Six-Year Review 3 Technical Support Document for Microbial Contaminant Regulations

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Table of Contents

List of Appendices

List of Exhibits

Acronyms

Acronym	Definition
ADOH	Australian Department of Health
AGI	Acute Gastrointestinal Illness
AOC	Assimilable Organic Carbon
APHA	American Public Health Association
ASTM	American Society of Testing and Materials
AWWA	American Water Works Association
BDF	Buffered, Demand-Free Water
CCL	Contaminant Candidate List
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
DBP	Disinfection Byproduct
D/DBPR	Disinfectants and Disinfection Byproducts Rules
DNA	Deoxyribonucleic Acid
DOP	Demonstration of Performance
DPD	N, N Diethyl-1,4 Phenylenediamine Sulfate
EA	Economic Analysis
EC	*E. coli*
EFH	Efficiency Factor Hom
EPA	United States Environmental Protection Agency
FACTS	Free Available Chlorine Testing with Syringaldazine
FBRR	Filter Backwash Recycling Rule
GAO	Government Accountability Office
GEE	Generalized Estimating Equation
GLI	Great Lakes Instruments
GLMM	Generalized Linear Mixed Models
GUP	Purchased Ground Water Under the Direct Influence of Surface Water
GWP	Purchased Ground Water
GWR	Ground Water Rule
GWUDI	Ground Water Under Direct Influence of Surface Water
HAA	Haloacetic Acid

HAV	Hepatitis A Virus
HCGI	Highly Credible Gastrointestinal Illness
HEA	Health Effects Assessment
HPC	Heterotrophic Plate Count
HSA	Hydrogeologic Sensitivity Assessment
ICR	Information Collection Request
IESWTR	Interim Enhanced Surface Water Treatment Rule
LED	Light-Emitting Diode
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
MDBP	Microbial and Disinfection Byproducts
MNV	Murine Norovirus
MPA	Microscopic Particulate Analysis
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MUG	4-methylumbelliferyl-β-D-glucuronide
NDWAC	National Drinking Water Advisory Council
NEMI	National Environmental Methods Index
NIH	National Institute of Health
NNDSS	National Notifiable Diseases Surveillance System
NPDWR	National Primary Drinking Water Regulation
NTU	Nephelometric Turbidity Unit
ONPG-MUG	Enzyme Substrate Coliform Test/Colilert
PCCL	Primary Contaminant Candidate List
PWS	Public Water System
qPCR	Quantitative Polymerase Chain Reaction
RICP	Research and Information Collection Partnership
RMCL	Recommended Maximum Contaminant Level
RNA	Ribonucleic Acid

RTCR	Revised Total Coliform Rule
SAL	Single Agar Layer
SCWA	Sonoma County Water Authority
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SWP	Purchased Surface Water
SWTD	Water Source, Treatment Facility or Distribution System
SWTR	Surface Water Treatment Rule
SYR	Six-Year Review
TC	Total Coliforms
TCR	Total Coliform Rule
THM	Trihalomethane
TT	Treatment Technique
UCMR	Unregulated Contaminant Monitoring Rule
USGS	United States Geological Survey
UV	Ultraviolet
WBDO	Waterborne Disease Outbreak
WBDOSS	Waterborne Disease and Outbreak Surveillance System

1 Introduction

The 1996 Safe Drinking Water Act (SDWA) amendments require the United States Environmental Protection Agency (EPA or the Agency) to periodically review existing national primary drinking water regulations (NPDWRs) and determine which, if any, needs to be revised.[1] The purpose of the review, called the Six-Year Review, is to identify those NPDWRs for which current health effects assessments, changes in technology, analytical methods, occurrence and exposure, implementation, and/or other factors that provides a health or technical basis to support a regulatory revision 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, 2003a) 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.

Under the third Six-Year Review ("Six-Year Review 3"), EPA is reviewing the regulated chemical, radiological and microbiological contaminants included in previous reviews, as well as the microbial and disinfection byproducts (MDBP) regulations. This is the first time EPA is conducting a Six-Year Review of the following microbial contaminant regulations:

- Surface Water Treatment Rule (SWTR)
- Interim Enhanced Surface Water Treatment Rule (IESWTR)
- Long-Term 1 Enhanced Surface Water Treatment Rule (LT1)
- Long-Term 2 Enhanced Surface Water Treatment Rule (LT2)
- Filter Backwash Recycling Rule (FBRR)
- Ground Water Rule (GWR).

In this document, the SWTR, the IESWTR and the LT1 are collectively referred to as the SWTRs because of the close association among the three rules (IESWTR and LT1 were amendments to the SWTR – additional information provided in Chapter 3).

EPA is reviewing the LT2 in response to the Executive Order 13563 *Improving Regulation and Regulatory Review* (also known as Retrospective Review) and as part of the Six-Year Review 3

[1] Under the SDWA, EPA must periodically review existing national primary drinking water regulations (NPDWRs) and, if appropriate, revise them. Section 1412(b)(9) of the SDWA states: "The Administrator shall, not less often than every 6 years, review and revise, as appropriate, each national primary drinking water regulation promulgated under this title. Any revision of a national primary drinking water regulation shall be promulgated in accordance with this section, except that each revision shall maintain, or provide for greater, protection of the health of persons."

process. Results from the review of the LT2 are discussed in a separate support document (USEPA, 2016a).

The remainder of this document provides a summary of available information and data relevant to determining if any of the microbial contaminant regulations are candidates for revision under the Six-Year Review. The information cutoff date for Six-Year Review 3 was December 2015. That is, information published during or before December 2015 was considered as part of the Six-Year Review 3. 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 3, the Agency anticipates providing consideration for that additional information in subsequent activities.

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 making a determination under the Six-Year Review 3 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 3 Review

This chapter provides an overview of the process the Agency used to review the NPDWRs discussed in the Six-Year Review 3. The protocol document, *EPA Protocol for the Third Review of Existing National Primary Drinking Water Regulations*, contains a detailed description of the process the Agency used to review the NPDWRs (USEPA, 2016b). 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). This Six-Year Review 3 process is very similar to the process implemented during the Six-Year Review 1 and the Six-Year Review 2, with some clarifications to the elements related to the review of NPDWRs included in the MDBP rules.

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 either:

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

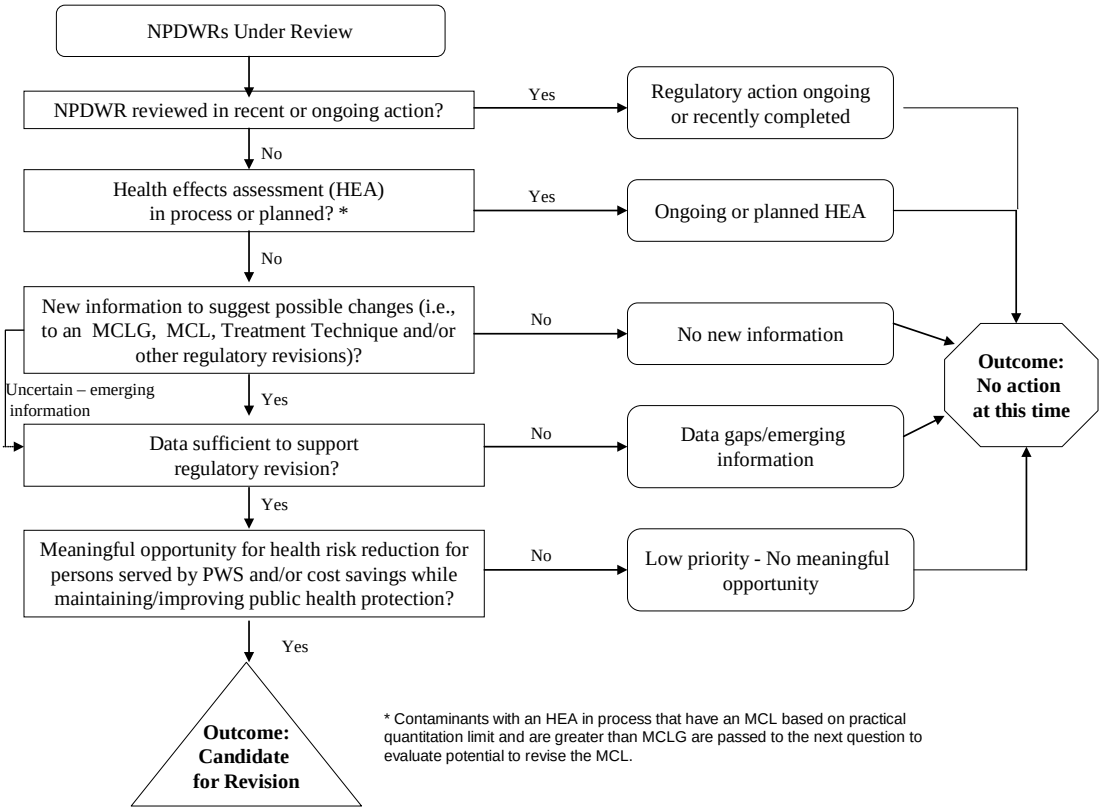
(2) the NPDWR is a candidate for revision.

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, other treatment technologies and regulatory requirements (e.g., monitoring). The MCL provisions are not applicable for evaluation of the microbial contaminants regulations which establish treatment technique requirements in lieu of MCLs. 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 review elements that EPA considered for each NPDWR during the Six-Year Review 3 include the following: initial review, health effects, analytical feasibility, occurrence and exposure, treatment feasibility, risk balancing, and other regulatory revisions. Further information about these review elements are described in the protocol document (USEPA, 2016b).

The Initial Review branch of the protocol identifies NPDWRs with recent or ongoing actions and excludes them from the review process to prevent duplicative agency efforts (USEPA, 2016b). The cutoff date for the NPDWRs reviewed under the Six-Year Review 3 was August 2008. Based on the Initial Review, EPA excluded the Aircraft Drinking Water Rule, which was promulgated in 2009, and the Revised Total Coliform Rule (RTCR) (the revision of the 1989 TCR), which was promulgated in 2013. Further, since most of the 1989 TCR requirements were replaced by the 2013 RTCR, the 1989 TCR was excluded from the Six-Year Review 3.

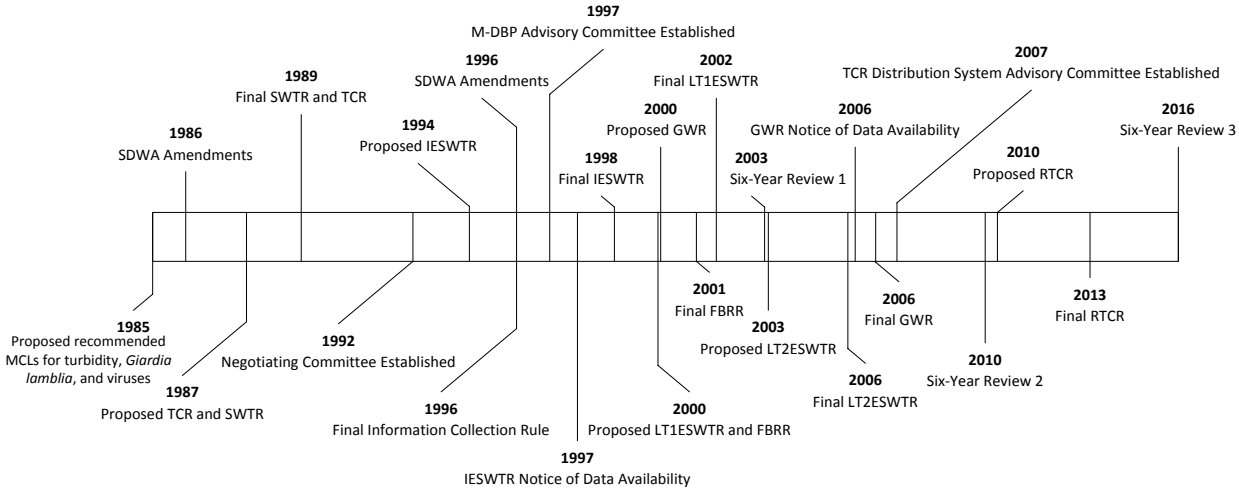
Exhibit 2.1: Six-Year Review Protocol Overview and Major Categories of Revise/Take No Action Outcomes



3 History of Microbial Regulations

This chapter provides a brief history of microbial contaminant regulations in the United States from 1975 to 2016. A timeline of selected events in the statutory and regulatory history, and regulatory review processes is shown in Exhibit 3.1. The microbial contaminant regulations covered in this Six-Year Review include: the Surface Water Treatment Rule (SWTR), the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Long-Term 1 Enhanced Surface Water Treatment Rule (LT1), the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2), the Filter Backwash Recycling Rule (FBRR), and the Ground Water Rule (GWR). The Total Coliform Rule (TCR) and the Revised Total Coliform Rule (RTCR) are not being reviewed under the Six-Year Review 3; therefore, they are described only briefly in this chapter. Note that the LT2 is discussed in more detail in a separate support document (USEPA, 2016a).

Exhibit 3.1: Timeline for Selected Activities Associated with Microbial Regulations for Drinking Water



EPA is also reviewing the Stage 1 and Stage 2 Disinfectant and Disinfection Byproducts Rules (D/DBPRs) as part of the Six-Year Review 3. See a separate support document for more information about these rules (USEPA, 2016f).

3.1 Surface Water Treatment Rule

3.1.1 Statutory Authority

The 1974 Safe Drinking Water Act (SDWA) authorized EPA to protect public health by regulating the nation's public drinking water supply. Although the SDWA was amended slightly in 1977, 1979 and 1980, the most significant changes occurred when the SDWA was reauthorized in 1986 and amended in 1996. To safeguard public health, the 1986 amendments required EPA to set maximum contaminant level goals (MCLGs) and maximum contaminant level (MCLs) for 83 contaminants.[2] The 1986 amendments authorized EPA to promulgate

[2] An MCLG is the level of a contaminant in drinking water below at which no known or anticipated adverse effect on the health of persons would occur. MCLGs allow for a margin of safety and are non-enforceable public health goals.

NPDWRs in the form of treatment techniques instead of MCLs where appropriate. EPA was also required to establish regulations for disinfection of all public water supplies and to specify filtration requirements for water systems that draw water from surface sources (USEPA, 1991a). The disinfection and filtration requirements were intended to protect the public from potential adverse health effects due to exposure to *Giardia lamblia*, viruses, *Legionella*, heterotrophic bacteria, and other pathogens that would be removed by those treatment techniques. The 1996 amendments are discussed in more detail later in this chapter.

3.1.2 Summary of the Rule

In response to the 1986 reauthorization of the SDWA, EPA promulgated the SWTR in 1989 (for more information about microbial rules prior to the SWTR, the reader is referred to Regli et al., 2003). The SWTR set MCLGs for *Legionella*, *Giardia lamblia*,[3] and viruses at zero since any exposure to these microbial pathogens presents a health risk. It required most systems using surface water or ground water under the direct influence of surface water (GWUDI) (also known as Subpart H systems, meaning subject to the requirements of Subpart H of 40 CFR Part 141) to remove and inactivate microbial contaminants through filtration and/or disinfection, respectively (USEPA, 1989).

To measure the performance of filtration systems, systems were required to monitor the turbidity of finished (treated) water. Specifically, the rule establishes treatment technique requirements for Subpart H systems to control for *Giardia lamblia* and viruses by at least 99.9 percent (3-log) and 99.99 percent (4-log) removal, respectively. For a few systems with sufficiently high quality source water and protective watershed control programs, the treatment requirement could be achieved by using disinfection only. However, those systems must meet the 3- and 4-log requirements through disinfection, as well as additional source water protection requirements.

The SWTR also established requirements for disinfectant residuals. In both filtered and unfiltered systems, the residual disinfectant concentration at the entry point to the distribution system may not be less than 0.2 mg/L for more than four hours. The main purpose of this requirement was to ensure continuity of disinfection. The SWTR also requires a detectable disinfectant residual or heterotrophic plate count (HPC) of 500/mL or less to be maintained throughout the distribution system in at least 95 percent of the measurements made (USEPA, 1989). The filtration and disinfection requirements of the SWTR were intended to protect against the potential adverse health effects of *Giardia*, viruses, *Legionella*, and heterotrophic bacteria, as well as many other pathogenic organisms that are removed by these treatment techniques.

EPA published a guidance manual to support the SWTR; it recommends various combinations of log-inactivation and log-removal of pathogenic organisms (USEPA, 1991b). Under the SWTR, the state is required to develop and implement enforceable criteria by which systems demonstrate they are achieving at least 3-log removal and/or inactivation of *Giardia* and 4-log removal and/or inactivation of viruses. Essentially, all states used the recommendations of the SWTR guidance manual to allot "credits" for filtration removal and disinfection inactivation to filtered systems,

[3] The current preferred taxonomic name is *Giardia duodenalis*, with *Giardia lamblia* and *Giardia intestinalis* as synonyms. However, *Giardia lamblia* was the name used to establish the MCLG in 1989. Elsewhere in this document this pathogen will be referred to as *Giardia* spp. or simply *Giardia* unless discussing information on an individual species.

which together demonstrate achievement of the removal and inactivation requirements (USEPA, 1991b).

3.1.3 History of Surface Water Treatment Rule

Prior to the 1989 SWTR, filtration and disinfection were not specifically required under federal law, although the majority of surface water systems used these treatment technologies. However, based on authority provided by the 1974 SDWA, EPA established interim MCLs in 1975 for turbidity: the monthly average turbidity MCL was 1 nephelometric turbidity unit (NTU), and the two-day average was 5 NTU (USEPA, 1976).

In November 1985, EPA proposed "recommended MCLs" (RMCLs, forerunners to MCLGs) for turbidity, *Giardia lamblia*, and viruses and solicited comment on the appropriateness of establishing RMCLs and NPDWRs for *Legionella* and HPC bacteria (USEPA, 1985).

In November 1987, EPA re-proposed MCLGs for *Giardia* and viruses (specifically enteric viruses), proposed an MCLG for *Legionella*, and proposed a regulation specifying criteria under which filtration would be required as a treatment technique (USEPA, 1987). The MCLGs for *Giardia* and viruses were re-proposed to address the change in terminology (from RMCL to MCLG) required by the 1986 SDWA amendments and to specify the types of viruses to be included; the values themselves did not change. Along with these criteria, EPA proposed procedures the states would use to determine which systems must install filtration. EPA also proposed disinfection treatment technique requirements for public water systems using surface water sources. The 1987 notice also withdrew the 1985 proposed RMCL for turbidity and instead proposed turbidity criteria for determining whether a public water system is required to filter and determining whether filtration alone, if required, is adequate (USEPA, 1987).

In May 1988, EPA published a notice of availability that solicited specific data, discussed alternatives to the proposed surface water treatment requirements and solicited comment on these alternative options (USEPA, 1988). For instance, EPA proposed alternative disinfectant residual monitoring requirements for systems serving fewer than 500 people to allow these systems to collect and analyze one grab sample of disinfectant residual instead of monitoring continuously.

The final SWTR was promulgated on June 29, 1989; specific components of that rule are described in more detail in Sections 3.1.3.1 to 3.1.3.4. Additional historical information related to the SWTR is in Regli et al. (2003).

3.1.3.1 Definitions of Surface Water and Ground Water Under Direct Influence of Surface Water

As part of the development of the SWTR, EPA needed to clarify which systems would be regulated under Subpart H. In particular, EPA needed to clarify when systems that could be considered as ground water systems, were more appropriate to regulate as surface water systems (for example, systems where the drinking water intake was in a riverbed, not in the river). Thus, to identify a system as either ground or surface water, the SWTR defined "ground water under the direct influence of surface water (GWUDI)." GWUDI is any water beneath the surface of the ground with: (1) significant occurrence of insects or other macroorganisms, algae or large-

diameter pathogens such as *Giardia lamblia*, or (2) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity or pH that closely correlate to climatological or surface water conditions. The final SWTR defined GWUDI as being regulated as surface waters because *Giardia* contamination of infiltration galleries, springs and wells have been found (Hoffbuhr et al., 1986; Hibler et al., 1987). Some contamination of springs and wells have resulted in giardiasis outbreaks (Craun and Jakubowski, 1986). Direct influence was to be determined for individual sources in accordance with criteria established by the state (54 FR 27486, USEPA, 1989). The GWUDI designation identifies PWSs using ground water that must be regulated as if they are surface water systems. All other PWSs using ground water are regulated by the GWR.

The 1998 IESWTR expanded the definition of GWUDI for systems serving 10,000 or more people to include *Cryptosporidium,* and the 2002 LT1 included *Cryptosporidium* in the GWUDI definition for systems serving fewer than 10,000 people.

The definition of GWUDI relies heavily on water quality parameters to indicate whether the source is at risk for *Giardia* or *Cryptosporidium* to pass from surface water to the ground water collector. It assigns the determination to state primacy programs and includes suggested elements of the decision-making process. The complete definition of GWUDI in 40 CFR 141.2 is:

> "*Ground water under the direct influence of surface water (GWUDI) means any water beneath the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as Giardia lamblia or Cryptosporidium, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation."*

The special primacy provision requirements of 40 CFR 142.16(b)(2)(B) specify that the state application for primacy program revision approval must include a description of how the state will accomplish the determination of which systems using a ground water source are GWUDI. The requirements also specify that the determinations had to be completed by June 29, 1994 for community water systems and by June 29, 1999 for non-community water systems. Federal regulations do not include GWUDI classification re-evaluation requirements nor ongoing monitoring of source water quality. State programs can impose such requirements.

Public Health Protection Goals from the SWTR Definition of Surface Water and GWUDI

EPA originally established the GWUDI source water classification to address the public health concern posed by an underground source of drinking water that is subject to *Giardia* (and subsequently *Cryptosporidium*) contamination from surface waters. *Giardia* and *Cryptosporidium* pose significant health risks for systems using ground water closely connected to surface water because they are not removed from water by natural filtration processes in the course of the water's passage from surface water through the subsurface to the well. Because

Cryptosporidium is not readily inactivated by disinfectants other than ultraviolet (UV) light, it poses a greater public health threat than *Giardia*.

The 2006 GWR addresses public health protection against bacterial and viral pathogens in PWSs that use ground water not subject to *Giardia* or *Cryptosporidium* contamination and regulated accordingly. PWSs regulated under the GWR are not required to filter and may or may not be disinfected. Currently, about 86,000 PWSs serving about 20 million people are undisinfected (USEPA, 2013a).

Some PWS wells, regulated under the GWR, were subsequently found to be contaminated by or at risk of contamination by *Giardia* or *Cryptosporidium* as a result of outbreaks (Bergmire-Sweat et al., 1999; Lee et al., 2001; Daly et al., 2010). These wells were misclassified as ground water and should have been determined to be GWUDI. A well misclassified as ground water rather than GWUDI may pose a public health hazard because the well water may be inadequately treated, receiving either no treatment or only disinfection, rather than disinfection combined with engineered filtration or an approved alternative based on a demonstration of performance (DOP). Reduced PWS misclassification will result in improved public health protection because fewer people will be exposed to *Giardia* or *Cryptosporidium* via untreated or inadequately treated (disinfected but unfiltered) ground water. Full protection against *Giardia* and *Cryptosporidium* can only result if a well is properly regulated as GWUDI and subject to the SWTR requirements.

GWUDI Classification Principles

Although the origin of some water molecules can be ascertained based on measuring the tritiated water component, it is otherwise impossible to identify whether a water molecule emanating from a well originated in surface water or in ground water. Scientific studies determine water molecule origins (water flowpath reverse tracking) by using surrogate measures such as various combinations of stable isotopes, dissolved solids, entrained solid particles, bioindicator particles, temperature, dyes and other dissolved and particulate tracers, and mathematical models. No single measurement or surrogate measure is unequivocal. Thus, a scientific determination of surface water exchange with ground water can be lengthy, time consuming, and expensive.

The transport of pathogens similar in size to *Giardia* (8 to 12 µm) or *Cryptosporidium* (4 to 6 µm*)* from surface water to a collector of an underground source of water requires: a) a hydraulic connection between the waters, b) high-to-low hydraulic gradient in the direction from surface water to the collector, however transient, and c) insufficient natural filtration to remove the pathogens. Temporary GWUDI periods can occur due to seasonal or intermittent induced surface water recharge or increases in average ground water velocities that decrease the amount of natural filtration provided by the aquifer's materials. A pumping well can increase average ground water velocity and alter or even reverse the ground water flow path if the natural hydraulic gradient from ground water to surface water is low or if the well pumps sufficient volumes of water to induce recharge of the subsurface aquifer by surface water.

GWUDI determination requires a regulatory decision regarding the public health risk resulting from a poorly understood, difficult to measure, and potentially continuously changing hydrogeologic process. Because the existing definition of GWUDI refers to "significant occurrence" of specific types of organisms and particulates that are believed to originate from

surface water, and "significant or relatively rapid shifts" in water characteristics that correlate to surface water conditions, state determination of GWUDI must necessarily interpret factors deemed "significant." This determination is made on a case-by-case basis for each water source. Most states were required to make GWUDI determinations for large numbers of wells.

To be effective, the GWUDI determination definition and implementing methodology must be simple and inexpensive despite the inherent complexity of the relationship between ground water and surface water. Because of analytical limitations, assaying for *Giardia* or *Cryptosporidium* as indicators of GWUDI is not cost effective and significant public health risk could be present even in the absence of pathogen recovery in one or more samples (e.g., Messner and Berger, 2015). Section 5.4 provides information on the methods for GWUDI determination.

3.1.3.2 Disinfectant Residuals in the Distribution System

In the proposed SWTR, EPA proposed to require all systems using surface water (both filtered and unfiltered) to maintain at least a 0.2 mg/L disinfection residual in at least 95 percent of the distribution system samples taken each month. If a system failed to comply with this requirement for any two consecutive months, it would be in violation of a treatment technique requirement. Also, unfiltered systems failing to meet this criterion would be required to filter. The purpose of this requirement was to limit contamination from outside the distribution system; limit growth of heterotrophic bacteria and *Legionella* within the distribution system; and provide a quantitative limit that, if exceeded, would trigger remedial action (USEPA, 1987).

EPA proposed a minimum disinfectant residual of 0.2 mg/L and concluded that such a level was feasible for most well-operated systems (USEPA, 1989). However, public comments indicated that, for many systems that are well operated (as evidenced by low levels of HPC in routine monitoring), it was not feasible to maintain the proposed minimum disinfectant residual without significantly changing existing disinfection practice (e.g., increasing existing chlorine dosages or switching to chloramine disinfection for the distribution system).

Based on these comments and additional information about disinfection practice at the time, EPA revised the proposed SWTR. The final SWTR requires "detectable" residuals in the distribution system in lieu of residuals of at least 0.2 mg/L. Residual concentrations can be measured as free chlorine, total chlorine, combined chlorine (total chlorine minus free chlorine), or chlorine dioxide. The absence of a residual at a site within the distribution systems indicates that the disinfectant level has been reduced, possibly as a result of localized contamination from outside the distribution system or from organic or inorganic materials within the distribution system. EPA recognized that the absence of a disinfectant residual at a distribution system site does not necessarily indicate microbiological contamination; such contaminants simply may not be present, even in the absence of a disinfectant residual. In other words, if microbial occurrence is low, the lack of a disinfectant residual is not a concern. Thus, under the final SWTR, sites that do not have "detectable" residuals, but have HPC measurements of 500/mL or less, are considered equivalent to sites with "detectable" residuals for purposes of determining compliance (USEPA, 1989) (refer to Chapter 5 for a list of methods approved for measurement of HPC).

The final rule requires a 0.2 mg/L disinfectant residual at the entry point to the distribution system. The residual disinfectant concentration at that location may not drop below 0.2 mg/L for more than four hours.

For systems using only surface water (or GWUDI) sources, the SWTR requires monitoring for disinfectant residual concentrations at the same locations and at the same times as total coliforms are sampled under the TCR, or RTCR as of April 2016. For systems that have both ground water (which may not be disinfected) and surface waters entering the distribution system, the state may allow monitoring for disinfectant residuals at points other than the sampling locations for total coliforms if such points are more representative of the treated (disinfected) surface water within the distribution system (USEPA, 1989).

For systems that cannot maintain a detectable disinfectant residual in the distribution system, if the state determines that a system has no means for having a sample transported and analyzed for HPC by a certified laboratory and adequate disinfection is provided by that system, the requirement to maintain a detectable disinfection residual does not apply. The state's judgment might be based upon considerations such as knowledge of the public water system's distribution system, maintenance of a cross-connection control program, source water quality, and/or past coliform monitoring results.

The SWTR requires continuous monitoring of the residual disinfectant concentration of the water entering the distribution system for systems serving more than 3,300 people, and the lowest value must be recorded each day, except that if there is a failure in the continuous monitoring equipment, systems may conduct grab sampling every four hours for no more than five days following the equipment failure (USEPA, 1989). Systems serving 3,300 or fewer people may take grab samples rather than monitoring continuously; sample frequencies range from one to four times per day and depend on population.

3.1.3.3 CT Values in Unfiltered Systems

The final SWTR requires 99.9 percent inactivation of *Giardia* and 99.99 percent inactivation of viruses in unfiltered systems. Under the proposed SWTR, a system would have been required to calculate CT, where “T” is disinfectant contact time, the time in minutes it takes the water to move between the point of disinfectant application and a point before or at the first customer during peak hourly flow, and “C” is the residual disinfectant concentration in mg/L before or at the first customer but at or after the point where contact time is measured (USEPA, 1989).

In May 1988, EPA published a notice of data availability (USEPA, 1988) soliciting comments on a different methodology to determine CT values for systems using ozone. This methodology would have allowed ozone concentrations to be measured as an average across the contact basin rather than at only the basin effluent, allowing systems to capture more accurate concentration data and account for the fact that ozone concentrations were likely to be low at the effluent location due to ozone’s high reactivity. All the commenters who addressed this issue supported the adoption of this provision in the final rule (USEPA, 1989). In addition, many commenters suggested applying this provision to all disinfectants. EPA agreed that this methodology results in a more accurate representation of actual disinfection conditions, especially in systems having source waters with a high oxidant demand, and those systems using ozone (because it dissipates

very rapidly). Accordingly, EPA adopted this methodology for all disinfectants in the final SWTR (USEPA, 1989).

Although the final SWTR provides CT value tables for free chlorine, ozone, chlorine dioxide, and chloramines for *Giardia* and viruses, EPA recognized that research in this field is ongoing and included a provision in the final rule that allows unfiltered systems using a disinfectant other than chlorine to demonstrate, by whatever means allowed by the state, that they are consistently meeting the 99.9 and 99.99 percent removal and/or inactivation requirements (USEPA, 1989). Such systems do not have to meet the CT values in the rule. However, note that the LT2 includes additional CT requirements for ozone, chlorine dioxide, and UV light to allow unfiltered systems to meet inactivation requirements for *Cryptosporidium* (USEPA, 2016a).

The SWTR does not require compliance with these CT value tables for filtered systems. Filtered systems are expected to meet the removal/inactivation requirements (as discussed earlier in Section 3.1.2) through a combination of disinfection and filtration, which will vary by system.

3.1.3.4 Filtration and Filtration Avoidance

The SWTR required filtered systems to meet turbidity criteria as part of a treatment technique. For systems using conventional treatment or direct filtration (direct filtration is similar to conventional filtration but does not include a sedimentation step), turbidity of samples representative of the filtered water had to be less than or equal to 0.5 NTU in at least 95 percent of the measurements taken each month (USEPA, 1989). The state was authorized to allow a turbidity limit of 1 NTU if the system could demonstrate that it was still capable of achieving the required removal and inactivation. At no time was turbidity to exceed 5 NTU. These turbidity requirements were later modified under the IESWTR and LT1.

