolbox option's effectiveness and implementation.

7.1.1 Description of Long Term 2 Enhanced Surface Water Treatment Rule Requirements

The purpose of the LT2 is to improve public health protection by reducing illness linked to *Cryptosporidium* and other microbial contaminants in drinking water and focusing on systems with elevated *Cryptosporidium* risk. The LT2 defined a range of additional treatment requirements for inactivation of *Cryptosporidium* and built on pre-existing filtration requirements for Subpart H water systems that practice conventional or direct filtration:

- The Surface Water Treatment Rule (SWTR) requires 99.99 percent (4-log) removal for viruses and 99.9 percent (3-log) removal and/or inactivation for *Giardia lamblia*
- The Interim Enhanced Surface Water Treatment Rule (IESWTR) and Long Term 1 Enhanced Surface Water Treatment Rule (LT1) require 99 percent (2-log) removal of *Cryptosporidium*

The LT2 required surface water and ground water under the direct influence of surface water (GWUDI) systems to perform two different rounds of source water monitoring for a period of one to two years for *Cryptosporidium* and/or *E. coli*. Large water systems were required to monitor their source water for *Cryptosporidium*. Smaller systems serving fewer than 10,000 people could monitor for *E. coli* unless the *E. coli* levels exceeded a trigger level, at which point they would then be required to conduct *Cryptosporidium* monitoring. Source water monitoring was not required for filtered systems that provided or intended to install 5.5-log of treatment for *Cryptosporidium* and unfiltered systems that provided or intended to install at least 3-log treatment for *Cryptosporidium*.

Unfiltered systems were required to also monitor source water for *Cryptosporidium* concentration and calculate a mean concentration to determine the appropriate treatment requirements: 2- or 3-log inactivation of *Cryptosporidium*.

Filtered systems were classified into one of four "bins" that defined additional *Cryptosporidium* treatment requirements based on the system's source water monitoring results. The lowest treatment bin, Bin 1, has no additional treatment requirements. The bins specify the additional or total required *Cryptosporidium* log treatment based upon the type of filtration treatment: conventional treatment; direct filtration; slow sand or diatomaceous earth filtration; or alternative filtration technologies. For conventional filtration treatment, the range was no additional treatment to 2.5 log treatment, while the range for direct filtration was no additional treatment to 3-log additional treatment. In general, treatment requirements for Bin 2 through Bin 4 varied from 1-log additional treatment to 5.5-log total *Cryptosporidium* treatment based upon source water concentration and filtration type
[40 CFR 141.711(a)].

To meet the *Cryptosporidium* treatment requirements for each bin classification, water systems were required to select from a "toolbox" of treatment or management options that prescribe the amount of log treatment credit applicable to each tool, as listed in Exhibit 7-1. The Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual describes the treatment and management strategies that are necessary for implementing each toolbox option (USEPA, 2010b). Utilities are provided flexibility to perform a site-specific demonstration if an additional credit is sought. EPA provided the Membrane Filtration Guidance Manual for clarification of design and implementation of use of membrane filtration as an LT2 tool (USEPA, 2005c).

Systems must prove that they are meeting operational or performance criteria to receive toolbox option credit. Systems that already use ozone, chlorine dioxide, UV light or membranes in addition to conventional treatment prior to the promulgation of the LT2, can receive LT2 toolbox credit if they meet the performance criteria for the chosen technology. Systems currently using chlorine or chloramine do not receive *Cryptosporidium* inactivation credits for these disinfectants under the LT2.

Exhibit 7-1. *Cryptosporidium* Treatment Credits for all Toolbox Options under Long Term 2 Enhanced Surface Water Treatment Rule [40 CFR 141.715(b)]

Toolbox Option	***Cryptosporidium* treatment credit with design and implementation criteria**
Source Protection and Management Toolbox Options	
Watershed Control Program	0.5-log credit. Unfiltered systems are not eligible.
Alternative Source/Intake Management	No prescribed credit. System-specific case approval by primacy agency
Pre-Filtration Toolbox Options	
Pre-sedimentation basin with coagulation	0.5-log credit during any month that pre-sedimentation basins achieve a monthly primacy agency-approved performance criteria.
Two-stage lime softening	0.5-log credit for two stage softening where chemical addition and hardness precipitation occur in both stages and all plant flow must pass thru both stages.
Bank filtration	0.5-log credit for 25-foot setback; 1.0-log credit for 50-foot setback; Aquifer must be unconsolidated sand containing at least 10 percent fines; average turbidity in wells must be less than 1 Nephelometric Turbidity Unit (NTU). Systems using wells followed by filtration when conducting source water monitoring must sample the well to determine bin classification and are not eligible for additional credit.
Treatment Performance Toolbox Options	
Combined Filter Performance	0.5-log credit for combined filter effluent turbidity ≤ 0.15 NTU in at least 95% of measurements each month.
Individual Filter Performance	0.5-log credit (in addition to 0.5-log combined filter performance credit) if individual filter effluent turbidity is ≤ 0.15 NTU in at least 95% of samples each month in each filter and is never greater than 0.3 NTU in two consecutive 15 minute measurements in any filter.
Demonstration of Performance	Credit awarded to treatment process or treatment train based on a demonstration to primacy agency
Additional Filtration Toolbox Options	
Bag or cartridge filters (individual filters)	Up to 2-log credit based on the removal efficiency demonstrated during challenge testing with a 1.0-log factor of safety.
Bag or cartridge filters (in series)	Up to 2.5-log credit based on the removal efficiency demonstrated during challenge testing with a 0.5-log factor of safety.
Membrane filtration	Log credit equivalent to removal efficiency demonstrated in challenge test for device if supported by direct integrity testing.
Second stage filtration	0.5-log credit for second separate granular media filtration stage if treatment train includes coagulation prior to first filter.
Slow sand filters	2.5-log credit as a secondary filtration step; 3.0-log credit as a primary filtration process. No prior chlorination allowed for either option.
Inactivation Toolbox Options	
Chlorine dioxide	Log credit based on measured CT[1] in relation to CT table
Ozone	Log credit based on measured CT in relation to CT table
UV	Log credit based on validated UV dose in relation to UV dose table; reactor validation testing required to establish UV dose and associated operating conditions.

[1] CT is defined as disinfectant residual concentration (C) multiplied by contact time (T). A CT value is a measure of disinfection effectiveness for the time that microorganisms in the water are in contact with a disinfectant.

Under the LT2, public water systems with uncovered finished water reservoirs (UCFWR) must either cover the storage facility or treat the water leaving the storage facility to achieve inactivation and/or removal of 4-log virus, 3-log *Giardia lamblia* and 2-log *Cryptosporidium* using a protocol approved by the state [40 CFR 141.714] (USEPA, 2006a).

Water systems were required to take measures to cover these reservoirs, treat the water leaving the reservoirs, replace them with other storage facilities (e.g., ground level storage) or take them out of service. All PWSs with UCFWRs in the United States are under administrative orders or compliance agreements to cover or treat their UCFWR.

7.1.2 Advances/Improvements/Innovations to Long Term 2 Enhanced Surface Water Treatment Rule Microbial Toolbox Requirements

This section presents a summary of literature that has become available since SYR3 and key new information related to each microbial toolbox option's effectiveness and implementation. The degree to which implementation issues have been identified varies by the toolbox option.

Exhibit 7-2 provides a summary of relevant new information for the LT2 toolbox options, with the exception of UV which is discussed in more detail following Exhibit 7-2. For each toolbox option, the table indicates whether the literature reviewed provided new information on *Cryptosporidium* risk reduction or whether there was relevant new design and implementation information. Overall, EPA has found that there are not any meaningful opportunities to revise the treatment criteria prescribed in the *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual* (USEPA, 2010b).

Several risk mitigation tools in the LT2 microbial toolbox have become better understood and implementation improvements have been described in recent literature. Examples of modified LT2 toolbox technologies include use of bauxite in slow sand filters; ceramic membrane filters and UV treatment technologies such as light-emitting diode (LED) lamps.

Although some studies showed lower doses of UV treatment required for log inactivation of the challenge organism male-specific-2 bacteriophage (MS2), others showed higher doses required to achieve the same log inactivation. Since UV dose outcomes described in this section were inconsistent in comparison to doses reported in previous EPA guidance, the new information about MS2 inactivation by UV is considered to support the existing LT2 microbial toolbox credits and basis of the original rule.

EPA provided new guidance:

- *Drinking Water Instrumentation Data Integrity Checklists* (USEPA, 2022a)
- *Guidance Manual for compliance with the Surface Water Treatment Rules: Turbidity Provisions* (USEPA, 2020a)
- *Generating High-Quality Turbidity Data in Drinking Water Treatment Plants to Support System Optimization and Monitoring* (USEPA, 2019c)

Exhibit 7-2. Potentially Relevant New Studies since 2015 for Existing Long Term 2 Enhanced Surface Water Treatment Rule Microbial Toolbox Options

Microbial Toolbox Option	New Information for LT2 Microbial Toolbox Options regarding Risk Reduction, Design or Implementation since SYR3
Watershed Control Program (WCP)	Schijven et al. (2015) provided a computational model to simulate microbial water quality of *Cryptosporidium* based upon fecal deposits from wildlife, birds and humans in the floodplain and ground water infiltration. Moltz et al. (2018) provided a watershed comparison of forest protection and forest buffers on increased drinking water treatment costs due to changes in microbial water quality. Ahmed et al. (2019) provided a review of microbial contaminants in stormwater runoff and a summary of log removals achieved with stormwater design mitigation strategies.
Alternative Source / Intake Management	EPA found no new information in the literature on this particular tool.
Pre-sedimentation Basin with Coagulation	EPA found no new information in the literature on this particular tool.
Two-stage Lime Softening	EPA found no new information in the literature on this particular tool.
Bank Filtration (BF)	Berger et al. (2018) found six aerobic spore samples paired as surface water /ground water are sufficient to meet uncertainty constraints in alluvial aquifers with large volume surface water induced recharge, for use as a surrogate to demonstrate performance of *Cryptosporidium* oocyst log reduction. There is no EPA-approved standard method for total aerobic spore assay in drinking water samples in alluvial aquifers. Mustafa et al. (2021) found that the correlation of higher well contaminant concentrations due to larger relative stream width can be neglected when the distance from the pumping well to the nearest river edge is more than twice the stream width. Low-frequency electromagnetic field (LF-EMF) treatment in a lab setting intended in conjunction with riverbank filtration for the removal of *E. coli* indicated removal rates correlated positively with increased strength: 100% *E. coli* removal at 6, 8, and 10 milliteslas (Selamat et al., 2019) Oudega et al. (2022) reported the results of a study that involved the attenuation of *Bacillus subtilis* spores, as a surrogate for *Cryptosporidium* and *Campylobacter*, in a sandy gravel aquifer. The purpose of the study was to estimate required setback distances for drinking water wells from potential sources of contamination, such as a river. Hydraulic gradients were controlled by varying the pumping rates in the subsurface at 1 L/s, 5L/s and 10 L/s. Observed removal rates were 0.2 – 0.3 log/m, with higher removals observed at lower pumping rates. A setback distance of approximately 700 m at the highest pumping rate was estimated.
Combined Filter Performance	Schmidt et al. (2020) cautions against misinterpretation and misuse of averaged log-reduction values since these values characteristically overstate performance that it represents, and recommended use of effective log reduction which averages reduction and then expresses this as log reduction. Ramsay et al. (2021) quantified grain displacement during filter backwash and found that grain movement during backwash is highly inhomogenous in three dimensions and the elapsed time of backwash. Significant displacement of tracer grains in all types

Microbial Toolbox Option	New Information for LT2 Microbial Toolbox Options regarding Risk Reduction, Design or Implementation since SYR3
	of backwash tests, including backwash concluding with subfluidization wash, may affect hydraulic and biological filter function. Ramsay et al. (2021) also concluded that extended air scours are without significant cleaning value. The 10 States Standards revised its policy statement for optimization of rapid rate filtration at surface water treatment plants. (GLUMRB, 2018). Nix and Taylor (2018) summarized new procedures for granular media filters for addressing filter-clogging algae and for suspected air binding.
Individual Filter Performance	Pang et al. (2022) assessed the efficiencies of three different filter media for removal of *C. parvum* surrogate (using glycoprotein coated 4.5 µm polystyrene microspheres) and found that despite the ceramic sand filter achieving log removal values greater than three consistently, the peak turbidity levels exceeded 0.30 NTU in 17% of the trials, which highlights the need to introduce supplementary tools alongside turbidity to monitor filter performance more sensitively. The sensitivity of biologically active filter performance associated with backwash was studied and it was found that the turbidity spike during ripening of 0.35 NTU significantly improved with the addition of single and double stage extended terminal subfluidization wash, with maximum turbidity values of 0.14 and 0.09 NTU, respectively (Piche, 2019). Piche also measured the particle size distribution passing thru biologically active filters and conventional filters, as measured before backwash and after backwash. Monis et al. (2017) evaluated *Cryptosporidium* surrogates for conventional coagulation and dual media filtration and found that all of the surrogates tested [modified microspheres, spores, high red fluorescent particles (algae), low red fluorescent particles (bacteria and other material), total particle counts using on-line particle meter, and on-line particle meter count of particles in the 3-6 µm range] were conservative indicators of oocyst removal with modified microspheres most closely matched oocysts in terms of removal behavior.
Demonstration of Performance (DOP)	EPA found no new information in the literature on demonstration of performance.
Bag or Cartridge Filters	Harmsco's HC/90-LT2 cartridge filter was found to reduce *Cryptosporidium* (using 2 µm spheres as surrogate) by 3.53 log and 3.72 log in two challenge tests (Harmsco, 2014). USEPA (2012) provided its generic verification protocol for product-specific challenge testing of full-scale bag and cartridge filters for *Cryptosporidium* removal credits, The protocol was developed by the previous EPA's Environmental Technology Verification (ETV) Drinking Water Systems Center, which is no longer certifying drinking water treatment effectiveness since certifications are now provided by third-party certification programs.
Membrane Filtration	Chen et al. (2021) conducted a review of 1,060 research papers from the Web of Science database and found that membrane filtration achieves a broad range of virus removal efficiency from 0.5-7 log removal values. Ceramic membranes are a type of artificial membrane made from inorganic materials such as alumina, titania, zirconia oxides or some glassy materials. Pore size can vary but is typically 0.1 µm. The first water treatment plant using ceramic membranes was placed into service in 2015 (Kinser, 2021). Since then, the use of ceramic membranes has expanded. Jaferey and Galjaard (2020) describe benefits of ceramic membranes as not having fiber integrity issues (fiber breakage), easier cleaning and disinfection, and having higher permeability which equates to lower energy consumption.

Microbial Toolbox Option	New Information for LT2 Microbial Toolbox Options regarding Risk Reduction, Design or Implementation since SYR3
	Although silver nanoparticles can be added to ceramic filters to improve disinfection performance, Abebe et al. (2015) found that there was no statistical difference between ceramic filtration *Cryptosporidium parvum* removal efficiency and log mean reduction due to in vivo silver deactivation. Similarly, Venis and Basu (2021), found that that ceramic water filters with silver only perform significantly better if there is storage time after filtration in the presence of the silver ceramic filter and they caution of unknown potential metallic influence on the biofilm layer internal to the filter over the filter's lifespan. Sharma et al. (2020) summarized advances in nanocellulose filtration technologies comprised of self-standing membranes, thin film nanofibrous composite membranes and nanocomposite barrier layers on differing scaffold. Barbhuiya et al. (2021) evaluated the electrochemical antimicrobial and antifouling surface effects of direct current applied to sulfur-doped laser induced graphene (LIG) filters and found that viral destruction of *Vaccinia lister* virus at 4-log removal, requires higher electrical potential due to smaller viral size than bacterial pathogens they previously studied at 6-log removal for *Pseudomonas aeruginosa* and mixed bacterial culture (Singh et al., 2018). Malkoske et al. (2020) reviewed optimal coagulation / flocculation prior to low pressure membrane filtration by comparing processes with (study Type 3) and without (study Type 2) settling prior to membrane filtration and found accumulated foulants with settling (study Type 3) may include lower concentrations of hydrolytic coagulants which could result in greater irreversible fouling. Patterson et al. (2021) also reviewed membrane manufacturer pilot-scale data to determine allowable flux values for different influent water quality conditions. Jacangelo et al. (2019) compared fluorescent dyes for integrity monitoring of reverse osmosis (RO) membranes that could be employed at full scale to establish and monitor for virus log removal values >3, which could also be extended to protozoa or bacteria assuming size exclusion as mechanism of removal. Marker-based direct integrity tests are increasingly being approved by state regulators for nanofiltration (NF) and RO processes (Alspach, 2019). Vickers (2018) introduced a proposed methodology for establishing pathogen removal credit for RO membranes that are primarily used for desalination or other applications. The proposed direct integrity testing methodology uses conductivity data to determine if the RO unit integrity is operating within established limits.
Second Stage Filtration	EPA found no new information in the literature on this particular tool.
Slow Sand Filters	New sand filters by using a water extract of Moringa oleifera (MO) seeds, termed functionalized sand (f-sand) filters can achieve ~7 log MS2 bacteriophage removal (Samineni et al., 2019) and achieve > 8 log removal of *E. coli* (Xiong et al., 2018). Slow sand filters with a 30 cm layer of bauxite performed with ~1 year of continuous filtration prior to *E. coli* breakthrough represents a significant improvement of the performance of slow sand filters (Urfer, 2017). Silica columns receiving water dosed with 10 mg/L chitosan coagulant achieved 4.75 log and 4.43 log reductions for *E. coli* and MS2, respectively (Holmes, 2019).

Microbial Toolbox Option	New Information for LT2 Microbial Toolbox Options regarding Risk Reduction, Design or Implementation since SYR3
Chlorine Dioxide	Gallandat et al. (2019) studied the maintenance of disinfectant residual of chlorine dioxide over 24 hours and found that chlorine dioxide decayed more rapidly in the distribution system across all of the tested conditions and required a dose of 4 mg/L to maintain a minimum of ≥ 0.2 mg/L except at zero turbidity.
Ozone	Carvajal et al. (2017) showed that change in total fluorescence, a surrogate for dissolved ozone, achieved better fit (at 1 LRV) of coliforms, *C. perfringens* spores and somatic coliphages, than the other surrogate measures studied: change in UV_{254} absorbance; and ozone to Total Organic Carbon (TOC) ratio (O_3:TOC). This study also cautioned that site-specific analysis would be more accurate to measure system performance because microbial reductions based upon seeded microorganisms could lead to overestimation of log credits due to less reduction in autochthonous microorganisms than for seeded microorganisms. Wolf et al. (2019) studied proxies to measure virus inactivation by ozone treatment and found that both carbamazepine and UV_{254} could be used to sufficiently track virus inactivation. Silva and Sabogal-Paz (2020) studied bench-scale ozone treatments of filter backwash water and found that regardless of condition no *Cryptosporidium* oocysts were found in the disinfected samples.

7.1.2.1 Ultraviolet

New information shows that there have been improvements in UV technology for low- and medium-pressure lamps and light-emitting diodes. Further, EPA has provided guidance about validation approaches of UV for drinking water systems and a protocol for state review of UV disinfection treatment plans.

Since SYR3, EPA has provided the following new guidance documents providing clarification for ultraviolet treatment technology:

- The Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems document described how UV dose monitoring algorithms that use the combined variable can be used to provide direct predictions of pathogen inactivation, thereby eliminating the need to apply the reduction equivalent dose (RED) bias factor, considerably simplifying the validation of UV disinfection. The document also described a calculated dose approach that does not require an on-line UVT monitor but calculates log inactivation and RED by the reactor using UV sensor readings, flow through the reactor, and UV sensitivity of the microbe whose log inactivation and RED is predicted (USEPA, 2020b).
- The UV Treatment Toolkit provides a protocol for state review of UV disinfection treatment plans and templates that address UV design, validation, operations, sensor calibration, and factors for awarding disinfection credit (USEPA, 2022b). In addition, it includes a recent update of alternative challenge microorganisms for demonstrating virus inactivation.

This SYR4 process reviewed new UV literature that has become available since SYR3. Previously published EPA guidance is shown in Exhibit 7-3 and Exhibit 7-4. Exhibit 7-5 through Exhibit 7-7 provide a summary of new findings of UV technology results for *Cryptosporidium* and the challenge organism type MS2 used as a surrogate with low pressure lamps, medium pressure lamps and light-emitting diodes, respectively. This new literature regarding UV studies challenged with *Cryptosporidium* and MS2 shows inconsistent log inactivation performance results when compared to doses reported in previous EPA guidance. With some studies achieving the same log inactivation at doses lower than those reported in previous EPA guidance and other studies achieving log inactivation at doses higher than those contained in guidance, the new information is not showing a consensus indication that research is achieving log inactivation at levels significantly lower than EPA prior published guidance. Additional information describing the dose outcome of the new articles is included in the discussion of the separate UV technologies below.

Exhibit 7-3 shows the UV doses required to achieve log inactivation (40 CFR 141.720(d)(1)) while Exhibit 7-4 shows the UV dose sensitivity for challenge microorganisms as reported in the *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA, 2006d).

Exhibit 7-3. Requirements for Ultraviolet Dose to Achieve Log Inactivation (millijoules per centimeter squared (mJ/cm^2)

Target Pathogens	UV Dose (mJ/cm^2) for 0.5 Log	UV Dose (mJ/cm^2) for 1.0 Log	UV Dose (mJ/cm^2) for 1.5 Log	UV Dose (mJ/cm^2) for 2.0 Log	UV Dose (mJ/cm^2) for 2.5 Log	UV Dose (mJ/cm^2) for 3.0 Log	UV Dose (mJ/cm^2) for 3.5 Log	UV Dose (mJ/cm^2) for 4.0 Log
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

Source: 40 CFR 141.720(d)(1)

Exhibit 7-4. Ultraviolet Sensitivity of Challenge Microorganisms – Reported Delivered Ultraviolet Dose to Achieve Log Inactivation

Microorganism	UV Dose (mJ/cm2) to Achieve 1-log Inactivation	UV Dose (mJ/cm2) to Achieve 2-log Inactivation	UV Dose (mJ/cm2) to Achieve 3-log Inactivation	UV Dose (mJ/cm2) to Achieve 4-log Inactivation	Reference
Bacillus subtilis	28	39	50	62	Sommer et al., 1998
MS2 phage	16	34	52	71	Wilson et al., 1992
Qß phage	10.9	22.5	34.6	47.6	Mackey et al., 2006
PRD-1 phage	9.9	17	24	30	Meng and Gerba, 1996
B40-8 phage	12	18	23	28	Sommer et al., 1998
ϕx174 phage	2.2	5.3	7.3	11	Sommer et al., 1998
E. coli	3.0	4.8	6.7	8.4	Chang et al., 1985
T7	3.6	7.5	11.8	16.6	Mackey et al., 2006
T1	~5	~10	~15	~20	Wright, 2006

Source: *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA, 2006d)

This SYR4 review did not find any peer-reviewed articles correlating *Cryptosporidium* log inactivation for ultraviolet treatment of drinking water to a new challenge microorganism other than those types of challenge microorganisms reported in Exhibit 7-4. Some articles presented ancillary information regarding UV challenge microorganisms as indicators of protozoa log inactivation. These challenge microorganisms are briefly listed here: *Clostridium perfringens,* a spore forming bacteria used as challenge microorganism for solar ultraviolet treatment (Gutiérrez-Alfaro et al., 2015); and PR772 bacteriophage, a surrogate of adenovirus inactivation was reported for sequential ultraviolet-chlorine disinfection of wastewater (Gao et al., 2023). Any use of a new UV challenge microorganism would require reactor-specific validation testing to establish the UV dose required, since UV inactivation credits for LT2 are not defined by the regulation based specifically on the challenge microorganism.