Under the SWTR, systems using slow sand and diatomaceous earth filtration must meet turbidity limits of 1 NTU in at least 95 percent of samples taken each month, although slow sand systems may apply to the state for a higher limit (USEPA, 1989). At no time can turbidity in slow sand and diatomaceous earth systems exceed 5 NTU. These requirements were not altered by the IESWTR or LT1.

The SWTR allowed systems using other filtration technologies not listed earlier in this section to demonstrate through pilot studies or other means that they met the removal and inactivation requirements (USEPA, 1989). Systems able to make such demonstrations were required to comply with the same turbidity limits as slow sand filtration systems. These requirements were later modified under the IESWTR and LT1 (see Sections 3.2 and 3.4).

To avoid filtration, surface water or GWUDI systems must meet certain source water quality conditions (USEPA, 1989). Source water concentrations of fecal coliform must be 20/100 mL or less, or total coliform concentrations must be 100/100 mL or less. Source water turbidity cannot exceed 5 NTU except in unusual and unpredictable circumstances, and such occurrences may not happen more than five times in ten years. The system must have redundant disinfection components and must meet all the disinfection requirements described in earlier sections. The system must have a watershed control program approved by the state and be subject to an annual on-site inspection to assess the program and disinfection treatment process. The system may not

have been identified as a source of a waterborne disease outbreak. It must have been in compliance with the MCL for total coliforms (or the new MCL for *E. coli* under the RTCR as described in Section 3.7).

3.1.4 The 1996 Safe Drinking Water Act Amendments, M-DBP Advisory Committee, and Notices of Data Availability

The SDWA amendments of 1996 codified the risk-balancing concept. They allowed EPA to establish an MCL "at a level other than the feasible level, if the technology, treatment techniques, and other means used to determine the feasible level would result in an increase in the health risk from drinking water by (i) increasing the concentration of other contaminants in drinking water; or (ii) interfering with the efficacy of drinking water treatment techniques or processes that are used to comply with other national primary drinking water regulations" (section 1412(b)(5)(A)). The amendments further required that MCLs or treatment techniques "minimize the overall risk of adverse health effects by balancing the risk from the contaminant and the risk from other contaminants the concentrations of which may be affected by the use of a treatment technique or process that would be employed to attain the maximum contaminant level or levels" (section 1412(b)(5)(B)). Section 1412(b)(8) of the SDWA, as amended on August 6, 1996, modified the language of the 1986 amendments, directing EPA to promulgate regulations requiring disinfection as a treatment technique *as necessary* for ground water systems (see Section 3.6).

To help meet the statutory deadlines established by Congress in the amendments and to maximize stakeholder participation, the Agency established the Microbial and Disinfectants/Disinfection Byproducts (M-DBP) Advisory Committee under the Federal Advisory Committee Act in 1997 to analyze new information and data, as well as to build consensus on the regulatory implications of this new information. The Committee consisted of 17 members representing EPA, state and local public health and regulatory agencies, local elected officials, drinking water suppliers, chemical and equipment manufacturers, and public interest groups (USEPA, 1998a).

The Committee met five times, from March through July 1997, to discuss issues related to the IESWTR and Stage 1 D/DBPR. Technical support for these discussions was provided by a technical work group established by the Committee. The Committee’s activities resulted in the collection, development, evaluation, and presentation of substantial new data and information related to key elements of both proposed rules (USEPA, 2003b).

3.2 Interim Enhanced Surface Water Treatment Rule

In response to a massive 1993 cryptosporidiosis outbreak in Milwaukee, Wisconsin (and in response to the 1996 SDWA amendments), EPA promulgated a rule that built onto the SWTR but focused on *Cryptosporidium* control, called the IESWTR. Because *Cryptosporidium* oocysts are not inactivated by traditional disinfectants such as chlorine, the rule instituted more stringent filtration requirements. While cryptosporidiosis is generally a self-limiting disease, with complete recovery in otherwise healthy persons, the disease can have very serious consequences in sensitive populations. The IESWTR was promulgated December 16, 1998 (USEPA, 1998a). It established an MCLG of zero for *Cryptosporidium* and required 99 percent (2-log) inactivation or removal of *Cryptosporidium* for filtered systems serving 10,000 people or more. The rule also

added *Cryptosporidium* to the definition of GWUDI and to the watershed control requirements for unfiltered public water systems; added requirements for covering new finished water reservoirs; required sanitary surveys for all surface water systems regardless of size; and included disinfection benchmarking provisions to assure continued levels of microbial protection while facilities took steps to comply with new disinfection byproduct standards under the Stage 1 D/DBPR, also promulgated in December 1998 (USEPA, 1998a, 1998b). Disinfection benchmarking required systems with disinfection byproduct levels exceeding certain thresholds to develop a disinfection profile (a record of log inactivation of *Giardia* achieved over one year) and to then determine the lowest monthly average inactivation during that period. This information was to be submitted to the state if the system proposed to change disinfection practices to comply with the Stage 1 D/DBPR. Systems using ozone or chloramines for primary disinfection were required to develop a benchmark for viruses as well.

For systems serving 10,000 or more and using conventional or direct filtration, the revised turbidity limits were 0.3 NTU for filtered water samples in 95 percent of the samples taken each month and no more than 1 NTU at any time. For systems using alternative filtration in which systems demonstrate to the state that they meet the removal and inactivation requirements, the turbidity limits were to be set by the state. The IESWTR also required continuous monitoring of turbidity in the effluent from individual filters (USEPA, 1998a).

3.3 Filter Backwash Recycling Rule

The purpose of the FBRR, promulgated June 8, 2001, is to further protect public health by requiring PWSs, where needed, to institute changes to the return of recycle flows to a plant's treatment process that may otherwise compromise microbial control (USEPA, 2001). 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 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 to a location such that all processes of a system's conventional or direct filtration, as defined in 40 CFR 141.2, are employed unless the state approved an alternate location by June 8, 2004 (40 CFR 141.76(c)).

3.4 Long-Term 1 Enhanced Surface Water Treatment Rule

The LT1, promulgated January 14, 2002, applies to public water systems that use surface water or GWUDI and serve fewer than 10,000 persons. The LT1, with some minor variations, extends the requirements of the IESWTR to small systems (USEPA, 2002).

3.5 Long-Term 2 Enhanced Surface Water Treatment Rule

The LT2, promulgated on January 5, 2006, 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 also requires covering of all uncovered finished water reservoirs, 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 *G*. lamblia and

99 percent (2-log) inactivation or removal of *Cryptosporidium* (USEPA, 2006a). Additional information about the LT2 is discussed in a separate support document (USEPA, 2016a).

3.6 Ground Water Rule

3.6.1 Statutory Authority

As mentioned in Section 3.1.1, the 1986 SDWA amendments directed EPA to promulgate regulations requiring disinfection at all PWSs, including those using ground water as a source. Although EPA began developing a rule requiring disinfection in ground water systems in 1992, releasing a "strawman" draft rule for comment on July 31, 1992 (USEPA, 1992), it did not finalize the rule prior to the 1996 SDWA amendments. The 1996 SDWA amendments directed EPA to promulgate regulations requiring disinfection as a treatment technique *as necessary* for ground water systems. In addition, section 1412(b)(8) required EPA to promulgate criteria for determining whether disinfection should be required as a treatment technique for any PWS served by ground water. The GWR implements section 1412(b)(8) of the SDWA, as amended, by establishing a regulatory framework for determining which ground water systems are susceptible to fecal contamination and requiring those systems to implement corrective actions.

3.6.2 Summary of the Rule

EPA promulgated the GWR on November 8, 2006 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 (i.e., Norwalk-like viruses). Enteric bacterial pathogens may include *Escherichia 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 to check for significant deficiencies;
- A flexible program for identifying higher risk systems through TCR 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; and
- Measures to protect public health:

- Treatment technique requirements to address sanitary survey 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.

Treatment technique 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 uncorrected significant deficiencies or fecal indicator-positive ground water source samples.

3.6.3 History of Ground Water Rule

Prior to the GWR, no federal regulation required either monitoring of ground water sources or corrective action upon finding fecal contamination or identifying a significant deficiency during a sanitary survey. In addition, a U.S. Government Accountability Office (GAO) report (1993) found that many sanitary surveys did not evaluate one or more of the components that EPA recommended be evaluated, and that efforts to ensure correction were often limited.

In addition, according to reports by the Centers for Disease Control and Prevention (CDC) between 1991 (the year in which the TCR became effective) and 2000, ground water systems were associated with 68 waterborne disease outbreaks that caused 10,926 illnesses (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; and Lee et al., 2002). The major deficiencies identified by the CDC as the likely cause of the outbreaks were source water contamination and inadequate treatment (or treatment failures).

EPA began developing the GWR in 1987 with the intention of requiring across-the-board disinfection, as directed by the 1986 SDWA amendments. A preliminary public meeting on issues related to ground water systems was held in 1990. By 1992, EPA had developed a draft proposed rule (a "strawman") (USEPA, 1992), which was made available for stakeholder review upon request. Most stakeholders who commented were concerned that the rule was crafted so that all ground water systems were assumed to be contaminated until monitoring proved otherwise and that disinfection waivers would be difficult to obtain (USEPA, 2006b).

In response to the 1996 SDWA amendments, EPA began to consider a new approach in which disinfection would not be mandatory for all ground water systems (USEPA, 2006b). This approach focused primarily on establishing a reasonable means for determining if a ground water source was vulnerable to fecal contamination (USEPA, 2006b). EPA evaluated the possibility of developing a vulnerability assessment tool that would consider hydrogeologic information and sources of fecal contamination.

The proposed GWR was published in the *Federal Register* on May 10, 2000 (USEPA, 2000). The primary elements of the proposed GWR were sanitary surveys, triggered monitoring, hydrogeologic sensitivity assessments (HSAs), routine source water monitoring, corrective

action and compliance monitoring. The proposed rule would require states to identify high priority systems through an HSA; wells located in karst, fractured bedrock, or gravel hydrogeologic settings were considered sensitive (USEPA, 2000). These wells are potentially at risk of fecal contamination because ground water velocities are high and fecal contamination can travel long distances over a short time. Systems in sensitive areas would have been required to conduct monthly routine monitoring. If a system did not have any fecal indicator-positive samples after twelve monthly samples, the state would have been allowed to reduce routine source water monitoring to quarterly. States would also have been allowed, after the first year of monthly samples, to waive source water monitoring altogether for a system if the state determined that fecal contamination of the well(s) was unlikely based on sampling history, land use, etc. (USEPA, 2000).

Given the importance of correctly targeting systems for source water monitoring, in conjunction with the State's desire for enough flexibility to ensure sensible decisions on a case-by-case basis, EPA decided in the final rule to redesign the source water monitoring provision. Accordingly, the final rule did not include a national requirement for HSAs and routine monitoring for systems in sensitive aquifers. Rather, EPA concluded that the States are in the best position to assess which systems would most benefit from a source water monitoring program. The final provision was similar to routine monitoring but was identified as optional for States. EPA recommended that States use HSAs as one tool to identify high risk systems for assessment source water monitoring.

3.7 Total Coliform Rule and Revised Total Coliform Rule

The 1989 TCR established the MCLG of zero for total coliforms (including fecal coliforms and *E. coli*). The TCR required monitoring for total coliforms in the distribution system and, if total coliform bacteria were detected, monitoring for fecal coliform/*E. coli*. The total coliform monitoring frequency was determined by the population served. Under the TCR, the MCL for total coliforms was based on the presence of total coliforms in five percent or more of samples per month or on the presence of fecal coliform or *E. coli* in any sample. For systems taking fewer than 40 samples per month, the MCL was based on the presence of coliforms in two or more samples per month. Also, all systems had to collect repeat samples at sites that were coliform-positive. In July 2007, EPA established the TCR Distribution System Advisory Committee to provide advice and make recommendations to the Agency on revisions to the TCR, and on what information about distribution systems is needed to better understand the public health impact from the degradation of drinking water quality in distribution systems (USEPA, 2007a). The RTCR, promulgated February 13, 2013, establishes an MCLG and an MCL for *E. coli* (no longer allowing for fecal coliform measurement), a more specific indicator of fecal contamination and potential harmful pathogens than total coliforms (USEPA, 2013a). The RTCR eliminates the MCLG and MCL for total coliforms and instead institutes a treatment technique for coliforms that requires assessment and corrective action. The rationale for this change is that many of the organisms detected by total coliform methods are not of fecal origin and do not have any direct public health implication.

3.8 Summary of Microbial Rules

Listed in Exhibit 3.2 is a summary of the NPDWRs for the microbial rules. For each microorganism, the rule(s) where it is referenced, MCLG, and MCL or TT are provided.

Exhibit 3.2: NPDWRs for Microbial Rules

Microorganism	MCLG	MCL or TT	Rule(s)
Giardia lamblia	Zero	TT	SWTR
Viruses	Zero (SWTR)	TT	SWTR, GWR
Legionella	Zero	TT	SWTR
Total coliforms (including fecal coliforms and *E. coli*)	Zero (under RTCR, only for *E. coli)*	TT	TCR, RTCR
Cryptosporidium	Zero	TT	IESWTR, FBRR, LT1, LT2
Heterotrophic bacteria (by the HPC method)	N/A	TT	SWTR
Turbidity	N/A	TT	SWTR, IESWTR, LT1

4 Health Effects

This chapter summarizes the results from EPA's review of new information related to human health risks from exposure to microbial contaminants in drinking water. EPA evaluated whether any new toxicological data, or waterborne endemic infection or infectious disease information, would justify revision of a maximum contaminant level goal (MCLG) for the microbial contaminant regulations. MCLGs are health goals set at a level at which no known or anticipated adverse health effects occur and which allow an adequate margin of safety. EPA reviewed data from the Waterborne Disease and Outbreak Surveillance System (WBDOSS) collected by the Centers for Disease Control and Prevention (CDC) (http://www.cdc.gov/healthywater/surveillance/index.html) and other available data that documented drinking water-associated outbreaks. EPA also reviewed available literature on endemic disease attributable to drinking water (e.g., Colford et al., 2009).

The review considered new information, published on or before December 2015, related to human health risks from exposure to microbial contaminants in drinking water. The review examined human health risks for systems regulated under the Surface Water Treatment Rules (SWTRs) and the Ground Water Rule (GWR). Information relevant to the Six-Year Review of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2) is provided in a separate document (USEPA, 2016a).

4.1 SWTRs

EPA promulgated the SWTR in June 1989. It requires all water systems using surface water sources or ground water under the direct influence of surface water (GWUDI) sources (also known as Subpart H systems) to remove (via filtration) and/or inactivate (via disinfection) microbial contaminants (54 FR 27486, USEPA, 1989). Under the SWTR, EPA established NPDWRs for *Giardia*, viruses, *Legionella*, turbidity, and heterotrophic bacteria and set MCLGs of zero for *Giardia lamblia*, viruses and *Legionella*. Under the Interim Enhanced Surface Water Treatment Rule (IESWTR) (63 FR 69477, USEPA, 1998b) and LT1 (67 FR 1812, USEPA, 2002), EPA established an NPDWR for *Cryptosporidium* and set an MCLG of zero. The MCLGs were set at zero since any exposure to these microbial pathogens presents a potential health risk. Additional information on rule history and the SWTRs is provided in Chapter 3.

4.1.1 MCLGs

The reader is referred to the LT2 support document (USEPA, 2016a) for EPA's assessment of health effects information related to the following pathogens: *Cryptosporidium*, *Giardia*, viruses and other pathogens (e.g., *E. coli*). EPA found no new health effects information that would suggest a need to consider a change from the MCLG of zero for *Cryptosporidium*, *Giardia*, *Legionella* or viruses, or for a more stringent pathogen log reduction[4] target.

[4] Log reduction refers to the reduction in pathogen concentration in water through removal or inactivation. For example, a 1-log reduction indicates the concentration is 10 times smaller (90 percent reduction), a 2-log reduction indicates the concentration is 100 times smaller (99 percent reduction).

New dose-response data from some waterborne pathogens are available from both human and animal exposure studies (Teunis et al., 2002a; 2002b; Armstrong and Haas, 2007; 2008; Buse et al., 2012). Concurrently, new models seek to use the new data to provide improved infectivity, morbidity and mortality predictions (Messner et al., 2014; USEPA, 2016a). The newer models are specifically designed to address low dose exposure typical of drinking water rather than high dose exposure typical of food ingestion or vaccine studies. However, because no new human feeding studies have used low doses, any conclusions are limited despite the low uncertainty bounds obtained in some statistical models.

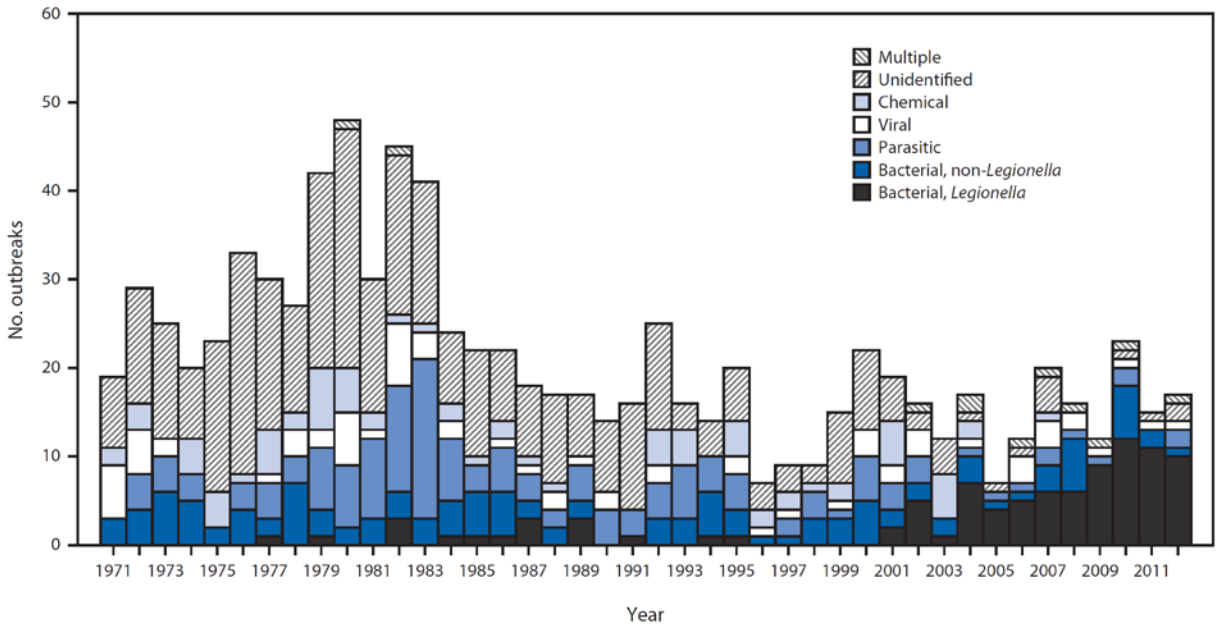
4.1.2 Drinking Water-Associated Disease Outbreaks

EPA reviewed published information from the WDOSS about the occurrences and causes of drinking water-associated outbreaks. This surveillance system is maintained by CDC, EPA, and the Council of State and Territorial Epidemiologists, and is the primary source of data concerning waterborne disease outbreaks (WBDOs) in the U.S. (CDC, 2015a). For an event to be defined as a WBDO by CDC, two criteria must be met: 1) two or more persons diagnosed with the illness must be linked epidemiologically by time, location of water exposure and case illness characteristics, and 2) the epidemiological evidence must implicate water as the probable source of the illness (https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6431a2.htm). WBDOs also include outbreaks associated with recreational water and other non-potable water sources. In this document, the disease outbreak data discussed is a subset of WBDOs associated with drinking water, or "drinking water-associated outbreaks."

Exhibit 4.1 shows the number of drinking water-associated outbreaks in the U.S. from 1971 to 2012 stratified by disease-causing agent (CDC, 2015a). When possible, CDC classifies outbreaks as being caused by chemical, viral, fungal, parasitic, bacterial (*Legionella)*, bacterial (non-*Legionella)* or multiple agents. The reported number of outbreaks peaked during 1979 to 1983 and declined since then; this decrease may be attributed to changes in surveillance or improved implementation of drinking water regulations, including the Total Coliform Rule (TCR) and the SWTR beginning in 1991 (Craun et al., 2010). In addition, many water systems have made voluntary improvements in this time frame, such as through the Partnership for Safe Water program to reduce the risk of waterborne cryptosporidiosis (National Research Council (NRC), 2006).

CDC noted that the level of surveillance and reporting activity, as well as reporting requirements, varies across states and localities. The capacity to investigate outbreak events and strengthen evidence linking outbreaks to drinking water also varies across states and localities. In addition, CDC noted that detection and investigation of drinking water-associated outbreaks might be incomplete as it can be difficult to definitively link illnesses with drinking water because most persons have daily exposure to tap water. For these reasons, outbreak surveillance data likely underestimate actual values, and should not be used to estimate the total number of outbreaks or cases of waterborne disease (CDC, 2015a).

Exhibit 4.1: Etiology of Drinking Water-Associated Outbreaks, by Year, in the United States, 1971 to 2012 (CDC, 2015a)



4.1.2.1 Deficiencies Assigned to Drinking Water-Associated Outbreaks

CDC publishes data from the WBDOSS in biennial reports (*Morbidity and Mortality Weekly Reports*) which include information on water sources, deficiencies, etiology and other characteristics associated with each drinking water-associated outbreak. CDC assigns one or more deficiencies to outbreaks associated with drinking water, other water and unknown water exposures (http://www.cdc.gov/healthywater/surveillance/deficiency-classification.html). The deficiencies provide information about how the water became contaminated, water system characteristics and factors leading to outbreaks.

Exhibit 4.2 summarizes the data on drinking water-associated outbreaks from 2003 through 2012. It presents the total number of drinking water-associated outbreaks, the number of outbreaks due to deficiencies related to water source, treatment facility or distribution system (SWTD), and the number of outbreaks due to premise plumbing deficiencies (and of which, those associated with *Legionella*) during this time period. Premise plumbing is the portion of the distribution system that is inside schools, hospitals, public and private housing, and other buildings (NRC, 2006). Note that the number of outbreaks due to other deficiency categories, such as unknown or insufficient information, is included in the total number of outbreaks but not presented in separate columns in Exhibit 4.2. The data presented in Exhibit 4.2 include all outbreaks associated with drinking water systems, including public, individual, or bottled water systems.

Exhibit 4.2: Summary of Drinking Water-Associated Outbreaks and Assigned Deficiencies – United States, 2003-2012

Years (Data Source)	Total Number of Drinking Water-Associated Outbreaks	Number of Outbreaks due to SWTD[1] Deficiencies		Number of Outbreaks due to Premise Plumbing Deficiency
		Number	Details	
2003-2004 (CDC, 2006)	30	11	• 1 untreated ground water • 1 untreated surface water • 2 untreated ground water and distribution system • 3 treatment • 3 distribution system • 1 treatment and distribution system	12 (8 caused by *Legionella*)
2005-2006 (CDC, 2008)	20	8	• 4 untreated ground water • 2 treatment • 2 treatment and distribution system	12 (10 caused by *Legionella*)
2007-2008 (CDC, 2011)	36	21	• 13 untreated ground water • 6 treatment • 1 distribution system • 1 treatment and distribution system	13 (12 caused by *Legionella*)
2009-2010 (CDC, 2013)	33	13	• 8 untreated ground water • 4 distribution system • 1 distribution system and untreated ground water	19 (19 caused by *Legionella*)
2011-2012 (CDC, 2015a)	32	6	• 4 untreated ground water • 1 untreated ground water and surface water • 1 distribution system	23 (21 caused by *Legionella*)

[1] SWTD = water source, treatment facility or distribution system

CDC re-analyzed its outbreak data for untreated ground water for the years 1971-2008 and found that untreated ground water continued to be a health risk in the U.S. (Wallender et al., 2014). The most recent CDC Surveillance Summary (CDC, 2015a) indicates that *Legionella* in premise plumbing and deficiencies in untreated ground water (most of which are public water system (PWSs) but also include some private wells) were responsible for the majority of all outbreaks in 2011-2012 (note: EPA does not have authority to regulate private wells). CDC noted that a reduction in outbreaks of gastrointestinal illness might be achieved when ground water systems are properly maintained and operated to reduce or inactivate microbial contamination and that ground water sources are further protected from fecal contamination. The report emphasized that ground water source protection can also be improved through awareness of and compliance with regulations such as EPA's GWR and RTCR (CDC, 2015a).

Collectively, the data indicate that, since 1971, drinking water-associated outbreaks may have been reduced as a result of drinking water regulations. However, opportunities remain to address disease outbreaks associated with distribution systems and untreated ground water and, at the same time, to potentially address some of the drinking water-associated outbreaks due to little to no disinfectant residual in the distribution system (Geldreich, 1992; Bartrand et al., 2014).

4.1.2.2 Disease Occurrence Associated with Legionella in Premise Plumbing

One etiologic agent of particular concern for drinking water-associated outbreaks is *Legionella.* *Legionella* bacteria can proliferate under favorable conditions at locations in the premise plumbing and in some parts of the distribution system that are further from the central parts of the system (often in building systems), where water has aged the longest and where there may be little to no disinfectant residual. Further, the quality of the water delivered to building systems and households can impact these pathogens' ability for growth and disease transmission. *Legionella* spp. colonize biofilm layers, particularly those found inside large, complex plumbing systems such as those of hospitals, hotels or long-term care facilities. This biofilm protects *Legionella* from biocides and allows the bacteria to multiply to concentrations that can facilitate transmission (CDC, 2008).

The 2003–2004 CDC Surveillance Summary was the first year that CDC reported *Legionella* outbreaks with other drinking water-associated outbreaks (CDC, 2006). CDC explained that this addition was in response to the changing epidemiology of drinking water-associated outbreaks. In 2003-2004, 8 of 30 (26 percent) drinking water-associated outbreaks were confirmed to be caused by *Legionella*.

In 2005-2006, there were 20 drinking water-associated outbreaks, 12 (60 percent) of which were confirmed to be caused by *Legionella* (CDC, 2008). The report noted that the majority of drinking water deficiencies in 2005-2006, such as those associated with biofilm growth in plumbing systems, were associated with contamination at points outside the jurisdiction of public water systems and which are not regulated by EPA (CDC, 2008).

CDC (2015a) provided a summary of *Legionella* observations over the period 2007 to 2012. The report noted that, although the total number of annual drinking water-associated outbreaks decreased from 2007 to 2012 (36 in 2007–2008; 33 in 2009–2010; and 32 in 2011–2012, see Exhibit 4.2), *Legionella* was responsible for increasing proportions of drinking water-associated outbreaks during this time frame (33 percent, 60 percent, and 66 percent of outbreaks, respectively). Also, the report noted that the trend had been driven by the increasing proportion of outbreaks associated with *Legionella* within community water systems (60 percent of *Legionella* outbreaks in 2007–2008; 76 percent in 2009–2010, and 84 percent in 2011–2012).

In 2011–2012, among 21 *Legionella* outbreaks in community water systems, 14 (67 percent) occurred in hospitals or health care facilities. The outbreak data illustrated the increased likelihood of *Legionella* outbreaks at health care facilities due to the inherent vulnerability of the population exposed, many of whom are elderly or immune-compromised. Although *Legionella* outbreaks do not represent the largest number of cases from drinking water-associated outbreaks, the outbreaks do represent the highest percentages of hospitalization and mortality, further emphasizing the importance of controlling this etiological agent (CDC, 2015a). For example, in the period 2011-2012, *Legionella* was responsible for 96 percent of hospitalizations and all deaths from the total reported drinking water-associated outbreaks.

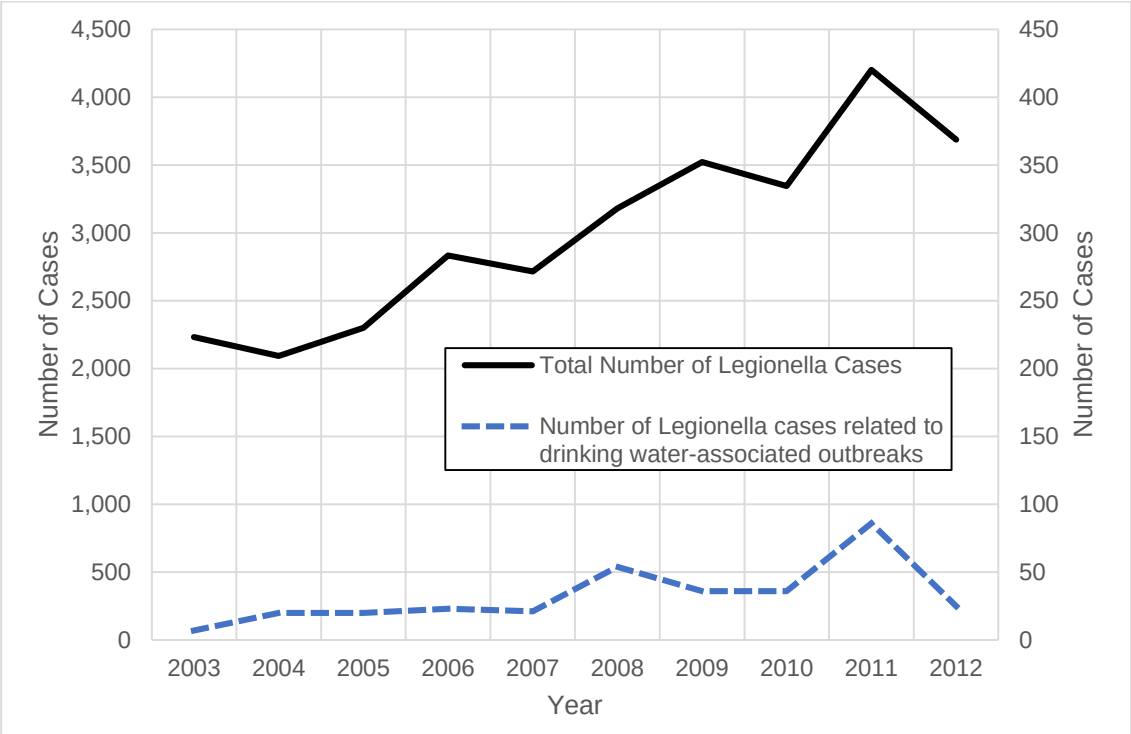
As discussed previously, *Legionella* cases reported as part of drinking water-associated outbreaks are only those cases that meet both criteria for classification laid out by CDC for most microbial contaminants – i.e., two or more linked cases of illness with epidemiological evidence

by time, location of water exposure, and case illness characteristics and identifying water as the probable cause. Lack of evidence or thorough investigation means that there may be underreporting of cases of *Legionella* related to drinking water-associated outbreaks.

Separately from outbreak surveillance, CDC also produces an annual summary of notifiable disease cases as reported by hospitals and state public health agencies to CDC. These data are collected in the National Notifiable Diseases Surveillance System (NNDSS) and are passive data – i.e., data voluntarily reported to CDC (same as the WBDOSS data) as opposed to active data collected directly by CDC. However, a study of three years of active surveillance data from the Active Bacterial Core Surveillance program showed that overall disease rates of legionellosis were similar using this active data and the passive NNDSS data (CDC, 2015b).

Exhibit 4.3 below shows the total number of cases of legionellosis increasing steadily from 2003 to 2012. Also shown (dotted line) is the number of *Legionella* cases related to drinking water-associated outbreaks over the same time period. While the number of cases linked to these outbreak is much smaller, a similar upward trend is observable.

Exhibit 4.3: Cases of *Legionella* in the U.S., 2003-2012



Sources: CDC, 2006; 2008; 2011; 2013; 2014; 2015a

4.1.2.3 Disease Occurrence Associated with Other Pathogens in Distribution Systems

In 2011-2012, non-*Legionella* bacteria, parasites and viruses accounted for just 22% of all WBDOs but 64.3% of all cases (CDC, 2015a). In particular, one outbreak of norovirus was

responsible for 119 cases or 28% of all cases over the two-year period. From 2003 to 2012 the most commonly reported etiological agents besides *Legionella* were *Campylobacter jejuni* and norovirus, together accounting for 20% of all WBDOs and 43% of all cases (CDC, 2006; 2008; 2011; 2013; 2015a).