Exhibit 7-5 provides a summary of the findings of UV technology results for *Cryptosporidium* and MS2 surrogate for low pressure lamps. Studies achieving the same log inactivation at doses lower than those reported in previous EPA guidance using low pressure lamps included Busse (2019) and Hull and Linden (2018), while studies of low pressure lamps achieving log inactivation at doses higher than those contained in guidance were Baldasso (2021), Younis (2019), Zyara (2016), and Blatchley (2019).

Exhibit 7-5. Examples of Potentially Relevant Low Pressure Lamp Ultraviolet Doses for Log Inactivation of Cryptosporidium and Male-Specific-2 Bacteriophage

Wavelength (nm)	Microorganism/ Surrogate	Medium	UV dose (mJ/ cm^2)	Log inactivation	Inactivation Rate Constant (cm^2/mJ)	Reference	Study Type
253.7	*Cryptosporidium (S. chilensis)*	Phosphate buffered saline (PBS)	7	2.2		Blyth et al., 2021	Bench scale
254	*Cryptosporidium*	Water	2	1.1		Busse et al., 2019	Bench scale
285	MS2	Water	60	3 (interpolated Table S1B)		Hull et al., 2019	Bench scale / Demo
254	MS2	Turbid Water	40 (calc)	2	0.05	Baldasso et al., 2021	Bench scale
254	MS2	Turbid Water	153 (calc)	4	0.026	Baldasso et al., 2021	Bench scale
253.7	MS2	Particle free $CaCl_2$ solution (2mM)	40	2.8		Feng et al., 2016	Bench scale
253.7	MS2	Particle free $CaCl_2$ solution (200 mM)	40	1.2		Feng et al., 2016	Bench scale
253.7	MS2	Water	35.7	2	0.0561	Mbonimpa et al., 2018	Bench scale
254	MS2	Irrigation Water	82	4		Younis et al., 2019	Bench scale
253.7	MS2	Dechlorin. Tap Water	117	3.35		Zyara et al., 2016	Bench scale
253.7	MS2	PBS	40	2.49 (calc)	0.062	Sholtes and Linden, 2019	Bench scale
254	MS2	Peptone buffered saline	40	2 (interpolated)		Blatchley et al., 2019	Full scale
255 or 265	MS2	PBS	40	3 (interpolated)		Hull and Linden, 2018	Bench scale

Exhibit 7-6 provides a summary of the findings of UV technology results for MS2 surrogate for medium pressure lamps. A study using medium pressure lamps achieving the same log inactivation at doses lower than those reported in previous EPA guidance included Wang (2019).

Exhibit 7-6. Examples of Potentially Relevant Medium Pressure Lamp Ultraviolet Doses for Log Inactivation of Male-Specific-2 Bacteriophage

Wavelength (nm)	Microorganism/ Surrogate	Medium	UV dose (mJ/ cm^2)	Log inactivation	Inactivation Rate Constant (cm^2/mJ)	Reference	Study Type	Notes
254	MS2	PBS	40	3		Wang et al., 2019	Bench scale	Collimated Beam
220	MS2	PBS	25	3.1-5.2		Wang et al., 2019	Bench scale	Collimated Beam

Exhibit 7-7 provides a summary of the findings of UV technology results for MS2 used as a surrogate for light-emitting diode lamps. Studies using LED lamps achieving log inactivation at UV doses lower than those reported in previous EPA guidance included: Beck et al. (other than 280 nanometer (nm) only), 2017; Sholtes et al., 2016; Jarvis et al., 2019; and Hull and Linden, 2018, while studies of LED lamps achieving log inactivation at doses higher than those contained in guidance were Kesharvarzfathy et al., 2020; Oguma et al. , 2019, Beck et al. (LED 280 nm only), 2017; Oguma et al., 2016; Hull et al., 2019.

Exhibit 7-7. Examples of Potentially Relevant Light Emitting Diode Ultraviolet Doses for Log Inactivation of Male-Specific-2 Bacteriophage

Wavelength (nm)	Microorganism/ Surrogate	Medium	UV dose (mJ/ cm^2)	Log inactivation	Inactivation Rate Constant (cm^2/mJ)	Reference	Study Type	Notes
254	MS2	PBS	42.3	1.94		Keshavarzfathy et al., 2020	Bench scale	Collimated Beam
255	MS2	PBS	40	3.16 (calc)	0.079	Sholtes and Linden, 2019	Bench scale	
260	MS2	Water	30.3	2		Beck et al., 2017	Bench scale	Collimated Beam
260	MS2	Buffered Water	58	4		Sholtes et al., 2016	Bench scale	Collimated Beam
265	MS2	Buffered Water	40	2.5		Song et al., 2018	Bench scale	Pulsed
265	MS2	PBS	105.2	4		Oguma et al., 2019	Bench scale	
266	MS2	Water	9	7		Kim et al., 2017	Bench scale	Collimated Beam
260 & 280	MS2	Water	32.8	2		Beck et al., 2017	Bench scale	Collimated Beam & Combined
265	MS2	PBS	20	1.6		Song et al., 2019	Bench scale	Combined
275	MS2	PBS	9.2	2		Jarvis et al., 2019	Demo	Collimated Beam
280	MS2	Water	38.5	2		Beck et al., 2017	Bench scale	Collimated Beam
280	MS2	PBS	122.1	4		Oguma et al., 2019	Bench scale	
285	MS2	Water	103.4	3		Oguma et al., 2016	Bench scale	
285	MS2	PBS	60	2 (interpolated Table S1B)		Hull et al., 2019	Bench scale/ Demo	Collimated Beam
255 or 265	MS2	PBS	40	3 (interpolated)		Hull and Linden, 2018	Bench scale	Combined
255 or 265	MS2	PBS	40	4 (interpolated)		Hull and Linden, 2018	Bench scale	Combined

7.1.2.2 Other New Information not included in existing Long Term 2 Enhanced Surface Water Treatment Rule Toolbox

Through the SYR4 process, EPA reviewed whether other new information pertaining to emerging technologies, which have not been included in the existing LT2 toolbox guidance manual, may be helpful for removal or inactivation of protozoa including *Cryptosporidium*. EPA summarizes that information here and finds that this information appears insufficient to develop quantification criteria for inactivation and removal credit for *Cryptosporidium*.

7.1.2.3 Turbo Coagulation

Turbo coagulation was described in the Surface Water Analytical Tool (SWAT) model guidance (USEPA, 2000) as removal of TOC ranging from 30-84 percent, which is generally superior to the values established by regulatory 3x3 matrix TOC removals as 15-50 percent. No new journal articles were found during the SYR4 period of review that referenced the term turbo coagulation or correlated *Cryptosporidium* removal at turbo coagulation performance levels.

7.1.2.4 Powdered activated carbon

Campinas et al. (2021a) studied the application of powdered activated carbon (PAC) in combination with other treatment methods such as membrane filtration by conducting pilot-scale research on the pressurized PAC/coagulation/ceramic microfiltration (MF) hybrid system (PAC/Alum/MF) with low turbidity and low natural organic matter surface water spiked with organic microcontaminants. Results indicated that PAC/Alum/MF was a full barrier against aerobic endospores as an indicator of protozoan/ *Cryptosporidium* (oo)cysts.

Also, there has been increased emphasis on optimizing the PAC treatment process through factors such as PAC dosage. Campinas et al. (2021b) conducted pilot trials of PAC/coagulation/sedimentation with low-turbidity surface waters, and four sets of operating conditions were considered to test different PAC types, doses, and contact times. The result indicated that the PAC dosage above 10 mg/L hampered the clarification of the studied waters with aerobic endospores used as indicators of protozoan oocysts.

7.2 Ground Water Rule

EPA promulgated the GWR on November 8, 2006, to increase protection against microbial pathogens, specifically viral and bacterial pathogens, in public water supplies that use ground water sources (USEPA, 2006b). The GWR established a risk-targeted approach to identify ground water systems susceptible to fecal contamination and requires action to correct significant deficiencies and fecal contamination identified by triggered source water monitoring, assessment source water monitoring or additional source water monitoring. (USEPA, 2006b). This approach involves a multifaceted strategy including sanitary surveys, source monitoring, high risk system identification, and appropriate treatment and compliance monitoring. Following a brief recap of the TT requirements under the GWR, EPA presents and discusses the analytical results with the SYR3 and SYR4 ICR data for assessing the national impacts collectively from those requirements in this section. This section also discusses new information relevant to the treatment provisions of the GWR.

7.2.1 Sanitary Surveys

As a condition of primacy delegation by EPA, primacy agencies must conduct on-site sanitary surveys of each ground water system by reviewing the adequacy of water source, facilities, equipment, operation, and maintenance of a PWS.

A sanitary survey is defined by the NPDWR as an onsite review of the water source, facilities, equipment, operation and maintenance of a public water system for the purposes of evaluating the adequacy of such source, facilities, equipment, operation and maintenance for producing and distributing safe drinking water (40 CFR 141.2(d)). The sanitary survey is intended to identify significant deficiencies (USEPA, 2019d) including deficiencies which may make a system susceptible to microbial contamination. Primacy agencies must conduct sanitary surveys every three years for most CWSs and every five years for NCWSs and CWSs that meet certain performance criteria. The systems need to take corrective actions to fix the identified deficiencies, as described in section 7.2.3.

7.2.2 Treatment Technique Requirements under Ground Water Rule

The GWR TT requirements require ground water systems to implement corrective action if a sanitary survey significant deficiency is identified or if the initial source sample or one of the five additional ground water source samples tests positive for fecal contamination.

7.2.3 Corrective Actions

A ground water system must take corrective action within 120 days, or within the approved corrective action plan schedule, upon receiving notification of a significant deficiency from the primacy agency or written notice from a laboratory that a ground water source sample collected was fecal indicator-positive (USEPA, 2006b).

Ground water systems must implement at least one of the following corrective actions: correction of significant deficiencies; providing an alternate source of water; eliminating the source of contamination; or providing treatment that reliably achieves at least 99.99 percent (4-log) treatment of viruses for each contaminated ground water source (USEPA, 2006b).

7.2.4 Analytical Results Reflecting Ground Water Rule Impacts from Treatment Techniques Requirements

As described and discussed in the Occurrence and Exposure chapter (Chapter 6), EPA analyzed the national compliance monitoring data records in SYR3 and SYR4 ICR collectively to assess the changes that occurred after the implementation of GWR and/or RTCR. Considering the related regulatory timelines indicated in Exhibit 6-5 in the Occurrence and Exposure chapter, the changes observed among ground water systems from years 2007 and 2008 (right before GWR became effective) to years 2014 and 2015 (after the Sanitary Survey was completed during the first round and right before RTCR became effective) may indicate changes driven by implementation of GWR especially among undisinfected ground water systems. After 2016, the changes may have been collectively driven by the GWR and RTCR among ground water systems, including undisinfected ground water systems. Although the SYR3/SYR4 ICR datasets do not allow EPA to evaluate the extent to which the individual corrective actions taken could lead to the overall changes, the datasets have enabled EPA to do the following:

1. Systematically identify disinfecting versus undisinfected ground water systems for each of the individual years in the datasets (see Section 6.4 in the Occurrence and Exposure chapter). Note that this approach does not allow determination of whether disinfecting systems are achieving 4-log inactivation/removal.

2. Evaluate changes in the number and percentages of disinfecting (vs. undisinfected) systems over time (see Section 6.4 of the Occurrence and Exposure chapter). It is difficult for EPA to determine the universe of ground water systems that must maintain 4-log treatment as treatment information is not always current in SDWIS/Fed.
3. Assess changes in total coliform positive / *E. coli* positive rates from pre-GWR to post-GWR (See Section 6.2.1 of the Occurrence and Exposure chapter.

As discussed in Chapter 6, since the GWR became effective, there is an increasing trend of number or percentages of ground water systems that are disinfecting. That may be somewhat attributable to the regulatory element that adding treatment of 4-log virus inactivation and removal is one of the corrective actions under the GWR. The decreasing trends of both total coliform positive and *E. coli* positive rates indicate that the GWR appeared to reduce microbial occurrence in the distribution system. Such a decreasing trend could be extended to the period after the RTCR became effective in 2016. However, the modeling results (see Section 6.4.2) suggested that some very small undisinfected ground water systems might continue having high total coliform positive / *E. coli* positive rates. Potential compliance challenges among small ground water systems are discussed in section 7.2.6 below.

7.2.4.1 Undisinfected Ground Water System Treatment

Undisinfected ground water systems that choose to install treatment to correct significant deficiencies or fecal contamination must provide at least 99.99 percent (4-log) inactivation (disinfection) or removal (filtration) of viruses. Treatment technologies or combination of technologies that have demonstrated the ability to achieve 4-log inactivation or removal of viruses are chlorine (chlorine gas or sodium hypochlorite), chlorine dioxide, ozone, ultraviolet (UV) radiation, anodic oxidation, reverse osmosis (RO), and nanofiltration (NF).

Since disinfection technology regulatory improvements are being considered the MDBP revision effort, this section does not include discussion of new treatment information that has come available other than those included in the LT2 section of this document (specifically, in section 7.1.2): membrane filtration, bag or cartridge filtration options, and disinfection options including chlorine, chlorine dioxide, ozone, and UV.

Information about disinfection practices for ground water systems is available online: https://www.epa.gov/dwreginfo/drinking-water-distribution-system-tools-and-resources#dbps. A limited discussion of the relationship between UV dose and virus inactivation of adenovirus follows.

7.2.4.2 Ultraviolet Virus Inactivation of Adenovirus

UV disinfection is less effective at inactivating some viruses, particularly adenovirus, due in part that UV-induced deoxyribonucleic acid (DNA) damage may be repaired during cell culture assays (Eisheid et al., 2009).

To demonstrate 3- or 4-log inactivation for viruses, validation testing would need to demonstrate greater than 6-log inactivation of MS2 phage. Such a demonstration requires an extremely high concentration in the reactor influent to allow for enumeration of the organisms in the effluent samples. Because of the need for serial dilutions, these high concentrations are difficult to measure and can introduce error into the experiment (USEPA, 2022b).

Research to find alternative challenge microorganisms for demonstrating virus inactivation is ongoing (USEPA, 2022b). Some recent validations have included *B. pumilus* spores, *A. brasiliensis*, and Adenovirus type-2 as high resistant test microorganisms for virus UV inactivation applications, but there are differing practices for applying these test microbes in validation testing and differing acceptance criteria are often encountered in validation reports (USEPA, 2022b).

The UV Treatment toolkit (USEPA, 2022b) clarifies that the *Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems* (USEPA, 2020b) document describes four alternative calculated dose procedures that do not require the use of *B. pumilus* spores, *A. brasiliensis*, and Adenovirus type-2, which often have higher observed dose response variability and no established QA/QC dose-response-bounds criteria.

EPA stated at the time of the publication of the final GWR (USEPA, 2006b) that it believed that UV technology could be used in a series configuration or in combination with other inactivation or removal technologies to provide a total 4-log treatment of viruses to meet the GWR's requirements. EPA also stated its belief that a UV reactor dose verification procedure for 4-log inactivation of a range of viruses may be developed in the future. With future development of UV validation procedures since the rule publication, it is now feasible for systems to demonstrate that they can achieve 4-log inactivation of viruses with UV treatment alone.

Linden et al. (2015) described that adenovirus is very resistant to UV light requiring a relatively high UV dose of 186 mJ/cm^2 based on LP UV light at 254 nm for 4-log inactivation credit; and that many of the test microbes used for UV reactor testing (e.g., MS2 phage, *B. subtilis* spores, and T1 phage) are too sensitive to UV light to demonstrate such high UV dose values.

7.2.5 Compliance Challenges for Small Systems

EPA has found in Chapter 6 that small undisinfected ground water systems are more likely to have higher total coliform rates than larger undisinfected ground water systems, and that thousands of them have total coliform rates above 5 percent. These findings coincide with an understanding of technical, managerial and financial limits for small system compliance and suggest a need to improve those compliance factors.

7.2.6 CT Tables for Log Inactivation of Viruses

As discussed earlier, one of the corrective actions appropriate for response to source water fecal contamination is providing 4-log viral inactivation/removal during treatment. Since the SYR3 process, EPA has recognized that some literature indicated the CT[5] tables for viruses existing in the Surface Water Treatment Rule (SWTR) Guidance Manual might not be sufficiently

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[5] CT is defined as disinfectant residual concentration (C) multiplied by contact time (T). A CT value is a measure of disinfection effectiveness for the time that microorganisms in the water are in contact with a disinfectant.

protective. Since the SWTRs are currently under consideration for a revision, the CT tables for log inactivation of viruses are not discussed in detail further here.

Malayeri et al. (2016) provides a summary of recent research regarding fluence UV dose required to achieve incremental log inactivation of bacteria, protozoa, viruses, and algae.

7.3 Revised Total Coliform Rule

EPA promulgated the RTCR on February 13, 2013 (and minor corrections on February 26, 2014) and the rule became effective on April 1, 2016. The RTCR is the revision to the 1989 TCR and protects public health through the reduction of potential pathways of entry for fecal contamination into distribution systems. The RTCR ensures the integrity of all PWSs[6] by requiring PWSs that are vulnerable to microbial contamination to find and fix operations and maintenance problems. Key RTCR provisions include: setting a MCLG and MCL for *E. coli*; setting a total coliform TT requirement; requiring PWSs to monitor for total coliforms and *E. coli* according to a specific sampling schedule and site plan; requiring assessments and corrective actions to identify and eliminate sanitary defects when monitoring results indicate that a system may be vulnerable to contamination due to the total coliform and *E. coli* positives; and requiring seasonal systems (i.e., NCWSs not operated on a year-round basis that start up and shut down at the beginning and end of each operating season) to monitor and certify the completion of state-approved start-up procedures. The RTCR also requires PN for violations and requires CWSs to include specific language in their CCRs when they must conduct an assessment or if they incur an *E. coli* MCL violation.

Systems that exceed a specified frequency of total coliform positive sample occurrences or incur an *E. coli* MCL violation trigger the rule’s TT requirements and must 1) conduct a Level 1 or Level 2 assessment to determine if any sanitary defects exist; and 2) correct any sanitary defects, which are defects that provide a pathway of entry for microbial contamination into the distribution system or failure of a barrier already in place. This approach is referred to as the “find and fix approach.” The RTCR specifies two levels of TT triggers and corresponding levels of assessment (Level 1 and Level 2) in response to those triggers. The degree and depth to which a PWS must examine its system depend on the TT trigger’s potential impact on public health.

The “find and fix” regulatory framework is supported by the *Revised Total Coliform Rule Assessments and Corrective Actions Guidance Manual: Interim Final* (USEPA, 2014b). As discussed in section 6.2.1 of the Occurrence and Exposure chapter, EPA analyzed the SYR4 ICR data and observed that both total coliform positive rates and routine *E. coli* positive rates have decreased after the implementation of RTCR between 2015 and 2018. Note that RTCR became effective on April 1, 2016 and the records were included from 2015 as a pre-RTCR implementation baseline. As shown in Exhibit 6-12, this decreasing trend is applicable to systems in different categories, i.e., source water types.

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[6] The RTCR applies to all PWSs except aircraft water systems, which are subject to the Aircraft Drinking Water Rule (40 CFR 141 Subpart X).

7.3.1 Description of Level 1 and Level 2 Assessments

Level 1 and 2 assessments are conducted in order to identify the possible presence of sanitary defects and defects in distribution system monitoring practices, including those defects that may have caused total coliform positive samples and triggered the assessment (40 CFR 141.2). Both assessments must include a review and identification of atypical events that could affect distributed water quality or indicate that distributed water quality was impaired; changes in distribution system maintenance and operation that could affect distributed water quality (including water storage); source and treatment considerations that impact distributed water quality, where appropriate (e.g., whether a ground water system is disinfecting); existing water quality monitoring data; and inadequacies in sample sites, sampling protocol, and sample processing.

Exhibit 7-8 lists the RTCR TT triggers for Level 1 and Level 2 assessments.

Exhibit 78-9. Revised Total Coliform Rule Treatment Technique Triggers for Level 1 and Level 2 Assessments

RTCR Assessment Level	Triggers
Level 1 Assessment Triggers	For systems taking 40 or more samples (including routine and repeat samples) per month, the PWS exceeds 5.0 percent total coliform positive samples for the month.
	For systems taking fewer than 40 samples (including routine and repeat samples) per month, the PWS has two or more total coliform positive samples in the same month.
	The PWS fails to take every required repeat sample after any single total coliform positive sample.
Level 2 Assessment Triggers	The PWS has an *E. coli* MCL violation.
	The PWS has a second Level 1 TT trigger within a rolling 12-month period unless the state has determined that the PWS found the sanitary defect that likely caused the first Level 1 TT trigger, and the PWS corrected or fixed the sanitary defect before the second Level 1 TT trigger occurred. With the state's approval, the system would not trigger a Level 2 assessment but would need to conduct a second Level 1 assessment.
	For PWSs with approved reduced annual monitoring, the system has a Level 1 TT trigger in two consecutive years.

Source: 40 CFR 141.859 (a)

A system must conduct a Level 1 or Level 2 assessment consistent with State requirements if the system exceeds one of the TT triggers discussed in Exhibit 7-8. The system must comply with any expedited actions or additional actions required by the State in the case of an *E. coli* MCL violation. A Level 2 assessment involves a more comprehensive investigation and review of available information, additional and internal and external resources, and other relevant practices (USEPA, 2020c).

When a PWS has a second Level 1 TT trigger within a rolling 12-month period, this triggers a Level 2 TT unless the state has "reset" the PWS by determining that the PWS found the sanitary defect that likely caused the first Level 1 TT trigger, and corrected or fixed the sanitary defect before a second Level 1 TT trigger occurred. When a PWS is "reset" with the state's approval, the system would not trigger a Level 2 assessment due to a second Level 1 TT trigger within a rolling 12-month period, but would instead need to conduct a second Level 1 assessment (40 CFR 141.859(a)(2)(ii).