In August 2013, a 4-year old boy in St. Bernard Parish, Louisiana died of meningoencephalitis. The causative agent, *Naegleria fowleri*, was found to be associated with tap water from the public water distribution system (Cope et al., 2015). *Naegleria fowleri* was detected in 50 percent of samples collected from the home and 25 percent of samples collected from the water distribution system. The source water for the St. Bernard Parish water system is the Mississippi River and treatment includes filtration, primary disinfection with chlorine and secondary disinfection with chloramines. During sample collection, total chlorine levels throughout the house were below the detection limit of the test (<0.02 mg/L) and water temperature in the service line (at the outside hose bib) to the house was 29 degrees C. At 3 of the 4 distribution system sampling locations where *Naegleria fowleri* was detected, there was no detectable total chlorine residual and water temperature was >30 degrees C.

Ercumen et al. (2014) conducted a meta-analysis to investigate the relationship between distribution system deficiencies and risk of endemic waterborne illness in consumers of tap water. The research specifically focused on the impact of routine distribution system problems on endemic gastrointestinal illness in populations drinking tap water versus point-of-use treated water. The study's findings suggested that tap water consumption is associated with endemic gastrointestinal illness in systems with malfunctioning distribution systems, including specific distribution-related deficiencies, such as loss of pipe integrity and inadequate disinfection residual. The authors acknowledge significant heterogeneity among study settings and water system characteristics, even within study subgroups (Ercumen et al., 2014).

In addition to epidemic illness, endemic illness (i.e., isolated cases not associated with an outbreak) accounts for an unknown but probably significant portion of waterborne disease and is more difficult to recognize (USEPA, 2006c).

Although most heterotrophic bacteria in drinking water are not pathogenic to humans, a few (*Pseudomonas* spp., *Acinetobacter* spp., *Moraxella* spp.) may be pathogenic to immunocompromised consumers (Bartram et al., 2003). As part of a risk assessment analysis of the probability of infection from drinking water, several heterotrophic bacterial species were identified as major causes of hospital-acquired infections with a high mortality rate (Rusin et al., 1997). However, Hunter (2003) found no epidemiological evidence that heterotrophic bacteria in drinking water can cause disease in the general population.

4.1.2.4 Burden of Disease

The precise burden of disease is not well quantified, whether epidemic or endemic. Five primarily waterborne diseases (giardiasis, cryptosporidiosis, Legionnaires' disease, otitis externa, and non-tuberculous mycobacterial infection) were responsible for over 40,000 hospitalizations per year at a cost of nearly $1 billion per year according to a recent estimate (Collier et al., 2012) using national medical insurance claim data from CDC. *Legionella* and non-tuberculous mycobacteria (NTM) together were responsible for 73 percent of the total hospitalizations and 89

percent of the total costs. It is important to note that this is a conservative estimate, as it accounts only for costs associated with hospitalization and not for lost wages or recovery time. A more recent analysis focused solely on pulmonary NTM infection costs – a subset of all NTM infections (Strollo et al., 2015). This analysis updated the case estimate for 2014 and included antibiotics cost in its estimate, which resulted in a projected 2014 estimate of 181,000 national annual cases at a cost of $1.7 billion.

4.1.3 GWUDI-Related Public Health Concerns

4.1.3.1 *Giardia* and *Cryptosporidium* Illnesses and Outbreaks Associated with Potentially Misclassified Ground Water Systems

A common cause of a WBDO is a failure in the multiple barrier system designed to protect public health. There are several summaries of *Giardia* and *Cryptosporidium* outbreaks in the U.S. and worldwide (Baldurssun and Karanis, 2011; Chalmers, 2012; Murphy et al., 2014; Hrudey and Hrudey, 2014).

Public water systems using ground water in the U.S. also experienced waterborne disease outbreaks due to *Giardia* and *Cryptosporidium* (summarized in Wallender et al., 2014, Solo-Gabriele and Neumeister, 1996). Ground water outbreaks result when natural filtration is inadequate and disinfection treatment, if provided, is insufficient to protect public health from epidemic disease. Endemic disease may occur for these same reasons.

Wallender et al. (2014) summarized CDC outbreak data for the years 1971-2008 and determined that GWUDI was a "contributing factor" in 18 of 172 (10 percent) outbreaks using untreated ground water (not including 76 outbreaks with insufficient information). Among the 248 total untreated ground water outbreaks during this time period, *Giardia* and/or *Cryptosporidium* was the etiological agent(s) for 16 outbreaks (six percent). Three quarters of the outbreaks involved PWSs. These findings indicate that some of the ground water systems examined by CDC that were not required to disinfect were contaminated with pathogens.

In reviewing the available information on outbreaks, it appears that two outbreak failure scenarios can result from either vertical or horizontal passage of a large bolus of pathogenic protozoa through the subsurface (sufficiently large so as to cause a recognized outbreak):

1) Untreated wells regardless of hydrogeologic setting

In the U.S. and elsewhere (e.g., Switzerland, Füschslin et al., 2012), *Giardia* or *Cryptosporidium* drinking water outbreaks (as compared with endemic illness due to drinking water) typically do not occur or are not recognized to occur in disinfected wells located in porous media (sand or sand and gravel) aquifers. One reason is that subsurface passage through sand and gravel reduces pathogen counts and disinfection is applied as a second barrier to inactivate some of the remaining pathogens. The subsurface natural filtration is similar to the removal achieved by slow sand filters in an engineered filtration system. The combination of subsurface passage in material containing unconsolidated sand and any additional treatment is typically adequate to reduce pathogen concentrations so that only generally unrecognized endemic rather than epidemic disease (an outbreak) may occur. This natural filtration principal is recognized as the basis for a

demonstration of performance (DOP) of alternative filtration treatment in the LT2 Toolbox Guidance section on Bank Filtration (USEPA, 2010c). A ground water collector that does not provide adequate natural filtration and/or does not receive adequate disinfection is at risk for pathogen contamination.

An outbreak that occurred due to the absence of any treatment in wells serving the PWS is demonstrated by the giardiasis outbreak in Bartlett, New Hampshire in 2007 (Daly et al., 2010). The PWS in Bartlett was approved by the state to supply water without treatment. The wells were emplaced into bedrock [probably fractured metamorphic (crystalline) bedrock], which likely facilitated infiltration of pathogen contamination. As a result of the giardiasis outbreak in 2007, it became apparent that the PWS had been incorrectly classified as ground water rather than as GWUDI.

2) "Inadequately treated" wells in fractured bedrock or karst limestone settings

"Inadequately treated" wells refer to those that do not achieve sufficient pathogen removal and inactivation to prevent outbreaks through natural and/or engineered filtration. "Inadequately treated" wells in fractured bedrock or karst limestone settings are at greater risk for a *Giardia* or *Cryptosporidium* outbreak because one of the multi-barriers (natural filtration) is not present or not sufficient. Outbreaks associated with disinfected but inadequately naturally filtered wells are more likely when the hydrogeologic setting is fractured bedrock or karst limestone. In these non-porous media settings, cysts (or oocysts) can travel long distances with little attenuation. Often in these cases, it is not recognized that one barrier (natural filtration) is underperforming or absent due to the aquifer type.

The cryptosporidiosis outbreak in Brushy Creek, Texas in 1998 (Lee et al., 2001; Bergmire-Sweat et al., 1999) resulted from inadequate treatment of a PWS well. The wells were located >400 m from surface water in karst limestone and were permitted to receive disinfection with no filtration. Because the well was located far from surface water, filtration was not required. Because the outbreak occurred in a region where a karst limestone aquifer was present, the PWS well was incorrectly classified as ground water rather than as GWUDI.

Although parasitic protozoan outbreaks associated with inadequately treated GWUDI wells in alluvial (sand and gravel) aquifers have not been recognized in the U.S., they have occurred elsewhere (e.g. Torbay, UK in 1992 and again in 1995; Hrudey and Hrudey, 2014). Even without recognized outbreaks, inadequately treated GWUDI wells remain at risk for endemic, rather than epidemic disease (outbreaks), due to protozoan contamination.

4.1.3.2 Randomized Controlled Intervention Study to Measure Endemic Drinking Water Disease

EPA regulations promulgated under the SDWA are designed to protect against both endemic and epidemic disease. Epidemic outbreaks represent the most easily identifiable, but still difficult to recognize, "tip of the waterborne disease pyramid," meaning that for each case that actually seeks medical care, many more are not recognized because they are either subclinical or do not seek medical care (Craun et al., 2006). Endemic disease is much more difficult to measure because it requires recognizing illness, identifying disease as waterborne (attributable risk) and

measuring the disease incidence when common sources are not identified. Researchers summarized the worldwide effort to measure endemic disease attributable to drinking water in developed countries (Murphy et al., 2014; Sinclair et al., 2015).

Endemic disease can be estimated using a randomized, controlled trial to compare two populations: one population that is supplied drinking water that receives no treatment or some treatment (e.g., in the U.S., treatment required under the SDWA) and a similar or identical population that is supplied drinking water that receives additional treatment. Three household intervention studies were conducted; two (Sydney, Australia and Davenport, Iowa) found no excess endemic diseases attributable to drinking water (Murphy et al., 2014; Sinclair et al., 2015) whereas the third (i.e., Sonoma County, California) found a statistically significant attributable risk to drinking water (Colford et al., 2009).

In the U.S., both household and community intervention randomized controlled trials have been conducted. Household intervention studies have used a filtration and an additional in-home UV light treatment device to provide extra treatment. Typically, these studies have a cross-over design and some have incorporated an inactive "placebo" device so participants are unaware of their device assignment (blinded trials) (Murphy et al., 2014). The cross-over design assigns each household to periods with the inactive device (i.e., no additional water treatment) and periods of additional treatment. Ideally, the household members, the plumbers doing the treatment installation, and the researchers all are unaware to which period additional treatment is provided. The advantage of the cross-over design is that the household members serve as their own controls, which reduces the influence of confounding factors in differing populations. Health effects, especially acute gastrointestinal illness (AGI), are self-reported using daily diaries.

In the analysis of the data collected during the trial, statistical analyses indicate whether the daily relationship between AGI and additional treatment is significant. If the relationship is significant, and accounting for differences within the population or between individuals, then an attributable risk to water is determined. An attributable risk to water implies a causal relationship between water and illness. Because of the randomized, controlled design, causality of the association between water and illness is strengthened; one population is studied over differing time periods and the only difference affecting the population is the amount of drinking water treatment at differing times. The following text describes the only available household intervention study conducted in a community receiving drinking water from a public water system using ground water (Colford et al., 2009).

In the Colford et al. (2009) study, point-of-use counter top devices were installed in participant homes. The devices were either sham treatment units (no additional treatment installed) or additional treatment units (1 µm filters demonstrated to remove virtually all bacteria and parasites and UV light disinfection previously demonstrated to provide 99.99 percent virus inactivation).

Colford et al. (2009) selected Sonoma County, CA to measure endemic disease using a randomized controlled trial (household intervention) for several reasons:

1) A cohort of older adults in the county were already participating in a longitudinal study of aging and physical performance (the National Institutes of Health (NIH) funding). The Sonoma County drinking water study was also funded by NIH.

2) A large enough community to meet participant recruitment goals (988 individuals enrolled).

3) Drinking water meeting all federal, state, and local SDWA requirements.

4) Only one drinking water source serving the community.

5) Sonoma County is a relatively short distance from the base location of the research team (Berkeley, CA).

Colford et al. (2009) found that study participants (>55 years old) had reduced (either at a population or individual level) health effects (measured as highly credible gastrointestinal illness, HCGI) with the additional drinking water treatment. EPA re-assessed the Colford et al. (2009) analysis and concluded that their statistical analysis was appropriate (see Appendix E for the EPA statistical modeling assessment). Colford et al. determined that the Sonoma County population had a measured 12 percent mean reduction in yearly gastrointestinal illness (12 percent attributable risk to drinking water) when receiving drinking water with extra treatment. One interpretation of this result is that the Sonoma County drinking water is causing 12 percent of the total yearly gastrointestinal disease burden that results from all exposure, including daycare, food, recreational water, surfaces, children, and hospital-acquired disease pathways.

The results of Colford et al. (2009) suggest that the drinking water produced by the Sonoma County Water Authority (SCWA) is making individuals aged 55 or older ill despite meeting all current local, state and federal drinking water regulations. Based on the available SCWA information (SCWA, 2013), a possible cause for the ill individuals was that none of the PWS well water received engineered filtration to achieve adequate *Giardia* and *Cryptosporidium* removal.

SCWA operated five horizontal wells each with a central caisson (large diameter well) and radial laterals (slotted pipe) to capture large volumes of water. These horizontal well laterals are 50 to 60 feet below the river bed; thus the ground water flow path from the river bed to the lateral is relatively short. The short subsurface residence time and travel distance would minimize *Giardia* and *Cryptosporidium* removal (USEPA, 2010c) and these horizontal wells are likely GWUDI.

The 1992-1993 GWUDI determination data for the SCWA horizontal collector wells were reported by California Department of Health Services, letter and report dated September 22, 1993 (California Department of Health Services, 1993). One well (horizontal collector well #5) was previously determined to be potentially GWUDI and a follow-up study was undertaken by SCWA for the state. As a result of the second study of paired total coliform river and well #5 samples and other data, the state determined that well #5 was GWUDI but awarded 2.5-log *Giardia* reduction (removal) credit based on alternative filtration technology (DOP for alternative treatment). Price et al. (1999) suggested that well #5 was GWUDI approximately 17 percent of the year. Well #5 was not used for about 2-4 months (in some years January,

February, and March but varied from year to year) during the high river stage (>5,000 cubic feet per second) higher risk period (SCWA, 2013). During the other 8-10 months per year, the well was likely operated similarly to the other four horizontal collector wells, providing drinking water that was disinfected but not subject to engineered filtration.

The GWUDI determination and alternative treatment (bank filtration) DOP for the SCWA PWS wells were conducted based on total coliform occurrence (California Department of Health Services, 1993) before EPA issued guidances (USEPA, 1992b; USEPA, 2010c) and were never subsequently re-classified. EPA recommended the use of microscopic particulate analysis (MPA) for GWUDI determination (USEPA, 1992b) and the use of aerobic spores for alternative treatment DOP (USEPA, 2010c) (see Section 5.4 for more details). As discussed in the guidance (USEPA, 2010c), total aerobic spores are recommended for use to demonstrate removal /inactivation of *Cryptosporidium* compared to total coliforms because total coliforms have been shown to be shorter lived and may be less mobile in the subsurface.

Assuming total coliforms have limited subsurface mobility, fewer total coliforms, as compared with aerobic spores and/or MPA bioparticles, could arrive at the well. Thus, the use of total coliforms as an indicator could result in a decision that the wells are more likely to be ground water rather than GWUDI. For the well that is recognized as GWUDI, the use of total coliforms as an indicator to determine *Giardia* removal credit would likely favor a decision to take the well offline for a shorter high risk period. In contrast, the use of a more mobile and longer lived *Giardia/Cryptosporidium* surrogate bioindicator (i.e., aerobic spores) would more likely favor a decision to take the well offline for a longer high risk period, or even continuously until additional engineered filtration is provided. If aerobic spores rather than total coliform data were used to determine the high *Giardia* (and *Cryptosporidium*) risk period for the SCWA well #5, the high risk period might be substantially longer than two to four months and perhaps, the well could be at high risk much of the year.

The measured 12 percent attributable risk of AGI from drinking water identified at Sonoma County (Colford et al., 2009) may indicate a vulnerability to the multi-barrier system that is intended to protect public health. The SCWA system is disinfected using chlorine and the chlorine residual level is about 0.6 mg/L at the entry point and 0.2 mg/L at the end of the distribution system (SCWA, 2013). Disinfection is ineffective at killing *Cryptosporidium* (USEPA, 2006a). Therefore, *Cryptosporidium* could potentially be the etiologic agent causing AGI. Data are lacking to determine if *Cryptosporidium* was indeed the cause of AGI. More data are needed to assess co-occurrence of aerobic spores and total coliforms in horizontal collector wells to determine if these wells should be classified as GWUDI. This information could help inform re-evaluation of GWUDI determinations to better protect public health.

4.1.3.3 Pathogenic Protozoa Occurrence in Ground Water Used for Public Drinking Water

Traditionally, GWUDI determination under the SWTR is assumed to identify a contamination risk from nearby surface water such as a river, stream, lake, reservoir, pond, canal, or other water body. Thus, the assumption is that the GWUDI threat results from near-horizontal flow from the water body to the adjacent well. EPA guidance and state programs often include a recommended minimum set-back distance from surface water beyond which GWUDI would not be expected.

On the other hand, the SWTR definition identifies any well as GWUDI if it is at direct risk from *Giardia, Cryptosporidium,* or other coccidian parasitic protozoa independent of the type, character or location of the source water.

However, in some hydrogeologic scenarios, such as very sensitive and vulnerable hydrogeologic settings (e.g. karst limestone, glacier flood deposits or fractured bedrock) it is possible that *Giardia* or *Cryptosporidium* can enter the well by vertical passage via infiltrating precipitation in the absence of any water body. For example, the 1994 Hydro-Nine cryptosporidiosis outbreak in Walla Walla, WA resulted from vertical passage of treated waste water containing *Cryptosporidium* and used for irrigation. It is surmised that the wastewater traveled from the surface downward through coarse, glacial and alluvial flood deposits and, as is reported in the CDC investigation, directly along a cracked well casing with an improper seal (McKinley, 1997; Dworkin et al., 1996).

A vertical water flow path (vertical from the surface versus horizontal from surface water) might not be identified using the bioindicators addressed by the current MPA guidance. For example, in the absence of a water body, it is unlikely that diatoms or other algae would be significant bioindicators because they require a continuously moist environment.

In a karst aquifer in France, 18 ground water samples were taken from the Norville (Haute-Normandie) public water supply well (5,000 customers. chlorine treatment) and tested for *Cryptosporidium* oocysts. Thirteen of the eighteen samples were found to be *Cryptosporidium* positive by solid-phase cytometry; the maximum concentration was four oocyst per 100 L (Khaldi et al., 2011). These data show that *Cryptosporidium* in karst ground water includes, for some highly vulnerable systems, *Cryptosporidium* occurrence resulting from poor *Cryptosporidium* removal during infiltration from the surface rather than poor removal during induced infiltration from nearby surface water. Because the SWTR definition assumes that all *Cryptosporidium* in PWS wells is transported from adjacent surface water, it is silent on the issue of *Cryptosporidium* transport directly from the surface, as apparently was the case in Norville, France. Karst aquifers are a vital ground water resource in the U.S. According to the United States Geological Survey (USGS), about 40 percent of the ground water used for drinking water comes from karst aquifers (USGS, 2012).

Pitkanen et al. (2015) sampled 20 small (<50 population served) ground water wells once in spring and once in autumn in Finland for *Giardia* and a suite of microbial indicators. Fourteen (of nineteen) wells were undisinfected (no information on one well). They found that 4 (of 20) wells, all undisinfected, had *Giardia* detection in the autumn sample. All samples, both spring and autumn, were negative for total coliforms.

Pathogenic protozoa occurrence results within the last decade from the non-GWUDI PWSs in the U.S. are not available because these PWSs are not required to sample ground water for *Giardia* or *Cryptosporidium.* EPA conducted a preliminary characterization of the number of the potentially misclassified GWUDI PWSs based on: (1) waterborne disease outbreak compilations; (2) the SYR2 ICR and the SYR3 ICR (total coliform detections, see Section 6.4 of this document); and (3) the Unregulated Contaminant Monitoring Rule (UCMR3) occurrence data (aerobic spore detections and concentrations, see Section 6.5 of this document).

4.2 GWR

EPA promulgated the GWR in 2006 (USEPA, 2006a) to provide protection against microbial pathogens in PWSs using ground water sources. Viruses are of particular concern because they can persist longer and can be more mobile in the subsurface than bacterial pathogens (USEPA, 2006).

The health effects associated with TC and/or other pathogen and indicator occurrence in undisinfected PWS wells was studied for 14 communities in Wisconsin (Borchardt et al., 2012). Borchardt et al. (2012) conducted a community intervention study in each of the 14 communities. Each undisinfected water supply was periodically treated using UV; at the same time, drinking water samples were assayed for a suite of viral pathogens using quantitative polymerase chain reaction (qPCR) and community members kept daily diaries to self-report highly credible AGI. The study found that the communities and time periods with the highest virus measures had correspondingly high AGI incidence.

Among the 14 communities, populations ranged from 1,363 to 8,300. The 14 enrolled communities were the first to volunteer to participate among communities with populations >1,000 and with four or fewer wells. Most wells tapped sandstone aquifers at depths from 23 to 169 m. One community is suspected of producing water from a karst aquifer. Borchardt et al. (2012) found a statistically significant association between enterovirus and norovirus concentrations measured by qPCR in tap water and AGI health effects in the consuming population in the 14 communities. Adenovirus concentrations were low and not positively associated with AGI. The estimated attributable risk to drinking water ranged from 6 percent to 22 percent, depending on the model selected. The risk may have been as high as 63 percent among children less than 5 years old during the period when norovirus was abundant in drinking water.

Because the qPCR method measures all viral genetic material (RNA or DNA) from both infectious and inactive virions, viral occurrence data based on qPCR alone are not definitive. However, the collection and analysis of health effects data, concurrent with qPCR virus occurrence data, substantially reduces uncertainty about viral infectivity, at least at sites where concurrent health data are available. Borchardt et al. (2012) demonstrated a statistically significant relationship between qPCR viral occurrence and health effects. In their study, data were collected to analyze the relationship between health effects and UV light treatment (and qPCR virus occurrence). Additional analysis is needed to characterize the AGI attributable risk to drinking water.

5 Analytical Methods

This chapter summarizes the analytical methods approved for contaminant monitoring or treatment technique requirements included under the Surface Water Treatment Rule (SWTR), Interim Enhanced Surface Water Treatment Rule (IESWTR), Long-Term 1 Enhanced Surface Water Treatment Rule (LT1), and Ground Water Rule (GWR). There are no methods related to the Filter Backwash Recycling Rule (FBRR). Methods information related to *Giardia* and *Cryptosporidium* are addressed in the LT2 support document (USEPA, 2016a), methods information related to distribution system water monitoring required for total coliforms and *E. coli* under the Revised Total Coliform Rule (RTCR) are addressed in the associated guidance documents (USEPA, 2012), and methods information related to disinfectant Maximum Residual Disinfectant Levels (MRDLs) are addressed in the Disinfectants and Disinfection Byproducts Rules (D/DBPR) support document (USEPA, 2016f).

The National Environmental Methods Index (NEMI) was used to confirm details related to methods not developed by EPA. NEMI is a database of analytical methods and summary data for analytical methods and is run by the National Water Quality Monitoring Council in conjunction with EPA and United States Geological Survey (USGS). NEMI can be searched by analytical method number.[5]

5.1 Methods for Treatment Technique Requirements Related to Raw and Finished Water Turbidity (SWTR, IESWTR and LT1)

In carrying out the combined filter effluent requirements and the individual filter effluent requirements of the SWTR, IESWTR and LT1, systems must use methods for turbidity measurements that were previously approved by EPA. The promulgation of the IESWTR and LT1 did not include any changes to the approved methods for turbidity. Exhibit 5.1 summarizes the analytical methods developed by EPA and others (e.g., Standard Methods (SM), Leck Mitchell, PhD, Great Lakes Instruments) that are approved for turbidity monitoring as part of the SWTR (USEPA, 1989) and modified over time (e.g., EPA approved a revised EPA Method 180.1 in August 1993), as well as those methods (i.e., alternate testing methods) that have been approved via EPA's Expedited Method Approval process since promulgation.[6] The alternate testing methods are listed in the Code of Federal Regulations (CFR), in Appendix A to Subpart C of 40 CFR Part 141.[7]

During the promulgation process of the IESWTR and LT1, EPA looked for voluntary consensus standards with regard to calibration of turbidimeters. During the IESWTR rule development phase, The American Society for Testing and Materials (now ASTM International) was in the process of developing such voluntary consensus standards; however, there did not appear to be any voluntary consensus standards available at the time IESWTR was promulgated nor were any comments received on the topic during the LT1 promulgation process.

[5] https://www.nemi.gov/home/

[6] EPA's Expedited Method Approval Process allows EPA to announce the approval of alternate methods to laboratories and Public Water Systems in a more timely manner than traditional rulemaking: http://water.epa.gov/scitech/drinkingwater/labcert/analyticalmethods_expedited.cfm

[7] http://www.ecfr.gov/cgi-bin/text-idx?SID=1ab89b8c14cb76ecd23585c6c2130ea2&node=pt40.23.141&rgn=div5#_top

Exhibit 5.1: Turbidity Analytical Methods Approved under the Surface Water Treatment Rule (§141.74)

Methodology category	Method[1]	Method citation	Additional Information
Nephelometric Method	Comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions.	Standard Methods for the Examination of Water and Wastewater 2130 B.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 2130 B-01 Formazin polymer is used as the primary standard reference suspension.[2]
Nephelometric Method	Comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension.	EPA 180.1 "Methods for the Determination of Inorganic Substances in Environmental Samples", EPA/600/R-93/100, August 1993.	A standard suspension (i.e., formazin, AMCO-AEPA-1, or Hach StablCal) is used to calibrate the instrument.
Laser Nephelometry (on-line)	Comparison of the intensity of light scattered by the sample under defined conditions, with the intensity of light scattered by a standard reference suspension.	Mitchell Method M5271, Revision 1.1. "Determination of Turbidity by Laser Nephelometry," March 5, 2009.	Primary standard suspensions are used to calibrate the instrument. A secondary standard is monitored periodically for deterioration using one of the primary standards. Laser light source: Monochromatic source operated at a nominal wavelength of 650 ±30nm. The light source shall be used as a directly received reference for the scattered nephelometric signal.
LED Nephelometry (on-line)	Comparison of the intensity of light scattered by the sample under defined conditions, with the intensity of light scattered by a standard reference suspension.	Mitchell Method M5331, Revision 1.1. "Determination of Turbidity by LED Nephelometry," March 5, 2009.	Primary standard suspensions are used to calibrate the instrument. A secondary standard is monitored periodically for deterioration using one of the primary standards. LED light source: Monochromatic source operated at a nominal wavelength of 525 ± 15nm. The light source shall be used as a directly received reference for the scattered nephelometric signal.
LED Nephelometry (on-line)	Comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension.	AMI Turbiwell, "Continuous Measurement of Turbidity Using a SWAN AMI Turbiwell Turbidimeter," August 2009.	The instrumentation is installed to read turbidity continuously. The light source shall be a white LED emitting visible light. The LED, all optical elements and detectors shall have a spectral peak response between 400 nm and 600 nm.
LED Nephelometry (portable)	Comparison of the intensity of light scattered by the sample at 90^0 to the beam path, with the intensity of light scattered by a standard reference suspension.	Orion Method AQ4500, Revision 1.0. "Determination of Turbidity by LED Nephelometry," May 8, 2009.	A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using a primary standard.

Methodology category	Method[1]	Method citation	Additional Information
Great Lakes Instruments (GLI)	Comparison of the intensity of light scatters by the sample under defined conditions with the intensity of the light scattered by a standard reference suspension.	GLI Method 2, "Turbidity," November 2, 1992	A standard suspension of formazin, prepared under closely defined conditions, is used to calibrate the instrument.
Hach FilterTrak	Comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension.	Hach FilterTrak Method 10133, "Determination of Turbidity by Laser Nephelometry," January 2000, Revision 2.0.	Calibration verification standards are used to check instrument performance and verify the instrument is operating correctly.

[1] This table includes methods added since the 1989 SWTR. Also includes those approved by the Expedited Method Approval Process.
[2] Formazin polymer is used as a primary turbidity suspension for water because it is more reproducible than other types of standards previously used for turbidity analysis. Styrene divinyl benzene beads (e.g., AMCO-AEPA-1 or equivalent) and stabilized formazin (e.g., Hach StablCalTM or equivalent) are acceptable substitutes for formazin.

5.2 Methods for Measuring Disinfection Residuals (SWTR) and Disinfection Profiling and Benchmarking (IESWTR, LT1)

This section addresses the methods related to monitoring to ensure disinfection CT is met as well as monitoring for disinfection profiling and benchmarking. It also addressed the approved test methods for distribution system residuals and metrics to indicate "detectable" residuals for each method.

5.2.1 Disinfectant Residuals

Disinfectant Residual Entering Distribution System

Methods related to primary disinfectants are also addressed in the D/DBPR support document (USEPA, 2016f). For the most part, the methods for meeting the CT requirement and the MRDL requirements in the D/DBPR are the same; however, there are a few differences.

The SWTR contains two methods that are not included in the D/DBPR.

- The Ozone Indigo Method is not included in the D/DBPR methods section as systems are not required to monitor for Ozone according to that rule.

- The Chlorine Dioxide (Amperometric Titration - SM 4500-ClO2 C) method is included in SWTR but not in the D/DBPR. Chlorine Dioxide (Amperometric Titration - SM 4500-ClO2 E) is included in the analytical methods section for both rules, but SM 4500-ClO2 C is not because it was outdated and inadequate for compliance sampling.

In addition, ASTM D1253-86(96) is included in the D/DBPR as an allowable method along with ASTM D1253-03 and ASTM D1253-08. Only ASTM D1253-03 and ASTM D1253-08 are included in the SWTR analytical method's section. Note there is a new version of the method that is listed on the ASTM website (ASTM D1253-14) at http://www.astm.org/Standards/D1253.htm.

All methods listed in this section (see Exhibit 5.2) can be used to ensure disinfection CT requirements are met. Surface water systems are also required under the SWTR (141.72(a)(3) and 141.72(b)(2)) to ensure that residual disinfectant concentration in the water entering the distribution system is not less than 0.2 mg/L for more than 4 hours. Methods listed in this section can all be used to ensure systems meet this requirement.

In addition, the SWTR contains a statement in 141.74(a)(2) that if approved by the state, disinfectant residual concentrations for free chlorine and combined chlorine may also be measured using DPD (N, N Diethyl-1,4 phenylenediamine sulfate) colorimetric test kits. Unlike the D/DBPR, the SWTR does not contain approved methods for measuring combined chlorine.

Disinfectant Residual in Distribution System

The residual disinfectant concentration must be detectable in the distribution system in at least 95 percent of samples taken each month (40 CFR 141.72(b)(3)(i)). Water in the distribution system with a measured heterotrophic bacteria concentration less than or equal to 500/mL, measured as heterotrophic plate count (HPC), can satisfy the requirement for a detectable disinfectant residual for purposes of determining compliance with this requirement. Methods listed in Exhibit 5.2 can also be used to measure disinfectant residuals in the distribution system. A discussion of organic chloramine issues that affect total chloramine measurements is provided in Section 7.2.3. The HPC methods are provided in Section 5.2.4.

5.2.1.1 Ozone

Because of the unique characteristics of ozone, the procedures for determining C and T for disinfection with ozone differ from those recommended for systems using other disinfectants. Ozone is a powerful oxidant that reacts rapidly with organic and inorganic substances present in the water and undergoes auto-decomposition. Therefore, its residual is much less stable than that of other disinfectants and dissipates rapidly. The T value can be determined through a tracer study or an equivalent method as approved by the state with air or oxygen applied during testing, using the same feed gas rate as used during operation. The C value can be determined for individual chambers of a contactor based on the residual measured at several points throughout the contact chamber, or at the exit of the chamber. EPA recommends using the average dissolved ozone concentration in the water for C.

Exhibit 5.2: Primary Disinfectant Residual Analytical Methods Approved under the Surface Water Treatment Rule (§141.74)

Analyte	Methodology category	Method[1]	Method citation	Additional Information
Chlorine (total)	Chlorine by Amperometry	The amperometric method is a special adaptation of the polarographic principle. Free chlorine is titrated at a pH between 6.5 and 7.5, a range in which the combined chlorine reacts slowly.	Standard Methods for the Examination of Water and Wastewater 4500-Cl D.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl D-00
	Chlorine by Amperometry	Determination of residual chlorine in water by direct amperometric titration	ASTM D1253-03 ASTM International http://astm.org.	Any year containing the cited version of the method may be used.
	Chlorine by Amperometry	Determination of residual chlorine in water by direct amperometric titration	ASTM D1253-08 ASTM International http://astm.org.	The methods listed are the only alternative versions that may be used.
	Amperometric Titration (Low level measurement	Modifies D by using a more dilute titrant and a graphical procedure to determine the end point.	Standard Methods for the Examination of Water and Wastewater 4500-Cl E.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl E-00
	DPD Ferrous Titrimetric	DPD is used as an indicator in the titrimetric procedure with ferrous ammonium sulfate.	Standard Methods for the Examination of Water and Wastewater 4500-Cl F.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl F-00
	Chlorine by DPD Colorimetric	This is a colorimetric version of the DPD method (4500-Cl F) and is based on the same principles.	Standard Methods for the Examination of Water and Wastewater 4500-Cl G.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl G-00
	Chlorine by DPD Colorimetric	Chlorine in the sample reacts with DPD indicator to form a pink color that is proportional to the chlorine concentration.[2]	"Hach Method 10260—Determination of Chlorinated Oxidants (Free and Total) in Water Using Disposable Planar Reagent-filled Cuvettes and Mesofluidic	

Analyte	Methodology category	Method[1]	Method citation	Additional Information
			Channel Colorimetry," Hach Company. April 2013.	
	Chlorine by Iodometric Electrode	Direct potentiometric measurement of iodine released on the addition of potassium iodide to an acidified sample. A platinum-iodide electrode pair is used in combination with an expanded-scale pH meter.	Standard Methods for the Examination of Water and Wastewater SM 4500-Cl I.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl I-00
	Residual Chlorine in Drinking Water Using an On-Line Chlorine Analyzer	On-line chlorine analyzer is used to continuously monitor the chlorine concentration and is calibrated using aqueous standards. The on-line analyzer accuracy is periodically verified/adjusted based on results from grab sample analyses	EPA Method 334.0. "Determination of Residual Chlorine in Drinking Water Using an On-line Chlorine Analyzer," August 2009. EPA 815-B-09-013.	
	ChloroSense Amperometric Sensor[3]	Electrochemical technique known as chronoamperometry. A reagent-free method of analyzing water for chlorine. Portable.	ChloroSense. "Measurement of Free and Total Chlorine in Drinking Water by Palintest ChloroSense," August 2009.	
Chlorine (free)	Chlorine by Amperometry	The amperometric method is a special adaptation of the polarographic principle. Free chlorine is titrated at a pH between 6.5 and 7.5, a range in which the combined chlorine reacts slowly.	Standard Methods for the Examination of Water and Wastewater 4500-Cl D.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl D-00
	Chlorine by Amperometry	Determination of residual chlorine in water by direct amperometric titration	ASTM D1253-03 ASTM International http://astm.org.	Any year containing the cited version of the method may be used.
	Chlorine by Amperometry	Determination of residual chlorine in water by direct amperometric titration	ASTM D1253-08 ASTM International http://astm.org.	The methods listed are the only alternative versions that may be used.
	DPD Ferrous Titrimetric	DPD is used as an indicator in the titrimetric procedure with ferrous ammonium sulfate.	Standard Methods for the Examination of Water and Wastewater 4500-Cl F.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd

Analyte	Methodology category	Method[1]	Method citation	Additional Information
				Standard Methods online versions approved: 4500-Cl F-00
	Chlorine by DPD Colorimetric	This is a colorimetric version of the DPD method (4500-Cl F) and is based on the same principles.	Standard Methods for the Examination of Water and Wastewater 4500-Cl G.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl G-00
	Chlorine by DPD Colorimetric	Chlorine in the sample reacts with DPD indicator to form a pink color that is proportional to the chlorine concentration.[4]	"Hach Method 10260—Determination of Chlorinated Oxidants (Free and Total) in Water Using Disposable Planar Reagent-filled Cuvettes and Mesofluidic Channel Colorimetry," Hach Company. April 2013.	
	Chlorine by Syringaldazine (FACTS)	Measures free chlorine over the range of 0.1 to 10 mg/L. A saturated solution of syringaldazine in 2-propanol is used.	Standard Methods for the Examination of Water and Wastewater 4500-Cl H.	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-Cl H-00
	Residual Chlorine in Drinking Water Using an On-Line Chlorine Analyzer	On-line chlorine analyzer is used to continuously monitor the chlorine concentration and is calibrated using aqueous standards. The on-line analyzer's accuracy is periodically verified/adjusted based on results from grab sample analyses	EPA Method 334.0. "Determination of Residual Chlorine in Drinking Water Using an On-line Chlorine Analyzer," August 2009. EPA 815-B-09-013.	
	ChloroSense Amperometric Sensor[5]	Electrochemical technique known as chronoamperometry. A reagent-free method of analyzing water for chlorine. Portable.	ChloroSense. "Measurement of Free and Total Chlorine in Drinking Water by Palintest ChloroSense," August 2009.	
Chlorine Dioxide	Amperometric Method I	The amperometric titration of chlorine dioxide is an extension of the amperometric method for chlorine. By performing four titrations with phenylarsine oxide, free chlorine (including hypochlorite and hypochlorous acid), chloramines, chlorite, and chlorine dioxide may be determined separately.	Standard Methods for the Examination of Water and Wastewater 4500-ClO2 C	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500- ClO2 C-00

Analyte	Methodology category	Method[1]	Method citation	Additional Information
	Amperometric Method II	Similar to 4500-ClO2 C, this procedure entails successive titrations of combinations of chlorine species. Subsequent calculations determine the concentration of each species.	Standard Methods for the Examination of Water and Wastewater 4500-ClO2 E	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500- ClO2 E-00
	ChlordioX Plus Amperometric Sensor[6]	Based on quantifying chemical reactions by measuring electrical energy produced or consumed by the reaction. Portable.	ChlordioX Plus. "Chlorine Dioxide and Chlorite in Drinking Water by Amperometry using Disposable Sensors," November 2013.	
	DPD Method	This method is an extension of the DPD method for determining free chlorine and chloramines in water. Chlorine dioxide appears in the first step of this procedure but only to the extent of one-fifth of its total available chlorine content corresponding to reduction of chlorine dioxide to chlorite ion.	Standard Methods for the Examination of Water and Wastewater 4500-ClO2 D	Standard Methods print editions approved: 18th, 19th, 20th
	Chlorine Dioxide and Chlorite in Drinking Water by Visible Spectrophotometry	Visible spectrophotometer is used to measure the absorbance of the reagent water blank and sample absorbance at 633 nm, which is the absorbance maximum for Lissamine Green B in the citric acid/glycine buffer. The absorbance difference between the reagent water blank and the samples is used to calculate the concentrations of chlorine dioxide.	EPA Method 327.0, Revision 1.1, "Determination of Chlorine Dioxide and Chlorite Ion in Drinking Water Using Lissamine Green B and Horseradish Peroxidase with Detection by Visible Spectrophotometry," May 2005, EPA 815-R-05-008.	
Ozone	Ozone by Indigo Colorimetric Method	In acidic solution, ozone rapidly decolorizes indigo. The decrease in absorbance is linear with increasing concentration.	Standard Methods for the Examination of Water and Wastewater 4500-O3 B	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 4500-O3 B-97

[1] This table includes methods added since the 1989 SWTR. Also includes those approved by the Expedited Method Approval Process.
[2] www.hach.com/asset-get.download.jsa?id=24364820994
[3] http://www.palintest.com/products/chlorosense/
[4] www.hach.com/asset-get.download.jsa?id=24364820994
[5] http://www.palintest.com/products/chlorosense/
[6] http://www.palintestusa.com/products/chlordiox-plus/

5.2.2 pH

The pH must be monitored because disinfection effectiveness of chlorine is pH-sensitive. When calculating CT, the pH is sampled at each monitoring point and at the same time as the residual disinfectant concentration (during peak hourly flow).

No pH analytical method is listed in the SWTR, IESWTR, or LT1. Methods for measuring pH are available at 141.23(k)(1)(21), and a reference to 141.23(k)(1)(21) is provided in 141.74(a)(1) of the SWTR. The methods listed in 141.23(k)(1)(21) are EPA Methods 150.1 or 150.2, ASTM method D1293-95, ASTM method D1293-95, 99, Method 4500-H^+B in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992), 19th (1995), and 20th (1998) editions and Standard Methods online version 4500-H^+ B-00.

There is a reference in 141.74(a)(1) to Appendix A to Subpart C of Part 141, which provides alternate testing methods that have been approved by EPA's Expedited Method Approval process since promulgation. Exhibit 5.3 summarizes the analytical methods approved via EPA's Expedited Method Approval process for pH.

Exhibit 5.3: pH Analytical Methods Approved via the Expedited Method Approval Process

Methodology category	Method	Method citation	Additional Information
pH in Water by Potentiometry	Determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode.	Standard Methods for the Examination of Water and Wastewater 4500-H^+ B.	Standard Methods print editions approved: 21st, 22nd
pH in Water	pH meter and associated electrodes are standardized against two reference buffer solutions that closely bracket the anticipated sample pH.	ASTM D 1293-12 ASTM International http://astm.org.	The methods listed are the only alternative versions that may be used.

5.2.3 Temperature

All disinfectants, except for UV light, are temperature sensitive. CT values vary with water temperature and, as a result, water temperature should be measured at each monitoring point and at the same time as the residual disinfectant concentration when calculating CT. The temperature should be recorded in degrees Celsius (°C) because the CT tables are based on temperature measured in °C.

No analytical method for temperature is provided in the SWTR, IESWTR, or LT1. Methods for measuring temperature are available at 141.23(k)(1)(25), but there does not appear to be a reference to 141.23(k)(1)(25) in 141.74(a)(1) of the SWTR. The methods listed in 141.23(k)(1)(25) are Method 2550 in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992), 19th (1995), and 20th (1998) editions and Standard Methods online version 2550-00.

There is a reference in 141.74(a)(1) to Appendix A to Subpart C of Part 141, which contains alternate testing methods that have been approved by EPA's Expedited Method Approval process since promulgation of the particular rule. Exhibit 5.4 summarizes the analytical methods approved via EPA's Expedited Method Approval process for temperature.

Exhibit 5.4: Temperature Analytical Method Approved by the Expedited Method Approval Process

Methodology category	Method	Method citation	Additional Information
Thermometric	Measured using any standard liquid-in-glass or electronic thermometer with an analog or digital readout.	Standard Methods for the Examination of Water and Wastewater 2550.	Standard Methods print editions approved: 21st, 22nd Standard Methods online versions approved: 2550-10

5.2.4 Heterotrophic Bacteria

Exhibit 5-5 provides the heterotrophic bacteria analytical methods that must be used to satisfy this SWTR requirement.

Exhibit 5.5: Heterotrophic Bacteria Analytical Methods Approved under the Surface Water Treatment Rule (§141.74)

Methodology Category	Method	Method citation	Additional Information
Culturable method	Heterotrophic Plate Count – Pour Plate Method	Standard Methods for the Examination of Water and Wastewater 9215B	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9215B-00, 9215B-04
Enzymatic detection method	Simplate	IDEXX SimPlate™ HPC Test Method for Heterotrophs in Water, November 2000	

Note: This table includes methods added since the 1989 SWTR. Also includes those approved by the Expedited Method Approval Process.

5.3 Methods for Treatment Technique Requirements Related to Filtration Avoidance (SWTR)

Under the SWTR, systems that are successfully avoiding filtration must monitor their source water quality conditions. As described in Section 3.1.3.4, a filtration avoidance system must have a fecal coliform concentration of 20/100 mL or less, or a total coliform concentration of 100/100 mL or less in the source water (40 CFR 141.71(a)(1)). If both fecal and total coliforms are measured, the system must meet the fecal coliform criterion. Systems are required to use an enumeration method. The analytical methods approved under 141.852 (RTCR) are presence/absence methods only and have not been evaluated or approved for enumeration. Exhibit 5.6 and Exhibit 5.7 list the approved analytical methods for total coliform analytical and fecal coliform, respectively, under the SWTR.

Exhibit 5.6: Total Coliform Bacteria Analytical Methods Approved under the Surface Water Treatment Rule (§141.74)

Methodology Category	Method	Method citation	Additional Information
Lactose Fermentation Method	Multiple-tube fermentation technique for members of the Total Coliform group	Standard Methods for the Examination of Water and Wastewater 9221 A,B,C	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9221A, B, C-99, 9221A,B,C-06
Membrane Filtration Methods	Membrane Filter Technique for Members of the Coliform Group	Standard Methods for the Examination of Water and Wastewater 9222 A,B,C	Standard Methods print editions approved: 18th, 19th, 20th, 21st Standard Methods online versions approved: 9222 A, B, C-97
	MI agar	"New medium for the simultaneous detection of total coliform and *Escherichia coli* in water", K.P. Brenner et al, 1993, Appl. Environ. Microbiol. 59:3534.	
Enzymatic detection method	Enzyme Substrate Coliform Test/Colilert (ONPG-MUG)	Standard Methods for the Examination of Water and Wastewater 9223	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9223 B-97, 9223B-04

Note: This table includes methods added since the 1989 SWTR. Also includes those approved by the Expedited Method Approval Process.

Exhibit 5.7: Fecal Coliform Bacteria Analytical Methods Approved under the Surface Water Treatment Rule (§141.74)

Methodology Category	Method	Method citation	Additional Information
Fecal Coliform Procedure (following Lactose Fermentation method)	Thermotolerant Coliform Test: EC Medium	Standard Methods for the Examination of Water and Wastewater 9221E	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9221E-99, 9221E-06
Fecal Coliform Procedure (direct test)	Thermotolerant Coliform Test: A1 Medium	Standard Methods for the Examination of Water and Wastewater 9221E	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9221E-99, 9221E-06
Membrane Filtration Method	Thermotolerant (Fecal) Coliform Membrane Filter Procedure	Standard Methods for the Examination of Water and Wastewater 9222D	Standard Methods print editions approved: 18th, 19th, 20th, 21st, 22nd Standard Methods online versions approved: 9222 A, B, C-97, 9222D-06

Note: This table includes methods added since the 1989 SWTR. Also includes those approved by the Expedited Method Approval Process.

5.4 Methods for GWUDI Determination (SWTR, IESWTR and LT1)

There are no EPA-approved methods for ground water under the direct influence of surface water (GWUDI) determinations included in the SWTR, IESWTR or LT1. Methods for microscopic particulate analysis (MPA) were published as a guidance (USEPA, 1992a) and may be used for such determinations, but they are not EPA-approved. There are also no regulatory requirements for use of total aerobic spore methods for GWUDI determination, although Standard Method 9218 (American Public Health Association (APHA), 2012) may be used for their analysis. Methods for MPA and total aerobic spores are discussed in this chapter because they are commonly used and are recommended in the EPA guidance (USEPA, 2012).

5.4.1 Microscopic Particulate Analysis

The 1991 SWTR Guidance Manual (USEPA, 1991b) includes as Appendix A, the EPA Consensus Method for *Giardia* Cyst Analysis that was in use at the time – in the late 1980's to early 1990's. The analytical method described in the appendix uses source water filtration, density-gradient sample separation, and sample concentration steps with observation of the processed sample using Brightfield/Phase contrast microscopy to identify individual *Giardia* cysts. When observing samples for the presence of cysts, one is also able to observe other particulates in the processed water sample. The SWTR Guidance Manual discusses the potential significance of particulates such as plant debris, diatoms and other algae, insects, and rotifers as indicators of direct surface water influence. The SWTR Guidance Manual did not attempt to establish a numerical GWUDI criterion based on particulate analysis. In 1992, EPA published new MPA guidance (USEPA, 1992b), as discussed in Section 5.4.2.

5.4.2 Aerobic Spores

Standard Methods for the Examination of Water and Wastewater Method 9218, Aerobic Endospores (APHA, 2012), uses heat treatment to inactivate any vegetative cells followed by plating the sample onto a non-selective nutrient medium and incubating the plates at 35°C. The endospores germinate to form bacterial colonies.

1991 GWUDI Guidance for the SWTR

The accompanying general guidance to the SWTR, including guidance on how to determine whether sources of water are GWUDI, was published by EPA in October 1990 and revised in March 1991 (USEPA, 1991b).

The SWTR Guidance Manual describes a multiple-step procedure for determining whether a source should be classified as GWUDI. The steps include:

1) Perform a records review to determine if the source is obviously surface water (e.g., a pond, lake, or stream).

2) If the source is a well, determine whether it is clearly a ground water source or whether further analysis is needed. The construction of the well and the hydrogeology of the aquifer including its porosity, transmissivity, and confining layers are considered. Wells

constructed in deep, protected aquifers which are not subject to contamination from surface water could be considered ground water.

3) If further analysis of the ground water source is needed, perform a complete review of the system's files and perform a sanitary survey. The existing records review focuses on source design and construction, evidence of direct surface water contamination, water quality analysis, indicators of waterborne disease outbreaks, operational procedures such as pumping rates, and customer complaints regarding water quality or other related infectious illness. Existing water quality records could include total and fecal coliform analysis, particulate analysis, and turbidity.

4) If existing records are limited or indicate a concern, conduct particulate analysis and other water quality sampling and analysis.

The 1991 SWTR Guidance Manual includes (as Appendix A), the EPA Consensus Method for *Giardia* Cyst Analysis that was in use at the time – in the late 1980's to early 1990's. The analytical method described in the appendix uses source water filtration, density-gradient sample separation, and sample concentration steps with observation of the processed sample using Brightfield/Phase contrast microscopy to identify individual *Giardia* cysts. When observing samples for the presence of cysts, the microscopist is also able to observe other bioparticles in the processed water sample. The SWTR Guidance Manual discusses the potential significance of bioparticles such as plant debris, diatoms and other algae, insects, and rotifers as indicators of direct surface water influence. The SWTR Guidance Manual did not attempt to establish a numerical GWUDI criterion based on bioparticle analysis.

The 1991 SWTR GWUDI determination definition and guidance is based on a new observation about bioparticle occurrence and utility for making a GWUDI decision. At that time, there was little or no scientific literature on *Giardia* (and *Cryptosporidium*) occurrence in ground water and thus parasitic protozoan co-occurrence with ground water indicators or surrogates was unknown. Some of the 1991 guidance was later shown to be inappropriate. For example, EPA (2010c) does not recommend particle counter analysis or turbidity as measures of *Cryptosporidium* (and *Giardia*) subsurface removal efficiency because the particles used as pathogen surrogates are not known to be of surface water origin. On the other hand, particle counting and turbidity remain important components for determining surface water treatment plant efficiency.

1992 Consensus Method for Determining GWUDI Using Microscopic Particulate Analysis

This method builds on the 1991 SWTR Guidance manual, establishes some consistency for the MPA methodology, provides a suggested numerical score for interpretation of the findings, and provides suggested bioparticle identity standards.

The MPA Consensus Method was designed to measure and evaluate the occurrence of a few bioindicator groups. Interpretation of the method's results is based on three assumptions.

a) First, public water supply wells continually or sporadically induce aquifer recharge from surface water as a result of well pumping.

b) Second, entrained within the induced surface water recharge are organisms that typically are found in surface water, such as diatoms and other algae, which rely on photosynthesis to survive. Also entrained are other organisms (e.g. rotifers, insects) that that are able to survive in shallow ground water adjacent to surface water (the hyporheic zone) in some stages of their life cycle and in surface water during other stages.

c) Third, the longer the flow path from surface water to the pumping well, given natural filtration materials in the aquifer (e.g., sand), the greater the amount of straining and removal of bioindicator organisms (lower counts in each group). Wells hydraulically connected to and supplied by recharged surface water and with limited natural filtration are assumed to have higher bioindicator counts, thus representing some risk for *Giardia* and *Cryptosporidium* also passing to the ground water collector from the surface water body.

The MPA Consensus Method attempts to equate, quantitatively, the significant occurrence of bioindicators to a risk score for GWUDI. The bioparticle groups each differ in their contributions to the overall risk analysis and include *Giardia*, coccidia (which includes *Cryptosporidium*), pigment-containing diatoms and chlorophyll-containing algae, some insects and insect larvae, certain rotifers, and plant debris.

Thus, the selected bioindicator groups are expected to occur in low numbers in ground water supplies that are not GWUDI. In the MPA scoring system, the organisms that photosynthesize and are found in surface water are given higher weighted scores to reflect their greater significance for indicating surface water influence. Bioindicators that live mostly in ground water but depend on surface water for some stage of their life cycle, are given lower weighted scores. These bioindicators (e.g. rotifers) are also expected to occur in low numbers if effectively removed by natural filtration.

The number of each indicator observed in 100 gallons of water contributes points toward the sample's total score and relative risk categorization. For example, an observation of from 1 to 10 diatoms in a 100 gallon sample would garner a "rare" diatom occurrence and would contribute 6 points to the total score, whereas >10 diatoms in 100 gallons would contribute 11 points toward the total. Any occurrence of *Giardia* or coccidia protozoan contributes at least 20 points.

The relative risk of surface water influence (GWUDI determination) is based on the total score. A total score of ≥20 is considered high risk for surface water influence, 10-19 is moderate risk, and ≤9 is low risk. The points assigned to each type of particulate and the ranges of points for each relative risk score were developed by consensus professional judgement of the authors and their listed scientific advisors.

The selection of MPA bioindicators used and the respective weights that are applied in the scoring process are designed to give greater significance to the most clearly surface water-related particles (pigmented diatoms and other green algae). Higher counts of clearly surface water organisms are given extra weight. Thus, a 'high risk' score will identify the "worst of the worst" wells: those presenting the most public health risk for *Giardia* or *Cryptosporidium* reaching the well from the surface water body.

Since the guidance publication, various parties and entities have surveyed the States to determine the GWUDI determination process in as many states as possible (e.g. Chaudhary et al, 2009). Inspection of the surveys indicates that many states use the MPA guidance numerical criteria and most use a numerical risk score of 15 or 16 as the defining boundary to determine which PWS systems should be considered to be GWUDI systems.

MPA Relevance and Limitations

The MPA Consensus Method differs from the microscopic methods for *Giardia* or *Cryptosporidium.* The use of the wound yarn (rather than cartridge) filter for MPA assay is the primary reason the method is not standard for pathogen detection. Detection of those organisms using the MPA Consensus Method would be due to chance, while not observing either pathogenic protozoan in an MPA sample result does not inform public health significance.

At the time of MPA Consensus Method development, the contributors recognized that the science was incomplete on some of the potential bioindicator particulates. For example, in discussing the merits of aquatic crustaceans, the method states (USEPA, 1992) *"The significance of these larger organisms in ground waters is unknown at this time."* Further, the authors acknowledge that limited recovery efficiency data were available at the time of method development and that GWUDI determinations should not be made solely on the basis of the results from one or two MPA samples.

The MPA method describes sample collection, analysis, and interpretation and does not consider the aquifer type or site-specific characteristics. The MPA method encourages the use of other pertinent information described in the SWTR Guidance Manual (such as hydrogeologic assessments and water quality monitoring results) for determining GWUDI along with MPA results.

The empirical use of a bioindicator particulate suite such as MPA for regulatory determination has apparently performed well for over two decades. One reason that MPA has apparently performed well is that it was based on hyporheic zone science, then in its infancy. However, very early in the development of the science, it was becoming apparent that the hyporheic zone science was diverging from GWUDI determination issues. For example, Stanford and Ward (1992, 1993) found that that stone fly nymphs (as large as 2.0 cm long) are found in alluvial aquifer ground water as much as 50 m away from surface water (Tobacco River infiltration galleries used for drinking water, Eureka, MT). Stone flies are organisms with immature life stages that live in shallow ground water. More recently, Lin et al. (2012), using microbial geonomics, identified a rich microbial community in wells about 250 m from the Columbia River in Hanford, WA.

As hyporheic zone science progressed, it was learned that the alluvial sands and gravels are diverse ecosystems with rich populations. As a result, MPA risk interpretation became increasingly dependent on organisms such as diatoms that unequivocally originate in surface water. MPA guidance recognized this issue and only pigmented diatoms are counted. Green pigment, indicative of recent photosynthesis suggests more recent residence in surface water as compared with brown diatoms. Similarly, the EPA LT2 Toolbox Guidance (USEPA, 2006a)

identifies pigmented diatom presence as a red flag indicating the possibility of *Cryptosporidium* occurrence. Informal experiments reported by Wilson et al. (1996) suggest that the transition from pigmented algae to non-pigmented cells occurs at about six months.

Currently, MPA results have value as a relatively quick, cheap and appropriate determinant of GWUDI if the results indicate a 'high' risk based primarily on bioindicators. However, the MPA method is not without controversy. For example, Jacangelo et al 2001, performed a small study on MPA variability as part of their GWUDI method investigation. They found that at low risk factors, the MPA readings were consistent between analysts in the study laboratory and readers were also consistent with high-risk slides, although the actual scores and type and quantity of bioindicators found by the analysts varied. For split samples analyzed by different laboratories, varied results were obtained including, on occasion, different risk categories ranging from low to high risk.

Newer Developments in GWUDI Determination Principles and Issues

There is overlap among the objectives of the SWTR GWUDI determination guidance (USEPA, 1991b), the EPA LT2 Toolbox Guidance on assessing alternative treatment by DOP (e.g., log removal for riverbank filtration systems) (USEPA, 2010c), and current knowledge about bioindicator removal by subsurface passage. Both the SWTR Guidance and the LT2 Toolbox Guidance documents recognize that relative public health risk is assessed by bioindicator counts. Both guidance documents use MPA, and especially diatom counts by MPA, to assess relative risk for the purpose of GWUDI determination. However, the LT2 Toolbox Guidance primarily recommends total aerobic bacterial spores (spores) to predict the removal of *Cryptosporidium*. Spores were not included in the existing GWUDI determination guidance because their utility was unrecognized at that time. Experience gained from implementing the LT2 Bank Filtration guidance at Casper, WY (e.g., Gollnitz et al., 2005) and assessments of GWUDI wells at other locations (Abbaszadegan et al., 2011) suggests that this new knowledge can be used to improve the existing SWTR GWUDI definition and accompanying guidance.

2010 EPA Bank Filtration Guidance under LT2

Bank filtration is a surface water pretreatment process that uses the bed or bank of a surface water body and the adjacent aquifer as a natural filter. Bank filtration systems are defined as relying on the natural properties of the system to remove microbial contaminants. It is an additional treatment option under the LT2 for systems using surface water to obtain additional *Cryptosporidium* removal credits. The natural filtration processes of bank filtration and the factors that govern its effectiveness are the same as those occurring in the recharge of ground water by a surface water source.

EPA summarized the scientific literature on natural filtration principles and issues in the Bank Filtration section of the LT2 Toolbox Guidance (USEPA, 2010c). The Bank Filtration section describes the process of natural filtration and provides guidance on a method to determine the appropriate *Cryptosporidium* log removal credit to assign for natural filtration based on a DOP. In the guidance, EPA suggests supplementing the MPA data with data from paired ground water and surface water samples assayed for two culturable bacterial groups: total aerobic spores and

total coliforms. The bank filtration chapter in the guidance suggests that, because aerobic spore removal are adequate surrogates for *Cryptosporidium*, any log reduction of aerobic spore counts comparing the surface water to water from the subsurface collector can be equated to a similar log reduction in *Cryptosporidium*. The guidance also suggests that presence/absence of diatoms (determined using MPA) and total coliforms in well water presents corroborating information on whether the total aerobic spore data at any particular site are serving as an adequate *Cryptosporidium* surrogate.

In the LT2 Toolbox Guidance, EPA suggests that MPA variability may be unavoidable because the MPA includes a range of bioindicators, each with differing surface water occurrence and structural stability during subsurface transport. For example, a single algal chain may break-up into numerous algal particles during subsurface transport, sampling, or laboratory handling. In addition, some bioindicators are counted even though they are only part of the original organism, such as plant debris or crustacean, arthropod and/or insect parts. In the LT2 Toolbox Guidance, EPA suggests favoring bioindicators that are identifiable as whole particles, such as diatoms, which, in the MPA protocol are counted only if they are whole (and pigmented green).

The advantage of favoring whole particles is that they can be used as surrogates for subsurface passage *Cryptosporidium* removal estimates. It is more difficult to accurately estimate log-removal by subsurface passage if a single bioparticle breaks into multiple bioparticles during transport. Because MPA relies on a range of bioindicators of differing bioparticle stability, the Toolbox does not recommend using MPA numerical results to determine *Cryptosporidium* removal credit. In the Toolbox, EPA also emphasizes the value of aerobic spores because they are environmentally resistant organisms that are unchanged during subsurface transport, sampling, or laboratory analysis and are only counted if they sporulate, indicating that they are viable.

As the result of EPA direct implementation of the Wyoming drinking water program, EPA Region 8 has adopted aerobic spores as the primary tool for wellfield management in Casper, WY. Wellfield management is a consequence of the agreement giving Casper 2-log *Cryptosporidium* removal credit by bank filtration. The purpose of the wellfield management plan is to use spores to inform wellfield operations such that all decisions lead to greater rather than lesser subsurface residence time for recharging groundwater. During infiltration basin relining operations, EPA recognized that high spore counts in wells showed that the basins were undergoing filtration ripening effects. Thus, EPA required all relined basins to discharge to waste for at least two weeks and until the spore counts return to background levels.

Abbaszadegan et al. (2011) supported EPA LT2 Toolbox Guidance (2010c) recommendations of using spores to estimate *Cryptosporidium* removal efficiency. The authors conclude that for aerobic spores, their size, shape, surface features, occurrence, and survival in aquifers make them favorable surrogates for predicting *Cryptosporidium* removal by subsurface passage in sandy alluvium. Figure 6.10 in Abbaszadegan et al. (2011) shows aerobic spore and MPA values from Sioux City and Cedar Rapids, IA plotted against each other. In the plot, the 35-40 samples appear to show a relationship such that higher spore counts correlate with higher MPA scores. The authors conclude that a preliminary analysis suggests “that aerobic spore counts in well

water may be a suitable indicative tool for evaluating the risk of a well as part of a GWUDI assessment."

At the time it was developed, MPA was viewed as a qualitative indicator of the potential for *Giardia* occurrence. A higher MPA score represented a greater possibility (in a phenomenological rather than a statistically significant association) of *Giardia* presence. With the development of the LT2 Toolbox Guidance for predicting *Cryptosporidium* removal using spores, EPA's focus shifted to methods that predict pathogenic protozoa removal rather than risk of occurrence. The two goals are complementary. Wells recognized as having high removal of all large bioparticles, including both pathogenic protozoa and MPA bioindicators, are less likely to be considered GWUDI wells because those large bioparticles are removed during subsurface passage.

Total Aerobic Spores as Indicators of Recent Surface Water Recharge/Infiltration

One potential GWUDI bioindicator for identifying surface water influence in locations where either horizontal or vertical flow paths predominate is total aerobic spores. Total aerobic spores include the ubiquitous *Bacillus subtilis.* They originate as common soil bacteria and, because they are long lived and environmentally resistant, are typically found at low levels in shallow ground water and at higher levels in all surface water. Typically, total aerobic spores are continuously washed into surface water but may also pass with infiltrating precipitation or other waters directly from the ground surface into ground water. Where well water has elevated spore concentrations as compared with ambient ground water (USEPA, 2010c), it is likely that these waters are directly affected by horizontal or vertical GWUDI or other recent surface water infiltration. At the time of SWTR promulgation and MPA guidance publication, total aerobic spores were not included as a possible bioindicator. Although MPA protocols identify "spores" in visual counts, these are fungal spores and not bacterial spores.