Primacy agencies provide PWSs specific directives and forms for conducting and documenting assessments. A Level 1 assessment must be conducted by the PWS, unless the state specifies otherwise. Level 2 assessments must be conducted by the state or parties approved by the state. Some examples of such approved parties could include state personnel; an operator certified by the state to operate a system of similar size, type and complexity; technical assistance provider such as a circuit rider; a supervisor or manager from the water system, supported by other experts or employees of the system; and/or a consultant/consulting engineer.

All sanitary defects identified during a Level 1 or Level 2 assessment must be corrected within 30 days of the date that the PWS learns it has exceeded a TT-trigger or within a schedule approved by the primacy agency.

A discussion of data quality considerations regarding the reporting of Level 1 and Level 2 assessments is included in Appendix C. Also included in Appendix C is a characterization of the recurrence of multiple RTCR assessments at individual PWS; frequency that RTCR assessments were unable to identify a sanitary defect or corrective action; and types of sanitary defects identified during RTCR assessments.

7.3.2 Description of Corrective Actions

Corrective actions are measures taken to address or fix any sanitary defect(s). The type of corrective action that a system performs will depend on the type of sanitary defect identified. The system must complete corrective actions within 30 days of triggering the assessment or on a timetable approved by the State. The objective of RTCR Level 1 and Level 2 assessments is to identify pathways of microbial drinking water contamination and to correct sanitary defects identified. Sanitary defects can be resolved using distribution system corrective actions specified by the RTCR corrective action guidance, tools of the distribution system toolbox or as approved by the primacy agency.

It should also be noted that in addition to corrective actions taken within distribution systems, treatment enhancements in the treatment train for improving the quality of water entering distribution systems can also be helpful to reduce total coliform / *E. coli* detections in distribution systems and can be part of considerations of corrective actions. For instance, the enhanced TOC removal or operation of filters in a biological mode will help improve the biological stability of the treated water and thus maintain residual levels throughout distribution systems, resulting in lower total coliform/ *E. coli* detection rates. However, these types of treatment enhancements are currently part of ongoing considerations for potential revisions of microbial and disinfection by-product rules and will not be covered in this document any further.

Since the RTCR, EPA has compiled information about tools that have been used to help the public water systems to manage and improve the water quality throughout the distribution system (see https://www.epa.gov/dwreginfo/drinking-water-distribution-system-tools-and-resources), which will be described herein as the distribution system toolbox. A discussion of the characterization of RTCR assessments and occurrence of sanitary defects in DS and corrective actions is highlighted below in Section 7.3.3.

7.3.3 Advances/Improvements/Innovations to Revised Total Coliform Rule Treatment Techniques

USEPA has developed many resources and tools related to distribution system water quality which may be helpful to PWSs and others seeking to address total coliform positives and *E. coli* positives as related to RTCR sanitary defects. These resources, which are summarized on USEPA's distribution system website, are referred to here as the distribution system toolbox (USEPA, 2023). The distribution system toolbox includes techniques such as disinfection, flushing, repair and replacement of distribution system components, pressure management, water age, storage facility maintenance, cross-connection control and backflow prevention, sampling, monitoring, operations plan, and corrosion control. Many of these distribution system improvements also are being considered under the MDBP rule revisions effort currently under consideration by the National Drinking Water Advisory Council, and they are not described further in this SYR4 support document.

ASDWA conducted a survey about distribution system practices that was completed by drinking water representatives from 41 states and territories (2020). The survey covered many of the same techniques as described in the toolbox. ASDWA found that at least 12 states (30 percent of respondents) have flushing requirements written in their state legislation to better ensure a safe and reliable distribution system (ASDWA, 2020). Of the 70 percent of state respondents that do not require a flushing program, many strongly recommend it. Some of the methods to encourage a flushing program include either requiring a flushing plan to be eligible for Drinking Water State Revolving Fund (DWSRF) funding or encouraging it to be a part of the water system's operations and maintenance plan during sanitary surveys (ASDWA, 2020). ASDWA also found that most states specify a requirement of 20 psi as a minimum pressure limit and that some states also have a maximum pressure limit; typically between 60 and 150 psi. They found that 53 percent of responding states require a cross-connection survey and half of those require the survey to include all water use equipment (e.g., cooling towers, spray misters, spas, and pools) (ASDWA, 2020).

The American Water Works Association (AWWA) also has developed guidance that may be helpful with addressing RTCR sanitary defects. For example, the AWWA M68 manual suggests that, to remove sediment and biofilm that may harbor nitrifying bacteria, storage facilities should be inspected and cleaned at least every five years (AWWA, 2017). AWWA conducted its fifth disinfection survey in 2017 which collected information from water systems on their common treatment practices (AWWA, 2018; AWWA, 2021). Survey responses were summarized for a total of 375 water systems, distributed across 44 states and one United States territory, and represented 0.7 percent of the approximately 52,700 community water systems in the United States. Systems noted that meeting minimum chlorine target levels is more challenging in the distribution system than it is for meeting the targets for primary disinfection. The report showed 12 percent of systems reported frequent difficulties in meeting their chlorine residual targets in the distribution system while the majority of the respondents reported having difficulty on occasion (AWWA, 2018). Gibson and Bartrand (2021) evaluated publicly available data for secondary disinfection practices of 3,823 CWSs and found that 831 systems do not provide residual (secondary) disinfection.

A more detailed explanation of new information regarding the RTCR corrective actions is included in Appendix D.

7.4 Aircraft Drinking Water Rule

The ADWR became effective in October 2011 and established barriers of protection from disease-causing organisms in the air carrier industry and to ensure that safe and reliable drinking water is provided to aircraft passengers and crew. The ADWR applies only to aircraft with onboard water systems that provide water for human consumption through pipes and regularly serve an average of at least 25 individuals daily, at least 60 days out of the year, and that board only finished water for human consumption. The ADWR assumes that no additional treatment is necessary for aircraft water systems if finished water is boarded. Air carriers develop and implement an operations and maintenance plan for each aircraft water system in active service that identifies the frequency of routine disinfection and flushing for aircraft water systems. In addition, air carriers develop a coliform sampling plan covering each aircraft owned or operated by the carrier and routinely disinfect and flush aircraft water systems at the frequency recommended by the water system manufacturer. The minimum frequency of sampling can range from 1 to 12 times per year and is based upon the chosen minimum frequency of routine disinfection and flushing of the aircraft [40 CFR 141.803(b)(3)].

7.4.1 Corrective Actions

The Interim Final Guidance Manual for the Aircraft Drinking Water Rule (ADWR) clarifies the appropriate corrective actions for the occurrence of total coliform positives and *E. coli* positives [40 CFR 141.803(c)(2&3)] (USEPA, 2010c). These corrective actions can include disinfection and flushing, follow-up sampling, restricting public access, and repeat sampling depending upon the water quality or operation and maintenance trigger. When restricting public access, notification is to be provided within 24 hours to the crew and posted in the aircraft to notify passengers of the restricted access.

Corrective actions required for *E. coli* positive include restriction of public access; conducting corrective action with disinfection and flushing; and follow-up sampling. Corrective disinfection and flushing are triggered by failure to collect appropriate coliform samples and the following positive sample situations: any repeat total coliform positive or *E. coli* positive sample; routine or follow-up *E. coli* positive sample; and routine total coliform positive sample if corrective disinfection and flushing option is selected. Corrective action disinfection and flushing is also required for boarded water that does not comply with FDA regulations, meet TNCWS standards or is otherwise determined to be unsafe.

7.4.2 New Information Available since Aircraft Drinking Water Rule Promulgation

Several studies have been identified since ADWR promulgation that address bacterial growth, disinfection and flushing, restricting public access, and other operations and maintenance topics. These studies underscored the benefits of corrective actions under ADWR and identified aspects that could improve communication and water transport.

7.4.2.1 Potential for Bacterial Growth and Temperature of Water

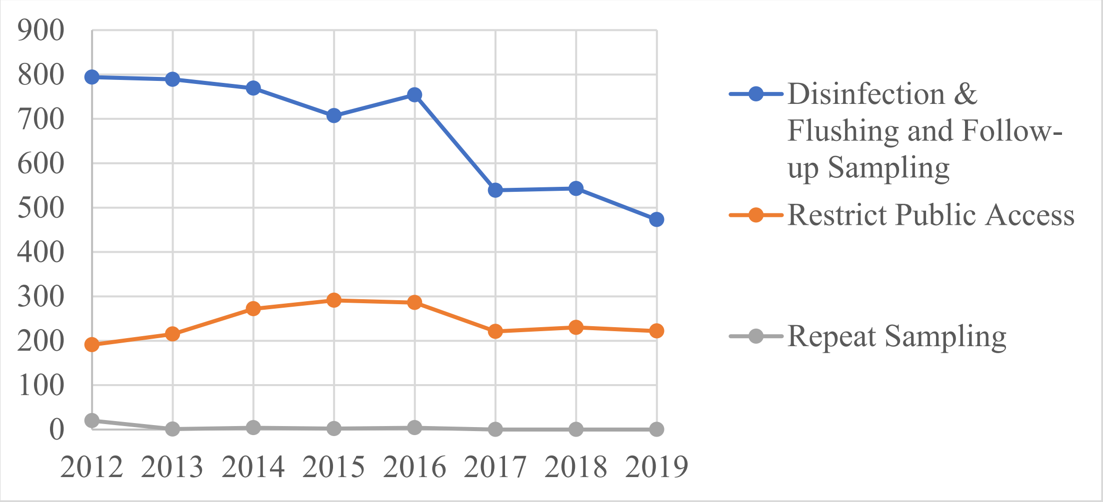
Handschuh et al. (2015) conducted a study that analyzed water quality from short-haul and long-haul aircraft and water service vehicles on a weekly basis. The study found a significant difference in that the long-haul aircraft showed a degraded microbial quality in comparison to short-haul aircraft, with the long-haul aircraft having a mean viable microbial count of 12,000 colony forming unit per milliliter (cfu/mL) as compared to short-haul count of 4800 cfu/mL during the September through December 2010 study period. The study suggested that long-haul aircraft may require more operations and maintenance activities to maintain water quality.

Handshuh et al. (2015) also found that for both long- and short-haul aircraft, there were higher levels of chlorine (free and total) discovered in the water service vehicle and water source than on the aircraft itself. The study also reported that the temperature of both the aircraft water and water service vehicle, and viable bacterial count of the water service vehicle, had a significant impact on on-board aircraft bacterial levels. The water service vehicle was identified as a significant source of increased microbial load within aircraft water tanks having a maximum viable microbial count of 140,000 cfu/mL during the Sept. – Dec. 2010 study period (Handshuh et al., 2015).

A study by Platkin (2019a), found that the number of ADWR violations by all aircraft in 2018 was significantly less than the number in 2012, the first year after the ADWR was implemented. For major aircraft, violations have decreased 69 percent (262 to 81) while violations among regional aircraft have decreased 71 percent (351 to 103).

EPA found that disinfection/flushing and follow-up sampling performed as a corrective action under ADWR (i.e., in response to total coliform positives / *E. coli* positives) occurred 39.5 percent less frequently in 2019 than in 2012 (See Exhibit 7-9) (USEPA, 2022c). Caution should be used when interpreting these data since a reduction in the occurrence of disinfection/flushing and follow-up sampling corrective actions does not necessarily imply there is a reduction in fecal risk since disinfection and flushing and follow-up sampling could be performed in situations of total coliform positive and *E. coli* negative sample results.

Exhibit 710-11. Aircraft Drinking Water Rule – Number of Systems Performing Corrective Actions by Year – 2012 to 2019



Source: *ADWR Compliance Public Reports – Aircraft Drinking Water Rule System Operations* (USEPA, 2022c)

7.4.2.2 Disinfection and Flushing

Szabo et al. (2019) studied a mock pilot-scale aircraft drinking water system to measure the effectiveness of routine disinfection and flushing in preventing coliform persistence. The authors found that coliform bacteria are not persistent on aircraft plumbing surfaces and following routine flushing using disinfectants consisting of chlorine dioxide (i.e., Purogene®), ozone or mixed oxidant. While coliform bacteria were not detected in the bulk mock aircraft plumbing surfaces and distribution plumbing, one exception was that the aerator installed in the lavatory faucet continued to be total coliform positive following the routine disinfection and flushing procedure.

Szabo et. al. (2019) concluded that faucet aerators could be a source of coliform contamination that may result in total coliform positive samples. The study proceeded to conduct experiments with the total coliform positive aerators and found that 30 minutes of soaking disinfection yielded coliform negative results (i.e., no detectable coliforms). The aerators soaked in commercially available and commonly used cleaning agents during the study contained 100 mL of either Glyco-San® or quaternary ammonium compounds (e.g., Lysol®).
EPA considers disinfection and flushing to be a more protective and pro-active public health measure than monitoring. For the final ADWR rule, EPA re-aligned the disinfection, flushing and monitoring frequencies to emphasize the importance of disinfection and flushing in comparison to monitoring. As a result, those air carriers that conduct more frequent disinfection and flushing do not have to monitor as frequently.

The ADWR requires that the air carrier conduct disinfection and flushing of the aircraft water system in accordance with, or is consistent with, the water system manufacturer's recommendations. The air carrier may conduct disinfection and flushing more frequently, but not less frequently, than the manufacturer recommends [40 CFR 141.804(b)(2)(i)].

Review of the ADWR PWS inventory as of June 2021 indicated that 97.6 percent of aircraft were scheduled to conduct routine disinfection and flushing a minimum of four times per year.

While it may seem prudent to establish requirements for sampling, disinfection and flushing for vehicles used to transport water, in fact, the sampling performed in the aircraft is intended to be representative of the entire aircraft water system including water received from transport. One aspect that adds complexity to the representative sampling of the aircraft is that the aircraft water tank may not be completely drained between fillings and therefore water from more than one source is usually commingled in the aircraft water system. Water tanks are generally only completely emptied and refilled when the water system is serviced, when the water on board has been completely consumed, and when the aircraft is not in operation during cold winter days to avoid the system freezing (Handschuh et al., 2015).

7.4.2.3 Restrict Public Access and Notification to Passengers and Crew

Restricted public access is required by ADWR as a corrective action for *E. coli* positive samples and is optional in total coliform positive / *E. coli* negative sample result situations (USEPA, 2010c). Restricted public access is defined as: physically disconnecting or shutting off the aircraft water system or otherwise preventing the flow of water through the tap(s); providing public notification via delivery methods such as broadcast via aircraft announcement, prominently displayed in lavatories for passengers and prominent notice in the galley for crew, or via hand delivery of notice; and providing alternatives to water from the aircraft water system, such as bottled water, antiseptic hand gels or wipes and other feasible measures that reduce or eliminate the need to use the aircraft water system (40 CFR 141.803(d)).

This SYR4 review identified ADWR restricted public access corrective actions by year for the period of 2012 to 2019. As shown in Exhibit 7-9, corrective actions for restricted public access remained relatively constant throughout the SYR4 review period.

Platkin (2019b) reported that representatives from the Air Line Pilots Association, International, expressed written comment to EPA at the time of ADWR rule proposal that although public notice of a coliform or *E. coli* positive result would be required, this public notice would not be provided to persons who may have already been sickened before the discovery of the water sample.

The ADWR does not require public notice to passengers of coliform or *E. coli* positive results that are obtained from an aircraft they have flown on the date of or before the date of water sample collection having positive results for coliform or *E. coli*. As mentioned previously with regard to representative sampling, one aspect that adds to the complexity to retroactive passenger notification of positive results is that the aircraft water tank may not be completely drained between fillings and therefore water from more than one source is usually commingled in the aircraft water system.

7.4.2.4 Repeat Sampling

This SYR4 review identified ADWR repeat sampling corrective actions by year for the period of 2012 to 2019. As shown in Exhibit 7-9, corrective actions for repeat sampling remained relatively constant throughout the SYR4 review period.

No additional new information was found regarding the ADWR corrective action of repeat sampling.

7.4.2.5 Other Operation & Maintenance Topics

The Airport Cooperative Research Program (ACRP), sponsored by the Federal Aviation Administration, provided a synthesis report of airport practice regarding airport community, water quality events and the ADWR in 2018. This report summarized numerous observations and conclusions regarding the implementation of ADWR including but not limited to the following operation and maintenance challenges: emergency communications, situational notification, and contractual and regulatory obligations including those to the U.S. FDA (ACRP, 2018).

A significant challenge identified by the ACRP is that airports and aircraft are not receiving prompt and accurate notification of a community PWS water quality issue for the water serving an airport. The airport contact stakeholders are currently often notified in the same manner and time frame as the general public, which often means notice is received late or not at all. The report suggested that appropriate airport personnel be added to the community PWS critical customer contact list. Additional suggestions were provided for communication of stakeholders within the airport affected entities (ACRP, 2018). Some synthesis participants suggested that water quality events be addressed by the airport similar to communicable disease responses (ACRP, 2018).

The report suggested additional research or collaboration regarding water cabinet quality and maintenance: connective hose condition and exposure to sunlight; water stagnation; water boarding procedures without proper flushing of equipment; options for airport water system treatment; and international terminal water quality maintenance (ACRP, 2018).

7.5 Filter Backwash Recycling Rule

EPA promulgated the Filter Backwash Recycling Rule (FBRR) on June 8, 2001 (66 FR 31086). The rule aimed to increase public health protection by addressing microbial contaminant risks associated with filter backwash recycling practices. The rule required certain systems to return recycled filter backwash water, sludge thickener supernatant, and liquids from dewatering processes to a location in the system such that all filtration processes of a system are employed, or at an alternate location if approved by the State. In addition, the rule required systems that employ conventional filtration or direct filtration to notify States of their recycling practices by June 8, 2004, and after then to keep and retain records on file about their recycle flows for subsequent review and evaluation by the State. There are no ongoing monitoring requirements associated with the FBBR.

EPA reviewed available State data collected under the ICR; however, the EPA did not identify any new and relevant information that would indicate that revisions to the NPDWR are appropriate at this time.

8 References

Abebe, L.S., Y-H Su, R.L. Guerrant, N.S. Swami, and J.A. Smith. 2015. Point-of-Use Removal of *Cryptosporidium* Parvum from Water: Independent Effects of Disinfection by Silver Nanoparticles and Silver Ions and by Physical Filtration in Ceramic Porous Media. *Environ. Sci. Technol*. 49:21, 12958-12967.

Airport Cooperative Research Program (ACRP). 2018. ACRP Synthesis 88 – Airport Community, Water Quality Events, and the Aircraft Drinking Water Rule, National Academy of Sciences.

Ahmed, W., K. Hamilton, S. Toze, S. Cook, and D. Page. 2019. A Review on Microbial Contaminants in Stormwater Runoff and Outfalls: Potential Health Risks and Mitigation Strategies. *Science of the Total Environment*, 692, 2019, 1304-1321.

Alspach, B. 2019. Charting the Reverse Osmosis Renaissance. *Journal AWWA*, 111:8, 85-87.

Association of State Drinking Water Administrators (ASDWA). 2019. A Study Examining Contamination of Total Coliform Samples. https://www.asdwa.org/2019/04/15/a-study-examining-contamination-of-total-coliform-samples/.

ASDWA. 2020. State Drinking Water System Survey. https://www.asdwa.org/wp-content/uploads/2020/09/ASDWA-Distribution-System-Survey-White-Paper-2020.pdf#:~:text=In%20May%202020%2C%20the%20Association%20of%20State%20Drinking,that%20could%20be%20used%20to%20inform%20future%20regulations.

Ashbolt, Nicholas J. 2015. Microbial contamination of drinking water and human health from community water systems. *Current Environmental Health Reports,* 2(1): 95-106.

Audebert, C., F. Bonardi, S. Caboche, K. Guyot, H. Touzet, S. Merlin, N. Gantois, C. Creusy, D. Meloni, A. Mouray, E. Viscogliosi, G. Certad, S. Benamrouz-Vanneste, and M. Chabé. 2020. Genetic basis for virulence differences of various *Cryptosporidium parvum* carcinogenic isolates. *Scientific Reports*. 10(1):7316.

American Water Works Association (AWWA). 2016. Water Treatment. https://www.awwa.org/portals/0/files/publications/documents/wsograde1excerpt.pdf.

AWWA. 2017. M68. Water Quality in Distribution Systems. Denver, CO: AWWA.

AWWA. 2018. *2017 Water Utility Disinfection Survey Report*. April 2018. Denver, Colo.: AWWA.

AWWA. 2020. *Disinfection of Water Storage Facilities*. ANSI/AWWA Standard C652. Denver, Colo.: AWWA.

AWWA. 2021. Emerging Trends in Disinfection: Lessons from AWWA's Disinfection Survey. *Journal AWWA*, 113(1) 20-28. https://doi.org/10.1002/awwa.1648

Baldasso, V., H. Lubarsky, N. Pichel, A. Turolla, M. Antonelli, M. Hincapie, L. Botero, F. Reygadas, A. Galdos-Balzategui, J.A. Byrne, and P. Fernandez-Ibañez. 2021. UVC inactivation of MS2-phage in drinking water – Modelling and field testing. *Water Research*, 203: 117496.

Barbhuiya, N. H., S.P. Singh, A. Makovitzki, P. Narkhede, Z. Oren, Y. Adar, and C.J. Arnusch. 2021. Virus inactivation in water using laser-induced graphene filters. *Materials*, 14(12), 3179.

Beck, S.E., H. Ryu, L.A. Boczek, J.L. Cashdollar, K.M. Jeanis, J.S. Rosenblum, O.R. Lawal, and K.G. Linden. 2017. Evaluating UV-C LED disinfection performance and investigating potential dual-wavelength synergy. *Water Research*, 109: 207-216.

Berger, P., M.J. Messner, J. Crosby, D.V. Renwick, and A. Heinrich. 2018. On the use of total aerobic spore bacteria to make treatment decisions due to *Cryptosporidium* risk at public water system wells. *International Journal of Hygiene and Environmental Health*, 221, 704-711

Blatchley, E.R, C. Shen, and K. Scheible. 2019. Design and Validation Protocols for UV Disinfection Systems. Water Research Foundation, Project No. ENER16C15/4791.

Blyth, J., M.R. Templeton, S-J Court, C. Luce, W. Cairns, and L. Hazell. 2021. Assessment of indigenous surrogate microorganisms for UV disinfection dose verification. *Water and Environment Journal*, 35(4): 1384-1392.

Borchardt, M.A., S.K. Spencer, B.A. Kieke, Jr., E. Lambertini, and F.J. Loge. 2012. Viruses in Nondisinfected Drinking Water from Municipal Wells and Community Incidence of Acute Gastrointestinal Illness. *Environmental Health Perspectives*, 120(9): 1272–1279.

Borchardt, M.A., B.A. Kieke, Jr., S. K. Spencer, E. Lambertini, T.R. Burch, and F.J. Loge. 2023, Community intervention trial for estimating risk of acute gastrointestinal illness from groundwater-supplied non-disinfected drinking water. *J Water Health* (2023) 21 (9): 1209–1227.