Over the past 15 years, EPA and others have gained experience using total aerobic spores. In particular, EPA has SWTR direct implementation authority in Wyoming and has applied knowledge gained by collecting and analyzing total aerobic spore data in GWUDI wells in Casper, WY to other locations in the U. S. Field demonstrations have shown that the spores perform well in demonstrating two-log removal at Casper, WY and Kennewick, WA (USEPA, 2010c). Spores also performed well in demonstrating that exceeding two log removal was not achievable at Kearney, NE so UV light or other engineered treatment was required (State of Nebraska, 2013). For example, as discussed above, Abbaszadegan et al. (2011) showed that high aerobic spore counts correlated with high MPA scores. Spore sampling of PWS wells in Quebec showed that aerobic spores were found in six of nine wells and 45 of 109 samples (Locas et al., 2008). The authors concluded that the aerobic spore presence is an indicator of a change in water quality and warrants further investigation to determine the source of contamination. These data and experience suggest that adding total aerobic spores to existing GWUDI determination methods would likely result in fewer wells being misclassified and improved public health protection.

Although spores have been utilized as a *Giardia* and *Cryptosporidium* surrogate, there have been relatively few laboratory studies. In a review paper, Headd and Bradford (2015) summarized and

compared current knowledge about spores and *Cryptosporidium*. No similar analysis has been performed to compare spores and *Giardia.*

Headd and Bradford (2015) found that aerobic spores measure approximately 1 µm (~ 0.8 to 1.5-1.8 µm) in diameter, compared with 4-6 µm for *Cryptosporidium* oocysts. Both aerobic spores and *Cryptosporidium* appear to be long lived in ground water. Aerobic spores and *Cryptosporidium* also exhibit similarities in surface properties which govern sand particle attachment and release during transport through porous media. Both have roughly similar zeta potentials at ground water pH values, both have similar isoelectric points and both have glycoproteins on the exterior surface. Because both are long lived in ground water, spores are expected to provide a conservative estimate of potential oocyst occurrence. Similarities in transport properties (e.g., zeta potential, isoelectric point and surface composition) suggest that spores could be a reasonable conservative surrogate for *Cryptosporidium* passage through the subsurface (Bradford et al., 2016, accepted for publication in 2015).

Current data suggest that total aerobic spores are an appropriate and suitable surrogate for *Giardia* and *Cryptosporidium* transport in the subsurface. Aerobic spores are long lived in the subsurface, similar in size to cysts and oocysts, and found in sufficiently high density in ground water and surface water so as to be easily detectable. Other than aerobic spores, there is no other bioparticle currently known to be suitable as a *Giardia* and *Cryptosporidium* surrogate.

5.5 Methods for Source Water Fecal Indicator Measurement under GWR

Ground water systems that trigger source water monitoring as a result of a total coliform-positive sample in the distribution system under the GWR must monitor their source water for a fecal indicator. Depending on which fecal indicator(s) are approved by the state, the system must monitor their source water for either *E. coli*, Enterococci, or Coliphage. The analytical methods for these fecal indicators that are approved compliance with the GWR are provided in Exhibit 5.8.

Exhibit 5.8: Analytical Methods Approved under the Ground Water Rule (§141.402)

Analyte	Methodology category	Method	Method citation	Additional Information
Escherichia coli	Enzymatic detection following lactose fermentation methods (Standard Methods 9221B, 9221D)	*Escherichia coli* Procedure Using Fluorogenic Substrate	Standard Methods for the Examination of Water and Wastewater 9221F	Standard Methods print editions approved: 20th, 22nd Standard Methods online version approved: 9221F-06
	Membrane filtration methods	Membrane Filtration with MI medium	EPA Method 1604: Total Coliforms and *Escherichia coli* in Water by Membrane Filtration Using a Simultaneous Detection Technique (MI Medium): September 2002. EPA 821-R-02-024	
		m-ColiBlue24 Test	Total Coliforms and *E. coli* Membrane Filtration Method with m-ColiBlue24® Broth, Method No. 10029 Revision 2, August 17, 1999	
		Chromocult	Chromocult® Coliform Agar Presence/Absence Membrane Filter Test Method for Detection and Identification of Coliform Bacteria and *Escherichia coli* in Finished Waters. November 2000. Version 1.0	
	Enzymatic detection following membrane filtration methods (Standard Methods 9222B, 9222C)	MF Partition Procedures – Nutrient Agar with MUG (NA- MUG)	Standard Methods for the Examination of Water and Wastewater 9222G	Standard Methods print editions approved: 20th
	Enzymatic detection methods	Enzyme Substrate Coliform Test Colilert Colilert18 Colisure	Standard Methods for the Examination of Water and Wastewater 9223B	Standard Methods print editions approved: 20th, 21st, 22nd Standard Methods online version approved: 9223B-04
		E*Colite Test	Charm E*Colite Presence/Absence Test for Detection and Identification of Coliform Bacteria and *Escherichia coli* in Drinking Water, January 9, 1998	
		Readycult	Readycult Coliforms 100 Presence Absence Test for Detection and Identification of Coliform Bacteria and *Escherichia coli* in Finished Waters. January 2007. Version 1.1	

Analyte	Methodology category	Method	Method citation	Additional Information
		Modified Colitag	Modified Colitag™ Test Method for the Simultaneous Detection of *E. coli* and other Total Coliforms in Water (ATP D05-0035), August 28, 2009	
		TECTA EC/TC	Presence/Absence Method for Simultaneous Detection of Total Coliforms and *Escherichia coli (E.coli)* in Drinking Water. April 2014.	
Enterococci	Multiple-Tube Fermentation	Fecal Enterococcus/Streptococcus Multiple-Tube Technique	Standard Methods 9230B	Standard Methods print editions approved: 20th, 21st, 22nd Standard Methods online version approved: 9230B-04
	Membrane Filtration Technique	Fecal Enterococcus/Streptococcus Membrane Filter Techniques	Standard Methods 9230C	Standard Methods print editions approved: 20t
		mEI medium	EPA Method 1600: Enterococci in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl-β-D-Glucoside Agar (mEI) EPA 821-R-02-22 (September 2002)	
	Enzymatic detection methods	Enterolert	Evaluation of Enterolert for Enumeration of Enterococci in Recreation Waters. 1996. Budnick, G.E., Howard, R.T., and Mayo, D.R. Appl. Environ. Microbiol. 62:3881.	
Coliphage	Two Step Enrichment Presence-Absence Procedure		EPA Method 1601: Male-specific (F^+) and Somatic Coliphage in Water by Two-step Enrichment Procedure; April 2001, EPA 821-R-01-030.	
		Fast Phage	Fast Phage Test Procedure. Presence/Absence for Coliphage in Ground Water with Same Day Positive Prediction. ATP Case No. D09-0007, Version 009. November 2012.	
	Single Agar Layer Procedure		EPA Method 1602: Male-specific (F^+) and Somatic Coliphage in Water by Single Agar Layer Procedure; April 2001, EPA 821-R-01-029.	

Note: This table includes those approved by the Expedited Method Approval Process.

5.6 Methods for Measuring Disinfectant Residuals in Ground Water (GWR)

Ground water systems that provide 4-log inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal, have notified the state that they provide 4-log virus treatment, and have submitted results to the state that they are providing 4-log treatment must continue to conduct compliance monitoring. 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 141.74(a)(2). See Section 5.2.1 of this document for the list of methods allowed.

6 Occurrence and Exposure

In the SWTR, EPA established requirements for disinfectant residual to control for opportunistic pathogens in the distribution system (e.g., *Legionella).* The disinfectant residual concentration entering the distribution system may not be less than 0.2 mg/L for more than four hours. A detectable disinfectant residual or heterotrophic bacteria of 500/mL or less (measured as HPC) must be maintained throughout the entire distribution system in at least 95 percent of the measurements made (USEPA, 1989). Additional background about these requirements is provided in Chapter 3 of this document. Coliform and *E. coli* occurrence can provide an indication of conditions supporting bacterial growth or an intrusion event into the distribution system. Detection of coliform bacteria is commonly associated with low distribution system disinfectant residuals. To assess the relationship between disinfectant residual and occurrence of indicators for pathogens in distribution systems, EPA evaluated information about chlorine residuals and total coliforms and *E. coli*.

This chapter summarizes the results of EPA's occurrence analyses of regulated microbial indicators, specifically total coliforms (TC) and *E. coli* (EC), and disinfectant residuals that are measured at the same time and location using compliance monitoring data from the Third Six-Year Review (SYR3) Information Collection Request (ICR) database (referred to as the "SYR3 ICR microbial dataset" in this report (USEPA, 2016c)). This chapter also presents the virus and aerobic spore data collected under the third Unregulated Contaminant Monitoring Rule 3 (UCMR 3) (USEPA, 2016d). Information in this chapter is organized as follows:

- Section 6.1 describes the SYR3 ICR microbial dataset - the primary data source used in this occurrence analysis.
- Section 6.2 describes the national level distribution of disinfectant residuals in distribution systems.
- Section 6.3 presents an analysis of the occurrence of TC and EC as functions of disinfectant residual types and residual levels.
- Section 6.4 presents a summary of the occurrence of TC in PWSs using undisinfected ground water.
- Section 6.5 describes the occurrence of viruses in PWSs using undisinfected ground water based on the UCMR 3 data.

The appendices to this chapter provide additional supporting information on several topics.

- Appendix A provides detailed information on the data quality assurance and quality control (QA/QC) evaluation of the SYR3 ICR microbial dataset. It also describes the strengths and limitations of the SYR3 ICR microbial dataset.
- Appendix B provides additional disinfectant residual analytical results for surface water and ground water systems not described in Section 6.2. Specifically, Appendix B includes a detailed evaluation of the disinfectant residuals relative to system type and system size, as well as seasonal changes, annual trends and geographic distribution.
- Appendix C provides additional analytical results addressing the patterns of occurrence of TC and EC related to disinfectant residuals not described in Section 6.3. Specifically, Appendix C includes a detailed evaluation of the occurrence of positive TC and EC

results compared to disinfectant residuals in distribution systems relative to system type and system size, as well as seasonal changes, annual trends and geographic distribution.
- Appendix D describes the process used to identify undisinfected ground water systems in the SYR3 ICR microbial dataset.
- Appendix F describes the national total coliform/*E. coli* detection rates in PWSs using undisinfected ground water.

6.1 SYR3 ICR Microbial Dataset

This section provides a description of the primary source of data, the SYR3 ICR database, and describes subsets of the database that were used for the various analyses in this chapter (Sections 6.2 to 6.4). A brief description of the UCMR 3 data is provided in Section 6.5.

The SYR3 ICR database was used for EPA's occurrence analyses of the microbial and disinfectant residual data. This database contains over 47 million records for disinfection byproducts (DBP), microbial, chemical and radiological compliance monitoring data from systems of all sizes. The SYR3 ICR database is the largest and most comprehensive source of PWS compliance monitoring data to date, with over 13 million records passing QA/QC procedures for DBPs and microbial contaminants. This database is further described in USEPA (2016g). Details on the QA/QC steps relevant to the SYR3 ICR microbial dataset are described in Appendix A of this document and USEPA (2016e).

As part of the SYR3 ICR, EPA requested compliance monitoring data regarding the presence/absence of total coliforms, *E. coli* and/or fecal coliforms (see Chapter 3 for additional information on compliance requirements). In addition, EPA requested data for disinfectant residual levels in the distribution system, because water systems that disinfect are required to monitor for the presence of a disinfectant residual when collecting coliform samples in the distribution system. Systems must collect "routine" total coliform samples on an annual, quarterly, or monthly basis, depending on their size and type and state requirements. Systems serving a larger population are required to take more samples than are required for small systems. When samples test positive for total coliforms, systems must take "repeat" samples at and near the same location. All samples that test positive for total coliforms must also test for either fecal coliforms or *E. coli*.

The SYR3 ICR database contains total coliform, *E. coli* and fecal coliform data from 2006 through 2011 for 46 states/entities.[8] Microbial contaminant data from 34 states/entities passed QA/QC criteria and are included in the final SYR3 ICR microbial dataset.[9] A detailed description of the QA/QC process is included in Appendix A. An initial evaluation of the dataset

[8] In the SYR3 ICR microbial dataset, the term "entities" includes the following: Region 1 Tribes, Region 4 Tribes, Region 5 Tribes, Region 8 Tribes, Region 9 Tribes, American Samoa and Navajo Nation.

[9] The State of Maine is included in this count of 34 states though only one record from Maine (from the year 2008) passed QA and is included in the final SYR3 ICR microbial dataset.

exposed a large degree of variability in the number of records provided by water systems from state to state, as discussed in Appendix A.

Two major subsets of data from the SYR3 ICR microbial dataset were used for analysis in this chapter. The first represents the TC/EC results paired with chlorine residual data[10] (free chlorine, total chlorine or both) (note: this is the first dataset available to evaluate the TC/EC data as function of chlorine residual at a national level). These chlorine residual data were measured in the field and reported with the TC/EC data. Some states provided a large amount of TC/EC data, but only a small portion of those data were paired with chlorine residual concentrations (note: some systems may report HPC in lieu of disinfectant residuals). As a result of the "data pairing" and related QA/QC process, approximately 70 percent of the original chlorine residual records, or 4 million records were used for analysis in Section 6.2; and approximately 50 percent of the original TC records, or 4.8 million records were used for analysis in Section 6.3. Exhibit A-2 in Appendix A documents the specific counts of records included and excluded in each step of the QA/QC process for the SYR3 ICR microbial dataset.

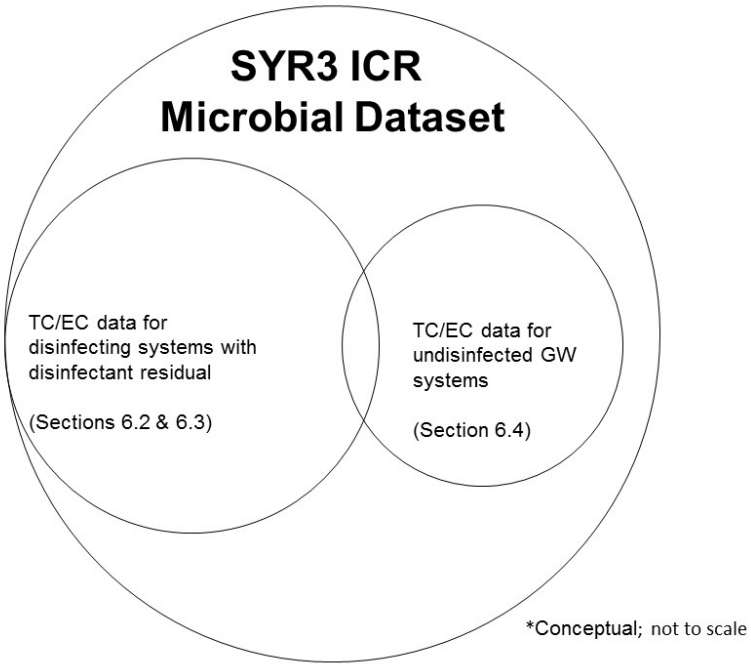
A second subset of the SYR3 ICR microbial dataset was used to represent "undisinfected" ground water systems. This subset was used in the analyses presented in Section 6.4 and Appendix F. The methodology for identifying this subset is presented in Appendix D.

Exhibit 6.1 provides a conceptual overview of the components of the SYR3 ICR microbial dataset, including the interrelationships between these two subsets of data. As shown in Exhibit 6.1, there is some overlap between the first and second datasets because: the first dataset includes all the TC/EC data paired with disinfectant residual data regardless of the residual levels, whereas in the second dataset, "undisinfected" refers to those ground water systems that either do not practice disinfection (thus, do not report any disinfectant residual data) or have disinfectant residuals less than 0.1 mg/L. As such, the TC/EC data paired with disinfectant residual levels of less than 0.1 mg/L are included in both datasets. The TC/EC data that were *not* paired with disinfectant residual data and *not* identified as undisinfected ground water systems (i.e., within the large circle but outside of the two inner circles in Exhibit 6.1) were not included in any of the analyses in this Chapter.

It is important to note that these analyses were conducted to help inform the Six-Year Review and that they are not meant to assess compliance with regulatory standards.

[10] Some states provided only their TC and EC data without the corresponding disinfectant residual concentrations. Some states do not store their disinfectant residual data in their state's drinking water database alongside directly linked to their coliform results.

Exhibit 6.1: Conceptual Overview of the Components of the SYR3 ICR Microbial Dataset



Note: "Undisinfected" ground water systems refers to those that do not practice disinfection or have very low disinfectant residuals (i.e., less than 0.1 mg/L), as described in Appendix D.

6.2 Disinfectant Residuals in Distribution Systems

This section characterizes disinfectant residual concentrations in distribution systems using the SYR3 ICR microbial dataset. Analyses are presented separately for the two source water types (surface water and ground water). Additional analyses, including an evaluation of potential seasonal, annual and geographic trends, are provided in Appendix B.

Exhibit 6.2 presents an inventory of free and total chlorine data associated with total coliform samples, and the systems providing those data, by source water type, system type and system size for all years from 2006 to 2011. Results for each year from 2006 through 2011 are presented in Appendix B.

Exhibit 6.2: Counts of Chlorine Residual Data by Source Water Type, System Type and System Size from SYR3 ICR Dataset (All Years; 2006-2011)

System Type	Source Water Type	Population Served Size Category	Number of Systems[1] with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
Community Water Systems	GW	≤100	3,536	1,533	133,419	52,861
		101-500	5,268	2,731	219,433	134,599
		501-1,000	1,913	1,319	89,922	76,801
		1,001-4,100	2,726	1,988	264,104	181,983
		4,101-33,000	1,383	1,089	525,889	310,376
		33,001-100,000	120	104	213,811	123,711
		>100,000	22	18	47,014	34,292
		Total GW	**14,968**	**8,782**	**1,493,592**	**914,623**
	SW	≤100	442	234	22,847	16,182
		101-500	976	660	45,633	43,295
		501-1,000	502	427	25,615	29,979
		1,001-4,100	1,172	1,011	125,569	122,295
		4,101-33,000	1,148	901	553,971	356,958
		33,001-100,000	196	137	395,702	229,562
		>100,000	90	72	362,228	294,808
		Total SW	**4,526**	**3,442**	**1,531,565**	**1,093,079**
Transient Non-Community Water Systems	GW	≤100	6,290	2,500	99,287	37,852
		101-500	2,184	1,029	39,883	13,275
		501-1,000	254	107	5,504	1,486
		1,001-4,100	92	37	5,442	1,099
		4,101-33,000	2	0	160	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**8,822**	**3,673**	**150,276**	**53,712**
	SW	≤100	297	133	9,644	2,089
		101-500	141	37	5,690	994
		501-1,000	30	11	1,025	318
		1,001-4,100	17	5	1,165	84
		4,101-33,000	7	1	993	21
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**492**	**187**	**18,517**	**3,506**
Non-Transient Non-Community Water Systems	GW	≤100	1,721	619	38,527	11,526
		101-500	1,439	532	38,334	10,111
		501-1,000	379	148	11,482	3,140
		1,001-4,100	271	129	21,534	8,075
		4,101-33,000	19	10	4,505	1,221
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**3,829**	**1,438**	**114,382**	**34,073**
	SW	≤100	97	38	3,644	1,411
		101-500	121	65	5,271	1,954
		501-1,000	32	14	1,790	858
		1,001-4,100	33	23	3,815	1,645

System Type	Source Water Type	Population Served Size Category	Number of Systems[1] with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		4,101-33,000	7	2	2,620	248
		33,001-100,000	1	0	4,156	0
		>100,000	0	1	0	3
		Total SW	**291**	**143**	**21,296**	**6,119**
Total	GW	≤100	11,547	4,652	271,233	102,239
		101-500	8,891	4,292	297,650	157,985
		501-1,000	2,546	1,574	106,908	81,427
		1,001-4,100	3,089	2,154	291,080	191,157
		4,101-33,000	1,404	1,099	530,554	311,597
		33,001-100,000	120	104	213,811	123,711
		>100,000	22	18	47,014	34,292
		Total GW	**27,619**	**13,893**	**1,758,250**	**1,002,408**
	SW	≤100	836	405	36,135	19,682
		101-500	1,238	762	56,594	46,243
		501-1,000	564	452	28,430	31,155
		1,001-4,100	1,222	1,039	130,549	124,024
		4,101-33,000	1,162	904	557,584	357,227
		33,001-100,000	197	137	399,858	229,562
		>100,000	90	73	362,228	294,811
		Total SW	**5,309**	**3,772**	**1,571,378**	**1,102,704**

[1] Based on the number of unique PWSIDs, regardless of the number of records for each system.

Throughout this chapter, counts from ground water systems represent data from systems with a primary source water type of GW (ground water) and GWP (purchased ground water). [11] Counts from surface water systems represent data from systems with a primary source water type listed as SW (surface water); SWP (purchased SW); GU (ground water under direct influence of surface water); and GUP (purchased GU). In addition, counts from non-community water systems (NCWSs) throughout this chapter represent data from non-transient non-community water systems and transient non-community water systems. For the purposes of the analyses presented in this report, "*E. coli*" and "EC" corresponds to *E. coli* plus fecal coliform samples noting that the vast majority of these additional assays were for *E. coli*.

As shown in Exhibit 6.2, there were a similar number of samples from ground water systems as from surface water systems. However, more than 80 percent of systems providing the free and/or total chlorine residual data were ground water systems. Approximately 60 percent of systems providing free and/or total chlorine residual data were community water systems (CWSs), the remainder being either transient or non-transient non-community water systems. More small systems than large systems provided chlorine residual data as there are more small systems than large systems nationally. The system size category with the largest number of samples had populations ranging from 4,101 to 33,000. This is a function of the product of the number of systems in this range and the number of monthly routine samples these systems are required to

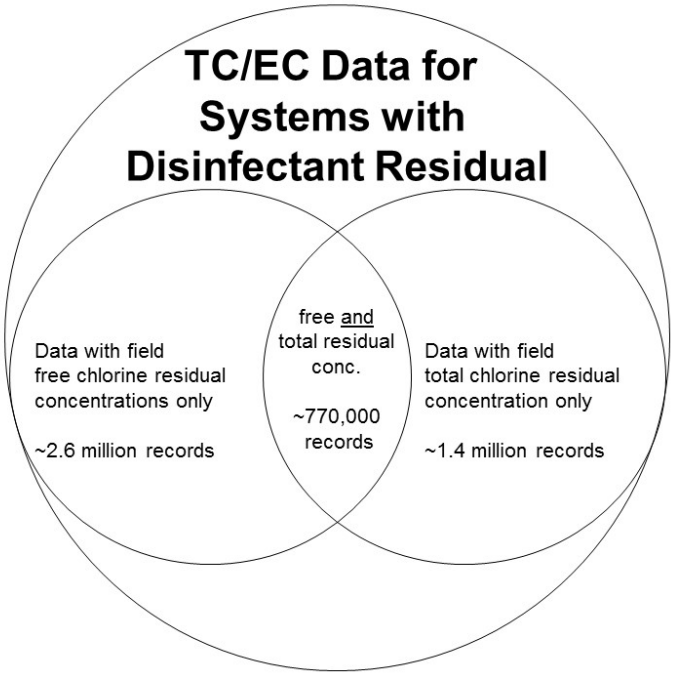
[11] Abbreviations used in this chapter such as GW, GWP, SW, SWP, and GU were taken from SYR3 ICR database.

take. There are many more small systems nationally than large but the smaller systems are required to take fewer monthly samples under the TCR. The larger systems are required to take many more monthly samples than the small systems under the TCR; however, there are fewer large systems. The total number of samples associated with the mid-sized systems (populations ranging from 4,101 to 33,000) ends up being the largest due to a large number of systems, as well as a substantial amount of samples per system.

As mentioned earlier, the SYR3 ICR microbial dataset contains total coliform, *E. coli* and fecal coliform data that were paired with (i.e., collected at the same time and location) field free and/or total chlorine residual data.

Exhibit 6.3 is a diagram characterizing the type of residual reported, i.e., free chlorine only, total chlorine only, or both free and total chlorine residual. Based on the data counts shown on Exhibit 6.3, approximately 55 percent of samples have free chlorine data only; 28 percent of samples have total chlorine data only; and 17 percent of samples have both free and total chlorine data reported. Because total chlorine is the sum of free chlorine and combined chlorine, samples where free chlorine was higher than total chlorine were not included in the analysis (as noted in Appendix A).

Exhibit 6.3: Diagram Characterizing Type of Residual Reported



The SYR3 ICR database does not have a simple data field to identify the disinfectant type of free chlorine versus chloramines for each system. In general, a water system using free chlorine in the distribution system (chlorine system) usually reports disinfectant residual concentrations as free chlorine; whereas a water system using chloramines (chloramine system) in the distribution system reports total chlorine or both free and total chlorine. Since the SWTR allows water

systems using free chlorine to report disinfectant residual concentrations as free, combined, total chlorine or both free and total chlorine, it is difficult to determine the disinfectant type solely based on the chlorine residual data. Therefore, EPA conducted data analyses based on the type of chlorine residual data reported (i.e., free and total chlorine), not the type of disinfectants (i.e., chlorine versus chloramines). The type of chlorine residual data reported (i.e., free and total chlorine) is not necessarily indicative of the type of disinfectants (i.e., chlorine versus chloramines) used. Given uncertainties in the chlorine residual data reporting described earlier, those systems that reported only free chlorine data are likely representing chlorine systems; those systems that reported only total chlorine data are likely representing chloramine systems; and those reported both free and total chlorine data are likely representing chloramine systems. However, EPA was unable to confirm the type of disinfectants (i.e., chlorine versus chloramines) used by the PWSs.

6.2.1 Chlorine Residuals for Surface Water Systems

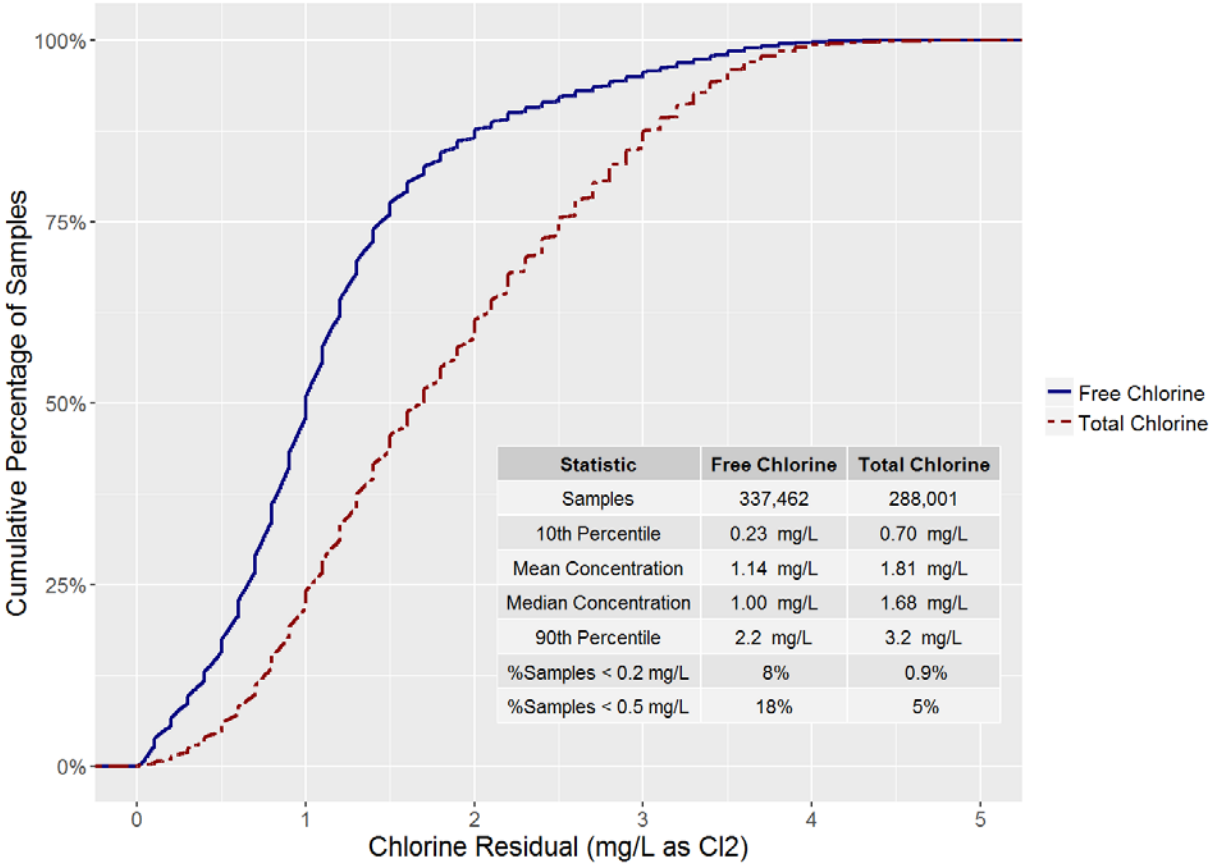
Exhibit 6.4 presents sample-level summary statistics, by year, for the free and total chlorine residual data associated with total coliform results in surface water, including: count, 10th percentile, median, average, 90th percentile and a count of samples greater than 4 mg/L (i.e., the MRDL under the Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules (D/DBPRs)). For each parameter, the values are relatively stable from year to year for surface water, except for a slight increase of the disinfectant residual level over the time of this survey. Additional analysis of yearly trends in the data is provided later in Appendix B.

Exhibit 6.4: Summary Statistics of Free and Total Chlorine Residual Concentrations in Surface Water, by Year

Year	Count	Chlorine Residual Concentration (mg/L)				Samples > 4 mg/L	
		10th Percentile	Median	Average	90th Percentile	Count	Percent of Total
Free Chlorine							
2006	199,834	0.20	0.82	0.96	1.83	65	0.03%
2007	233,109	0.23	0.90	1.10	2.20	768	0.33%
2008	238,586	0.24	0.97	1.15	2.40	469	0.20%
2009	247,021	0.19	0.93	1.13	2.40	608	0.25%
2010	315,366	0.20	0.97	1.11	2.20	1,053	0.33%
2011	337,462	0.23	1.00	1.14	2.20	1,012	0.30%
Total Chlorine							
2006	116,248	0.60	1.51	1.70	3.00	471	0.41%
2007	124,588	0.50	1.50	1.66	3.00	491	0.39%
2008	135,662	0.50	1.43	1.63	3.00	541	0.40%
2009	177,732	0.60	1.65	1.78	3.20	1,147	0.65%
2010	260,473	0.69	1.68	1.82	3.20	1,880	0.72%
2011	288,001	0.70	1.68	1.81	3.20	2,053	0.71%

Exhibit 6.5 provides a cumulative distribution plot presenting the free and total chlorine residual concentrations in surface water samples, for the year 2011. The results are presented for the year 2011 only, which is the latest and largest dataset over the sample period.