Burch, T.R., J.P. Stokdyk, N. Rice, A.C. Anderson, J.F. Walsh, S.K. Spencer, A.D. Firnstahl, and M.A. Borchardt. 2022. Statewide Quantitative Microbial Risk Assessment for Waterborne Viruses, Bacteria, and Protozoa in Public Water Supply Wells in Minnesota. *Environmental Science and Technology*, 56(10): 6315-6324.

Busse, M., M. Becker, B.M. Applegate, J.W. Camp Jr., and E.R. Blatchley III. 2019. Responses of *Salmonella typhimurium* LT2, *Vibrio harveyi*, and *Cryptosporidium parvum* to UVB and UVA radiation. *Chemical Engineering Journal*, 371: 647-658.

Calderon, R.L., and G.F. Craun. 2006. Estimates of endemic waterborne risks from community-intervention studies. *Journal of Water and Health,* 4(S2): 89-99.

Campinas, M., R.M.C. Viegas, R. Coelho, H. Lucas, and M.J. Rosa. 2021a. Adsorption/ Coagulation/ Ceramic Microfiltration for Treating Challenging Waters for Drinking Water Protection. *Membranes*, 11(2): 91.

Campinas, M., C. Silva, R.M.C. Viegas, R. Coelho, H. Lucas, and M.J. Rosa. 2021b. To what extent may pharmaceuticals and pesticides be removed by PAC conventional addition to low-turbidity surface waters and what are the potential bottlenecks? *Journal of Water Process Engineering*, 40: 101833.

Carvajal, G., A. Branch, P. Michel, S.A. Sisson, D.J. Roser, J.E. Drewes, and S.J. Khan. 2017. Robust evaluation of performance monitoring options for ozone disinfection in water recycling using Bayesian analysis. *Water Research*, 124: 605-617.

Centers for Disease Control and Prevention (CDC). 2017. Parasites – *Cryptosporidium* (also known as "*Crypto*"). Page last reviewed: August 16, 2017. https://www.cdc.gov/parasites/crypto/illness.html

Chalmers, R.M., K. Elwin, S.J. Hadfield, and G. Robinson. 2011. Sporadic human cryptosporidiosis caused by *Cryptosporidium cuniculus*, United Kingdom, 2007-2008. *Emerg Infect Dis.*, 17(3): 536-8.

Chang, J.C.H., S.F. Osoff, D.C. Lobe, M.H. Dorfman, C.M. Dumais, R.G. Qualls, and J.D. Johnson. 1985. UV inactivation of pathogenic and indicator microorganisms. *Applied and Environmental Microbiology,* 49: 1361–1365.

Chappell, C.L., P.C. Okhuysen, R.C. Langer-Curry, D.E. Akiyoshi, G. Widmer, and S. Tzipori. 2011. *Cryptosporidium meleagridis*: infectivity in healthy adult volunteers. *American Journal of Tropical Medicine and Hygiene*, 85(2): 238.

Chen, C., L. Guo, Y. Yang, K. Oguma, and L.A. Hou. 2021. Comparative effectiveness of membrane technologies and disinfection methods for virus elimination in water: A review. *Science of the Total Environment*, 801: 149678.

Colford, Jr., J.M., S. Roy, M.J. Beach, A. Hightower, S.E. Shaw, and T.J. Wade. 2006. A review of household drinking water intervention trials and an approach to the estimation of endemic waterborne gastroenteritis in the United States. *Journal of Water and Health*, 4 (S2): 71-88.

Collier, S.A., L. Deng, E.A. Adam, K. M. Benedict, E.M. Beshearse, A.J. Blackstock, B.B. Bruce, G. Derado, C. Edens, K.E. Fullerton, J.W. Gargano, A.L. Geissler, A.J. Hall, A.H. Havelaar, V.R. Hill, R.M. Hoekstra, S.C. Reddy, E. Scallan, E.K. Stokes, J.S. Yoder, and M.J. Beach. 2021. Estimate of Burden and Direct Healthcare Cost of Infectious Waterborne Disease in the United States. *Emerging Infectious Diseases.* 27(1):140-149.

Eisheid, A.C., J.N. Meyer, and K.G. Linden. 2009. UV Disinfection of Adenoviruses: Molecular Indications of DNA Damage Efficiency. *Applied and Environmental Microbiology*, 75(1): 23-28.

Feng, Z., R. Lu, B. Yuan, Z. Zhou, Q. Wu, and T.H. Nguyen. 2016. Influence of solution chemistry on the inactivation of particle-associated viruses by UV irradiation. *Colloids and Surfaces B Biointerfaces*, 148: 622-628.

Fout, G.S., M.A. Borchardt, B.A. Kieke, and M.R. Karim. 2017. Human virus and microbial indicator occurrence in public-supply groundwater systems: meta-analysis of 12 international studies. *Hydrogeology Journal*, 25(4): 903-919.

Gallandat, K., D. Stack, G. String, and D. Lantagne. 2019. Residual Maintenance Using Sodium Hypochlorite, Sodium Dichloroisocyanurate, and Chlorine Dioxide in Laboratory Waters of Varying Turbidity. *Water*, 11(6): 1309.

Gao, Y., Z. Sun, Y. Guo, Z. Qiang, and W. Ben. 2023. Virus inactivation by sequential ultraviolet-chlorine disinfection: Synergistic effect and mechanism. *Chemosphere*, 314: 137632

Gerdes ME, Miko S, Kunz JM, Hannapel EJ, Hlavsa MC, Hughes MJ, Stuckey MJ, Francois Watkins LK, Cope JR, Yoder JS, Hill VR, Collier SA. 2023. Estimating Waterborne Infectious Disease Burden by Exposure Route, United States, 2014. *Emerg Infect Dis*. Jul;29(7):1357-1366.

Gibson, M.C. and T.A. Bartrand. 2021. Understanding Community Water System Disinfection Practices in the United States. *Journal AWWA*, 113(6):38-46.

Gilpin, B.J., T. Walker, S. Paine, J. Sherwood, G. Mackereth, T. Wood, T. Hambling, C. Hewison, A. Brounts, M. Wilson, P. Scholes, B. Robson, S. Lin, A. Cornelius, L. Rivas, D.T.S. Hayman, N.P. French, J. Zhang, D.A. Wilkinson, A.C. Midwinter, P.J. Biggs, A. Jagroop, R. Eyre, M.G. Baker, and N. Jones. 2020. A large scale waterborne Campylobacteriosis outbreak, Havelock North, New Zealand. *Journal of Infection*. 81: 390-395.

Great Lakes Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (GLUMRB). 2018. Recommended Standards For Water Works- Policies for the Review and Approval of Plans and Specifications for Public Water Supplies. Water Supply Committee, GLUMRB. https://www.health.ny.gov/environmental/water/drinking/regulations/docs/2018_recommended_standards.pdf.

Gutiérrez-Alfaro, S., A. Acevedo, J. Rodríguez, E.A. Carpio, and M.A. Manzano. 2015. Solar photocatalytic water disinfection of *Escherichia coli*, *Enterococcus* spp. and Clostridium Perfringens using different low-cost devices. *J. Chem. Technol. Biotechnol.*, 91: 2026-2037.

Handschuh, H., J. O’Dwyer, and C.C. Adley. 2015. Bacteria that travel: the quality of aircraft water. *International Journal of Environmental Research and Public Health*, 12(11): 13938-13955.

Handschuh, H., M.P. Ryan, J. O’Dwyer, and C.C. Adley, 2017. Assessment of the bacterial diversity of aircraft water: identification of the frequent fliers. *PloS One*, 12(1): e0170567.

Harmsco 2014. *Cryptosporidium* surrogate HC/90-LT2 Filter Performance Test: 2.0 micron latex spheres, IBR Laboratories, May 2014.

Heinrich, A., D.V, Renwick, R. Weisman, A. Greene, S. Regli, K. Roland, and K. Rotert. 2022. Using Sanitary Survey Findings to Identify Risk Management Challenges. *JAWWA*. 114:5: 34-45.

Hill, C., D. Owen, S. Trussell, A. Evans, E. Houtz, S. Sriboonlue, S.Triolo, and K. Thompson. 2018. Alternative Water Source Requirements for Conventional Drinking Water Treatment. Water Research Foundation. Project #4665.

Holmes, E. 2019. Development and evaluation of chitosans as transformative coagulants-flocculants to improve sand filter drinking water treatment. University of North Carolina at Chapel Hill.

Hull, N.M. and K.G. Linden. 2018. Synergy of MS2 disinfection by sequential exposure to tailored UV wavelengths. *Water Research*, 143: 292-300.

Hull, N., W.H. Herold, and K.G. Linden. 2019. UV LED water disinfection: Validation and small system demonstration study. *AWWA Water Science*, July/August 2019, e1148.

Hunter P.R. and G. Nichols. 2002. Epidemiology and clinical features of *Cryptosporidium* infection in immunocompromised patients. *Clin Microbiol Rev*. 15(1): 145-54.

Jacangelo, J.G., A. Subramani, S. Gray, and M. Cran. 2019. Methods for Integrity Testing and Online Monitoring of NF and RO Membranes. Water Research Foundation. Project No. Reuse-12-07/4757.

Jaferey, I. and G. Galjaard. 2020. Back to Ceramics: Centuries old material proves its mettle in maximizing financial and operational performance. *Water Environment & Technology*, June 2020, 33-37.

Jarvis, P., O. Autin, E.H. Goslan, and F. Hassard. 2019. Application of Ultraviolet Light-Emitting Diodes (IV-LED) to Full-Scale Drinking Water Disinfection. *Water*, 11(9): 1894.

Juranek, D.D. 1995. Cryptosporidiosis: sources of infection and guidelines for prevention. *Clin Infect Dis.* 21 Suppl 1:S57-61.

Keithlin, J., J. Sargeant, M.K. Thomas, and A. Fazil. 2014. Systematic review and meta-analysis of the proportion of *Campylobacter* cases that develop chronic sequelae. *BMC Public Health*, 14: 1203.

Keshavarzfathy, M., A.H. Malayeri, M. Mohseni, and F. Taghipour. 2020. UV-LED fluence determination by numerical method for microbial inactivation studies. *Journal of Photochemistry & Photobiology A: Chemistry*, 392: 112406.

Kim, D-K., S-J. Kim, and D-H. Kang. 2017. Inactivation modeling of human enteric virus surrogates, MS2, Qβ, and ΦX174, in water using UVC-LEDs, a novel disinfecting system. *Food Research International*, 91: 115-123.

Kinser, K. 2021. Membrane Filtration: Past, Present and Future. *Journal AWWA*. 113: 72-75.

Koehler, A.V., M.J. Whipp, S.R. Haydon, and R.B. Gasser RB. 2014. *Cryptosporidium cuniculus* – new records in human and kangaroo in Australia. *Parasit Vectors.* 7: 492.

Kotloff, K.L., J.P. Nataro, W.C. Blackwelder, D. Nasrin, T.H. Farag, S. Panchalingam, Y. Wu, S.O. Sow, D. Sur, R.F. Breiman, A.S. Faruque, A.K. Zaidi, D. Saha, P.L. Alonso, B. Tamboura, D. Sanogo, U. Onwuchekwa, B. Manna, T. Ramamurthy, S. Kanungo, J.B. Ochieng, R. Omore, J.O. Oundo, A. Hossain, S.K. Das, S. Ahmed, S. Qureshi, F. Quadri, R.A. Adegbola, M.

Antonio, M.J. Hossain, A. Akinsola, I. Mandomando, T. Nhampossa, S. Acácio, K. Biswas, C.E. O'Reilly, E.D. Mintz, L.Y. Berkeley, K. Muhsen, H. Sommerfelt, R.M. Robins-Browne, and M.M. Levine. 2013. Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): a prospective, case-control study. *Lancet.* 382(9888): 209-22.

Linden, K.G., H.B. Wright, and S. Beck. 2015. Guidance for Implementing Action Spectra Correction with Medium Pressure UV Disinfection. Water Research Foundation Report #4376.

Mac Kenzie, W.R., N.J. Hoxie, M.E. Proctor, M.S. Gradus, K.A. Blair, D.E. Peterson, J.J. Kazmierczak et al. 1994. A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through the public water supply. *New England Journal of Medicine*, 331(3): 161-167.

Mackey, E.D., H.B. Wright, T. Hargy, J. Clancy, and A. Cabaj. 2006 (in press). *Optimization of UV Reactor Validation*. American Water Works Association Research Foundation, Denver, CO.

Malayeri, A.H., M. Mohseni, B. Cairns, and J.B. Bolton. 2016. Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae, IUVA News, 2016.

Malkoske, T.A., P.R. Berube, and R.C. Andrews. 2020. Coagulation/flocculation prior to low pressure membranes in drinking water treatment: a review. *Environ. Sci.: Water Res. Technol.*, 6: 2993.

Mattioli, M.C., K.M. Benedict, J. Murphy, A. Kahler, K.E. Kline, A. Longenberger, P.K. Mitchell, S. Watkins, P. Berger, O.C. Shanks, and C.E. Barrett. 2021. Identifying septic pollution exposure routes during a waterborne norovirus outbreak-A new application for human-associated microbial source tracking qPCR. *Journal of Microbiological Methods*, 180: 106091.

Mbonimpa, E.G., E.R. Blatchley III, B. Applegate, and W.F. Harper, Jr. 2018. Ultraviolet A and B wavelength-dependent inactivation of viruses and bacteria in the water. *Journal of Water and Health*, 16(5): 796-806.

Meng, Q.S., and C.P. Gerba. 1996. Comparative inactivation of enteric adenovirus, poliovirus and coliphages by ultraviolet irradiation. *Water Research,* 30(11): 2665–2668.

Messner, M.J., and P. Berger. 2016. *Cryptosporidium* Infection Risk: Results of New Dose-Response Modeling. *Risk Anal.* 36(10): 1969-1982.

Messner, M., S. Shaw, S. Regli, K. Rotert, V. Blank, and J. Soller. 2006. An approach for developing a national estimate of waterborne disease due to drinking water and a national estimate model application. *Journal of Water and Health,* 4(S2): 201-240.

Messner, M.J., P. Berger, and J. Javier. 2017. Total coliform and *E. coli* in public water systems using undisinfected ground water in the United States. *International Journal of Hygiene and Environmental Health*, 220(4): 736-743.

Miller, T.A., M.W. Ware, L.J. Wymer, and F.W. Schaefer III. 2007. Chemically and genetically immunocompromised mice are not more susceptible than immunocompetent mice to infection with *Cryptosporidium muris*. *Veterinary Parasitology*, 143(2): 99-105.

Moltz, H.L.N., R. Mandel, K.R. Bencala, J.B. Palmer, A. Nagel, and S. Kaiser. 2018. Forest Cover Impacts on Drinking Water Utility Treatment Costs in a Large Watershed. Water Research Foundation, Project 4651, 2018.

Monis, P., M. Lau, M. Harris, D. Cook, and M. Drikas. 2017. Risk-based management of drinking water safety in Australia: Implementation of health based targets to determine water treatment requirements and identification of pathogen surrogates for validation of conventional filtration. *Food and Waterborne Parasitology*, 2017(8-9): 64-74.

Mor, S.M., A. DeMaria, Jr., J.K. Griffiths, and E.N. Naumova. 2009. Cryptosporidiosis in the elderly population of the United States. *Clin Infect Dis.* 48(6): 698-705.

Mustafa, S., A. Bahar, A.R.Z. Abidin, Z.A. Aziz, and M. Darwish. 2021. Three dimensional model for solute transport induced by groundwater abstraction in river-aquifer systems. *Alexandria Engineering Journal*. 60: 2573-2582.

Naumova, E. N., A.I. Egorov, R.D. Morris, and J.K. Griffiths. 2003. The Elderly and Waterborne *Cryptosporidium* Infection: Gastroenteritis Hospitalizations before and during the 1993 Milwaukee Outbreak. *Emerging Infectious Diseases*, 9(4): 418-425.

National Drinking Water Advisory Council (NDWAC). 2000. Working Group Meeting on Contaminant Candidate List Regulatory Determinations and the 6-Year Review of Existing Regulations. Available online at: https://www.epa.gov/sites/production/files/2015-11/documents/march_1_2_2000_meeting_on_ccl_and_6_year_review.pdf

Nix, D.K., and J.S. Taylor. 2018. *Filter Evaluation Procedures for Granular Media*. Second Edition. AWWA, Denver, CO.

National Research Council (NRC). 2004. *Indicators for Waterborne Pathogens*. https://www.ncbi.nlm.nih.gov/books/NBK215663/pdf/Bookshelf_NBK215663.pdf.

Oudega, T.J., G. Linder, R. Sommer, A.H. Farnleitner, G. Kerber, J. Derx, M.E. Stevenson and A.P. Blaschke. 2022. Transport and removal of spores of Bacillus subtilis in an alluvial gravel aquifer at varying flow rates and implications for setback distances. *Journal of Contaminant Hydrology*, 251: 104080.

Oguma, K., S. Rattanakul, and J. Bolton. 2016. Application of UV Light-Emitting Diodes to Adenovirus in Water. *Journal Environmental Engineering*, 142(3): 04015082.

Oguma, K., S. Rattanakul, and M. Masaike. 2019. Inactivation of health-related microorganisms in water using UV light-emitting diodes. *Water Supply*, 19(5): 1507-1514.

Pang, L., A. Tham, P. Nilprapa, A. Cocker, P. MacDonald, R. Adams, B. Robson, D. Wood, V. Ward, and C. Nokes. 2022. *Cryptosporidium* surrogate removal in pilot-scale rapid sand filters comprising anthracite, pumice or engineered ceramic granular media, and its correlation with turbidity. *Journal of Water Process Engineering*, 46: 102614.

Patterson, M.E., Z. Bohrerova, T.A. Wolfe, and L.K. Weavers. 2021. Developing Design Criteria for Emerging Technologies in Ohio, *Journal AWWA*, 113, September 2021, 24-34.

Pedati, C., S. Koirala, T. Safranek, B.F. Buss, and A.V. Carlson. 2019. Campylobacteriosis outbreak associated with contaminated water supply – Nebraska, 2017. Centers of Disease Control and Prevention, *Morbidity and Mortality Weekly Report*, February 22, 2019.

Piche, A., A. Campbell, S. Cleary, I. Douglas, and O.D. Basu. 2019. Investigation of backwash strategy on headloss development and particle release in drinking water biofiltration. *Journal of Water Process Engineering*, 32: 100895.

Pitkanen, T. 2013. Review of *Campylobacter* spp. In drinking and environmental waters. *Journal of Microbiological Methods*. 95: 39-47.

Platkin, C. 2019a. Aircraft Water Study. Diet Detective. New York City Food Policy Center, September 13, 2019.

Platkin, C. 2019b. Background Aircraft Drinking Water Rule and Other Helpful Information, Diet Detective, New York City Food Policy Center, August 29, 2019.

Puzon, G.J., H.C. Miller, N. Malinowski, T. Walsh, and M.J. Morgan. 2020. Naegleria fowleri in drinking water distribution systems. *Current Opinion in Environmental Science & Health*, 16: 22-27.

Ramsay, L., F. Du, M. Lund, H. He, and D.A. Søborg. 2021. Grain Displacement during Backwash of Drinking Water Filters. *Water Supply*, 21(1): 356-367

Reynolds, K.A., K.D. Mena, and C.P. Gerba. 2008. Risk of waterborne illness via drinking water in the United States. *Reviews of Environmental Contamination and Toxicology,* 192: 117-158.

Samineni, L., B. Xiong, R. Chowdhury, A. Pei, L. Kuehster, H. Wang, R. Dickey, P.E. Soto, L. Massenburg, T.H. Nguyen, C. Maranas, D. Velegol, M. Kumar, and S. Velegol. 2019. 7 Log Virus Removal in a Simple Functionalized Sand Filter. *Environmental Science & Technology*, 53(21): 12706-12714.

Schaeffer, F., K. Tower, and A.S. Weiss'eld. 2012. What's Up with Aircraft Drinking Water? *Clinical Microbiology Newsletter*, 34(2): 9-13.

Schijven, J., J. Derx, A.M.R. Husman, A.P. Blaschke, and A. Farnleitner. 2015. QMRAcatch: Microbial Quality Simulation of Water Resources including Infection Risk Assessment. *Journal of Environmental Quality*, 44: 1491-1502.

Schmidt, P.J. and C.L. Chappell. 2016. Comment on "*Cryptosporidium* Infection Risk: Results of New Dose-Response Modeling" — Discussion of Underlying Assumptions and Their Implications. *Risk Analysis,* 36(12): 2189-2192.

Schmidt, P.J.; W.B. Anderson, and M.B. Emelko. 2020. Describing water treatment process performance: Why average log reduction can be a misleading statistic. *Water Research*, 176: 115702.

Selamat, R., I. Abustan, M.R. Arshad, and N.H.M. Kamal. 2019. Removal of Escherichia Coli Using Low-Frequency Electromagnetic Field in Riverbank Filtration, chapter in *Water and Wastewater Treatment*. London, UK: IntechOpen.

Shaheen, M., C. Scott, and N.J. Ashbolt. 2019. Long-term persistence of infectious *Legionella* with free-living amoebae in drinking water biofilms. *International Journal of Hygiene and Environmental Health*, 222(4): 678-686.

Sharma, P.R., S.K. Sharma, T. Lindstrom, and B.S. Hsiao. 2020. Nanocellulose-Enabled Membranes for Water Purification: Perspectives. *Advanced Sustainable Systems*, 4:5: 1900114.

Sholtes, K. and K.G. Linden. 2019. Pulsed and continuous light UV LED: microbial inactivation, electrical and time efficiency. *Water Research*, 165: 114965.

Sholtes, K.A., K. Lowe, G.W. Walters, M.D. Sobsey, K.G. Linden,and L.M. Casanova. 2016. Comparison of ultraviolet light-emitting diodes and low-pressure mercury-arc lamps for disinfection of water. *Environmental Technology*, 37(17): 2183-2188.

Silva, H.G. and L.P. Sabogal-Paz. 2020. Filter backwash water and floated residue containing pathogenic protozoa: detection method and treatment alternatives. *Water, Air & Soil Pollution*, 231: 129.

Singh, S.P., Y. Li, J. Zhang, J.M. Tour, and C.J. Arnusch. 2018. Sulfur-Doped Laser-Induced Porous Graphene Derived from Polysulfone-Class Polymers and Membranes. *ACS Nano*, 12(1); 289-297.

Soller, J.A. 2009. The potential implications of person-to-person transmission of viral infection for US EPA's Groundwater Rule. *J Water Health,* 7(2): 208–223.

Sommer, R., T. Haider, A. Cabaj, W. Pribil, and M. Lhotsky. 1998. Time dose reciprocity in UV disinfection of water. *Water Science and Technology,* 38: 145–150.

Song, K., F. Taghipour, and M. Mohseni. 2018. Microorganisms inactivation by continuous and pulsed irradiation of ultraviolet light-emitting diodes (UV-LEDs). *Chemical Engineering Journal*, 343: 362-370.

Song, K., F. Tahipour, and M. Mohseni. 2019. Microorganisms inactivation by wavelength combinations of ultraviolet light-emitting diodes (UV LEDs). *Science of the Total Environment*, 665: 1103-1110.

Stiff, R.E., A.P. Davies, B.W. Mason, H.A. Hutchings, and R.M. Chalmers. 2017. Long-term health effects after resolution of acute *Cryptosporidium parvum* infection: a 1-year follow-up of outbreak-associated cases. *Journal of Medical Microbiology*, 66(11): 1607-1611.

Stokdyk, J.P., S.K. Spencer, J.F. Walsh, J.R. de Lambert, A.D. Firnstahl, A.C. Anderson, L.-I. Rezania, and M.A. Borchardt. 2019. *Cryptosporidium* Incidence and Surface Water Influence of Groundwater Supplying Public Water Systems in Minnesota, USA. *Environmental Science and Technology*. 53(7): 3391-3398.

Stokdyk, J.P., A.D. Firnstahl, J.F. Walsh, S.K. Spencer, J.R. de Lambert, A.C. Anderson, L.W. Rezania, B.A. Kieke, Jr., and M.A. Borchardt. 2020. Viral, bacterial, and protozoan pathogens and fecal markers in wells supplying groundwater to public water systems in Minnesota, USA. *Water Res.,* 178: 115814.

Szabo, J., M. Rodgers, J. Mistry, J. Steenbock, and J. Hall, 2019. The effectiveness of disinfection and flushing procedures to prevent coliform persistence in aircraft water systems. *Water Supply*, 19(5): 1339-1346.

Urfer, D. 2017. Use of bauxite for enhanced removal of bacteria in slow sand filters. *Water Science & Technology: Water Supply*, 17(4): 1007-1015.

United States Environmental Protection Agency (USEPA). 1998. National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment; Final Rule. 63 FR 69477. December 16, 1998.

USEPA. 2000. Surface Water Analytical Tool (SWAT): Program Description and Assumptions, Version 1.1, Office of Ground Water and Drinking Water, Standards and Risk Reduction Division, November 2000, prepared with Malcom Pirnie under Cadmus Group.

USEPA. 2002. National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule. 67 FR 1812. January 14, 2002.

USEPA. 2003. National Primary Drinking Water Regulations; Announcement of Completion of EPA's Review of Existing Drinking Water Standards. 68 FR 42907. July 18, 2003.

USEPA. 2005a. Method 1622: *Cryptosporidium* in Water by Filtration/IMS/FA. EPA 815–R–05–001. December 2005.

USEPA. 2005b. Method 1623: *Cryptosporidium* and *Giardia* in Water by Filtration/IMS/FA. EPA 815–R–05–002. December 2005.

USEPA. 2005c. *Membrane Filtration Guidance Manual*. EPA 815-R-06-009. November 2005.

USEPA. 2006a. National Primary Drinking Water Regulations: Long-Term 2 Enhanced Surface Water Treatment Rule; Final Rule. 71 FR 654. January 5, 2006.

USEPA. 2006b. National Primary Drinking Water Regulations: Ground Water Rule; Final Rule. 71 FR 65574. November 8, 2006.

USEPA. 2006c. *Source Water Monitoring Guidance for Public Water Systems*. EPA 815-R-06-005. February 2006.

USEPA. 2006d. *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule*. EPA 815-R-06-007. November 2006.

USEPA. 2009. National Primary Drinking Water Regulations: Drinking Water Regulations for Aircraft Public Water Systems. 74 FR 53590. October 19, 2009.

USEPA. 2010a. National Primary Drinking Water Regulations; Announcement of the Results of EPA's Review of Existing Drinking Water Standards and Request for Public Comment and/or Information on Related Issues. 75 FR 15499. March 29, 2010.

USEPA. 2010b. *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual*. EPA 815-R-09-016. April 2010.

USEPA. 2010c. *Interim Final Guidance Manual for the Aircraft Drinking Water Rule*. EPA 816-R-10-020. October 2010.

USEPA. 2012. Environmental Technology Verification Protocol: Protocol for the Product Specific Challenge Testing of Bag and Cartridge Filter Systems, Drinking Water Systems Center, 12/01/EPADWCTR, prepared by NSF International, March 2012.

USEPA. 2013. National Primary Drinking Water Regulations: Revisions to the Total Coliform Rule; Final Rule. 78 FR 10269. February 13, 2013.

USEPA. 2014a. National Primary Drinking Water Regulations: Minor Corrections to the Revisions to the Total Coliform Rule. 79 FR 10665. February 26, 2014.

USEPA. 2014b. *Revised Total Coliform Rule Assessments and Corrective Actions Guidance Manual: Interim Final*. EPA 815-R-14-006. September 2014.

USEPA. 2016a. *Six-Year Review 3 Technical Support Document for Microbial Contaminant Regulations*. EPA-810-R16-010. December 2016.

USEPA. 2016b. *Six-Year Review 3 Technical Support Document for Long-Term 2 Enhanced Surface Water Treatment Rule*. EPA-810-R-16-011. December 2016.

USEPA. 2016c. *Revised Total Coliform Rule (RTCR) Data Entry Instructions with Examples*. EPA 816-B-16-005. December 2016.

USEPA. 2016d. Quick Guide to Drinking Water Sample Collection. September 2016.

USEPA. 2019a. Information Collection Request Submitted to OMB for Review and Approval; Comment Request; Contaminant Occurrence Data in Support of the EPA's Fourth Six-Year Review of National Primary Drinking Water Regulations. 84 FR 58381. October 31, 2019.

USEPA. 2019b. Safe Drinking Water Information System (SDWIS) Federal Reports Advanced Search. Available on the Internet at: https://ordspub.epa.gov/ords/sfdw/f?p=108:1:::NO:1::.

USEPA. 2019c. *Generating High-Quality Turbidity Data in Drinking Water Treatment Plants to Support System Optimization and Monitoring*. EPA 815-B-19-010. June 2019.

USEPA. 2019d. *How to Conduct a Sanitary Survey of Drinking Water Systems*. EPA 816-R-17-001. August 2019.

USEPA. 2020a. *Guidance Manual for Compliance with the Surface Water Treatment Rules: Turbidity Provisions*. EPA 815-R-20-004. June 2020

USEPA. 2020b. *Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems*. EPA 600-R-20-094. April 2020.

USEPA. 2020c. *The Revised Total Coliform Rule (RTCR) State Implementation Guidance—Final*. EPA 816-R-20-003. June 2020.

USEPA. 2021. Understanding the significance and potential growth of pathogens in pipes water systems. https://www.epa.gov/water-research/understanding-significance-and-potential-growth-pathogens-piped-water-systems. Page last updated: August 19, 2021.

USEPA. 2022a. *Drinking Water Instrumentation Data Integrity Checklists*. EPA 815-B-22-002. January 2022.

USEPA. 2022b. *Ultraviolet (UV) Treatment Toolkit: Technical Resource for States using EPA's Ultraviolet Disinfection Guidance Manual to Evaluate UV Technology*. EPA 815-B-21-007. May 2022.

USEPA. 2022c. ADWR Compliance Public Reports – Aircraft Drinking Water Rule System Operations. https://sdwis.epa.gov/ords/arcs/f?p=130:109. Accessed Online May 23, 2022.

USEPA. 2023. Drinking Water Distribution System Tools and Resources. https://www.epa.gov/dwreginfo/drinking-water-distribution-system-tools-and-resources. Accessed Online April 18, 2022. Site last updated: April 12, 2023

USEPA. 2024a. *EPA Protocol for the Fourth Review of Existing National Primary Drinking Water Regulations*. EPA-815-R-24-018. February 2024.

USEPA. 2024b. *The Data Management and Quality Assurance/Quality Control Process for the Fourth Six-Year Review Information Collection Rule Dataset*. EPA-815-R-24-017. February 2024.

Venis, R.A. and O.D. Basu. 2021. Mechanisms and efficacy of disinfection in ceramic water filters: A critical review. *Environmental Science and Technology*, 51(24): 2934-2974.

Vickers, J.C. 2018. Proposed methodology for determining reverse osmosis unit integrity for pathogen removal credit. *Journal-American Water Works Association*, 110(8), E27-E41.

Wallender, E.K., E.C. Ailes, J.S. Yoder, V.A. Roberts, and J.M. Brunkard. 2014. Contributing factors to disease outbreaks associated with untreated groundwater. *Ground Water*. 52(6): 886-97.

Wang, Y., E. Araud, J.L. Shisler, T.H. Nguyen, and B. Yuan. 2019. Influence of algal organic matter on MS2 bacteriophage inactivation by ultraviolet irradiation at 220 nm and 254 nm. *Chemosphere*, 214: 195-202.

World Health Organization (WHO). 2004. *Guidelines for Drinking-Water Quality, Third Edition. Volume 1: Recommendations*. https://www.who.int/publications/i/item/9789241547611.

WHO. 2009. *Guide to Hygiene and Sanitation in Aviation, 3rd Edition*. https://www.who.int/publications/i/item/9789241547772.

Wilson, B.R., P.F. Roessler, E. Van Dellen, M. Abbaszadegan, and C.P. Gerba. 1992. Coliphage MS-2 as a UV water disinfection efficacy test surrogate for bacterial and viral pathogens. Proceedings of the Water Quality Technology Conference, Toronto, November 15 – 19, pgs. 219-235.

Wolf, C., A. Pavese, U. von Gunten, and T. Kohn. 2019. Proxies to monitor the inactivation of viruses by ozone in surface water and wastewater effluent. *Water Research*, 166: 115088.

Wright, H.B., D. Gaithuma, T. Dzurny, C. Schulz, A. Cabaj, and A. Schmalweiser. 2006. Design and performance guidelines for UV sensor systems. American Water Works Association Research Foundation, Denver, CO (in preparation).

Xiong, B., B. Piechowicz, Z. Wang, R. Marinaro, E. Clement, T. Carlin, Al Uliana, M. Kumar, and S.B. Velegol. 2018. Moringa oleifera f-sand Filters for Sustainable Water Purification. *Environmental Science & Technology Letters*, 5(1): 38-42.

Younis, B.A., L. Mahoney, W. Schweigkofler, and K. Suslow. 2019. Inactivation of plant pathogens in irrigation water runoff using a novel UV disinfection system. *European Journal of Plant Pathology*, 153(3): 907-914.

Zyara, A.M., E. Torvinen, A-M Veijalainen, and H. Heinonen-Tanski. 2016. The Effect of UV and Combined Chlorine/UV Treatment on Coliphages in Drinking Water Disinfection. J *Water Health*, 14 (4): 640–649.

9 List of Appendices

Appendix A. Additional Analyses on the Six-Year Review 4 Microbial Data

This appendix provides additional summaries of the SYR4 microbial data that were not presented within the body of Chapter 6.

Exhibit A-1 presents a state-level summary of the total coliform, *E. coli*, fecal coliform, and *Cryptosporidium* data from the SYR4 ICR dataset that passed QA and were included as part of the SYR4 analyses presented in various analyses of Section 6. For the SYR4 process, EPA evaluated total coliforms in finished water, *E. coli* / fecal coliforms in finished water and raw water, and *Cryptosporidium* in source (raw) water for binning purposes. The *E. coli* / fecal coliform results are presented separately for raw and finished water since different data were used to support different analyses (i.e., finished water data as part of RTCR and raw water data as part of GWR). The other analytes are not presented separately for raw water and finished water results.

Exhibit A-1. Summary of Six-Year Review 4 Microbial Data, By State[1,2]

State	Total Coliforms	*E. coli*				Fecal Coliforms				*Cryptosporidium*
		Finished	Raw	Unknown	Total	Finished	Raw	Unknown	Total	
AK	103,898	10,395	1,353	53,666	65,414	175	1	2647	2,823	0
AL	284,580	27,620	61,560	1,470	90,650	5	1	0	6	2,310
AR	394,314	5,468	580	41	6,089	0	0	0	0	0
AS	13,186	0	0	13,184	13,184	0	0	0	0	0
AZ	219,468	37,728	5,074	60	42,862	24	2	0	26	728
CO	352,349	0	0	204,889	204,889	0	0	24	24	2,012
CT	382,725	110,026	32,726	77,102	219,854	2	2	10	14	1,053
DC	13,693	1,803	48	7,797	9,648	0	0	0	0	48
DE	70,366	12,524	516	2	13,042	2	1	0	3	0
FL	2,342,672	0	0	350	350	0	0	21	21	0
HI	16,035	13,332	219	42	13,593	13	0	0	13	0
IA	425,813	200,743	79	6,465	207,287	2	0	1	3	498
ID	193,935	333	761	13,357	14,451	1	0	2	3	159
IL	1,526,019	365,549	273,277	12,218	651,044	49	113	73	235	1,494
IN	398,481	12,059	1,643	0	13,702	0	0	0	0	0
KS	279,741	203,682	5,221	59	208,962	11	0	0	11	927
KY	427,911	1,742	64	143	1,949	0	0	0	0	0
LA	179,619	142,670	4,388	359	147,417	11	3	0	14	0
MD	60,832	32,435	1,388	258	34,081	1,091	1	0	1,092	0
ME	145,575	73,458	3,921	379	77,758	2	0	0	2	56
MN	225,927	0	0	15,141	15,141	0	0	12	12	416
MO	601,095	213,536	2,287	67,050	282,873	1	0	0	1	0
MP	13,364	0	0	12,020	12,020	0	0	0	0	0
MT	260,675	166,580	34,956	15,116	216,652	4,238	490	214	4,942	0
NC	926,048	625,697	2,385	268	628,350	4	0	0	4	0
ND	95,674	804	71	61	936	1	0	0	1	0
NE	218,891	153,709	12	187	153,908	0	0	0	0	0
NH	155,791	0	0	156,191	156,191	0	0	0	0	0

State	Total Coliforms	*E. coli*				Fecal Coliforms				*Cryptosporidium*
		Finished	Raw	Unknown	Total	Finished	Raw	Unknown	Total	
NJ	935,126	13,886	8,109	689	22,684	55	9	0	64	793
NN	7,447	0	0	6,789	6,789	0	0	0	0	0
NV	81,129	10,045	730	2,724	13,499	0	0	0	0	359
NY	541,960	68,925	11,433	7,874	88,232	104	319	15	438	209
OH	1,022,164	107,099	4,226	1,443	112,768	106	6	0	112	9
OK	398,661	228,441	6,913	1,432	236,786	0	0	0	0	1,235
OR	477,951	8,062	8,000	16	16,078	0	1	0	1	821
PA	854,438		11,108	235,709	246,817	0	6	724	730	0
RI	61,041	5,831	5,062	33,985	44,878	216	117	1,459	1,792	166
SC	9,563	772	2,602	4,136	7,510	0	0	2	2	0
SD	117,852	0	0	66,507	66,507	0	0	0	0	0
TN	91,984	0	0	84	84	0	0	1,449	1,449	0
TX	2,637,545	1,265,898	77,248	15,976	1,359,122	1,064	62	6	1,132	693
UT	297,343	79,741	11,742	769	92,252	5	5	0	10	417
VA	703,226	307,532	35,071	754	343,357	131	19	0	150	2,467
VT	126,345	95,904	2,612	7,968	106,484	1	0	0	1	192
WA	949,429	224,814	8	0	224,822	191	0	0	191	0
WI	693,211	0	0	545,150	545,150	0	0	0	0	420
WV	187,869	966	2,505	611	4,082	4	0	7	11	1,716
WY	108,011	76,445	1,199	10,042	87,686	482	0	927	1,409	213
01	2,722	0	0	2,708	2,708	0	0	0	0	0
02	912	0	0	84	84	0	0	0	0	0
04	3,591	24	33	0	57	0	3	0	3	71
05	19,648	98	6	41	145	1	0	0	1	0
06	21,655	9,490	164	486	10,140	43	0	4	47	11
07	2,468	2,029	3	205	2,237	0	0	0	0	0
08	21,291	10,754	811	2,175	13,740	22	0	2	24	9
09	21,764	0	0	17,844	17,844	0	0	0	0	40
10	21,089	46	189	289	524	0	1	0	1	0
Total	**20,746,112**	**4,928,695**	**622,303**	**1,624,365**	**7,175,363**	**8057**	**1162**	**7599**	**16,818**	**19,542**

[1] Six-Year Review 4 microbial data that passed quality assurance on which the Section 6 analyses were based.

[2] Under SYR4, very limited data were submitted for coliphage (3 records) and enterococci (8 records).

As part of the GWR and RTCR analysis, EPA evaluated annual trends through consideration of “common systems” across the years, as well as only those systems with a high level of completeness. “Common systems” refers to systems with data in all years. The inclusion of only these systems eliminates year-to-year variation in the number of systems in the analysis. To further reduce the annual variability in the underlying data, EPA also focused many of the analyses on only those system-months with at least 90 percent of completeness of routine total coliform monitoring records (i.e., those system months where a system collected at least 90 percent of their required routine total coliform samples based on system size). As shown in Exhibit A-2, the focus on only the “common systems with 90% completeness” excludes a significant portion of systems from the analysis.

Exhibit A-2. Comparison of Summary of the Maximum Percentage Variation in the Number of Systems and the Number of Annual Routine Total Coliform Samples for all Public Water Systems without 90% completeness and Common Systems with 90% completeness

	#Systems or #RTTC	2007	2008	2010	2011	2014	2015	2018	2019	Max % Variation
All PWSs for Individual Years	#Systems	70,685	70,278	74,953	74,691	86,237	85,415	95,516	95,099	35.9%
	#RTTC (without 90% Completeness)	1,226,098	1,327,476	1,589,336	1,647,311	1,861,738	1,883,681	2,231,731	2,304,040	87.9%
Common PWSs for All Years	#Systems	48,292	48,292	48,292	48,292	48,292	48,292	48,292	48,292	0%
	#RTTC (with 90% Completeness)	897,301	964,469	962,858	972,586	960,727	968,790	963,481	961,707	8.4%

Exhibit A-3 through Exhibit A-5 present a summary of the changes in the percent of ground water systems with disinfection for various system sizes with common systems across the years with records with 90% completeness. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-7 for all system sizes.

Exhibit A-3. Changes in Percent of GW Systems with Disinfection Serving Fewer than 1,000 People (Common systems with 8 years of data and >= 90% completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	**39,070**	**39,070**	**39,070**	**39,070**	**39,070**	**39,070**	**39,070**	**39,070**
#Disinfecting Systems	**16,892**	**15,738**	**18,152**	**16,853**	**17,970**	**17,366**	**19,245**	**19,280**
#Non Disinfecting Systems	**22,178**	**23,332**	**20,918**	**22,217**	**21,100**	**21,704**	**19,825**	**19,790**
%disinfecting Systems	43.24%	40.28%	46.46%	43.14%	45.99%	44.45%	49.26%	49.35%
%disinfecting Systems (Ave @ 2 years)	41.76%		44.80%		45.22%		49.30%	
Relative Change		7.28%		0.95%		9.02%		
Overall Change	18.07%							

Exhibit A-4. Changes in Percent of GW Systems with Disinfection Serving 1,000 People or More but Less Than 10,000 People (Common systems with 8 years of data and >= 90% completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	3,455	3,455	3,455	3,455	3,455	3,455	3,455	3,455
#Disinfecting Systems	2,887	2,721	3,054	2,953	3,124	3,131	3,191	3,197
#Non Disinfecting Systems	568	734	401	502	331	324	264	258
%disinfecting Systems	83.56%	78.76%	88.39%	85.47%	90.42%	90.62%	92.36%	92.53%
%disinfecting Systems (Ave @ 2 years)	81.16%		86.93%		90.52%		92.45%	
Relative Change		7.11%		4.13%		2.13%		
Overall Change	13.91%							

Exhibit A-5. Changes in Percent of GW Systems with Disinfection Serving 10,000 People or More (Common systems with 8 years of data and >= 90% completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	297	297	297	297	297	297	297	297
#Disinfecting Systems	288	281	288	285	290	292	293	292
#Non Disinfecting Systems	9	16	9	12	7	5	4	5
%disinfecting Systems	96.97%	94.61%	96.97%	95.96%	97.64%	98.32%	98.65%	98.32%
%disinfecting Systems (Ave @ 2 years)	95.79%		96.46%		97.98%		98.48%	
Relative Change		0.70%		1.57%		0.52%		
Overall Change	2.81%							

Exhibit A-6 through Exhibit A-8 present a summary of the annual total coliform detection rates for disinfecting and undisinfected ground water systems for various system sizes. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-10 for all system sizes.

Exhibit A-6. Changes of %RTTC+ Rates among Disinfecting and Undisinfected Systems Serving Fewer than 1,000 People ("Common Systems" with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
#Disinfecting Systems	16,892	15,738	18,152	16,853	17,970	17,366	19,245	19,280
#RTTC	174,235	181,321	202,355	191,731	203,224	197,845	203,058	203,789
#RTTC+	3,742	3,744	4,018	3,437	3,176	3,456	3,121	3,099
%RTTC+	2.15%	2.06%	1.99%	1.79%	1.56%	1.75%	1.54%	1.52%
Ave @ 2 years	2.11%		1.89%		1.65%		1.53%	
Relative difference		-10.31%		-12.40%		-7.61%		
Overall Difference	-27.41%							
Year	2007	2008	2010	2011	2014	2015	2018	2019
#Non Disinfecting Systems	22,178	23,332	20,918	22,217	21,100	21,704	19,825	19,790
#RTTC	151,547	168,483	141,403	156,526	140,720	147,426	137,882	136,766
#RTTC+	6,033	6,313	5,755	6,055	5,090	5,135	3,767	3,672
%RTTC+	3.98%	3.75%	4.07%	3.87%	3.62%	3.48%	2.73%	2.68%
Ave @ 2 years	3.86%		3.97%		3.55%		2.71%	
Relative difference		2.72%		-10.56%		-23.71%		
Overall Difference	-29.90%							

Exhibit A-7. Changes of %RTTC+ Rates among Disinfecting and Undisinfected Systems Serving 1,000 People or More but Less Than 10,000 People ("Common Systems" with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
#Disinfecting Systems	2,887	2,721	3,054	2,953	3,124	3,131	3,191	3,197
#RTTC	98,373	106,355	119,597	118,509	125,074	126,416	126,541	125,988
#RTTC+	692	671	673	594	643	691	662	587
%RTTC+	0.70%	0.63%	0.56%	0.50%	0.51%	0.55%	0.52%	0.47%
Ave @ 2 years	**0.67%**		**0.53%**		**0.53%**		**0.49%**	
Relative difference		**-20.26%**		**-0.31%**		**-6.75%**		
Overall Difference	**-25.88%**							
Year	2007	2008	2010	2011	2014	2015	2018	2019
#Non Disinfecting Systems	568	734	401	502	331	324	264	258
#RTTC	16,164	23,743	10,798	14,747	8,228	8,165	6,274	6,471
#RTTC+	218	296	172	177	137	186	115	131
Ave @ 2 years	1.35%	1.25%	1.59%	1.20%	1.67%	2.28%	1.83%	2.02%
Ave @ 2 years	1.30%		1.40%		1.97%		1.93%	
Relative difference		7.62%		41.17%		-2.17%		
Overall Difference	48.63%							

Exhibit A-8. Changes of %RTTC+ Rates among Disinfecting and Undisinfected Systems Serving 10,000 People or More ("Common Systems" with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Disinfecting Systems	288	281	288	285	290	292	293	292
#RTTC	82,688	86,459	89,623	89,406	89,390	91,075	91,590	92,184
#RTTC+	222	176	126	136	180	175	188	199
%RTTC+	0.27%	0.20%	0.14%	0.15%	0.20%	0.19%	0.21%	0.22%
Ave @ 2 years	0.24%		0.15%		0.20%		0.21%	
Relative difference		-37.99%		34.44%		7.02%		
Overall Difference	-10.78%							
Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Non Disinfecting Systems	9	16	9	12	7	5	4	5
#RTTC	1,694	2,540	2,016	2,104	1,776	1,266	880	1,250
#RTTC+	8	12	7	15	17	17	15	3
%RTTC+	0.47%	0.47%	0.35%	0.71%	0.96%	1.34%	1.70%	0.24%
Ave @ 2 years	0.47%		0.53%		1.15%		0.97%	
Relative difference		12.22%		116.95%		-15.46%		
Overall Difference	105.84%							

Exhibit A-9 through Exhibit A-11 present a summary of the annual *E. coli* detection rates for disinfecting and undisinfected ground water systems for various system sizes. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-11 for all system sizes.