Exhibit 6.5: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Surface Water (in 2011)



Statistic	Free Chlorine	Total Chlorine
Samples	337,462	288,001
10th Percentile	0.23 mg/L	0.70 mg/L
Mean Concentration	1.14 mg/L	1.81 mg/L
Median Concentration	1.00 mg/L	1.68 mg/L
90th Percentile	2.2 mg/L	3.2 mg/L
%Samples < 0.2 mg/L	8%	0.9%
%Samples < 0.5 mg/L	18%	5%

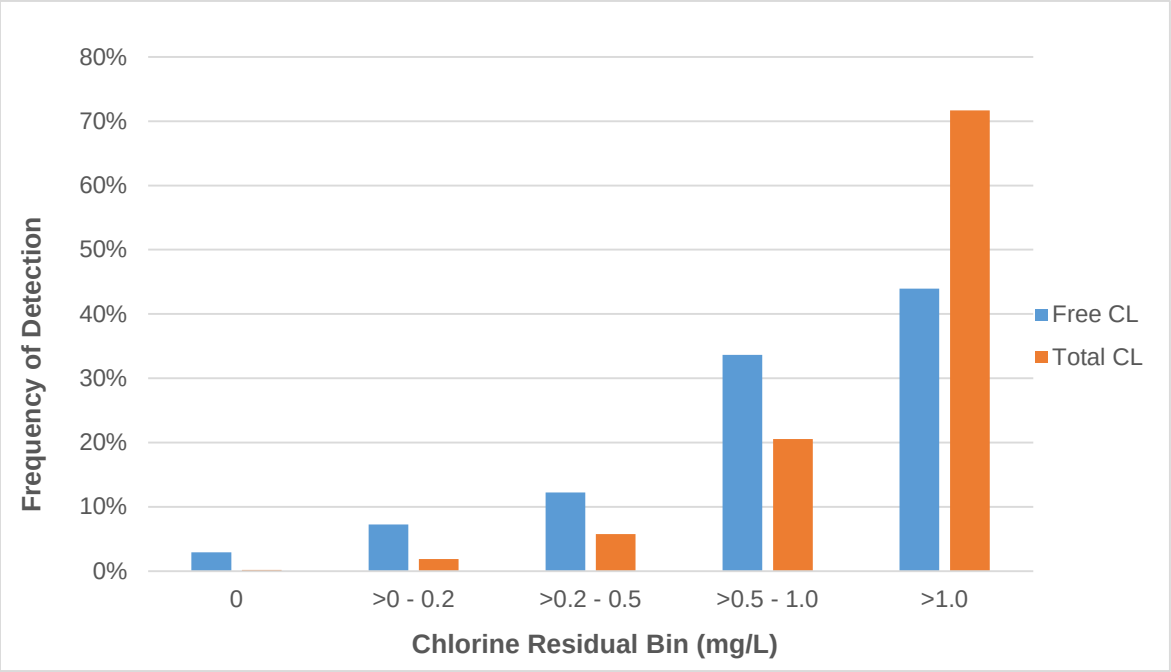
The jagged "staircase" curves are due to the presence of multiple samples with the same chlorine residual concentration (which is itself due to the limited precision of the analytical methods and the number of decimal places stored in the database). The cumulative distribution curve shows that total chlorine concentrations are higher as a group than free chlorine concentrations, as expected. The percent of samples < 0.2 mg/L is higher for free chlorine (8 percent) than total chlorine (0.9 percent). This could reflect higher doses of chloramines often used in a PWS and/or relative persistence of combined chlorine (i.e., the sum of the mono-, di-, and tri-chloramines) compared to free chlorine (Kirmeyer et al., 2004; USEPA, 2007b).

Exhibit 6.6 presents the frequency of detection for the free and total chlorine residual data associated with total coliform results in surface water. Results were generated separately for five bins of free and total chlorine residual concentrations:

- Bin 1: concentrations equal to 0[12];
- Bin 2: concentrations greater than 0 and less than or equal to 0.2 mg/L;
- Bin 3: concentrations greater than 0.2 mg/L and less than or equal to 0.5 mg/L;
- Bin 4: concentrations greater than 0.5 mg/L and less than or equal to 1.0 mg/L;
- Bin 5 concentrations greater than 1.0 mg/L.

The majority of surface water samples have free chlorine and total chlorine residual concentrations of 0.5 mg/L or greater, with each successively higher bin including a larger proportion of all samples. More samples fell into the lower bins for free chlorine compared to total chlorine. There was a higher frequency of samples observed with values at or below 0.2 mg/L among the free chlorine samples than among the total chlorine samples.

Exhibit 6.6: Free and Total Chlorine Residual - Frequency of Detection in Surface Water (All Years; 2006-2011)



[12] Many systems reported free and/or total chlorine residual concentrations equal to 0. Those data have been retained in this analysis, though the "0 mg/L" likely means "not detected" and not necessarily 0 mg/L. These data are interpreted as "below detection limit" for the analyses presented in this chapter.

6.2.2 Chlorine Residuals for Ground Water Systems

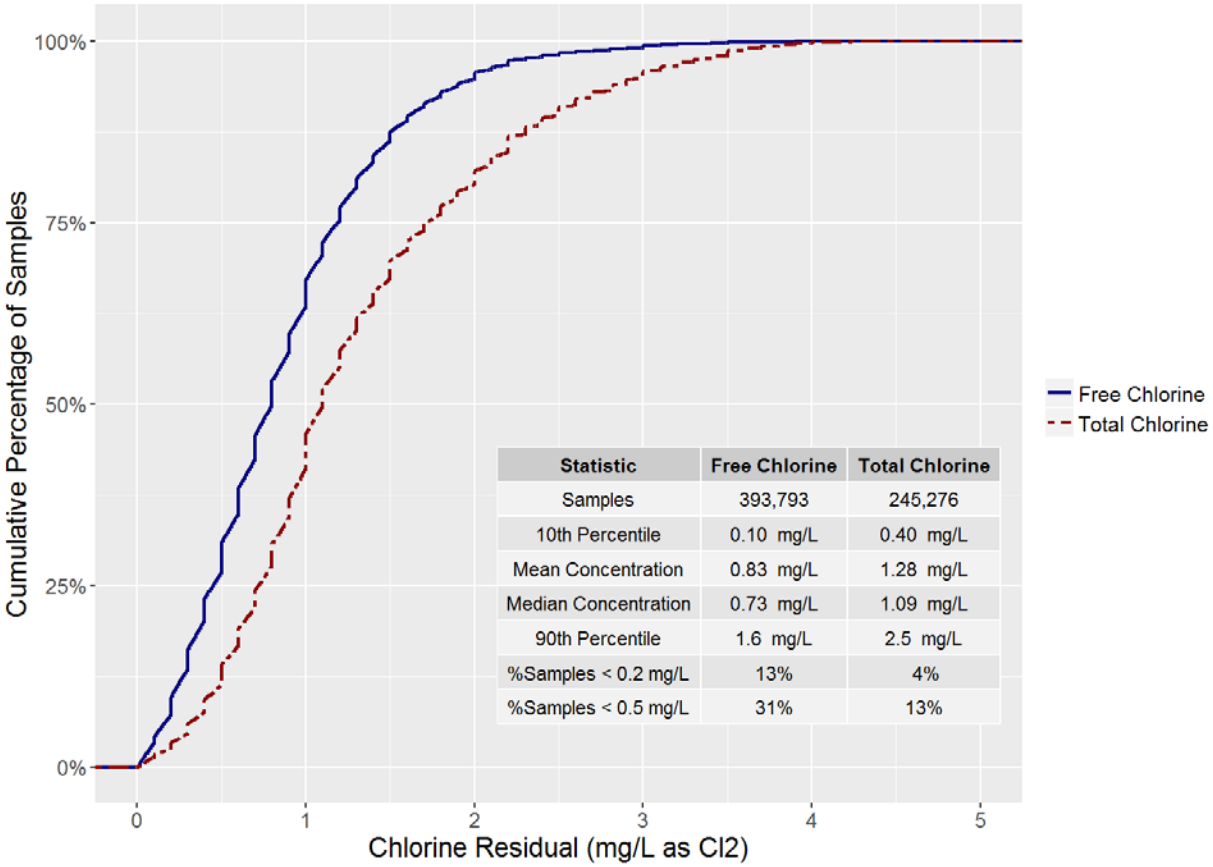
Exhibit 6.7 presents sample-level summary statistics, by year, for the free and total chlorine residual data associated with total coliform results in ground water. Summary statistics include: count, 10th percentile, median, average, 90th percentile and a count of samples greater than 4 mg/L. For each statistic, the values are relatively stable from year to year. Additional analysis of yearly trends in the data is provided later in Appendix B. The chlorine residual concentrations in ground water, as shown in Exhibit 6.7, are generally lower than those in surface water, as shown in Exhibit 6.4.

Exhibit 6.7: Summary Statistics of Free and Total Chlorine Residual Concentrations in Ground Water, by Year

Year	Count	Chlorine Residual Concentration (mg/L)				Samples > 4 mg/L	
		10th Percentile	Median	Average	90th Percentile	Count	Percent of Total
Free Chlorine							
2006	213,056	0.00	0.50	0.62	1.22	124	0.06%
2007	230,669	0.00	0.50	0.60	1.20	93	0.04%
2008	233,075	0.00	0.50	0.61	1.25	130	0.06%
2009	322,909	0.02	0.60	0.75	1.55	202	0.06%
2010	364,748	0.10	0.70	0.80	1.59	209	0.06%
2011	393,793	0.10	0.73	0.83	1.60	253	0.06%
Total Chlorine							
2006	105,116	0.30	0.87	1.02	2.00	403	0.38%
2007	118,715	0.30	0.90	1.06	2.10	285	0.24%
2008	133,740	0.30	0.90	1.07	2.13	357	0.27%
2009	171,874	0.33	1.00	1.22	2.40	428	0.25%
2010	227,687	0.40	1.05	1.27	2.50	580	0.25%
2011	245,276	0.40	1.09	1.28	2.50	586	0.24%

Exhibit 6.8 provides a cumulative distribution plot presenting the free and total chlorine residual concentrations in ground water samples for the year 2011. The jagged "staircase" curves are due to the presence of multiple samples with the same chlorine residual concentration (which is itself due to the limited precision of the analytical methods and the number of decimal places stored in the database). Similar to the plot for surface water, the cumulative distribution curve for ground water shows that total chlorine concentrations are higher as a group than free chlorine concentrations.

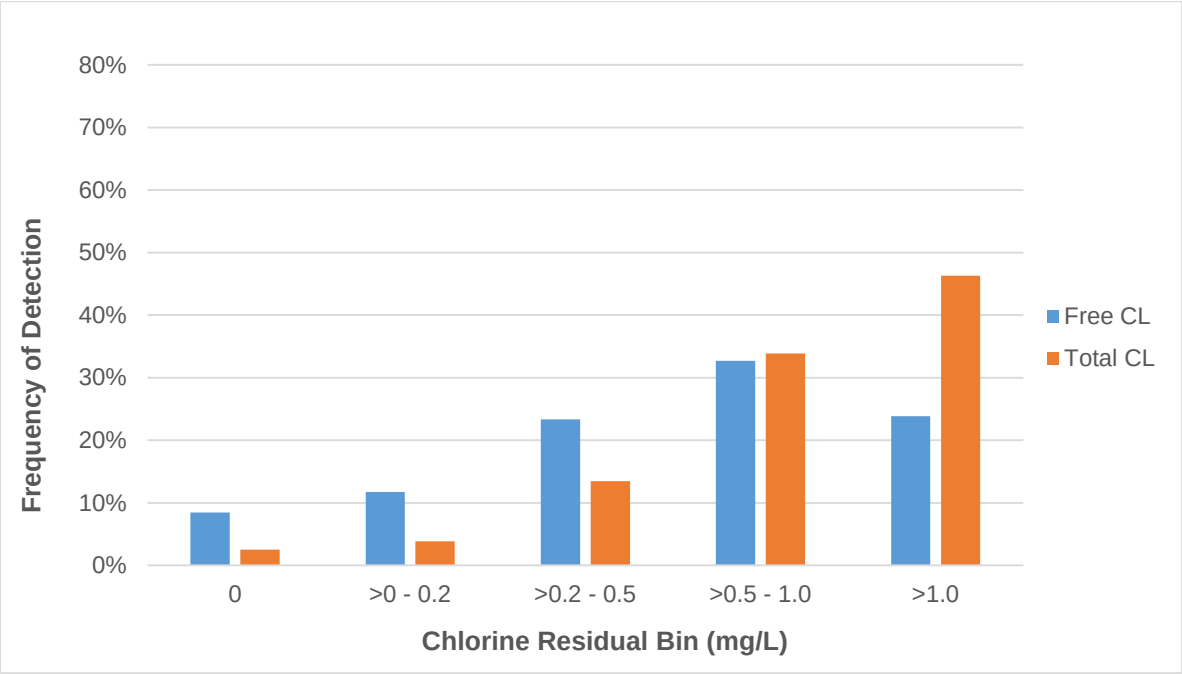
Exhibit 6.8: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Ground Water (in 2011)



Statistic	Free Chlorine	Total Chlorine
Samples	393,793	245,276
10th Percentile	0.10 mg/L	0.40 mg/L
Mean Concentration	0.83 mg/L	1.28 mg/L
Median Concentration	0.73 mg/L	1.09 mg/L
90th Percentile	1.6 mg/L	2.5 mg/L
%Samples < 0.2 mg/L	13%	4%
%Samples < 0.5 mg/L	31%	13%

As shown in Exhibit 6.9, the majority of ground water samples have free chlorine and total chlorine residual concentrations of 0.2 mg/L or greater. More samples fell into the lower bins for free chlorine compared to total chlorine. In addition, the proportion of free chlorine residual samples in ground water decreased from the bin of concentrations greater than 0.5 mg/L to 1.0 mg/L to the bin of concentrations greater than 1.0 mg/L. There was a higher frequency of samples observed with values at or below 0.5 mg/L among the free chlorine samples than among the total chlorine samples.

Exhibit 6.9: Free and Total Chlorine Residual - Frequency of Detection in Ground Water (All Years; 2006-2011)



6.2.3 Limitations of Data Analysis

The chlorine residual data used for this analysis were collected from 2006 through 2011. These data do not fully reflect impacts of the implementation of the LT2, GWR and RTCR, which were promulgated in 2006, 2010 and 2013, respectively.

As indicated previously, the SYR3 ICR microbial dataset consists of data from 34 states/entities. EPA recognized a large degree of variability in the number of records provided by water systems from state to state. Only the data from SDWIS states were included in the final SYR3 ICR microbial dataset because they provided TC/EC data in a usable format that were also paired with disinfectant residual data (USEPA, 2016e).

6.2.4 Considerations for Potential System-Level Analyses

Although not performed under the Six-Year Review 3, the SYR3 ICR dataset could be used to evaluate impacts of potential revisions to the distribution system minimum disinfection residual requirements (regulatory implication forecast analysis). This analysis could be conducted on a system-level to estimate the number and percent of public water systems that would exceed various benchmarks and the corresponding estimations of population served by those systems.

Under the SWTR, the residual disinfectant concentration in the distribution system "cannot be undetectable in more than five percent of the samples each month, for any two consecutive months that the system serves water to the public." (40 CFR 141.72). The residual disinfectant

concentration must be measured at least at the same points in the distribution system and at the same time as total coliforms are sampled (40 CFR 141.74). The monitoring frequency for total coliforms for community water systems is based on the population served by the system (40 CFR 141.21). For example, a system serving 25 to 1,000 people is required to collect at least one sample per month; a system serving 17,201 to 21,500 people is required to collect at least 20 samples per month; and a system serving 3,960,001 people or more is required to collect at least 480 samples per month.

System-level analyses could be generated separately for surface water (including GWUDI), and ground water systems, as well as for CWSs and NCWSs in different system sizes. Similar to sample-level analyses presented in Section 6.2 of this document, system-level analyses could be generated using only residual disinfectant records taken from the distribution system. General considerations for potential analyses are described below:

- Create a subset of data for the system-level analysis.
    - Use the 2011 dataset - the latest and largest dataset over the sample period.
    - Exclude the free chlorine records that are paired with total chlorine. That is, if there are both free and total at the same time/place, only use the total chlorine data.
    - Exclude data from systems that were in violation of the TCR. Inclusion of data from these non-compliant systems may bias results high.
    - Establish criteria for defining systems to be included in the dataset. For example, one criterion is that a system must have at least one free or total residual disinfectant record each month for at least six months.
- Establish benchmark values as potential numeric definitions for "detectable" or minimum disinfectant residual concentrations, e.g., 0.1, 0.2, 0.3, 0.4, and 0.5 mg/L for free chlorine and total chlorine.
- Estimate the number and percent of systems that would exceed various benchmarks and the corresponding population served by those systems:
    - Calculate the percentage of records that are below a benchmark value for each system in each month. Depending upon data availability, this could yield 12 monthly percentages for each system.
    - Determine the number of systems that have monthly percentages (calculated above) exceeding five percent for any two consecutive months.
    - Determine the population served by these systems.

6.3 Occurrence of Total Coliforms and *E. coli* as Function of Disinfectant Residual Types and Levels in Distribution Systems

This section analyzes the occurrence of total coliform positive results (TC+) and *E. coli* positive results (EC+) compared to disinfectant residuals in distribution systems. All analyses are at the sample-level and are presented separately by:

- source water type (surface water and ground water);
- free and total chlorine; and

- five bins of free and total chlorine residual concentrations:
    - Bin 1: concentrations equal to 0[13];
    - Bin 2: concentrations greater than 0 and less than or equal to 0.2 mg/L;
    - Bin 3: concentrations greater than 0.2 mg/L and less than or equal to 0.5 mg/L;
    - Bin 4: concentrations greater than 0.5 mg/L and less than or equal to 1.0 mg/L;
    - Bin 5 concentrations greater than 1.0 mg/L.

Appendix C includes an evaluation of seasonal changes, annual trends, geographic distribution and system size trends.

Exhibit 6.10 presents an inventory of routine and repeat TC and EC records that were paired with the disinfectant residual data. It is important to note that for the TC/EC data analysis in Section 6.3, EPA applied an additional screen to the dataset: TC+ results are included only if there was a corresponding EC/FC sample and EC/FC results are only included if they had a corresponding TC+. (See Appendix A for more details on this QA step 11.) Thus, slightly fewer data points were used for the TC/EC occurrence analysis in Section 6.3 compared to what is presented in Exhibit 6.10.

More than 80 percent of systems providing TC data were ground water systems. The number of CWSs reporting TC records was approximately twice the number of NTNCWSs and TNCWSs combined; however, the number of routine samples reported by CWSs was an order of magnitude greater than the number of routine samples reported by either NTNCWSs or TNCWSs.

Exhibit 6.11 presents a breakdown of routine and repeat TC and EC positive records in the SYR3 ICR microbial dataset, with a count by bin of free and total chlorine residual concentration. These counts are presented for all available years of data (2006 through 2011). In addition, as described in Section 6.1, as well as Appendix A, the analyses presented in Section 6.3 are based on a subset of the entire SYR3 ICR TC, EC and disinfectant residuals data (referred to as the "SYR3 ICR microbial data" in this report).

[13] Many systems reported free and/or total chlorine residual concentrations equal to 0. Those data have been retained in this analysis, though the "0 mg/L" likely means "not detected" and not necessarily 0 mg/L. These data are interpreted as "below detection limit" for the analyses presented in this chapter.

Exhibit 6.10: Counts of Total Coliform and *E. coli* Records by Source Water Type, System Type and System Size from SYR3 ICR Dataset (All Years; 2006-2011)

System Type	Source Water Type	Population Served Size Category	Routine Samples[1]						Repeat Samples					
			Total Coliforms				*E. coli*[2]		Total Coliforms				*E. coli*[2]	
			Total # Systems	Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]	Total # Systems	Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]
Community Water Systems	GW	≤100	3,775	167,744	2,816	1.68%	141	0.08%	1,101	8,298	1,336	16.10%	46	0.55%
		101-500	5,750	308,994	4,093	1.32%	203	0.07%	1,631	11,841	1,394	11.77%	60	0.51%
		501-1,000	2,155	140,130	1,413	1.01%	53	0.04%	540	3,619	324	8.95%	25	0.69%
		1,001-4,100	3,130	375,105	2,483	0.66%	110	0.03%	954	6,436	443	6.88%	10	0.16%
		4,101-33,000	1,513	694,922	2,373	0.34%	110	0.02%	661	5,692	233	4.09%	18	0.32%
		33,001-100,000	132	276,565	689	0.25%	31	0.01%	93	1,582	76	4.80%	9	0.57%
		>100,000	22	69,714	527	0.76%	7	0.01%	21	774	50	6.46%	0	0.00%
		Total GW	**16,477**	**2,033,174**	**14,394**	**0.71%**	**655**	**0.03%**	**5,001**	**38,242**	**3,856**	**10.08%**	**168**	**0.44%**
	SW	≤100	512	35,477	405	1.14%	40	0.11%	149	1,051	105	9.99%	9	0.86%
		101-500	1,183	81,659	942	1.15%	70	0.09%	376	2,877	211	7.33%	12	0.42%
		501-1,000	645	51,537	559	1.08%	33	0.06%	207	1,418	139	9.80%	8	0.56%
		1,001-4,100	1,490	222,287	1,411	0.63%	75	0.03%	518	3,395	170	5.01%	12	0.35%
		4,101-33,000	1,344	797,365	2,833	0.36%	134	0.02%	664	7,098	293	4.13%	4	0.06%
		33,001-100,000	211	545,541	1,054	0.19%	46	0.01%	153	2,595	81	3.12%	6	0.23%
		>100,000	103	538,645	1,721	0.32%	67	0.01%	82	4,020	157	3.91%	3	0.07%
		Total SW	**5,488**	**2,272,511**	**8,925**	**0.39%**	**465**	**0.02%**	**2,149**	**22,454**	**1,156**	**5.15%**	**54**	**0.24%**
Transient Non-Community Water Systems	GW	≤100	6,930	123,147	3,412	2.77%	183	0.15%	1,368	9,859	3,433	34.82%	148	1.50%
		101-500	2,383	46,653	1,264	2.71%	72	0.15%	504	3,061	664	21.69%	61	1.99%
		501-1,000	277	6,330	86	1.36%	5	0.08%	47	239	53	22.18%	0	0.00%
		1,001-4,100	97	5,711	36	0.63%	3	0.05%	22	126	10	7.94%	0	0.00%
		4,101-33,000	2	160	6	3.75%	0	0.00%	1	9	0	0.00%	0	0.00%
		33,001-100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		>100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		Total GW	**9,689**	**182,001**	**4,804**	**2.64%**	**263**	**0.14%**	**1,942**	**13,294**	**4,160**	**31.29%**	**209**	**1.57%**
	SW	≤100	385	11,581	167	1.44%	18	0.16%	74	594	60	10.10%	15	2.53%
		101-500	148	6,366	81	1.27%	6	0.09%	42	313	53	16.93%	4	1.28%
		501-1,000	30	1,288	19	1.48%	1	0.08%	8	94	18	19.15%	0	0.00%
		1,001-4,100	17	1,226	9	0.73%	1	0.08%	3	12	0	0.00%	0	0.00%
		4,101-33,000	7	1,014	5	0.49%	0	0.00%	3	17	0	0.00%	0	0.00%
		33,001-100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		>100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		Total SW	**587**	**21,475**	**281**	**1.31%**	**26**	**0.12%**	**130**	**1,030**	**131**	**12.72%**	**19**	**1.84%**

System Type	Source Water Type	Population Served Size Category	Routine Samples[1]						Repeat Samples					
			Total Coliforms				*E. coli*[2]		Total Coliforms				*E. coli*[2]	
			Total # Systems	Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]	Total # Systems	Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]
Non-Transient Non-Community Water Systems	GW	≤100	1,823	46,945	800	1.70%	47	0.10%	353	2,280	615	26.97%	26	1.14%
		101-500	1,542	45,261	587	1.30%	26	0.06%	288	1,849	362	19.58%	18	0.97%
		501-1,000	404	13,097	125	0.95%	8	0.06%	59	371	72	19.41%	1	0.27%
		1,001-4,100	288	25,371	222	0.88%	14	0.06%	81	570	92	16.14%	4	0.70%
		4,101-33,000	20	4,876	22	0.45%	1	0.02%	8	58	3	5.17%	0	0.00%
		33,001-100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		>100,000	0	0	0	0.00%	0	0.00%	0	0	0	0.00%	0	0.00%
		Total GW	**4,077**	**135,550**	**1,756**	**1.30%**	**96**	**0.07%**	**789**	**5,128**	**1,144**	**22.31%**	**49**	**0.96%**
	SW	≤100	104	4,822	43	0.89%	2	0.04%	19	111	8	7.21%	0	0.00%
		101-500	132	6,623	44	0.66%	3	0.05%	34	126	6	4.76%	0	0.00%
		501-1,000	33	2,294	16	0.70%	2	0.09%	7	50	13	26.00%	1	2.00%
		1,001-4,100	37	4,438	23	0.52%	1	0.02%	12	73	5	6.85%	0	0.00%
		4,101-33,000	7	2,868	1	0.03%	0	0.00%	1	3	0	0.00%	0	0.00%
		33,001-100,000	1	4,156	1	0.02%	0	0.00%	1	3	0	0.00%	0	0.00%
		>100,000	1	3	3	100.00%	0	0.00%	1	3	0	0.00%	0	0.00%
		Total SW	**315**	**25,204**	**131**	**0.52%**	**8**	**0.03%**	**75**	**369**	**32**	**8.67%**	**1**	**0.27%**
Total	GW	≤100	12,528	337,836	7,028	6.15%	371	0.11%	2,822	20,437	5,384	77.89%	220	1.08%
		101-500	9,675	400,908	5,944	5.33%	301	0.08%	2,423	16,751	2,420	53.04%	139	0.83%
		501-1,000	2,836	159,557	1,624	3.32%	66	0.04%	646	4,229	449	50.54%	26	0.61%
		1,001-4,100	3,515	406,187	2,741	2.17%	127	0.03%	1,057	7,132	545	30.96%	14	0.20%
		4,101-33,000	1,535	699,958	2,401	4.54%	111	0.02%	670	5,759	236	9.27%	18	0.31%
		33,001-100,000	132	276,565	689	0.25%	31	0.01%	93	1,582	76	4.80%	9	0.57%
		>100,000	22	69,714	527	0.76%	7	0.01%	21	774	50	6.46%	0	0.00%
		Total GW	**30,243**	**2,350,725**	**20,954**	**0.89%**	**1,014**	**0.04%**	**7,732**	**56,664**	**9,160**	**16.17%**	**426**	**0.75%**
	SW	≤100	1,001	51,880	615	3.48%	60	0.12%	242	1,756	173	27.30%	24	1.37%
		101-500	1,463	94,648	1,067	3.09%	79	0.08%	452	3,316	270	29.03%	16	0.48%
		501-1,000	708	55,119	594	3.26%	36	0.07%	222	1,562	170	54.95%	9	0.58%
		1,001-4,100	1,544	227,951	1,443	1.89%	77	0.03%	533	3,480	175	11.86%	12	0.34%
		4,101-33,000	1,358	801,247	2,839	0.88%	134	0.02%	668	7,118	293	4.13%	4	0.06%
		33,001-100,000	212	549,697	1,055	0.22%	46	0.01%	154	2,598	81	3.12%	6	0.23%
		>100,000	104	538,648	1,724	100.32%	67	0.01%	83	4,023	157	3.91%	3	0.07%
		Total SW	**6,390**	**2,319,190**	**9,337**	**0.40%**	**499**	**0.02%**	**2,354**	**23,853**	**1,319**	**5.53%**	**74**	**0.31%**

[1] A subset of these records was used in the Section 6.3 analyses (EPA removed TC+ Results that did not have a corresponding EC sample and vice versa).
[2] For the analyses presented in this report, "*E. coli*" and "EC" corresponds to *E. coli* plus fecal coliform samples.
[3] The "% Positive" for EC samples was calculated as the number of EC+ samples divided by the total number of TC sample

EPA found that there was a lower rate of occurrence of both TC and EC positives as the free or total chlorine residual increased to higher levels. For routine samples with free chlorine, the highest percent of samples that were TC+ or EC+ (2.3 percent and 0.11 percent, respectively) occurred when free chlorine was equal to 0 mg/L ("not detected"). These percentages dropped by more than half for the >0 – 0.2 mg/L bin, then appeared to flatten when free chlorine was > 0.2 mg/L. The TC+ rate was less than one percent when chlorine residuals were greater than or equal to 0.2 mg/L of free chlorine. The trend is similar for total chlorine routine samples except that for TC, the percent of positive samples was slightly higher for the >0 – 0.2 mg/L bin than for the 0 mg/L bin. Also, percent positive TC and EC results for the >0.2 mg/L – 0.5 mg/L bin were slightly higher than for the >0.5 mg/L – 1.0 mg/L bin and the > 1.0 bin, indicating a possible tailing off of the TC+ and EC+ occurrence at 0.5 mg/L for total chlorine compared to tailing at 0.2 mg/L free chlorine. This relationship between chlorine residuals and occurrence of TC and EC positives was similar to results reported by the Colorado Department of Public Health and Environment (Ingels, 2015). In addition, this relationship is consistent with the findings of LeChevallier et al. (1996) which stated that disinfectant residuals of 0.2 mg/L or more of free chlorine, or 0.5 mg/L or more of total chlorine, are associated with reduced levels of coliform bacteria.

As one might expect, the percentage of positive TC samples was much higher overall for repeat samples (13.9 percent for free chlorine and 6.9 percent for total chlorine, on average) than for routine samples (0.6 percent for free chlorine and 0.5 percent for total chlorine, on average). More than 40 percent of repeat TC samples were positive when free chlorine was zero, compared to a slightly lower repeat TC+ occurrence of approximately 29 percent when the total chlorine was zero. Similar to routine samples, repeat TC+ occurrence declined as free and total chlorine residual increased, with a flattening of occurrence at 0.5 mg/L for both free and total chlorine residuals.

The highest percent of EC+ in repeat samples occurred when free chlorine was zero (2.0 percent) and when total chlorine was >0 – 0.2 mg/L (1.01 percent). Unlike routine sample results, the percent positive of EC repeat samples increased slightly from the >0.5 – 1.0 mg/L bin to the > 1.0 mg/L bin for both free and total chlorine.