Exhibit A-9. Changes of %RTEC+ Rates among Disinfecting and Undisinfected Systems Serving Fewer than 1,000 People (“Common Systems” with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Disinfecting Systems	16,892	15,738	18,152	16,853	17,970	17,366	19,245	19,280
#RTTC	174,235	181,321	202,355	191,731	203,224	197,845	203,058	203,789
#RTEC+	178	180	175	154	121	108	149	143
%RTEC+	0.10%	0.10%	0.09%	0.08%	0.06%	0.05%	0.07%	0.07%
Ave @ 2 years	0.10%		0.08%		0.06%		0.07%	
Relative difference		-17.19%		-31.58%		25.78%		
Overall Difference	-28.74%							
Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Non Disinfecting Systems	22,178	23,332	20,918	22,217	21,100	21,704	19,825	19,790
#RTTC	151,547	168,483	141,403	156,526	140,720	147,426	137,882	136,766
#RTEC+	268	263	214	219	200	167	160	121
%RTEC+	0.18%	0.16%	0.15%	0.14%	0.14%	0.11%	0.12%	0.09%
Ave @ 2 years	0.17%		0.15%		0.13%		0.10%	
Relative difference		-12.52%		-12.31%		-19.93%		
Overall Difference	-38.57%							

Exhibit A-10. Changes of %RTEC+ Rates among Disinfecting and Undisinfected Systems Serving 1,000 People or More but Less Than 10,000 People (“Common Systems” with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Disinfecting Systems	2,887	2,721	3,054	2,953	3,124	3,131	3,191	3,197
#RTTC	98,373	106,355	119,597	118,509	125,074	126,416	126,541	125,988
#RTEC+	33	28	38	27	31	33	27	23
%RTEC+	0.03%	0.03%	0.03%	0.02%	0.02%	0.03%	0.02%	0.02%
Ave @ 2 years	**0.03%**		**0.03%**		**0.03%**		**0.02%**	
Relative difference		**-8.88%**		**-6.72%**		**-22.20%**		
Overall Difference	**-33.87%**							
Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Non Disinfecting Systems	568	734	401	502	331	324	264	258
#RTTC	16,164	23,743	10,798	14,747	8,228	8,165	6,274	6,471
#RTEC+	6	5	6	4	1	1	0	1
%RTEC+	0.04%	0.02%	0.06%	0.03%	0.01%	0.01%	0.00%	0.02%
Ave @ 2 years	0.03%		0.04%		0.01%		0.01%	
Relative difference		42.13%		-70.49%		-36.67%		
Overall Difference	-73.44%							

Exhibit A-11. Changes of %RTEC+ Rates among Disinfecting and Undisinfected Systems Serving 10,000 People or More ("Common Systems" with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Disinfecting Systems	288	281	288	285	290	292	293	292
#RTTC	82,688	86,459	89,623	89,406	89,390	91,075	91,590	92,184
#RTEC+	6	9	8	5	6	7	5	6
%RTEC+	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Ave @ 2 years	0.01%		0.01%		0.01%		0.01%	
Relative difference		-17.81%		-0.83%		-16.88%		
Overall Difference	-32.25%							
Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
#Non Disinfecting Systems	9	16	9	12	7	5	4	5
#RTTC	1,694	2,540	2,016	2,104	1,776	1,266	880	1,250
#RTEC+	1	0	0	0	1	0	0	0
%RTEC+	0.06%	0.00%	0.00%	0.00%	0.06%	0.00%	0.00%	0.00%
Ave @ 2 years	0.03%		0.00%		0.03%		0.00%	
Relative difference		-100.00%		--		-100.00%		
Overall Difference	-100.00%							

Exhibit A-12 through Exhibit A-14 present a summary of the annual total coliform detection rates for all ground water systems for various system sizes. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-8 for all system sizes.

Exhibit A-12. Changes of %RTTC+ Rates among All Ground Water Systems Serving Fewer than 1,000 People ("Common Systems" with 90% Completeness)

Year	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
All Systems	39,070	39,070	39,070	39,070	39,070	39,070	39,070	39,070
#RTTC	325,782	349,804	343,758	348,257	343,944	345,271	340,940	340,555
#RTTC+	9,775	10,057	9,773	9,492	8,266	8,591	6,888	6,771
%RTTC+	3.00%	2.88%	2.84%	2.73%	2.40%	2.49%	2.02%	1.99%
Ave @ 2 years	2.94%		2.78%		2.45%		2.00%	
Relative difference		-5.22%		-12.16%		-18.05%		
Overall Difference	-31.78%							

Exhibit A-13. Changes of %RTTC+ Rates among All Ground Water Systems Serving 1,000 People or More but Less Than 10,000 People (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	3,455	3,455	3,455	3,455	3,455	3,455	3,455	3,455
#RTTC	114,537	130,098	130,395	133,256	133,302	134,581	132,815	132,459
#RTTC+	910	967	845	771	780	877	777	718
%RTTC+	0.79%	0.74%	0.65%	0.58%	0.59%	0.65%	0.59%	0.54%
Ave @ 2 years	0.77%		0.61%		0.62%		0.56%	
Relative difference		-20.24%		0.83%		-8.87%		
Overall Difference	-26.71%							

Exhibit A-14. Changes of %RTTC+ Rates among All Ground Water Systems Serving 10,000 People or More (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	297	297	297	297	297	297	297	297
#RTTC	84,382	88,999	91,639	91,510	91,166	92,341	92,470	93,434
#RTTC+	230	188	133	151	197	192	203	202
%RTTC+	0.27%	0.21%	0.15%	0.17%	0.22%	0.21%	0.22%	0.22%
Ave @ 2 years	0.24%		0.16%		0.21%		0.22%	
Relative difference		-35.90%		36.72%		2.76%		
Overall Difference	-9.94%							

Exhibit A-15 through Exhibit A-17 present a summary of the annual *E. coli* detection rates for all ground water systems for various system sizes. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-9 for all system sizes.

Exhibit A-15. Changes of %RTEC+ Rates among All Ground Water Systems Serving Fewer than 1,000 People (“Common Systems” with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	39,070	39,070	39,070	39,070	39,070	39,070	39,070	39,070
#RTTC	325,782	349,804	343,758	348,257	343,944	345,271	340,940	340,555
#RTEC+	446	443	389	373	321	275	309	264
%RTEC+	0.14%	0.13%	0.11%	0.11%	0.09%	0.08%	0.09%	0.08%
Ave @ 2 years	0.13%		0.11%		0.09%		0.08%	
Relative difference		-16.42%		-21.47%		-2.79%		
Overall Difference	-36.20%							

Exhibit A-16. Changes of %RTEC+ Rates among All Ground Water Systems Serving 1,000 People or More but Less Than 10,000 People ("Common Systems" with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	3,455	3,455	3,455	3,455	3,455	3,455	3,455	3,455
#RTTC	114,537	130,098	130,395	133,256	133,302	134,581	132,815	132,459
#RTEC+	39	33	44	31	32	34	27	24
%RTEC+	0.03%	0.03%	0.03%	0.02%	0.02%	0.03%	0.02%	0.02%
Ave @ 2 years	0.03%		0.03%		0.02%		0.02%	
Relative difference		-4.05%		-13.57%		-21.96%		
Overall Difference	-35.29%							

Exhibit A-17. Changes of %RTEC+ Rates among All Ground Water Systems Serving 10,000 People or More ("Common Systems" with 90% Completeness)

Year	2007	2008	2010	2011	2014	2015	2018	2019
All Systems	297	297	297	297	297	297	297	297
#RTTC	84,382	88,999	91,639	91,510	91,166	92,341	92,470	93,434
#RTEC+	7	9	8	5	7	7	5	6
%RTEC+	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Ave @ 2 years	0.01%		0.01%		0.01%		0.01%	
Relative difference		-22.89%		7.50%		-22.48%		
Overall Difference	-35.74%							

Exhibit A-18 through Exhibit A-20 present a summary of the average annual total coliform detection rates for three groups of systems: all PWSs, all disinfecting ground water systems, and all undisinfected ground water systems. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-12 for all system sizes.

Exhibit A-18. Summary of Changes of %RTTC+ Rates by System Categories Serving Fewer than 1,000 People (All PWS, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-6.2%		-10.8%		-18.0%		
	Overall Change	-31.4%							
Disinfecting ground water systems	Relative Change		-10.3%		-12.4%		-7.6%		
	Overall Change	-27.4%							
Undisinfected GW Systems	Relative Change		2.7%		-10.6%		-23.7%		
	Overall Change	-29.9%							

Exhibit A-19. Summary of Changes of %RTTC+ Rates by System Categories Serving 1,000 People or More but Less Than 10,000 People (All PWS, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-15.6%		-0.4%		-5.6%		
	Overall Change	-20.7%							
Disinfecting ground water systems	Relative Change		-20.3%		-0.3%		-6.8%		
	Overall Change	-25.9%							
Undisinfected GW Systems	Relative Change		7.6%		41.2%		-2.2%		
	Overall Change	48.6%							

Exhibit A-20. Summary of Changes of %RTTC+ Rates by System Categories Serving 10,000 People or More (All PWS, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-22.7%		16.7%		1.2%		
	Overall Change	-8.8%							
Disinfecting ground water systems	Relative Change		-38.0%		34.4%		7.0%		
	Overall Change	-10.8%							
Undisinfected GW Systems	Relative Change		12.2%		117.0%		-15.5%		
	Overall Change	105.8%							

Exhibit A-21 through Exhibit A-23 present a summary of the average annual *E. coli* detection rates for three groups of systems: all PWSs, all disinfecting ground water systems, and all undisinfected ground water systems. These results presented separately for systems of differing sizes correspond to the analysis presented in Exhibit 6-13 for all system sizes.

Exhibit A-21. Summary of Changes of %RTEC+ Rates by System Categories Serving Fewer than 1,000 People (All PWS, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	Year	2007	2008	2010	2011	2014	2015	2018	2019
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-17.7%		-16.4%		-4.9%		
	Overall Change	-34.6%							
Disinfecting ground water systems	Relative Change		-17.2%		-31.6%		25.8%		
	Overall Change	-28.7%							
Undisinfected GW Systems	Relative Change		-12.5%		-12.3%		-19.9%		
	Overall Change	-38.6%							

Exhibit A-22. Summary of Changes of %RTEC+ Rates by System Categories Serving 1,000 People or More but Less Than 10,000 People (All PWS, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	**Year**	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-9.9%		2.4%		56.3%		
	Overall Change	44.2%							
Disinfecting ground water systems	Relative Change		-8.9%		-6.7%		-22.2%		
	Overall Change	-33.9%							
Undisinfected GW Systems	Relative Change		42.1%		-70.5%		-36.7%		
	Overall Change	-73.4%							

Exhibit A-23. Summary of Changes of %RTEC+ Rates by System Categories Serving 10,000 People or More (All Public Water Systems, Disinfecting Ground Water systems, Undisinfected Ground Water Systems)

System Types	**Year**	**2007**	**2008**	**2010**	**2011**	**2014**	**2015**	**2018**	**2019**
	2-Year Period	Before GWR		Right after GWR		Right after SS under GWR		After few years of RTCR	
All PWSs	Relative Change		-48.2%		84.6%		-8.9%		
	Overall Change	-12.9%							
Disinfecting ground water systems	Relative Change		-17.8%		-0.8%		-16.9%		
	Overall Change	-32.3%							
Undisinfected GW Systems	Relative Change		-100.0%		#DIV/0!		-100.0%		
	Overall Change	-100.0%							

Appendix B. Additional Analyses on the Aircraft Drinking Water Rule Data

This appendix provides the analytical results for the Aircraft Drinking Water Rule (ADWR) data that were not presented within the body of Chapter 6. Exhibit B-1 presents a count of the number of samples and systems for each air carrier for the years 2012-2019. The average sample count per air carrier was 2,186 with a median of 389 and a maximum of 22,492. The average system count per air carrier was 163 with a median of 54 and a maximum of 1,284.

Exhibit B-1. Number of Samples and Aircraft Systems by Air Carrier; 2012-2019

Air Carrier	Count of Samples	Count of Systems
AIR WISCONSIN AIRCRAFTS CORPORATION	1,683	71
AIRBORNE ENERGY SOLUTIONS LIMITED	4	1
AIRTRAN AIRWAYS INC	630	134
ALASKA AIRCRAFTS INC	2,848	271
ALLEGIANT AIR LLC	1,383	155
AMERICAN AIRCRAFTS INC	17,098	1,284
AMERISTAR AIR CARGO INC	180	5
ATLAS AIR INC	152	13
CHAUTAUQUA AIRCRAFTS INC	609	74
COLGAN AIR INC	14	6
COMAIR INC	94	34
COMPASS AIRCRAFTS LLC	1,742	62
CONOCOPHILLIPS ALASKA	50	5
DELTA AIR LINES INC	22,492	1,130
ENDEAVOR AIR INC	3,508	272
ENVOY AIR INC	3,886	314
EXECUTIVE AIR CRAFT LTD	22	3
EXPRESSJET AIRCRAFTS INC	4,983	453
FALCON AIR EXPRESS INC	142	8
FRONTIER AIRCRAFTS INC	1,290	143
GOJET AIRCRAFTS LLC	960	59
HAWAII ISLAND AIR INC	4	2
HAWAIIAN AIRCRAFTS INC	1,781	77
HORIZON AIR INDUSTRIES INC	138	30
JETBLUE AIRWAYS CORPORATION	3,851	254
MESA AIRCRAFTS INC	1,988	147
MIAMI AIR INTERNATIONAL INC	130	12
MSG FLIGHT OPERATIONS LLC	26	1
NATIONAL AIR CARGO GROUP INC	0	0
NORTH AMERICAN AIRCRAFTS	20	5
OMNI AIR INTERNATIONAL INC	168	17
ORANGE AIR LLC	6	2
PIEDMONT AIRCRAFTS INC	308	60
PSA AIRCRAFTS INC	2,024	151
REPUBLIC AIRWAYS INC	3,464	268
RYAN INTERNATIONAL AIRCRAFTS INC	6	3
SHUTTLE AMERICA CORPORATION	1,277	112

Air Carrier	**Count of Samples**	**Count of Systems**
SIERRA PACIFIC AIRCRAFTS INC	36	4
SKYWEST AIRCRAFTS INC	9,148	541
SONGBIRD AIRWAYS, INC	12	5
SOUTHWEST AIRCRAFTS CO	11,075	920
SPIRIT AIRCRAFTS INC	1,564	147
SUN COUNTRY AIRCRAFTS	469	48
SWIFT AIR LLC	240	33
TEM ENTERPRISES INC	96	15
THE DOW CHEMICAL COMPANY	20	2
TRANS STATES AIRCRAFTS LLC	718	81
UNITED AIRCRAFTS, INC	12,057	897
US AIRWAYS INC	2,716	396
USA JET AIRCRAFTS INC	12	6
VIRGIN AMERICA INC	812	67
VISION AIRCRAFTS INC	32	6
WORLD AIRWAYS INC	14	3
WORLD ATLANTIC AIRCRAFTS	88	9
Total	**118,070**	**7,816**

Exhibit B-2 presents a count of the number of systems with total coliform and *E. coli* data, and the associated total coliform and *E. coli* positivity rate, broken down by year for the years 2011-2021. Approximately 34.8 percent of the systems reported at least one total coliform sample with a positive result during the period 2011-2021. When looking only at the years 2012-2019, approximately 32.8 percent of the systems reported at least one total coliform sample with a positive result.

Approximately 2.74 percent of the systems with *E. coli* data reported at least one *E. coli* sample with a positive result during the period 2011-2021 (2.40 percent when using the second set of *E. coli* assumptions). Approximately 2.45 percent of the systems with *E. coli* data reported at least one *E. coli* sample with a positive result when considering only the years 2012-2019 (2.12 percent when using the second set of *E. coli* assumptions).

These results imply that the positive samples are spread among a wide variety of aircraft rather than a small number of aircraft.

Exhibit B-2. Number of Systems with Total Coliform and *E. coli* Data, and Total Coliform and *E. coli* Positivity Rate by Year; 2011-2021

Year	**Total Coliforms**			***E. coli***			***E. coli* (Alternative Approach)**[1]		
	# Systems with Data	**# Systems with Total Coliform Positives**	**% Systems with Total Coliform Positives**	**# Systems with Data**	**# Systems with *E. coli* positives**	**% Systems with *E. coli* positives**	**# Systems with Data**	**# Systems with *E. coli* positives**	**% Systems with *E. coli* positives**
2011[2]	1,992	253	12.70%	1,331	9	0.68%	1,992	9	0.45%
2012	5,429	707	13.02%	4,359	29	0.67%	5,429	29	0.53%
2013	5,508	640	11.62%	3,945	24	0.61%	5,508	24	0.44%

Year	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
	# Systems with Data	**# Systems with Total Coliform Positives**	**% Systems with Total Coliform Positives**	**# Systems with Data**	**# Systems with *E. coli* positives**	**% Systems with *E. coli* positives**	**# Systems with Data**	**# Systems with *E. coli* positives**	**% Systems with *E. coli* positives**
2014	5,602	584	10.42%	3,924	15	0.38%	5,602	15	0.27%
2015	5,687	576	10.13%	3,871	22	0.57%	5,687	22	0.39%
2016	5,753	602	10.46%	3,865	25	0.65%	5,753	25	0.43%
2017	5,835	414	7.10%	4,120	17	0.41%	5,835	17	0.29%
2018	6,017	433	7.20%	4,293	22	0.51%	6,017	22	0.37%
2019	6,105	353	5.78%	4,386	17	0.39%	6,105	17	0.28%
2020[3]	5,538	210	3.79%	3,930	18	0.46%	5,538	18	0.33%
2021[4]	1,926	66	3.43%	1,395	3	0.22%	1,926	3	0.16%
Total (2011-2021)	8,093	2,820	34.84%	7,091	194	2.74%	8,093	194	2.40%
Total (2012-2019)	7,816	2,567	32.84%	6,776	166	2.45%	7,816	166	2.12%

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

[2] The 2011 data does not represent an entire calendar year as it represents the period of February to December 2011.

[3] Due to the COVID-19 pandemic there were a large number of inactive aircraft in comparison to the preceding and following years.

[4] The 2021 data does not represent an entire calendar year as it represents the period of January to May 2021.

Exhibit B-3 and Exhibit B-4 presents a count of the number of total coliform and *E. coli* samples and the associated total coliform and *E. coli* positivity rates broken down by size and manufacturer/model for the years 2012-2019. For total coliforms, an average of 3.6 percent of samples provided for a given size and manufacturer/model category were positive. The median was 1.2 percent, with a minimum of 0 percent and a maximum of 25 percent. The 90th percentile was approximately 11 percent.

For *E. coli*, an average of 0.2 percent of samples provided for a given size and manufacturer/model category were positive. The median was 0 percent, the minimum was 0 percent and the maximum was 2.7 percent. The 90th percentile was approximately 0.5 percent. The *E. coli* alternative approach showed an average of 0.1 percent and a 90th percentile of approximately 0.3 percent.

Exhibit B-3. Number of Total Coliform and *E. coli* Samples, and Total Coliform and *E. coli* Positives, by Size and Manufacturer and Model; 2012-2019

Size	Manufacturer, Model	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
		Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive
L	AIRBUS, 330	10	0	0.00%	0	0	0.00%	10	0	0.00%
L	AIRBUS, A330	1,724	37	2.15%	73	2	2.74%	1,723	2	0.12%
L	AIRBUS, A350	58	0	0.00%	0	0	0.00%	58	0	0.00%
L	BOEING, 747	606	34	5.61%	294	0	0.00%	606	0	0.00%
L	BOEING, 767	1,271	29	2.28%	159	0	0.00%	1,271	0	0.00%
L	BOEING, 777	3,072	35	1.14%	1,799	0	0.00%	3,072	0	0.00%
L	BOEING, 787	222	1	0.45%	204	0	0.00%	222	0	0.00%
L	BOEING, B747	14	0	0.00%	14	0	0.00%	14	0	0.00%
L	DOUG, DC1030	0	0	0.00%	0	0	0.00%	0	0	0.00%
L	DOUG, MD11	14	2	14.29%	14	0	0.00%	14	0	0.00%
L	EMB, ERJ170	12	0	0.00%	12	0	0.00%	12	0	0.00%
M	AIRBUS, 320	2,028	41	2.02%	1,368	2	0.15%	2,028	2	0.10%
M	AIRBUS, 321	20	1	5.00%	12	0	0.00%	20	0	0.00%
M	AIRBUS, A220	12	0	0.00%	0	0	0.00%	12	0	0.00%
M	AIRBUS, A231	10	2	20.00%	4	0	0.00%	10	0	0.00%
M	AIRBUS, A319	1,254	24	1.91%	887	2	0.23%	1,253	2	0.16%
M	AIRBUS, A320	7,502	214	2.85%	4,483	6	0.13%	7,501	6	0.08%
M	AIRBUS, A321	3,448	112	3.25%	1,812	9	0.50%	3,448	9	0.26%
M	AIRBUS, A330	306	5	1.63%	5	0	0.00%	306	0	0.00%
M	BOEING, 737	28,282	1,023	3.62%	22,239	25	0.11%	28,280	25	0.09%
M	BOEING, 747	30	0	0.00%	30	0	0.00%	30	0	0.00%
M	BOEING, 757	7,288	186	2.55%	2,472	4	0.16%	7,288	4	0.05%
M	BOEING, 767	3,825	143	3.74%	1,519	8	0.53%	3,825	8	0.21%
M	BOEING, 777	34	3	8.82%	4	0	0.00%	34	0	0.00%
M	BOEING, 787	522	6	1.15%	365	0	0.00%	522	0	0.00%
M	BOEING, B737	468	34	7.26%	232	2	0.86%	468	2	0.43%
M	BOEING, B757	8	0	0.00%	0	0	0.00%	8	0	0.00%
M	BOEING, DC982	4	0	0.00%	4	0	0.00%	4	0	0.00%
M	BOEING, DC983	2	0	0.00%	2	0	0.00%	2	0	0.00%
M	DOUG, DC950	6	0	0.00%	0	0	0.00%	6	0	0.00%
M	DOUG, DC982	946	11	1.16%	573	0	0.00%	946	0	0.00%
M	DOUG, DC983	1,515	16	1.06%	1,186	0	0.00%	1,515	0	0.00%
M	DOUG, MD83	280	3	1.07%	279	0	0.00%	280	0	0.00%
M	DOUG, MD88	3,066	54	1.76%	105	1	0.95%	3,066	1	0.03%
M	DOUG, MD90	482	2	0.41%	2	0	0.00%	482	0	0.00%
M	DOUG, MD9030	1,116	17	1.52%	17	0	0.00%	1,116	0	0.00%
S	ACE, 123	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	ACE, 737	4	1	25.00%	4	0	0.00%	4	0	0.00%
S	ADAMS, 7897	16	0	0.00%	16	0	0.00%	16	0	0.00%
S	AIRBUS, 319	886	2	0.23%	613	0	0.00%	886	0	0.00%
S	AIRBUS, A220	48	1	2.08%	1	0	0.00%	48	0	0.00%

Size	Manufacturer, Model	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
		Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive	Total Samples	# Positive	% Positive
S	AIRBUS, A318	14	0	0.00%	14	0	0.00%	14	0	0.00%
S	AIRBUS, A319	3,934	66	1.68%	1,387	8	0.58%	3,933	8	0.20%
S	AIRBUS, A321	1,094	19	1.74%	899	0	0.00%	1,094	0	0.00%
S	BOEING, 707	4	0	0.00%	4	0	0.00%	4	0	0.00%
S	BOEING, 717	2,601	21	0.81%	459	0	0.00%	2,601	0	0.00%
S	BOEING, 737	1,705	33	1.94%	1,074	2	0.19%	1,705	2	0.12%
S	BOEING, 757	94	1	1.06%	84	0	0.00%	94	0	0.00%
S	BOEING, 767	34	1	2.94%	34	0	0.00%	34	0	0.00%
S	BOEING, 777	16	0	0.00%	14	0	0.00%	16	0	0.00%
S	BOEING, B737	24	0	0.00%	24	0	0.00%	24	0	0.00%
S	BOMBDR, BD100	1,683	180	10.70%	1,680	5	0.30%	1,683	5	0.30%
S	BOMBDR, CL6002	17,070	2,228	13.05%	15,635	63	0.40%	17,066	63	0.37%
S	BOMBDR, CRJ900	0	0	0.00%	0	0	0.00%	0	0	0.00%
S	BOMBDR, DHC8402	356	84	23.60%	216	3	1.39%	356	3	0.84%
S	BOMBDR, Q400	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	CNDAIR, CL6002	1,836	126	6.86%	1,391	10	0.72%	1,832	10	0.55%
S	DOUG, DC915	4	0	0.00%	4	0	0.00%	4	0	0.00%
S	DOUG, DC931	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	DOUG, DC932	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	DOUG, DC934	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	DOUG, DC950	150	3	2.00%	3	0	0.00%	150	0	0.00%
S	DOUG, DC983	2	0	0.00%	2	0	0.00%	2	0	0.00%
S	DOUG, DC987	8	2	25.00%	8	0	0.00%	8	0	0.00%
S	DOUG, MD88	80	2	2.50%	2	0	0.00%	80	0	0.00%
S	EMB, 140	20	0	0.00%	14	0	0.00%	20	0	0.00%
S	EMB, EMB135	1,039	113	10.88%	793	16	2.02%	1,039	16	1.54%
S	EMB, EMB145	6,182	1,182	19.12%	5,656	21	0.37%	6,182	21	0.34%
S	EMB, EMB175	12	0	0.00%	12	0	0.00%	12	0	0.00%
S	EMB, ERJ170	8,203	307	3.74%	6,784	10	0.15%	8,203	10	0.12%
S	EMB, ERJ190	1,484	41	2.76%	1,108	2	0.18%	1,484	2	0.13%
Total		**118,070**	**6,448**	**5.46%**	**78,114**	**201**	**0.26%**	**118,056**	**201**	**0.17%**

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

Exhibit B-4. Total Coliform and *E. coli* Positivity Rate, by Location and Year; 2011-2021

Year	Location	Total Coliforms			*E. coli*			*E. coli* (Alternative Approach)[1]		
		# Samples	# Total Coliform Positives	% Total Coliform Positives	# Samples	# *E. coli* positives	% *E. coli* positives	# Samples	# *E. coli* positives	% *E. coli* positives
2011	Galley	2,615	33	1.26%	1,077	2	0.19%	2,615	2	0.08%
2012	Galley	6,632	69	1.04%	4,352	4	0.09%	6,630	4	0.06%
2013	Galley	6,801	71	1.04%	4,103	4	0.10%	6,801	4	0.06%
2014	Galley	7,122	84	1.18%	4,294	2	0.05%	7,122	2	0.03%
2015	Galley	7,083	88	1.24%	4,029	2	0.05%	7,083	2	0.03%
2016	Galley	7,384	97	1.31%	4,285	6	0.14%	7,384	6	0.08%
2017	Galley	6,389	82	1.28%	4,416	2	0.05%	6,389	2	0.03%
2018	Galley	6,426	83	1.29%	4,508	6	0.13%	6,426	6	0.09%
2019	Galley	6,440	61	0.95%	4,525	1	0.02%	6,440	1	0.02%
2020	Galley	5,922	54	0.91%	4,172	2	0.05%	5,922	2	0.03%
2021	Galley	2,028	17	0.84%	1,471	2	0.14%	2,028	2	0.10%
2011	Lavatory	3,118	345	11.06%	1,736	8	0.46%	3,116	8	0.26%
2012	Lavatory	8,075	965	11.95%	5,931	29	0.49%	8,072	29	0.36%
2013	Lavatory	8,195	821	10.02%	5,390	27	0.50%	8,195	27	0.33%
2014	Lavatory	8,536	806	9.44%	5,551	15	0.27%	8,534	15	0.18%
2015	Lavatory	8,353	773	9.25%	5,157	22	0.43%	8,350	22	0.26%
2016	Lavatory	8,439	836	9.91%	5,227	24	0.46%	8,439	24	0.28%
2017	Lavatory	7,259	569	7.84%	5,256	19	0.36%	7,258	19	0.26%
2018	Lavatory	7,477	582	7.78%	5,550	20	0.36%	7,474	20	0.27%
2019	Lavatory	7,459	461	6.18%	5,540	18	0.32%	7,459	18	0.24%
2020	Lavatory	6,653	275	4.13%	4,882	23	0.47%	6,653	23	0.35%
2021	Lavatory	2,096	78	3.72%	1,542	3	0.19%	2,095	3	0.14%
Total (All Years)		**140,502**	**7,250**	**5.16%**	**92,994**	**241**	**0.26%**	**140,485**	**241**	**0.17%**
Total (2012-2019)		**118,070**	**6,448**	**5.46%**	**78,114**	**201**	**0.26%**	**118,056**	**201**	**0.17%**

[1] Under the *E. coli* “Alternative Approach,” any *E. coli* sample paired with a total coliform “Absent” was included as an *E. coli* “Absent” sample.

A count of the number of total coliform samples and associated total coliform positivity rates broken down by year and disinfection/flushing frequency for the years 2012-2019 is presented in Exhibit B-5. A count of the number of *E. coli* samples and associated *E. coli* positivity rates broken down by year and disinfection/flushing frequency for the years 2012-2019 are presented in Exhibit B-6 and Exhibit B-7, for the first and second set of *E. coli* assumptions, respectively.

More than 99 percent of total coliform samples were from systems that performed disinfection and flushing four times per year. For those systems, the average total coliform positivity rates for a given year was greater than 5 percent. Similarly, more than 99 percent of *E. coli* samples were from systems that performed disinfection and flushing four times per year under both sets of *E. coli* assumptions. For those systems, the average *E. coli* positivity rate for a given year was approximately 0.26 percent under the first set of *E. coli* assumptions, and 0.17 percent under the second set of *E. coli* assumptions.

Exhibit B-5. Total Coliform Sample Count and Positivity Rate, by Disinfection and Flushing Frequency, by Year; 2012-2019

	Total Coliforms											
	2x per year			**3x per year**			**4x per year**			**Unknown**		
Year	**Total Samples**	**# Total Coliform Positives**	**% Total Coliform Positives**	**Total Samples**	**# Total Coliform Positives**	**% Total Coliform Positives**	**Total Samples**	**# Total Coliform Positives**	**% Total Coliform Positives**	**Total Samples**	**# Total Coliform Positives**	**% Total Coliform Positives**
2012	68	2	2.94%	180	6	3.33%	14,293	1,010	7.07%	166	16	9.64%
2013	66	0	0.00%	158	9	5.70%	14,650	871	5.95%	122	12	9.84%
2014	94	1	1.06%	32	0	0.00%	15,460	885	5.72%	72	4	5.56%
2015	60	8	13.33%	12	0	0.00%	15,354	853	5.56%	10	0	0.00%
2016	16	0	0.00%	0	0	0.00%	15,795	931	5.89%	12	2	16.67%
2017	16	0	0.00%	4	0	0.00%	13,620	651	4.78%	8	0	0.00%
2018	16	0	0.00%	0	0	0.00%	13,877	664	4.78%	10	1	10.00%
2019	16	0	0.00%	0	0	0.00%	13,877	522	3.76%	6	0	0.00%
Total	**352**	**11**	**3.13%**	**386**	**15**	**3.89%**	**116,926**	**6,387**	**5.46%**	**406**	**35**	**8.62%**

Exhibit B-6. *E. coli* Positivity Rate, by Disinfection and Flushing Frequency, by Year; 2012-2019

	E. coli											
	2x per year			**3x per year**			**4x per year**			**Unknown**		
Year	**Total Samples**	**# *E. coli* positive**	**% *E. coli* positive**	**Total Samples**	**# *E. coli* positive**	**% *E. coli* positive**	**Total Samples**	**# *E. coli* positive**	**% *E. coli* positive**	**Total Samples**	**# *E. coli* positive**	**% *E. coli* positive**
2012	68	0	0.00%	27	0	0.00%	10,124	33	0.33%	64	0	0.00%
2013	65	0	0.00%	21	0	0.00%	9,351	31	0.33%	56	0	0.00%
2014	94	0	0.00%	0	0	0.00%	9,713	17	0.18%	38	0	0.00%
2015	60	0	0.00%	0	0	0.00%	9,118	24	0.26%	8	0	0.00%
2016	16	0	0.00%	0	0	0.00%	9,484	29	0.31%	12	1	8.33%
2017	16	0	0.00%	4	0	0.00%	9,644	21	0.22%	8	0	0.00%
2018	16	0	0.00%	0	0	0.00%	10,032	26	0.26%	10	0	0.00%

E. coli												
Year	2x per year			3x per year			4x per year			Unknown		
	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive
2019	16	0	0.00%	0	0	0.00%	10,043	19	0.19%	6	0	0.00%
Total	**351**	**0**	**0.00%**	**52**	**0**	**0.00%**	**77,509**	**200**	**0.26%**	**202**	**1**	**0.50%**

Exhibit B-7. *E. coli* Positivity Rate using Alternative Approach, by Disinfection and Flushing Frequency, by Year; 2012-2019

E. coli (Alternative Approach)[1]												
Year	2x per year			3x per year			4x per year			Unknown		
	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive	Total Samples	# *E. coli* positive	% *E. coli* positive
2012	68	0	0.00%	180	0	0.00%	14,288	33	0.23%	166	0	0.00%
2013	66	0	0.00%	158	0	0.00%	14,650	31	0.21%	122	0	0.00%
2014	94	0	0.00%	32	0	0.00%	15,458	17	0.11%	72	0	0.00%
2015	60	0	0.00%	12	0	0.00%	15,351	24	0.16%	10	0	0.00%
2016	16	0	0.00%	0	0	0.00%	15,795	29	0.18%	12	1	8.33%
2017	16	0	0.00%	4	0	0.00%	13,619	21	0.15%	8	0	0.00%
2018	16	0	0.00%	0	0	0.00%	13,874	26	0.19%	10	0	0.00%
2019	16	0	0.00%	0	0	0.00%	13,877	19	0.14%	6	0	0.00%
Total	**352**	**0**	**0.00%**	**386**	**0**	**0.00%**	**116,912**	**200**	**0.17%**	**406**	**1**	**0.25%**

[1] Under the *E. coli* "Alternative Approach," any *E. coli* sample paired with a total coliform "Absent" was included as an *E. coli* "Absent" sample.

Appendix C. Revised Total Coliform Rule Level 1 and Level 2 Assessment Characterization and Data Quality Considerations

Data Quality Considerations for Level 1 and Level 2 Assessments and Sanitary Defect Designation

As described in EPA's Data Entry Instructions for RTCR, inaccurate and incomplete data limits EPA's and the public's understanding of the state of compliance with the Safe Drinking Water Act, as well as limits the review of RTCR effectiveness during this SYR4 review process (USEPA, 2016c).

This subsection clarifies the reporting methods for TT triggers, sanitary defect identification and RTCR corrective actions database accounting methods since discrete data extraction limited to sanitary defects only may not appropriately capture the reported occurrence of sanitary defects. The following factors affect the accounting of sanitary defects: whether Level 1 and Level 2 assessment site visits were reported by primacy agencies in Agency-specific databases and reported to SDWIS/Fed; whether Level 1 and Level 2 assessments were performed during the same site visit as a sanitary survey; and whether the SDWIS/Operational Data System (SDWIS/ODS) appropriate accounts for sanitary defects reported in SDWIS State version 3.33 as significant deficiencies.

Although primacy agencies are not required by RTCR reporting requirements of 40 CFR 142 to submit data elements regarding completion of Level 1 assessments or Level 2 assessments or scheduled corrective actions, the RTCR Data Entry Instructions (USEPA, 2016c) clarify that primacy agencies should report the following RTCR data elements for accurate and complete data acceptance into the EPA national database of record including: RTCR TT trigger incurred, primacy agency minimum requirement to satisfy RTCR TT trigger; and actual site visit/assessment conducted in response to primacy agency RTCR TT Trigger requirement; and expedited/corrective actions for assessments (USEPA, 2016c).

A Level 1 assessment, Level 2 assessment and sanitary survey each consists of a minimum evaluation of eight site visit data object category evaluations, also known as elements. When there are multiple findings within a site visit category/element, the primacy agency is required to report the finding having the highest severity for that category/element. The ranking of highest to lowest severity of findings is as follows: sanitary defect (highest severity), significant deficiency, minor deficiency, recommendations made, no deficiencies or recommendations, not evaluated, or not applicable (USEPA, 2016c). RTCR provides primacy agencies the authority in 40 CFR 141.859(b)(4)(iii-iv) to require expedited and additional actions, such as minor deficiencies or recommendations, to be completed even if no sanitary defects are identified when there is an *E. coli* MCL violation (USEPA, 2016c).

A database data quality error is assigned to the primacy agency data due to failure to report all eight required RTCR assessment site visit category/elements (USEPA, 2016c) when a site visit is entered for a RTCR assessment. However, the SDWIS database is limited on its alert of discrepancies/errors for lack of reporting of the occurrence of an RTCR TT trigger event; lack of reporting a site visit for an assessment and lack of designation of corrective action event schedule timeline (USEPA, 2016c).

Primacy agencies were required to provide examples of significant deficiencies for each of the eight elements of a sanitary survey under the GWR and IESWTR. The difference between significant deficiencies and sanitary defects can vary based on how the primacy agency identified significant deficiencies. Sanitary defects are defined by the RTCR to be deficiencies that could provide a pathway of entry for microbial contamination into the distribution system or are indicative of a failure or imminent failure in a barrier that is already in place. Some sanitary defects could also be significant deficiencies.

RTCR guidance describes that a complete sanitary survey covering all applicable elements is allowed to fulfill the requirements of a Level 1 or Level 2 TT trigger if allowed by the primacy agency, and the sanitary survey (including sanitary survey report and corrective actions) is completed within 30 days of when the RTCR TT trigger happens (USEPA, 2016c). When a RTCR Level 1 or Level 2 assessment is combined with a sanitary survey it is described as an Integrated Assessment (USEPA, 2020c) and is described with site visit codes: L1SS, L2SS (USEPA, 2016c). If a Level 1 or Level 2 assessment is combined with a partial sanitary survey it is reported with site visit codes L1PS, L2PS.

When a primacy agency allows sanitary surveys to meet the RTCR Level 1 and/or Level 2 TT triggers, then there is a potential that some sanitary defects could also be significant deficiencies. When this happens, the primacy agency should use the report the category/element finding as a sanitary defect, which is the highest severity finding (USEPA, 2016c).

SDWIS State 3.33 has a data element limitation where it will not allow the primacy agency to report any RTCR assessment outcome of a sanitary defect. As a workaround, the *Revised Total Coliform Rule (RTCR) Data Entry Instructions with Examples* (USEPA, 2016c) specified that the finding be designated as a significant deficiency when a sanitary defect was identified. The instructions further clarified that when the database user entered a significant deficiency and also enters site visit as any type of Level 1 or Level 2 assessment (LV1A, LV2A, L1SS, L2SS, L1PS, L2PS) that SDWIS/ODS would convert the values reported as significant deficiencies to sanitary defect in EPA's national database (USEPA, 2016c). Although this workaround could be an effective option for tracking sanitary defects, unfortunately the SDWIS/Fed site visit extract used for the data period of April 1, 2016 to December 31, 2019, showed no significant deficiencies were converted to sanitary defects for any element for Level 1 and Level 2 assessments reported as integrated assessments or partial assessments. This would seem to mean that the only sanitary defects maintained in the SDWIS/Fed national database were reported directly via state database migration of other than SDWIS State 3.33.

For the SDWIS/Fed site visit dataset used below, the values of sanitary defects were based on the combination of reported significant deficiencies and sanitary defects performed during Level 1 assessments and Level 2 assessments having site visit objects: LV1A, LV2A, L1SS, L2SS, L1PS, L2PS, because significant deficiencies were not appropriately reported as sanitary defects in SDWIS/Fed from SDWIS State 3.33 as described above.

Characterization of Level 1 and 2 Assessments

In order to characterize the occurrence of Level 1 and Level 2 assessments, this SYR4 review considered two datasets. For the first dataset of this analysis an extract of the SDWIS/Fed "event and milestone" data was reviewed for the period of April 1, 2016 to December 31, 2019 to determine the frequency that RTCR assessments were triggered. This data was used to identify whether Level 1 and Level 2 assessments were triggered and how often assessments were triggered by an individual PWS. When a RTCR Level 1 or Level 2 assessment is triggered it is reported using data elements, RTL1 and RTL2 respectively, in the event and milestone database. Reporting of a triggered RTCR assessment as an "event and milestone" is different from reporting of RTCR violations in the SDWIS/Fed database

The second data set, SDWIS/Fed site visit dataset for the period of April 1, 2016 to December 31, 2019 covered 40 states (not including Alabama, District of Columbia, Georgia, Kentucky, Mississippi, Minnesota, North Carolina, Pennsylvania, South Carolina, Tennessee, Washington, Guam, Puerto Rico, U.S. Virgin Islands) and including Navajo Nation, American Samoa, and Northern Mariana Islands. The SDWIS/Fed site visit dataset was used to show the occurrence of sanitary defects and significant deficiencies identified during Level 1 and Level 2 assessments. A more detailed explanation of data quality considerations regarding the reporting of sanitary defects for SDWIS/Fed site visit is included in Appendix C above.

Exhibit C-1 and Exhibit C-2 show the recurrence of multiple RTCR Level 1 and Level 2 assessments, respectively, at individual water systems by year. Exhibit C-1 shows that there was a decreasing trend in the total number of water systems having two or more Level 1 assessments as time progressed from the initial RTCR implementation, when comparing years having a full calendar year of data, 2017 to 2019.

Exhibit C-1. Summary of Frequency of Recurring Revised Total Coliform Rule Level 1 Assessments[1] Triggered by an Individual Public Water System by Year

Year	Total PWS Triggering Level 1 per year	Count of PWS with exactly 1 Level 1 Trigger per year	Count of PWS with 2 or more Level 1 Triggers per year	Percent of PWS with 2 or more Level 1 Triggers per year	Count of PWS with exactly 2 Level 1 Triggers per year	Count of PWS with exactly 3 Level 1 Triggers per year	Count of PWS with ≥4 Level 1 Triggers per year
2016[2]	1,967	1,836	131	6.7%	123	7	1
2017	2,369	2,290	79	3.3%	76	2	1
2018	2,506	2,418	88	3.5%	80	7	1
2019	1,861	1,809	52	2.8%	47	5	0

[1] There was a total of 9081 Level 1 assessments reported as triggered in this dataset from April 1, 2016 to December 31, 2019. Source: SDWIS/Fed "Event and Milestone" data

[2] Represents partial year from April 1 to December 31, 2016 due to RTCR implementation start date of April 1, 2016.

Exhibit C-1 shows that for the period of April 1, 2016 to December 31, 2019, that there were approximately 3 percent of water systems that incurred a second Level 1 assessment (reported as a Level 1 assessment) in the same calendar year. Recurrence of Level 1 TT trigger within 12 months of the preceding Level 1 TT trigger is defined as a Level 2 TT trigger. Therefore, accurate data reporting of multiple Level 1 assessments in the same year may only occur due to the primacy agency designating the water system as “reset” due to identifying and resolving the underlying finding of the initial Level 1 assessment at that same water system. Alternatively, data reporting of two recurring instances of Level 1 assessment may indicate improper data entry of the second Level 1 TT trigger that the state should have reported as Level 2 assessment if the “reset” provision did not apply.