Exhibit 6.11: Summary of Total Coliform and *E. coli* Samples for Each Bin of Free and Total Chlorine Residual Concentrations from SYR3 ICR Dataset (2006-2011)

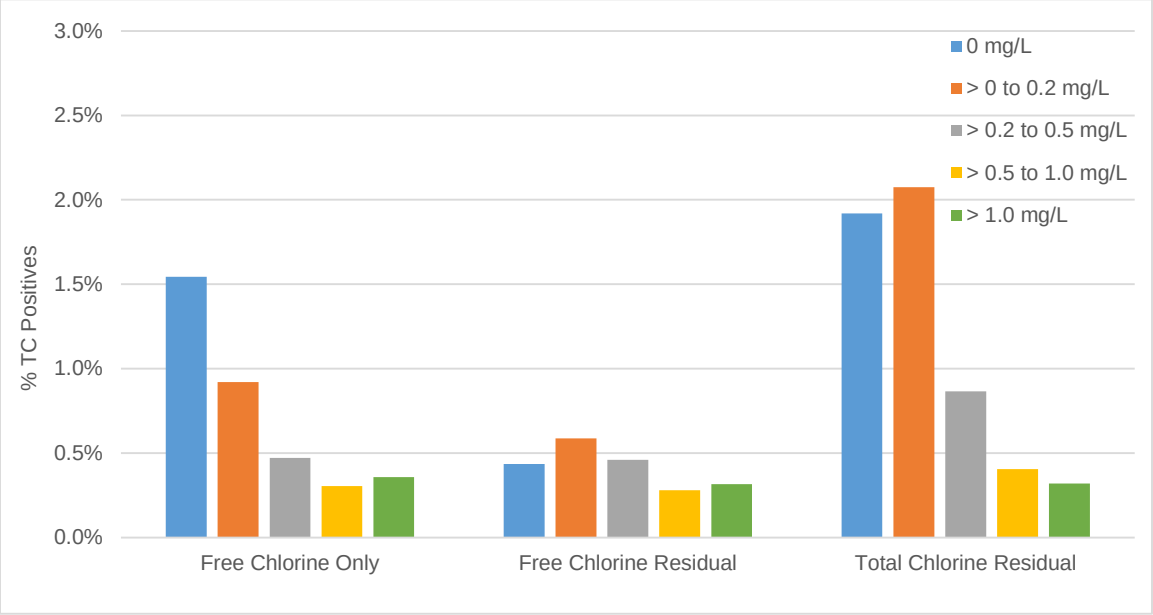
Surface and Ground Water Systems		Routine Samples					Repeat Samples				
Group[1]	Disinfectant Residual Level (mg/L)	Total Coliforms			*E. coli*[2]		Total Coliforms			*E. coli*[2]	
		Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]	Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive[3]
Free Chlorine	0	194,354	4,463	2.3%	221	0.11%	13,677	5,663	41.4%	278	2.03%
	>0 - 0.2	319,378	3,293	1.0%	169	0.05%	9,101	1,396	15.3%	80	0.88%
	>0.2 - 0.5	602,059	3,677	0.6%	196	0.03%	11,501	753	6.5%	30	0.26%
	>0.5 - 1.0	1,103,795	4,252	0.4%	197	0.02%	14,676	615	4.2%	16	0.11%
	>1.0	1,109,384	5,057	0.5%	229	0.02%	16,010	626	3.9%	27	0.17%
	Subtotal	**3,328,970**	**20,742**	**0.6%**	**1,012**	**0.03%**	**64,965**	**9,053**	**13.9%**	**431**	**0.66%**
Total Chlorine	0	26,903	571	2.1%	48	0.18%	1,248	359	28.8%	6	0.48%
	>0 - 0.2	59,370	1,339	2.3%	73	0.12%	1,292	220	17.0%	13	1.01%
	>0.2 - 0.5	198,128	1,868	0.9%	77	0.04%	2,679	194	7.2%	8	0.30%
	>0.5 - 1.0	566,203	2,636	0.5%	138	0.02%	5,365	225	4.2%	5	0.09%
	>1.0	1,254,425	4,770	0.4%	235	0.02%	12,259	584	4.8%	25	0.20%
	Subtotal	**2,105,029**	**11,184**	**0.5%**	**571**	**0.03%**	**22,843**	**1,582**	**6.9%**	**57**	**0.25%**

[1] There is some overlap between these two groups (i.e., some TC and EC records were paired with both free and total chlorine residual concentrations).
[2] As described in Section 6.1, for the purposes of the analyses presented in this report, "*E. coli*" and "EC" corresponds to *E. coli* plus fecal coliform samples.
[3] The "% Positive" for EC samples was calculated as the number of EC+ samples divided by the total number of TC samples.

6.3.1 Occurrence in Surface Water

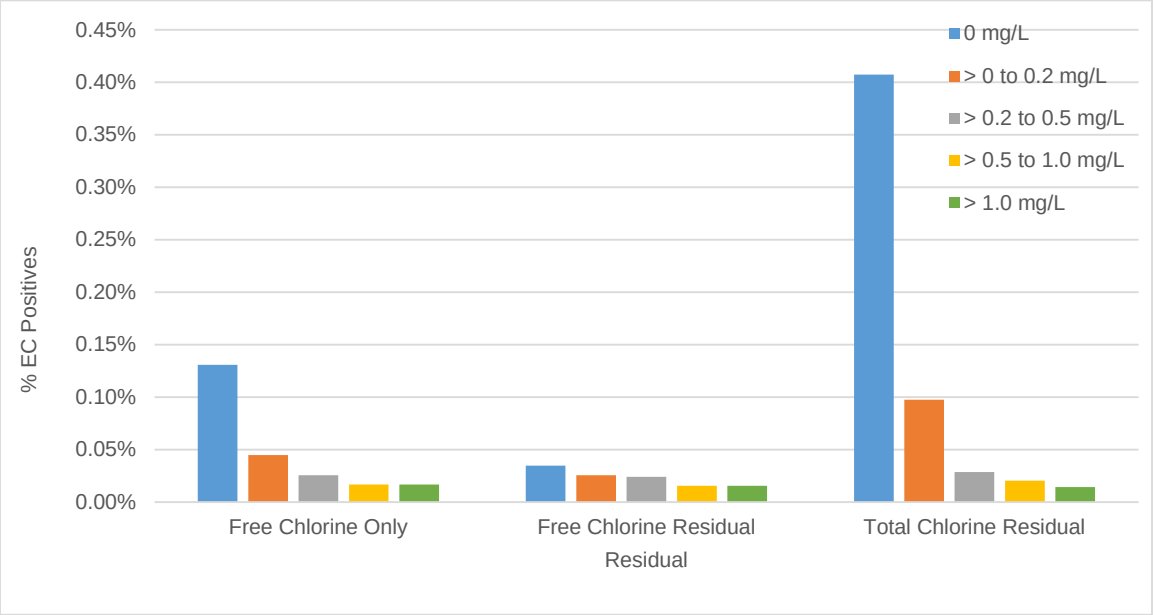
Exhibit 6.12 and Exhibit 6.13 present the frequency of detection of total coliform and *E. coli*, respectively, over six years of data in surface water. These analyses are based on routine samples taken in the distribution system. The exhibits show a larger proportion of TC+ and EC+ in surface water associated with total chlorine residual data than free chlorine residual data. For both TC and EC, there was a higher level of occurrence in the smaller chlorine residual bins. However, the trend is relatively flat for the "free chlorine residual" group because of the bias introduced by some records that reported zero or very low free chlorine but high total chlorine values (e.g. in a chloramine system) (see Section 6.3.3). After those records (reported both free and total chlorine data) are excluded, the "free chlorine only" group showed a higher level of TC+ or EC+ rate in the smaller chlorine residual bins (e.g., 1.5 percent TC+ for the "0 mg/L" bin and 0.9 percent TC+ for the ">0-0.2 mg/L" bin), as expected.

Exhibit 6.12: Total Coliforms - Frequency of Detection in Surface Water as Function of Disinfectant Types and Concentrations (2006-2011)



Note: Routine samples only.

Exhibit 6.13: *E. coli* - Frequency of Detection in Surface Water (2006-2011)



Note: Routine samples only.

Exhibit 6.14: Number of Total Coliform and *E. coli* Samples and Positives in Surface Water Paired with Free and Total Chlorine Data, by Source Water Type

Group	Disinfectant Residual Level (mg/L)	Total Coliforms in Surface Water			*E. coli* in Surface Water	
		Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive
Free Chlorine Only	0	11,464	177	1.54%	15	0.13%
	>0 - 0.2	51,560	475	0.92%	23	0.04%
	>0.2 - 0.5	161,096	760	0.47%	41	0.03%
	>0.5 - 1.0	432,981	1,319	0.30%	72	0.02%
	>1.0	559,272	2,003	0.36%	94	0.02%
	Subtotal	**1,216,373**	**4,734**	**0.39%**	**245**	**0.02%**
Free Chlorine	0	46,173	201	0.44%	16	0.03%
	>0 - 0.2	113,869	668	0.59%	29	0.03%
	>0.2 - 0.5	191,822	883	0.46%	46	0.02%
	>0.5 - 1.0	528,813	1476	0.28%	82	0.02%
	>1.0	690,577	2185	0.32%	107	0.02%
	Subtotal	**1,571,254**	**5,413**	**0.34%**	**280**	**0.02%**

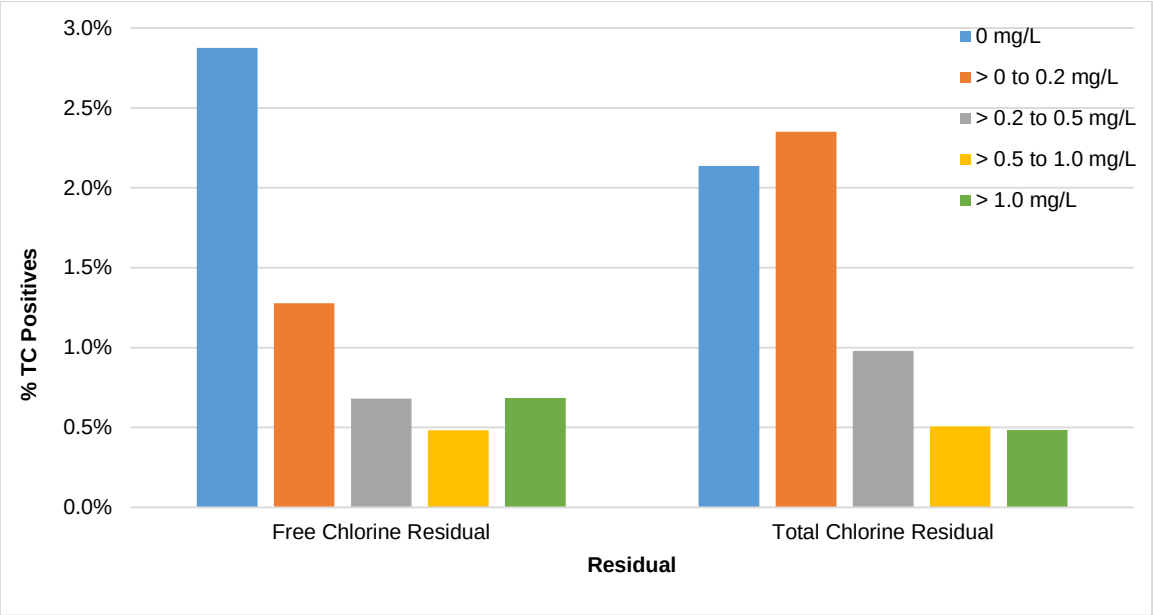
Group	Disinfectant Residual Level (mg/L)	Total Coliforms in Surface Water			*E. coli* in Surface Water	
		Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive
Total Chlorine	0	1,719	33	1.92%	7	0.41%
	>0 - 0.2	20,531	426	2.07%	20	0.10%
	>0.2 - 0.5	63,282	548	0.87%	18	0.03%
	>0.5 - 1.0	226,637	918	0.41%	46	0.02%
	>1.0	790,495	2,525	0.32%	113	0.01%
	Subtotal	**1,102,664**	**4,450**	**0.40%**	**204**	**0.02%**

Note: Routine samples only. This exhibit presents underlying data/denominator for Exhibit 6-12 and Exhibit 6-13.

6.3.2 Occurrence in Ground Water

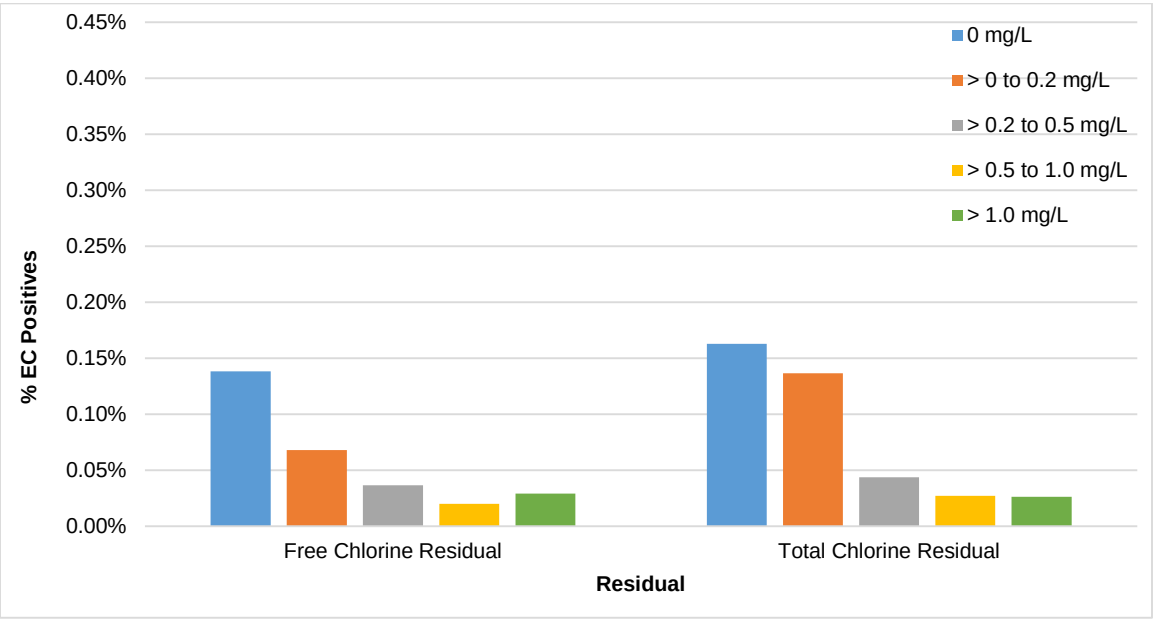
Exhibit 6.15 and Exhibit 6.16 present the frequency of detection of total coliform and *E. coli*, respectively, over six years of data in ground water. These analyses are based on routine samples taken in the distribution system. The "free chlorine only" data is not presented in these exhibits because the "free chlorine residual" data did not show the data bias as observed in surface water results (as discussed in Section 6.3.1). This would be expected because ground water systems are less likely to use chloramine, except when ammonia is present in source water. Compared to the surface water results shown in Exhibit 6.12 and Exhibit 6.13, the ground water exhibits show a similar proportion of TC+ and EC+ in ground water associated with free chlorine residual data compared to total chlorine residual data. Similar to the surface water results, for both TC and EC occurrence in ground water, there was a higher level of occurrence in the smaller chlorine residual bins.

Exhibit 6.15: Total Coliforms - Frequency of Detection in Ground Water (2006-2011)



Note: Routine samples only.

Exhibit 6.16: *E. coli* - Frequency of Detection in Ground Water (2006-2011)



Note: Routine samples only.

Exhibit 6.17: Number of Total Coliform Samples in Ground Water Paired with Free and Total Chlorine Data, by Source Water Type

Group	Disinfectant Residual Level (mg/L)	Total Coliforms in Ground Water			*E. coli* in Ground Water	
		Total # Samples	# Positive Samples	% Positive	# Positive Samples	% Positive
Free Chlorine	0	148,181	4,262	2.88%	205	0.14%
	>0 - 0.2	205,509	2,625	1.28%	140	0.07%
	>0.2 - 0.5	410,237	2,794	0.68%	150	0.04%
	>0.5 - 1.0	574,982	2,776	0.48%	115	0.02%
	>1.0	418,807	2,872	0.69%	122	0.03%
	Subtotal	**1,757,716**	**15,329**	**0.87%**	**732**	**0.04%**
Total Chlorine	0	25,184	538	2.14%	41	0.16%
	>0 - 0.2	38,839	913	2.35%	53	0.14%
	>0.2 - 0.5	134,846	1,320	0.98%	59	0.04%
	>0.5 - 1.0	339,566	1,718	0.51%	92	0.03%
	>1.0	463,930	2,245	0.48%	122	0.03%
	Subtotal	**1,002,365**	**6,734**	**0.67%**	**367**	**0.04%**

Note: Routine samples only. This exhibit presents underlying data/denominator for Exhibit 6-12 and Exhibit 6-13.

6.3.3 Limitations of Data Analysis

The limitations of the chlorine residual data analysis, as discussed in Section 6.2.4, also apply to the TC/EC analyses. Inclusion of records that reported both free and total chlorine data (which accounts for about 17 percent of total records) in the TC/EC analysis could potential create bias to the results, as described below.

In some cases, zero or very low free chlorine and high total chlorine values are reported for the same sample. This would be expected in chloramine systems where all the chlorine should be combined with ammonia and reported as total. Since the primary goal of the analyses is to evaluate TC/EC occurrence together with the occurrence of low residual values, it is possible that including the results with both free and total chlorine residual concentrations might be biasing TC/EC occurrence downward in the lower concentration bins for free chlorine when total chlorine is also present (i.e., in a chloramines system). Exhibit 6.18 demonstrates the potential impacts of this bias, showing lower TC occurrence in the free chlorine residual bins of 0 and >0 – 2 mg/L when free chlorine and total chlorine are reported together (0.5 percent for both bins) than when free chlorine is reported alone (3.4 percent and 1.3 percent, respectively).

There are other samples where free chlorine is a significant proportion of total chlorine. It is possible that a free chlorine system would have samples with more total than free chlorine when they have ammonia in their source water and they do not practice breakpoint chlorination. These

systems may experience reduced disinfection effectiveness compared to the situation where none of the free chlorine were combined with ammonia. These samples (i.e. those with free chlorine as a high portion of total chlorine) may also misrepresent TC/EC occurrence in the total chlorine bins since the majority of the residual disinfectant is in the form of free chlorine. Exhibit 6.19 shows potential impacts of the bias, showing lower TC/EC occurrence in all bins for samples with both free and total chlorine residual compared to samples where only total chlorine residual is reported.

While Exhibit 6.18 and Exhibit 6.19 show the overall bias on all the records (i.e., surface water and ground water results combined), the bias on the surface water results is discussed in Section 6.3.1.

Exhibit 6.18: Comparison of Free Chlorine Only Samples with Free Chlorine Samples Paired with Total Chlorine

Free Chlorine Residual (mg/L)	Free Chlorine Only					Free Chlorine Samples Paired with Total Chlorine					All Free Chlorine Samples				
	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+
Routine Samples															
0	120,414	4,124	3.4%	196	0.16%	73,940	339	0.5%	25	0.03%	194,354	4,463	2.3%	221	0.11%
>0 - 0.2	213,808	2,810	1.3%	148	0.07%	105,570	483	0.5%	21	0.02%	319,378	3,293	1.0%	169	0.05%
0.2 - 0.5	493,937	3,196	0.6%	159	0.03%	108,122	481	0.4%	37	0.03%	602,059	3,677	0.6%	196	0.03%
0.5 - 1.0	853,445	3,667	0.4%	157	0.02%	250,350	585	0.2%	40	0.02%	1,103,795	4,252	0.4%	197	0.02%
>1.0	882,575	4,603	0.5%	192	0.02%	226,809	454	0.2%	37	0.02%	1,109,384	5,057	0.5%	229	0.02%
Sum	**2,564,179**	**18,400**	**0.7%**	**852**	**0.03%**	**764,791**	**2,342**	**0.3%**	**160**	**0.02%**	**3,328,970**	**20,742**	**0.6%**	**1,012**	**0.03%**
Repeat Samples															
0	12,670	5,435	42.9%	270	2.13%	1,007	228	22.6%	8	0.79%	13,677	5,663	41.4%	278	2.03%
>0 - 0.2	7,741	1,267	16.4%	70	0.90%	1,360	129	9.5%	10	0.74%	9,101	1,396	15.3%	80	0.88%
0.2 - 0.5	10,107	685	6.8%	25	0.25%	1,394	68	4.9%	5	0.36%	11,501	753	6.5%	30	0.26%
0.5 - 1.0	12,530	545	4.3%	15	0.12%	2,146	70	3.3%	1	0.05%	14,676	615	4.2%	16	0.11%
>1.0	14,233	572	4.0%	23	0.16%	1,777	54	3.0%	4	0.23%	16,010	626	3.9%	27	0.17%
Sum	**57,281**	**8,504**	**14.8%**	**403**	**0.70%**	**7,684**	**549**	**7.1%**	**28**	**0.36%**	**64,965**	**9,053**	**13.9%**	**431**	**0.66%**

Exhibit 6.19: Comparison of Total Chlorine Only Samples with Total Chlorine Samples Paired with Free Chlorine

Total Chlorine Residual (mg/L)	Total Chlorine Only					Total Chlorine Samples Paired with Free Chlorine					All Total Chlorine Samples				
	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+
Routine Samples															
0	6,907	299	4.3%	33	0.48%	19,996	272	1.4%	15	0.08%	26,903	571	2.1%	48	0.18%
>0 - 0.2	47,373	1,170	2.5%	59	0.12%	11,997	169	1.4%	14	0.12%	59,370	1,339	2.3%	73	0.12%
0.2 - 0.5	144,827	1,587	1.1%	63	0.04%	53,301	281	0.5%	14	0.03%	198,128	1,868	0.9%	77	0.04%
0.5 - 1.0	344,818	2,031	0.6%	98	0.03%	221,385	605	0.3%	40	0.02%	566,203	2,636	0.5%	138	0.02%
>1.0	796,313	3,755	0.5%	158	0.02%	458,112	1,015	0.2%	77	0.02%	1,254,425	4,770	0.4%	235	0.02%
Sum	**1,340,238**	**8,842**	**0.7%**	**411**	**0.03%**	**764,791**	**2,342**	**0.3%**	**160**	**0.02%**	**2,105,029**	**11,184**	**0.5%**	**571**	**0.03%**
Repeat Samples															

Total Chlorine Residual (mg/L)	Total Chlorine Only					Total Chlorine Samples Paired with Free Chlorine					All Total Chlorine Samples				
	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+	# TC	# TC+	% TC+	# EC	% EC+
0	509	144	28.3%	1	0.20%	739	215	29.1%	5	0.68%	1,248	359	28.8%	6	0.48%
>0 - 0.2	903	150	16.6%	8	0.89%	389	70	18.0%	5	1.29%	1,292	220	17.0%	13	1.01%
0.2 - 0.5	1,970	158	8.0%	2	0.10%	709	36	5.1%	6	0.85%	2,679	194	7.2%	8	0.30%
0.5 - 1.0	3,346	150	4.5%	5	0.15%	2,019	75	3.7%	0	0.00%	5,365	225	4.2%	5	0.09%
>1.0	8,431	431	5.1%	13	0.15%	3,828	153	4.0%	12	0.31%	12,259	584	4.8%	25	0.20%
Sum	**15,159**	**1,033**	**6.8%**	**29**	**0.19%**	**7,684**	**549**	**7.1%**	**28**	**0.36%**	**22,843**	**1,582**	**6.9%**	**57**	**0.25%**

6.4 Occurrence of Total Coliforms in PWSs Using Undisinfected Ground Water

As part of the Six-Year Review 3, EPA conducted an analysis of total coliforms/*E. coli* data (TC/EC) from the SYR3 microbial dataset that represents undisinfected ground water systems. EPA analyzed data collected in 2011 for approximately 38,000 small (serving fewer than 4,101 people) undisinfected PWSs. EPA used statistical modeling to characterize distributions of TC detection rates for each of nine groupings of PWSs based on system type (community, non-transient non-community and transient non-community) and population served (less than 101, 101 to 1000 and 1001 to 4,100 people).

Among the three PWS types, on average, undisinfected transient PWSs have a 4.3 percent TC detection rate as compared with 3% for undisinfected non-transient PWSs and 2.5 percent for undisinfected community PWSs. Within each type of PWS, the smaller systems have higher median TC detection than the larger systems. All TC-positive samples were assayed for EC. Among TC-positive samples from small undisinfected PWSs, EC is detected in about five percent of samples, regardless of PWS type or size. EPA evaluated the upper tail of the TC detection rate distributions and found that significant percentages of some system types have high TC detection rates. For example, assuming the PWSs providing data are nationally representative, then five percent of the ~52,000 small undisinfected transient PWSs in the U.S. have TC detection rates of 20 percent or more. More details about the analysis are provided in Appendix F.

6.5 Occurrence of Viruses and Aerobic Spores in PWSs Using Undisinfected Ground Water

Borchardt et al. (2012) assayed 1,204 tap water samples using qPCR from 14 undisinfected ground water systems and detected at least one virus in 287 (24 percent) samples. These results are consistent with other PWS ground water studies (USEPA, 2006). Perhaps most significantly, Borchardt et al. (2012) detected 51 (4 percent) norovirus positive samples with about 40 detections in the first six-month surveillance period. Significant AGI health effects were reported during this first surveillance period, especially among children less than five years old.

EPA hypothesizes that a norovirus disease outbreak occurred in many of the 14 communities during the first surveillance period. The outbreak was likely abetted by consumption of untreated drinking water. Norovirus illness in the community resulted in norovirus shedding in septage and sewage, and fecal contamination eventually arrived in untreated drinking water samples. Consuming untreated, norovirus contaminated drinking water, likely resulted in additional health effects in the communities. The infection cycle was halted only when most community members not initially genetically immune, had been exposed, infected and become immune. By the time the outbreak ended, as many as 63 percent of children under 5 years old had been exposed, infected and ill, all during the first surveillance period

Enterovirus was detected in 109 (9 percent) samples with detections in all 4 surveillance periods (lowest period had 10 detections). Enterovirus-related illness appears to reflect endemic, rather than epidemic disease in the community, although the large number of enterovirus genotypes

observed suggests that each genotype could, like norovirus, cause short period epidemics. Again, the forthcoming scientific analysis should better document this phenomenon.

As a result of the potential public health risk associated with undisinfected PWS wells reported by Borchardt et al. (2012) for Wisconsin, the Minnesota State Legislature requested a study of ground waterborne viruses. The first-year results are published (Borchardt et al., 2015). Eighty-two randomly selected (from 567 wells total) PWS wells were each sampled 6 times in a year using qPCR and 245 virus assay results are reported (Borchardt et al., 2012); each well (but one) sampled 3 times. Human enteric virus was detected in 41 samples from 34 wells. Seven samples were positive for enterovirus and four samples each were positive for norovirus and rotavirus. Nineteen samples were positive for adenovirus. [Note: one well is positive for *E. coli* (Borchardt et al., 2015)]. Borchardt et al. concluded that the virus occurrence in Minnesota is, at least based on early results, similar to previous results from Wisconsin. An epidemiological study (three communities, three control communities) is now underway.

Under the UCMR 3, EPA sampled about 800 randomly selected undisinfected wells and evaluated them for the presence of viruses and virus indicators using EPA Method 1615. These data show (posted on EPA UCMR website) that only two undisinfected PWS systems were virus positive by cell culture and no more than 16 PWSs were virus positive by qPCR.

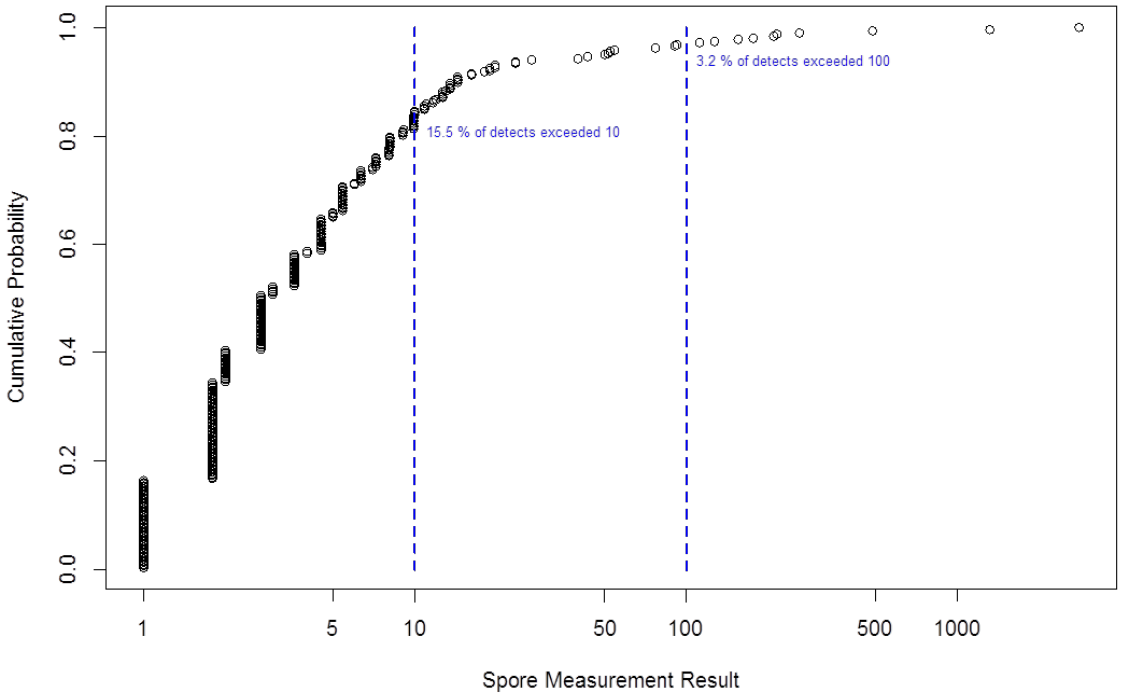
The UCMR 3 virus results contrast significantly with the results from Borchardt et al. (2012). One important difference is that Borchardt sampled prior to any treatment in these undisinfected wells (e.g., softening, Fe/Mn removal). In contrast, most wells in UCMR 3 virus study were sampled after softening or other treatment. It is unknown if the difference in sampling point affected virus recovery. Francy et al. (2004) also sampled undisinfected PWSs for enteric virus with sampling prior to any softening or Fe/Mn removal. They found 2 of 38 wells positive for enterovirus by cell culture.

Available UCMR 3 data show that 252 of 793 (32 percent) of PWSs (about two thirds of wells sampled once, others sampled twice) are aerobic spore positive. In comparison, only 41 (5 percent) and 53 (7 percent) PWSs were, respectively, enterococci or total coliform positive. These data reflect the long lived nature of the spore as compared to the vegetative cell form of soil bacteria.

The soil bacteria are entrained within infiltrating precipitation and are transported from the surface or near surface to the well. These soil bacteria are found everywhere and, if found in a well, represent a ground water recharge pathway with sufficient pore space and permeability to permit bioparticle transport within that pathway. Because the aerobic spores are environmentally resistant they are most likely to be found in well water as compared with the other soil bacteria, total coliform and enterococci. The total coliform and enterococci are vegetative cells incapable of producing a spore form and thus are more likely to be detrimentally affected by environmental stress. The UCMR 3 virus data, as would be expected, have substantially more PWSs positive for soil bacterial spores (32 percent) as compared with the soil bacterial vegetative cells (5 percent enterococci and 7 percent for total coliform) because the spores are more resistant to environmental stress.

The UCMR 3 aerobic spore concentrations spanned three orders of magnitude, as shown in Exhibit 6.20. For example, approximately 15 percent of detections are between 10 and 100 spore-forming units per 100 mL and approximately three percent of detections exceeded 100 spore-forming units per 100 mL. For those having concentrations of over 100 spore-forming units per 100 mL, these PWS wells likely have a greater component of more recent surface water and could be unrecognized GWUDI wells. These wells currently are undisinfected; treatment such as filtration and disinfection could be warranted. For those having concentrations of between 10 and 100 spore-forming units per 100 mL, further investigation may be warranted to evaluate a need for disinfection or any other corrective action. We also suggest that these undisinfected PWSs having high spore concentrations (e.g., over 100 spore-forming units per 100 mL) should be re-evaluated as possible misclassified GWUDI systems.

Exhibit 6.20: UCMR 3 Aerobic Spore Concentration Cumulative Distribution Function



Statistical analysis (not shown) produced no significant associations between any indicator microorganism and any pathogen or between any group of infiltration microorganisms and any group of sewage/septage/fecal microorganisms.

7 Treatment

This chapter summarizes the results from EPA's review of information related to the treatment of microbial contaminants in drinking water to support the evaluation of treatment feasibility part of the Six-Year Review. EPA conducted a scientific review of available information, published on or before December 2015, to determine if information would suggest an opportunity to revise the treatment technique (TT) requirements in the microbial contaminant regulations to provide greater protection of public health. The review focused on the major provisions of the microbial contaminant regulations where new information was identified.

7.1 Introduction

This section provides a brief overview of major TT requirements in the microbial contaminant regulations and highlights the ones that EPA identified for further discussion in this chapter. Additional background about these regulations is provided in Chapter 3 of this document.