Exhibit C-2. Summary of Frequency of Recurring Revised Total Coliform Rule Level 2 Assessments[1] Triggered by an Individual Public Water System by Year

Year	Total PWS Triggering Level 2 per year	Count of PWS with exactly 1 Level 2 Trigger per year	Count of PWS with 2 or more Level 2 Triggers per year	Percent of PWS with 2 or more Level 2 Triggers per year	Count of PWS with exactly 2 Level 2 Triggers per year	Count of PWS with exactly 3 Level 2 Triggers per year	Count of PWS with ≥4 Level 2 Triggers per year
2016[2]	602	504	98	16%	84	13	1
2017	1,152	911	241	21%	188	38	15
2018	1,351	1,028	323	24%	246	51	26
2019	1,013	803	210	21%	168	24	18

[1] There was a total of 5268 Level 2 assessments reported as triggered in this dataset from April 1, 2016 to December 31, 2019. Source: SDWIS/Fed “Event and Milestone” data

[2] Represents partial year from April 1 to December 31, 2016 due to RTCR implementation start date of April 1, 2016.

For Level 2 assessments shown in Exhibit C-2, there were approximately 20 percent of water systems that incurred a second Level 2 assessment in the same calendar year for the years having a full calendar year of data, 2017-2019. This means more than 20 percent of water systems triggering Level 2 assessments in each of the calendar years 2017, 2018, and 2019 had recurring *E. coli* positivity; or multiple coliform positivity (e.g., two L1 triggers occurred within 12 months); or a recurrence of failure to perform appropriate coliform monitoring within the same calendar year. This would indicate sanitary defect conditions for these PWS, since defects had not been effectively resolved in accordance with the Level 2 corrective action requirements or timeline.

Exhibit C-3 shows the number of Level 1 and Level 2 assessments occurring between April 1, 2016 to December 31, 2019 that did not identify sanitary defects or other corrective actions.

Exhibit C-3. Summary of Data Provided by Federal Safe Drinking Water Information System Database Site Visit Entries Showing Revised Total Coliform Rule Level 1 and Level 2 Assessments during April 1, 2016 to December 31, 2019 that did not Identify a Sanitary Defect or Other Corrective Action

Type of Findings Reported for Required RTCR Elements	Count of Level 1 Assessments without Identified Finding	Percent of Level 1 Assessments without Identified Finding	Count of Level 2 Assessment without Identified Finding	Percent of Level 2 Assessments without Identified Finding

No Sanitary defect[1] Found for All Required Elements	5395	65%	2556	45%
No Finding of Any Type[2] for All Required Elements	3952	47.6%	1804	31.8%

[1] Sanitary defect for this purpose includes: significant deficiencies as described in the data quality considerations discussion in Appendix C above.

[2] For this purpose, no finding of any type means that no sanitary defect, significant deficiency, minor deficiency or recommendation was reported.

Source: SDWIS/Fed site visits extract, 40 states plus Navajo Nation and territories

Also, the frequency of recurring Level 2 assessments shown in Exhibit C-2 did not show a decreasing trend for recurring Level 2 assessments when comparing full calendar years of data from 2017 to 2018. This may be because 45 percent of Level 2 assessments that occurred during the period of April 1, 2016 to December 31, 2019 did not find a sanitary defect to fix, as noted in Exhibit C-3. It is not implicit that the 45 percent of Level 2 assessments without sanitary defect correlate directly to the 20 percent of systems that triggered more than one Level 2 assessment in the same calendar year, although the lack of an identifiable sanitary defect complicates a water system's ability to implement a corrective action to resolve coliform positive detect(s).

A complicating factor for RTCR assessments is that they are performed on a lagging basis and can be completed over a 30-day timeframe following collection of the initial coliform sample. This can make identification of a sanitary defect difficult due to the delayed nature of the assessment. The lagging nature of this process is due to several factors such as, up to 30 hours for sample hold time, microbial incubation time of method analysis, time interval prior to repeat sampling (i.e., 24 to 72 hours) and time interval between notifying the PWS of the sample result and performing the assessment.

Exhibit C-4 shows the types of sanitary defects that were identified during Level 1 and Level 2 assessments between April 1, 2016 to December 31, 2019. Likewise, Exhibit C-5 shows the types of corrective actions other than sanitary defects that were identified during Level 1 and Level 2 assessments that occurred between April 1, 2016 to December 31, 2019.

Exhibit C-4. Summary of Data Provided by Federal Safe Drinking Water Information System Database Site Visit Entries[1] showing the Types of Sanitary Defect (and Significant Deficiencies) identified by Revised Total Coliform Rule Level 1 and Level 2 Assessments during April 1, 2016 to December 31, 2019

Sanitary Defect[2] Element Reported for RTCR Assessment	RTCR Element Required Reporting Status (USEPA, 2016c)	Count of Level 1 Assessments that Reported Sanitary Defect Element	Percent of Level 1 Assessments with Sanitary Defect Element[1]	Count of Level 2 Assessments that Reported Sanitary Defect Element	Percent of Level 2 Assessments with Sanitary Defect Element[1]
Source Water	Required	974	11.7%	1644	29.0%
Management Operation	Required	587	7.1%	480	8.5%
Treatment	Required	554	6.7%	545	9.6%

Finished Water	Required	351	4.2%	563	9.9%
Distribution	Required	973	11.7%	1183	20.9%
Data Verification	Required	580	7.0%	236	4.2%
Compliance	Required	40	0.5%	132	2.3%
Pump	Required	87	1.0%	128	2.3%
Security	Optional	6	0.1%	10	0.2%
Other	Optional	803	9.7%	530	9.4%
Financial	Optional	5	0.1%	2	0.0%

[1] There was a total of 8305 Level 1 RTCR Assessments and 5668 Level 2 Assessments having SDWIS/Fed Site Visit entries reported during April 1, 2016 to December 31, 2019 in this dataset. Source: SDWIS/Fed Site Visits, 40 states plus Navajo Nation and territories.

[2] Sanitary Defect for this purpose includes: significant deficiencies and sanitary defects identified during RTCR assessments as described in the data quality considerations discussion in Appendix C above.

Issues with source water and issues in the distribution system represent the largest two types of sanitary defects for both Level 1 and Level 2 RTCR assessments. This is also the same with regard to other corrective actions identified by Level 1 and Level 2 RTCR assessments. The third most relevant sanitary defect applicable to other corrective actions was management of the water system as shown in
Exhibit C-5.

Exhibit C-5. Summary of Data Provided by Federal Safe Drinking Water Information System Database Site Visit Entries1 showing the Types of Other Corrective Actions, Including Recommendations, and Minor Deficiencies identified by Revised Total Coliform Rule Level 1 and Level 2 Assessments during April 1, 2016 to December 31, 2019

Element of Corrective Action (Minor Deficiency or Other Recommendation) Reported for RTCR Assessments	**Count of Level 1 Assessments that Identified Element of Other Corrective Action**	**Percent of Level 1 Assessments with Element of Other Corrective Action Identified[1]**	**Count of Level 2 Assessments that Identified Element of Other Corrective Action**	**Percent of Level 2 Assessments with Element of Other Corrective Action Identified[1]**
Source Water	565	6.8%	488	8.6%
Management Operation	532	6.4%	465	8.2%
Treatment	271	3.3%	267	4.7%
Finished Water	205	2.5%	273	4.8%
Distribution	742	8.9%	494	8.7%
Data Verification	231	2.8%	214	3.8%
Compliance	74	0.9%	86	1.5%
Pump	80	1.0%	105	1.9%
Security	20	0.2%	70	1.2%
Other	54	0.7%	68	1.2%

Element of Corrective Action (Minor Deficiency or Other Recommendation) Reported for RTCR Assessments	Count of Level 1 Assessments that Identified Element of Other Corrective Action	Percent of Level 1 Assessments with Element of Other Corrective Action Identified[1]	Count of Level 2 Assessments that Identified Element of Other Corrective Action	Percent of Level 2 Assessments with Element of Other Corrective Action Identified[1]
Financial	6	0.1%	20	0.4%

[1] There was a total of 8305 Level 1 RTCR Assessments and 5668 Level 2 Assessments having SDWIS/Fed Site Visit entries reported during April 1, 2016 to December 31, 2019 in this dataset. Source: SDWIS/Fed Site Visits, 40 states plus Navajo Nation and territories.

This SYR4 review did not include a review of available information to determine whether detailed information of the exact nature of sanitary defects was identified in SDWIS for RTCR assessments.

Appendix D. Revised Total Coliform Rule Corrective Actions and Assessment of Data Quality

This SYR4 review studied new information regarding distribution system corrective actions as well as SDWIS data quality limitations regarding RTCR assessments.

New Information Pertaining to Sanitary Defects and Corrective Actions

When a PWS triggers a Level 1 or Level 2 assessment because a sanitary defect was identified that could be the cause of total coliform positive or *E. coli* positive samples, a corrective action is required (40 CFR 141.859(c)).

- **Failure to Disinfect After Maintenance**

Existing practices used for repair and replacement of water mains pose potential risk of microbial contamination. Available guidelines and industry standards outline proper planning and standard operating procedures (SOPs) to address risk of contamination degradation of water quality associated with water main repair and replacement.

If a finished water storage facility is drained for maintenance or inspection, disinfection must occur before being placed into service. ANSI/AWWA C652 (AWWA, 2020), provides the guidance for proper disinfection.

The Ten States Standards (GLUMRB, 2018) stresses the importance of a sufficient number of valves in the distribution system to minimize sanitary hazards during repairs. In commercial districts valves should not be located at greater than 500-foot intervals, in other districts one block or 800-foot intervals, and in areas that serve widely scattered customers (or where there is no expected future development) valves should not exceed one mile.

- **Lack of Flushing Programs**

Flushing entails allowing water to discharge from the distribution system by opening a connection. Flushing can have many benefits in a distribution system including reduction of water age and addressing water quality complaints (USEPA, 2022a). Flushing is listed as an acceptable corrective action to address sanitary defects in the *Revised Total Coliform Rule Assessments and Corrective Actions Guidance Manual: Interim Final* (USEPA, 2014b). Detail on proper flushing techniques or applications is not provided by the manual and flushing is not clearly listed as an appropriate corrective action for particular coliform response situations (Hill et al., 2018).

The State drinking Water Distribution Survey conducted by ASDWA (2020) was completed by drinking water representatives from 41 states and territories. At least 12 states (30 percent of respondents) have flushing requirements to better ensure a safe and reliable distribution system written in their state legislation (ASDWA, 2020). Of the 70 percent of state respondents that do not require a flushing program, many strongly recommend it. Some of the methods to encourage a flushing program include either requiring a flushing plan to be eligible for Drinking Water State Revolving Fund (DWSRF) funding or encouraging it to be a part of the water system's operations and maintenance plan during sanitary surveys (ASDWA, 2020).

Hill et al. (2018) points out a lack of regular flushing programs as a common cause of total coliform and *E. coli* detections in the distribution system while noting that specific causes will vary from system to system.

Spot flushing, a conventional flushing technique, can be performed on particular areas of the distribution system to decrease water age in areas such as dead-end water mains by drawing in fresh water. Spot flushing can be triggered by a water quality issue or customer complaints, or can be scheduled regularly in known areas of issue (USEPA, 2022a; Hill et al., 2018).

Unidirectional Flushing (UDF) starts at the point where clean water enters the system and systematically flushes through the system. This flushing typically involves a higher velocity due to closing nearby isolation valves to direct flow. UDF can be used as a regular maintenance practice and can achieve complete turnover in the defined UDF area if applied to all mains. A flushing velocity and terminating criteria can be defined for the specific utility in the flushing program (Hill et al., 2018).

Automatic flushing stations can also be used as an on-going water age management technique. These can be programmed to flush specific portions of the system at specified velocities and intervals. They can be semi-permanent or portable (Hill et al., 2018).

Flushing and secondary disinfection can work together in the distribution system to maintain adequate disinfection residual and control microbial activity on the pipe walls. Hill et al. (2018) established a guidance toolbox for use of flushing under the RTCR which has four steps discussed in terms of being a corrective action. The steps begin with conducting a coliform assessment to determine the likely cause. Next a decision matrix is consulted to assess if flushing is appropriate, then the matrix is used to decide the proper flushing technique. Last other potential actions can be identified using a summary table for various coliform occurrence pathways (Hill et al., 2018).

Hill et al. (2018) suggests that flushing is an appropriate corrective action for coliform events from pipe wall biofilm regrowth and release. However, does not correct factors of coliform events that arise from treatment breakthrough, direct DS contamination, or source water contamination and should be used a secondary corrective action for those instances (Hill et al., 2018).

- **Main Breaks**

PWSs should have a written SOP for proper main repair and disinfection practices that meet AWWA standard C651. Maintenance staff and contractors should have access to the SOP and any resources needed to comply with it.

- **Pressure Loss in Distribution System**

The five best available technologies, TTs, or other means of achieving compliance with the MCL for *E. coli* are identified in the RTCR. Distribution system pressure management is one of these identified options as follows:

"*Proper maintenance of the distribution system including appropriate pipe replacement and repair procedures, main flushing programs, proper operation and maintenance of storage tanks and reservoirs, cross connection control, and continual maintenance of positive water pressure in all parts of the distribution system…"* (40 CFR 141.63 (e)(3)).

Thirty-eight states have a design or operational standard for minimum pressure (ASDWA, 2020).). To ensure fire fighters have sufficient pressure in the system and to avoid instances of negative pressure, most states specify 20 psi. Some states also have a maximum pressure limit, typically between 60 and 150 psi (USEPA, 2024b).

The potential for contaminants to enter the distribution system during pressure events (i.e., main breaks and pressure surges) through physical gaps can be reduced by an effective pressure management strategy. *E. coli*, total coliform bacteria, worms, hydro-seed, propylene glycol, ethylene glycol, and irrigation water can enter a water distribution system via backflow (AWWA, 2017).

- **Breaches in Finished Water Storage Facilities**

Finished water storage facility vent and overflow screens can have significant physical gaps that can lead to contamination of storage facilities and, consequently, distribution systems. This stored water is delivered directly to the customers and thus creates a public health risk. Physical gaps in vents and overflows can come from damaged screens, no screens, or screens with openings too large to prevent intrusion of insects and animals. The water in the facility can be an attraction for small animals (e.g., birds, bats, rodents, snakes and insects) and they can potentially enter through these physical gaps causing contaminants such as opportunistic waterborne pathogens to enter the system (USEPA, 2019d).

EPA's sanitary survey guidance states that overflow pipes should not discharge directly to the ground or to any storm or sewer line to prevent contamination (USEPA, 2019d). The guidance also states that rooftop tank vents should have a corrosion resistant fine mesh screen to prevent entrance of birds, insects, and small debris as a flapper valve alone could be prevented from closing completely by debris, ice, or snow. To prevent the storage facility from imploding caused by a vacuum effect of a clogged screen, the screen must be designed to fail. The vent should face downward or be covered to protect the storage facility contents from rain (USEPA, 2019d).

Regular tank cleaning and inspection can remove the accumulated sediment and help locate breaches in a finished water storage facility. EPA's review of state regulations in 2017 found that some states require or recommend periodic comprehensive inspections but other states have no such requirements. EPA's review of sanitary survey reports in the SDWIS database (Heinrich et al., 2022) also confirmed that some water systems have no tank inspection program.

AWWA's M68 manual suggests that, in order to remove sediment and biofilm that may harbor nitrifying bacteria, storage facilities should be inspected and cleaned at least every five years (AWWA, 2017).

- **Cross-Connection Control and Backflow Prevention Program**

The AWWA M68 manual (2017) notes that only a robust and active cross-connection control program can ensure that a distribution system is truly not affected by outside conditions. Possible indicators of cross-connection and backflow incidents in distribution systems can include (AWWA, 2017):

- Drops in operating pressure
- Customer complaints
- Water meter anomalies
- Drops in disinfectant residual
- Detections of total coliform and HPC bacteria changes

The M68 manual emphasizes using cross-connection control and backflow-prevention programs to prevent, eliminate, and/or control cross-connections (AWWA, 2017).

Due to potential for hydrants to be a source of cross-connection, the GLUMRB 10 States Standards (2018) state that hydrants and flushing lines must be equipped with backflow prevention devices.

The SDWIS analysis of data between 2010 and 2017 performed by EPA found that unprotected existing or potential cross-connections were the most prevalent deficiencies identified at 26.9 percent of all surveys (Heinrich et al., 2022).

EPA found, as of May 2020, that 49 of the 50 US states (with the exception of Delaware) have developed and implemented cross-connection control programs. According to the ASDWA State Drinking Water Distribution System Survey, 53 percent of responding states require a cross-connection survey and half of those included all water use equipment (e.g., cooling towers, spray misters, spas, and pools) (ASDWA, 2020).

- **Inadequate Disinfectant Residuals**

AWWA conducted its fifth disinfection survey in 2017 which collected information from water systems on their common treatment practices (AWWA, 2018). Survey responses were summarized for a total of 375 water systems, distributed across 44 states and one United States territory.

Systems noted that meeting minimum chlorine target levels is more challenging in the distribution system than it is for meeting the targets for primary disinfection. The report showed 12 percent of systems reported frequent difficulties in meeting their chlorine residual targets in the distribution system while the majority of the respondents reported having difficulty on occasion.

Gibson and Bartrand (2021) evaluated disinfection practices of CWSs used publicly available data. Of the total 3,823 systems in the statistically representative sample, 831 reported that they do not provide residual (secondary) disinfection (Gibson and Bartrand, 2021).

Many factors influence the concentration of the disinfectant residual in the distribution system, and its effectiveness in controlling microbial growth and biofilm formation. These factors include the assimilable organic carbon (AOC) level, the type and concentration of disinfectant, water temperature, pipe material, and system hydraulics. The number of variables associated with biofilm control has led researchers to reach differing conclusions regarding the effectiveness of secondary disinfectants at controlling biofilm growth.

The ability to control (but not eliminate) biofilms using secondary disinfection is impacted by the disinfectant residual concentration used in the system. If the concentrations are too low, the disinfectant residual becomes ineffective at controlling biofilm growth. Several studies have shown that biofilm growth is reduced when sufficient disinfectant residuals are maintained in the bulk water passing through pipes.

This advantage was maintained at a higher dose of chlorine in the presence of organic matter that could react with chlorine. Puzon et al. (2020) further characterized *N. fowleri* presence in biofilm, noting a diverse community composition can contribute to the organism's ability to successfully colonize a biofilm and demonstrate considerable resistance to chlorine disinfection.

The presence of sessile *Legionella*, particularly within Free-living amoebae (FLA), may be due to biofilm build-up and conditions that favor its continued presence in a biofilm such as inconsistent temperature, slower water velocity, and disinfectant concentration. Shaheen et al. (2019) suggest that diminished or absent disinfectant residual in conjunction with other environmental conditions such as optimal temperature and nutrient inflow may encourage FLA growth.

To date, a range of amoebae that may support *Legionella* and mycobacteria cell growth have been identified in drinking water. It has been found that slight water temperature changes can influence the growth potential of different pathogenic strains of *Legionella* and their supporting host amoebae. These data describe critical numbers of *Legionella* in water pipe biofilms (slimes), shower head water, and bathroom aerosols that could be inhaled (USEPA, 2021).

- **Contaminated Sampling Taps**

The detection of coliform bacteria in a water sample by any of the four analytical techniques is a warning of possible contamination. One positive test does not conclusively prove contamination AWWA, 2016). Samples are often contaminated by improper sampling technique, improperly sterilized bottles, and laboratory error (AWWA, 2016).

Ouro Koumai voiced concerns that coliform-positive samples were sometimes erroneously attributed to poor sampling technique rather than a call to action to identify and address the source of contamination (ASDWA, 2019).

Heinrich et al. (2022) conducted a study which intended to identify the most frequent deficiencies found by reviewing sanitary survey information collected by primacy agencies. This study found that that 22.9 percent of all systems surveyed had a deficiency of “failure to monitor according to system’s monitoring plan(s) or established procedures”. That placed it as the second most commonly identified deficiency (Heinrich et al., 2022). EPA provided a guide for drinking water sample collection (USEPA, 2016d).

- **Addition or Upgrade of On-Line Monitoring and Control**

Controlling and monitoring disinfectant dosages and water quality parameters can also be performed through the use of a supervisory control and data acquisition (SCADA) system at the treatment facility. Disinfectant dosing equipment can be monitored and analyzers can be placed in the treatment process to monitor water quality parameters. Monitoring water quality parameters via SCADA in a distribution system is possible; however, it can be costly. Determining the number and location of the analyzers is challenging and highly dependent upon the system size. Typically, analyzer equipment will draw samples from an above grade pipe or a sample tap to an analyzer that is placed in a building. Sample locations will require analyzer equipment, a building, electric power and, in the case of some systems, integration to the PWS’s existing SCADA system. Method requirements for on-line amperometric chlorine monitors are more time intensive and difficult than grab sampling (USEPA, 2014).

Installing online pressure monitoring and control will help minimize future incidents of pressure loss that can allow entry of contaminants into the distribution system. It can also help a PWS determine if there are any physical problems in the system, e.g., a crack in a pipe, a leaking valve, etc., that cause changes to the water quality of the system.

On-line distribution system monitoring through the SCADA system can alert operators if there are possible issues with the distribution system; however, monitoring the water quality or pressure will not identify the source of the contamination nor will it necessarily identify the location of the contamination (USEPA, 2014)

- **Addition of Security Measures**

PWSs may need to install security measures in circumstances where the assessment or onsite inspection reveals vandalism or security breaches that could lead to water contamination. Measures that PWSs may take to correct security breaches include installing a fence or locking buildings to restrict access to the system. Other possible security measures include employing a full time, on-site security staff and using alarms and cameras to detect security breaches (USEPA, 2014).

PWSs should prioritize their security measures and concentrate on the most vulnerable parts of their system, such as unstaffed facilities (e.g., finished water storage tanks). An important implementation issue is determining the extent to which the water system needs to be secured. This would depend on how widely spread the system/facility is, the number and complexity of the treatment trains, the extent of the watershed, the distance of the treatment plant from the influent wells, accessibility of the distribution system, etc. (USEPA, 2014)

- **Development and Implementation of an Operations Plan**

PWSs may need to develop an operations plan or improve their existing one when the assessment identifies gaps in the way the system is operated that could have led to or contributed to the sanitary defect identified. For example, a broken valve might have been prevented if routine inspections were part of the operations plan. An operations plan can integrate all operations and maintenance functions to meet the goals of flow, pressure and water quality. The AWWA G200-04 standard describes the critical requirements for the effective operation and management of drinking water distribution systems. According to this standard, a water system should develop SOPs, comprehensive monitoring plans, routine inspections and emergency response plans (USEPA, 2014).

- **Corrosion control for Microbial Control**

The distribution system toolbox factsheet, Impact of Corrosion Control on Disinfectant Residual, covers the association of low disinfectant residual and the corresponding potential for microbial growth with corroding metals and associated corrosion products in finished water. The factsheet covers potential strategies to address corrosion-related considerations and find potentially corrosive microbial growth (USEPA, 2024b). This SYR4 review was not intended to identify any new information pertaining to distribution system corrosion control.