SWTR. The SWTR requires all water systems using surface water or GWUDI sources (also known as Subpart H systems) to remove (via filtration) and/or inactivate (via disinfection) microbial contaminants to protect the public from potential adverse health effects due to exposure to *Giardia lamblia*, viruses, *Legionella*, heterotrophic bacteria, and other pathogens (USEPA, 1989). Specifically, it requires at least 99.9 percent (3-log) removal/inactivation of *G. lamblia* and at least 99.99 percent (4-log) removal/inactivation of viruses. Other major TT provisions include turbidity criteria for filtered systems, disinfection residual requirements prior to point of entry to the distribution system and within the distribution system, and filtration avoidance criteria for unfiltered systems. (USEPA, 1989). EPA published concentration x time (CT) tables for PWSs to determine log-inactivation credit for the use of a disinfectant to meet the disinfection TT requirements (USEPA, 1989; USEPA, 1991b).

IESWTR. The IESWTR applies to all PWSs using surface water or GWUDI, which serve 10,000 or more people. The IESWTR established TT requirements for *Cryptosporidium* by requiring filtered systems to achieve at least a 99 percent (two-log) removal, tightening turbidity performance criteria, requiring a sanitary survey for all surface water and GWUDI systems, and setting disinfection profiling and benchmarking requirements to prevent increases in microbial risk while systems complied with the Stage 1 D/DBPR (USEPA, 1998b).

LT1. The LT1 extended the requirements from the IESWTR for systems serving fewer than 10,000 people (USEPA, 2002).

LT2. The LT2 Rule 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 also requires covering of all uncovered finished water reservoirs or for water to be treated (at least 2, 3, 4 inactivation or removal of *Cryptosporidium*, *Giardia*, and viruses respectively (USEPA, 2006a). EPA reviewed the LT2 microbial toolbox treatment and management strategy options for *Cryptosporidium*. Results of that review are provided in the LT2 support document (USEPA, 2016a).

Filter Backwash Recycling Rule. EPA did not identify any treatment-related topics in the FBRR (USEPA, 2001).

Ground Water Rule. There is no distribution system disinfectant residual requirement under the GWR (USEPA, 2006b). The CT criteria provided in the SWTRs apply to those ground water systems that are required to disinfect. EPA did not identify any other treatment-related topics in the GWR.

Based on the available information, EPA identified the following TT requirements of the SWTRs (including SWTR, IESWTR and LT1) that warrant further examination in this Six-Year Review:

- Requirements to maintain a minimal disinfectant residual in the distribution system (Section 7.2), and
- CT criteria for virus disinfection (Section 7.3).

7.2 Disinfectant Residual Requirements in Distribution Systems

7.2.1 Background

The term "disinfectant residual" refers to the amount of disinfectant remaining in the water after application at some prior time, and after some amount of that applied has been exhausted. For example, a chlorine residual is the difference between the total chlorine added and that consumed by oxidizable matter (i.e., the chlorine demand of the water). The first step of the disinfection process, before the water enters the distribution system, is referred to as "primary disinfection." Primary disinfection kills or inactivates bacteria, viruses, and many other potentially harmful organisms. Additional disinfectant can be added in a second step, called secondary disinfection, sometime after primary disinfection but prior to entry to the distribution system or at booster disinfection facilities in the distribution system. Secondary disinfection, with possible booster disinfection within the distribution system, is intended to maintain a disinfectant residual throughout the distribution system to protect drinking water quality to the customers' taps.

Distribution systems are vulnerable to contamination by a number of pathways, including the infiltration of water external to the distribution system and by microbial growth (especially naturally occurring bacteria such as *Legionella* and mycobacteria) when distribution system conditions are favorable. Under the SWTR, the residual disinfectant concentration at the entry point to the distribution system may not be less than 0.2 mg/L for more than four hours. The residual disinfectant concentration in the distribution system "cannot be undetectable in more than 5 percent of the samples each month, for any 2 consecutive months that the system serves water to the public." (40 CFR 141.72). A detectable residual may be established by: (1) an analytical measurement, or (2) having a heterotrophic bacteria concentration less than or equal to 500 per mL measured as heterotrophic plate count (HPC). The purpose of these disinfectant residual requirements, as descried in the proposed SWTR (USEPA, 1987), was to:

- Ensure that the distribution system is properly maintained and identify and limit contamination from outside the distribution system when it might occur,
- Limit growth of heterotrophic bacteria and *Legionella* within the distribution system, and
- Provide a quantitative limit, which if exceeded would trigger remedial action.

Once drinking water is disinfected to meet public health standards, the residual disinfectant level in the distribution system must be maintained as a final barrier in protecting against waterborne disease. Maintaining this residual disinfectant reduces bacterial growth and mitigates against possible contamination by pathogens that may have intruded into the system. Disinfectants also naturally degrade based on demand and water age. Operators must manage disinfectant levels on a frequent and ongoing basis to protect consumers. One of the major purposes for requiring distribution system residuals has historically been described as an indicator (when there is an absence of a residual) for localized contamination and/or intrusion into the distribution system.

7.2.2 Summary of Technical Review

EPA evaluated information related to the maintenance of a minimum disinfectant level in the distribution system and determined that a detectable concentration of disinfectant residual in the distribution system may not be adequately protective of public health due to microbial pathogens. This is based on concerns about analytical methods and the potential for false positives (Westerhoff et al., 2010; Wahman and Pressman, 2015; AWWA, 2015). Maintaining a disinfectant residual above a set numerical value in the distribution system may improve public health protection from a variety of pathogens. Such a change could have benefits for controlling occurrence of all types of pathogens in distribution systems, except for those most resistant to disinfection, such as Cryptosporidium and mycobacteria. EPA noted that maintaining a disinfectant residual above a set numerical value in the distribution system would need to also consider impacts on the formation of DBPs (refer to the risk-balancing provisions of the SYR3 protocol).

In summer 2015, the American Water Works Association (AWWA) provided EPA with input developed by it Disinfection Residual Strategy Panel related to the maintenance of a secondary disinfectant residual in drinking water distribution systems (AWWA, 2015). AWWA noted that the input primarily focused on eight topics related to the public health considerations associated with drinking water distribution systems. These eight topics related to: analytical methods for disinfectant residual; organic chloramines; the TCR sampling framework; minimum numerical disinfectant residual requirements and performance objectives; institutional premise plumbing; disinfectant residuals in ground water systems; cross-connection control; and public notification (AWWA, 2015).

7.2.3 Detectable Residuals for Systems Using Chloramine Disinfection

For surface water systems or GWUDI systems, the SWTR requires that a disinfectant residual cannot be undetectable in more than five percent of samples each month for any two consecutive months (see Section 7.2.1). EPA identified two issues that have implications for the protectiveness of allowing a detectable residual as a surrogate for bacteriological quality: organic chloramines and nitrification. Organic chloramines affect the effectiveness of disinfectant residuals because they:

- form during the use of free chlorine or chloramines,
- interfere with commonly used analytical methods for free and total chlorine measurements, and

- are poor disinfectants compared to free chlorine and monochloramine (Wahman and Pressman, 2015).

Organic chloramines are known to be weaker disinfectants than free chlorine or inorganic chloramines, showing little or no bactericidal activity. For example, the CT (concentration x time) required to reach 99 percent (two–log) inactivation (CT99) of Escherichia coli (ATCC 25922) exposed to free chlorine, monochloramine and organic chloramines was approximately 0.5 and 10 mg Cl2 – min/L for free chlorine and monochloramine, respectively, while the organic chloramine was very similar in measured residual concentration to the control experiment and showed minimal inactivation of *E. coli*.

Because chloramination involves introduction of ammonia into drinking water, and decomposition of chloramines can further release ammonia in the distribution system, chloramine use comes with the risk of distribution system nitrification (i.e., the biological oxidation of ammonia to nitrite and eventually nitrate). Drinking water distribution system nitrification is undesirable and can result in water quality degradation (e.g., disinfectant depletion, increased heterotrophic bacteria occurrence or nitrite/nitrate formation). Information shows that maintaining a high enough level of total chlorine or monochloramine residuals in the distribution system can help prevent both nitrification and residual depletion (Stanford et al, 2014).

7.2.4 State Implementation of Disinfectant Residual Requirements

States may adopt federal drinking water regulations or promulgate more stringent drinking water requirements, including those for disinfectant residuals. Twenty states require a minimum free chlorine residual of 0.2 mg/L or more (Ingels, 2015; Wahman and Pressman, 2015). Five of the 20 states set standards more stringent than 0.2 mg/L: Florida, Illinois, Iowa, and Delaware require 0.3 mg/L; in its Emergency Distribution Disinfection Rule, Louisiana required at least 0.5 mg/L free chlorine throughout the distribution system at all times. For minimum total chlorine residual, state requirements vary from 0.05 mg/L (New Jersey) to 1.00 mg/L or higher (Kansas, Oklahoma, Iowa, Ohio, and North Carolina). In its Emergency Distribution Disinfection Rule, Louisiana required a chloramine residual (measured as total chlorine) of 0.5 mg/l throughout the distribution system at all times for systems that feed ammonia. North Carolina has a numeric requirement for total chlorine residual but not for free chlorine residual. Exhibit 7.1 and Exhibit 7.2 present the state requirements for free and total chlorine, respectively, as of January 2015.

Colorado has amended its minimum disinfectant residual requirements in the distribution system to be greater than or equal to 0.2 mg/L, effective April 1, 2016 (Ingels, 2015). Pennsylvania recently proposed to strengthen its disinfectant residual requirements by increasing the minimum disinfectant residual in the distribution system to 0.2 mg/L free or total chlorine (Pennsylvania Bulletin, 2016). In March 2016, Louisiana finalized requirements that chlorinating public water systems maintain at least 0.5 mg/L free chlorine and chloraminating systems maintain at least 0.5 mg/L total chlorine residual throughout the distribution system at all times.

In 2013, Louisiana promulgated an Emergency Distribution Disinfectant Residual Rule that required routine, continuous disinfection of all public water systems. The rule was promulgated

to control *Naegleria fowleri*, an amoeba found in several public water systems. For systems using chlorine disinfection, the free chlorine residual at the entry point to the distribution system had to be 0.5 mg/L for pH less than 7.0; 0.6 mg/L for pH of 7.0 to 8.0; 0.8 mg/L for pH of 8.0 to 9.0; and 1.0 mg/L for pH greater than 9.0. Disinfectant residual monitoring was required at 25 percent more sites than required by the TCR and daily residual measurements were required at the point of maximum residence time in the distribution system. A minimum free or total chlorine disinfectant levels of 0.5 mg/L was required to be maintained at all times in finished water storage tanks and the entire distribution system (Louisiana Department of Health and Hospitals, 2013). Systems using chloramine disinfection were also required to develop and submit a nitrification control plan. The rule initially became effective on November 6, 2013 and was renewed five times between March 2014 and July 2015. In March 2016, the Louisiana State Sanitary Code was amended to make the Emergency Rule's requirements permanent. The March 2016 rule maintains the requirements of the Emergency Rule and strengthens monitoring requirements for public water systems using chloramine disinfection. The Rule also requires public water systems using chloramines to monitor for nitrification and to take corrective action as needed, in accordance with an approved nitrification plan.

Exhibit 7.1: Distribution System Minimal Residual Requirements by States - Free Chlorine

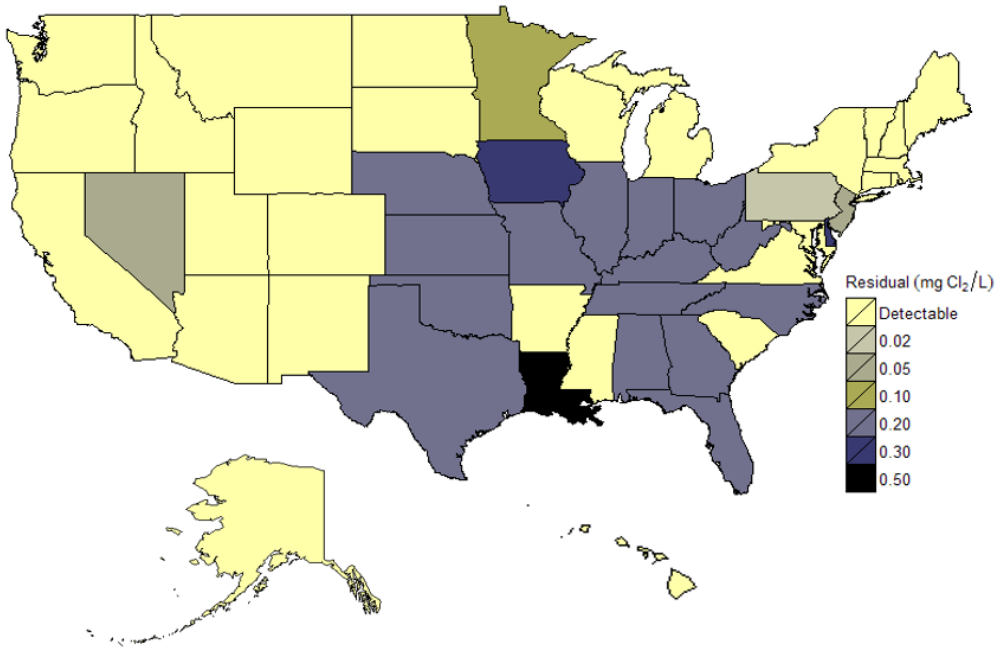
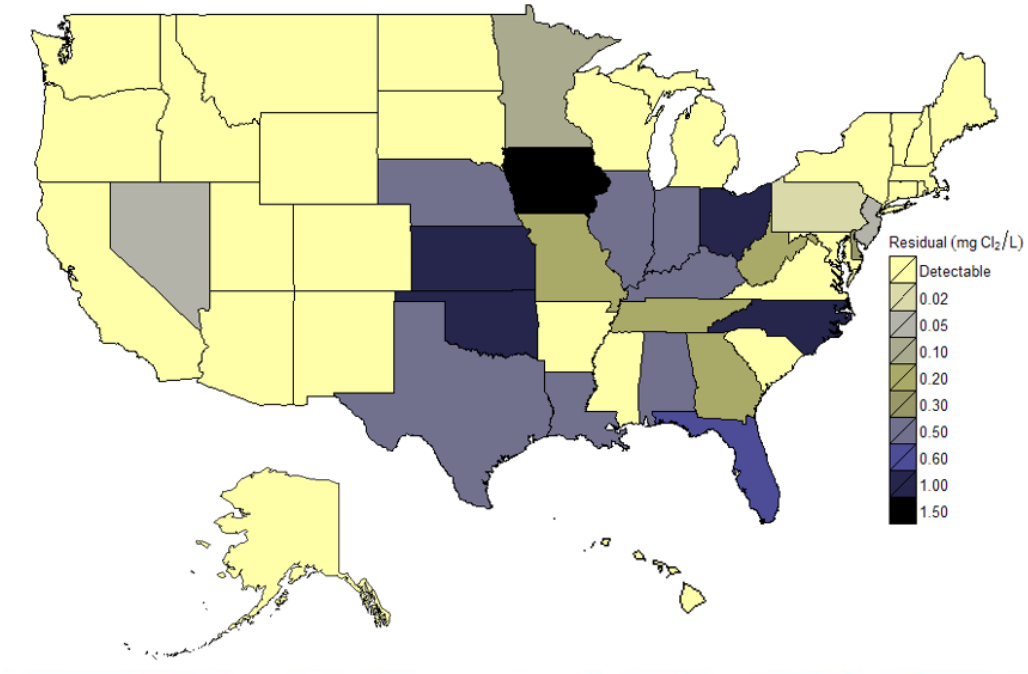


Exhibit 7.2: Distribution System Minimal Residual Requirements by States - Total Chlorine



Most states have requirements for the design, construction, operation and maintenance of distribution systems. Under the TCR/RTCR, each system must develop and monitor disinfectant residuals according to a written sample siting plan, which is subject to state review and revision. The AWWA Disinfection Residual Strategy Panel noted that there appears to be lack of consistency of distribution system requirements set by states and that there is concern that the TCR/RTCR sampling framework may not be optimized to find distribution system problem areas for residual monitoring purposes (AWWA, 2015). The current sampling protocol for drinking water disinfectant residual is tied to total coliform sampling sites as required under the TCR/RTCR. Depending on drinking water distribution system hydraulics, the Panel noted that the TCR/RTCR sampling framework may not provide an accurate assessment of when there is an absence of a disinfectant residual at a specific location not associated with TCR/RTCR sampling (AWWA, 2015). Areas of the drinking water distribution system that can be particularly vulnerable to microbial contaminations are dead ends, areas near improperly functioning valves, pressure zone boundaries, blending zones and areas of the system under lower flow conditions. Additional considerations in selecting distribution system sampling locations may include sensitive population areas (e.g., near schools or hospitals), pipe types relative to corrosion (e.g., old, unlined cast iron) and storage facilities. The Panel noted that continuous monitoring of disinfectant residuals, which may not be feasible in some cases (e.g., in very small systems or in locations without power or sanitary disposal), should be encouraged wherever feasible, with priority given to system critical control points, such as areas near storage facilities, maximum residence time sites, and sites with organic chloramine issues (AWWA, 2015).

7.2.5 Disinfectant Residuals for Control of *Legionella* in Premise Plumbing Systems

Since the reporting of disease outbreaks due to *Legionella* began in 2001, *Legionella* has been shown to cause more drinking-water-related outbreaks than any other microorganism. Addressing premise plumbing issues is particularly challenging. Premise plumbing may be largely outside of water utilities' operations and management control. Also, the characteristic features of premise plumbing (e.g., low disinfectants residuals, stagnation, and warm temperature) has a greater tendency to support growth and persistence of opportunistic pathogens.

Studies indicate that distribution systems can play a role in influencing the transmission and contamination of *Legionella* in premise plumbing systems (Lin et al., 1998; States et al., 2013). Hospitals served by PWSs using chloramines reported fewer outbreaks of legionellosis than those using free chlorine (Kool et al., 1999; Heffelfinger et al., 2003). Some building systems supplied by PWSs which have switched to chloramines have seen marked reduction in the colonization of *Legionella* (Flannery et al., 2006; Moore et al., 2006). One implication of these studies is the importance of being able to reliably measure and sustain chloramine residuals to increase the likelihood of its effectiveness at controlling *Legionella* in premise plumbing systems. On the other hand, some studies have indicated that the occurrence of another pathogen, non-tubercular Mycobacterium, may increase under chloramination conditions (Pryor et al., 2004; Moore et al., 2006; Duda et al., 2014).

Legionella species can multiply in warm, stagnant water environments, such as in community water storage tanks with low disinfectant residuals during warm months. Cohn et al. (2014) observed increased incidence of legionellosis among institutions and private homes near a community water system storage tank when the disinfectant residual in the storage tank dropped (from greater than 0.2 mg/L to less than 0.2 mg/L) during hot summer months. Based on these findings, the authors recommended that, regardless of total coliform occurrence, remedial actions be taken (e.g., flushing of mains, checking for closed valves that can result in hydraulic dead-ends, and possibly installing re-chlorination stations) when low chlorine residuals are observed during hot summer months. They also noted that this storage tank had been cleaned subsequent to the outbreak (Cohn et al., 2014; Ashbolt, 2015).

To help address concerns about *Legionella*, EPA developed a document entitled Technology for *Legionella* Control in Premise Plumbing Systems: Scientific Literature Review (USEPA, 2016h). This document summarizes information about the effectiveness of different approaches to control *Legionella* in a building's premise plumbing system. EPA expects that this document will improve public health protection by helping primacy agencies, facility operators, facility owners, technology developers and vendors make science-based risk management decisions to control of *Legionella* growth in buildings.

EPA also reviewed the scientific literature on the effectiveness of disinfectant residuals at controlling biofilm growth. Many factors influence the concentration of the disinfectant residual in the distribution system; and therefore, the ability of the residual to control microbial growth and biofilm formation. These factors include the availability of nutrients (such as assimilable

organic carbon (AOC)), the type and concentration of disinfectant, water temperature, pipe materials, and system hydraulics.

Biofilms in distribution systems have been associated with enhanced corrosion of pipes and deterioration of water quality. Biofilms can provide ecological niches that are suited to the potential survival of pathogens (Walker and Morales, 1997; Baribeau et al., 2005; Behnke et al., 2011; Wang et al., 2012; Biyela et al., 2012; Revetta et al., 2013; Ashbolt, 2015). The biofilm can protect microorganisms from disinfectants and can enhance nutrient accumulation and transport (Baribeau et al., 2005).

7.2.6 HPC Alternative to Detectable Residual Measurement

Under the SWTR, a system may demonstrate that its HPC levels are less than 500 per mL, at any sampling locations, in lieu of demonstrating the presence of a detectable disinfectant residual at that location, per primacy agency approval. Criteria used in the Netherlands for systems operating without a distribution system disinfectant residual provides an example of an alternative criteria than the HPC criterion. In the Netherlands, chlorine is not used routinely for primary or secondary disinfection. They focus on maintaining a high-quality distribution system with sufficient pressure to prevent ingress of contamination during normal operation (Smeets et al., 2009). The leakage rate in Netherlands is low, generally less than three percent. Variable pumps, pressure dampening devices and automated distribution control are used to minimize pressure fluctuations and surges that could result in negative pressure in the distribution system. Additionally, Dutch water systems use the following general approach to control microbial activity in the distribution system without a disinfectant residual (Smeets et al., 2009):

- Produce a biologically stable drinking water;
- Use distribution system materials that are non-reactive and biologically stable; and
- Optimize distribution system operations and maintenance practices to prevent stagnation and sediment accumulation.

For the determination of a biologically stable water they use AOC as an indicator. Aeration and sand filtration generally can achieve biostable water with AOC levels below 10 µg carbon per liter. All materials in the Netherlands have to be tested with the biofilm formation potential test before they can be used in drinking water. The majority of the distribution systems consist of biostable asbestos cement or polyvinyl chloride (Smeets et al., 2009).

7.2.7 Research and Information Collection Partnership Findings

EPA also reviewed key findings by the Research and Information Collection Partnership (RICP) on drinking water distribution system issues and research and information collection priorities. The RICP is a working group formed on the recommendation of the Total Coliform Rule Distribution System Advisory Committee to identify specific high-priority research and information collection activities and to stimulate water distribution system research and information collection (USEPA, 2008).

The RICP partners are EPA and Water Research Foundation. EPA examined information from the 10 high priority RICP areas in the context of the Six-Year Review, particularly information related to the effectiveness of sanitary survey and corrective action requirements under the IESWTR. However, the RICP found limited new information that would shed light on the frequency and magnitude of distribution system vulnerability events (e.g., backflow events, storage tank breaches), associated risk implication, and costs for preventing such events from occurring. The RICP report identifies potential follow-up research areas that could help to address these gaps (USEPA and Water Research Foundation, 2016).

7.3 CT Criteria for Virus Disinfection

7.3.1 Background

Primary drinking water treatment processes (e.g., coagulation and filtration) are less effective at removing viruses than removing other pathogen types of concern (e.g., bacteria and protozoa) (USEPA, 1991b). Therefore, the disinfection process is very important for inactivation of infectious viruses in drinking water. The efficacy of disinfection can be measured as a CT value. In the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (USEPA, 1991b), EPA recommends a CT value of 8 mg/L-min to achieve a 4-log inactivation of viruses with chlorine at 5 ºC, pH 6–9. EPA also recommends a CT value of 1,988 mg/L-min to achieve a 4-log inactivation of viruses with chloramines at 5 ºC, pH 8 (1991). EPA obtained these CT values from bench-scale inactivation experiments conducted in buffered, demand-free (BDF) water with dispersed hepatitis A virus (HAV) (USEPA, 1991b). Over the years, many studies have indicated that HAV is less chlorine-resistant than enteroviruses, such as Coxsackie virus B5 (CB5), and also less chloramine-resistant than adenovirus 2 (AD2). CB5 has generally been related to less severe health effects and a lower frequency of WBDOs compared to HAV. For example, CB5 causes hand, foot and mouth disease in children whereas HAV may cause hepatitis with significant inflammation of the liver when infection occurs later in life (Sinclair et al., 2005). In the EPA CCL selection process, HAV was ranked higher than enterovirus based on the WBDO, occurrence, and health effects of the pathogens (USEPA, 2009a).

More than 100 known enteric viruses can be excreted in large numbers in human feces of infected individuals and are potentially transmitted by water. Those of particular significance, either due to severity or frequency of infection include HAV, enteroviruses, Norwalk-type viruses, rotaviruses, adenoviruses and reoviruses. EPA included some of these viruses on the Contaminant Candidate List 2 (CCL2) (i.e., adenoviruses, caliciviruses, Coxsackie virus, and echoviruses), Contaminant Candidate List 3 (CCL3) (i.e., adenovirus, caliciviruses, enterovirus, and HAV) and Contaminant Candidate List 4 (CCL4) (i.e.., adenoviruses, caliciviruses, enterovirus, and HAV) as potential microbiological contaminants of concern in public drinking water systems (USEPA, 2005; 2009b and 2016i). The publication of the CCL2 and CCL3 has prompted new disinfection studies on the suite of CCL2 and CCL3 viruses. EPA reviewed these new studies, along with other relevant studies, as data/information sources as part of the Six-Year Review 3.

The analysis did not include *G. lamblia* disinfection or virus disinfection by other disinfectants (such as ozone, chlorine dioxide and UV light) because new information do not indicate a potential for a change to CT values for those disinfectants.

7.3.2 Summary of Technical Review

EPA evaluated whether the current CT criteria based on HAV (USEPA, 1991b) are sufficiently protective against other types of viruses. Many studies have indicated that HAV is less chlorine-resistant than some enteroviruses, such as Coxsackie virus B5 (Black et al., 2009; Cromeans et al., 2010; Keegan et al., 2012), and also less chloramine-resistant than adenovirus (Sirikanchana et al., 2008; Hill and Cromeans, 2010). Based on this review, EPA identified a potential need to update CT values for virus inactivation by free chlorine or chloramines, particularly for water with a relatively high pH. This assessment is also relevant to the LT2 and the GWR, which refer to the same CT tables in the original *1991 SWTR Guidance Manual* (USEPA, 1991b).

7.3.3 Basis of CT Values for Virus Inactivation in the EPA Guidance Manual

7.3.3.1 Free Chlorine

EPA developed CT values (USEPA, 1991b) for 2-, 3-, and 4-log virus inactivation by chlorine based on HAV data provided by Sobsey et al. (1988) in a research report. Sobsey et al. (1988) conducted bench-scale experiments with dispersed HAV in buffered, demand free (BDF) water at 5 ºC. To set the CT standards, EPA grouped CT values for pH range of 6 to 9 together, created a separate set of values for pH 10, and applied a safety factor of three to the original CT values. The EPA CT values for chlorine incorporate a safety factor of three to account for differences between dispersed versus aggregated HAV and the use of BDF versus environmental water. EPA determined CT values at temperatures other than 5 ºC by assuming a two-fold decrease in CT values for every 10 ºC increase. Exhibit 7.3 presents the CT values at 5 ºC from the original study and those established in the EPA guidance manual.

Exhibit 7.3: CT Values for Inactivation of HAV at 5 ºC

Log Inactivation	Sobsey et al. (1988)					USEPA (1991)	
	pH 6	pH 7	pH 8	pH 9	pH 10	pH 6–9	pH 10
Inactivation of HAV by 0.5 mg/L of Free Chlorine[1]							
2	1.18	0.70	1.00	1.25	9.8	4	30
3	1.75	1.07	1.51	1.9	14.6	6	44
4	2.33	1.43	2.03	2.55	19.3	8	60
Inactivation of HAV[5] by 10 mg/L of Chloramines[2]							
2	NA	NA	857	NA	NA	857	
3	NA	NA	1,423	NA	NA	1,423	
4	NA	NA	1,988	NA	NA	1,988	

[1] A safety factor of three was applied to the laboratory data to derive the EPA values.
[2] No safety factor was applied to the laboratory data to derive the EPA values. Pre-formed chloramines were used.
All units are mg/L-min.
NA = Not applicable because values at individual pH values was not provided.
HAV = Hepatitis A virus.

Sobsey et al. (1988) also generated data for Coxsackie virus B5 (CB5), and coliphages MS2 and bacteriophage ΦX174, and demonstrated that CB5 was more resistant to disinfection than HAV and MS2 and ΦX174 across the range of pH values tested (CB5 data in Section 7.3.5). EPA selected HAV as a target virus for setting the guidelines primarily because of the severity and frequency of the disease it caused (USEPA, 1991b).

7.3.3.2 Chloramines

EPA adopted the chloramines CT values from Sobsey et al. (1988) without applying a safety factor to their laboratory data (Exhibit 7.3). Sobsey et al. (1988) used preformed chloramines (i.e., chlorine mixed with ammonia before addition) in the laboratory experiments. However, in the field application of chloramines at a drinking water facility, systems often add chlorine prior to ammonia, which provides a very short, but sufficient contact with free chlorine to inactivate viruses that are resistant to chloramines, such as rotaviruses (USEPA, 1991b). Because field chloramination is more effective than the preformed chloramines used in the laboratory experiments, EPA did not apply a safety factor to the laboratory data. Systems that apply preformed chloramines, although not very common, should not use the EPA CT values as a guideline because they may not be adequate for inactivating rotaviruses (USEPA, 1991b).

In their study, Sobsey et al. determined monochloramine inactivation of HAV under only one experimental condition – pH 8, 5 ºC, and 10 mg/L of monochloramine. Since systems typically apply chloramines to drinking water at concentrations of 1 to 2 mg/L, contact times would have to be on the order of several hundred to even a few thousand minutes to achieve 4-log inactivation of HAV and other enteric viruses. Many water systems are not likely to achieve such long contact times. Therefore, systems often use free chlorine as a primary disinfectant to

achieve the EPA CT values, and chloramines as a secondary disinfectant to maintain a stable disinfectant residual in the distribution system and minimize trihalomethane (THM) or haloacetic acid (HAA) formation.

7.3.4 Information on Virus Inactivation by Free Chlorine

Since the development of the CT tables, researchers and others have published literature regarding virus disinfection, inactivation kinetics, CT value estimation, and recommendations. However, comparisons between their studies is difficult because of differences in the viruses examined, experimental conditions investigated, and analytical/calculation methods used. In general, the published data on different viruses tested shows the variability of inactivation observed for a range of viruses under different conditions. It is not the intent of this document to perform a meta-analysis of the published CT values. This document describes the relevant new information published since 2006, and refers to only a few older papers, as needed for context. Some researchers have examined both chlorine and chloramines disinfection in the same studies; results for chloramines are presented in Section 7.3.5. Relative Resistance of Viruses to Chorine Disinfection.

Black et al. (2009) conducted experiments in BDF water (5 ºC, pH 7.5 and 9.0) to determine the chlorine CT values for CB5, echovirus 1 and 12, and poliovirus 1 (PV-1). Exhibit 7.4 presents their reported CT values, along with the EPA required values. The results of this study suggest that commonly used concentrations of free chlorine and contact times at drinking water treatment plants (1 mg/L for 30 to 60 min) at a pH of 7.5 would inactivate all of the study viruses and meet the EPA requirements for 2-, 3-, and 4-log inactivation, except for CB5. At pH 9.0, CT values exceeded the EPA values by more than double for most of the viruses. This suggests that higher pH levels may require longer contact times to achieve adequate disinfection of CB5. The greater resistance of CB5 to chlorine disinfection is attributed to purified CB5 aggregating rapidly at all pH values (Jensen et. al., 1980).

Exhibit 7.4: CT Values for Virus Inactivation with 1.0 mg/L of Free Chlorine at 5ºC

pH	Log Inactivation	Black et al. (2009)[1,2]				USEPA (1991)
		CB5[3]	E1[4]	E12[4]	PV-1[5]	
7.5	2	**5.4**	1.6	2.1	1.4	4
	3	**8.4**	3.5	4.4	3	6
	4	**11.5**	6.2	7.4	5.3	8
9.0	2	**14**	3.3	**8.4**	**8.2**	4
	3	**18.7**	**8.5**	**18.5**	**14.7**	6
	4	**22.9**	**16.6**	**32.3**	**22.3**	8

[1] The Black et al. (2009) values do not include a safety factor, whereas the USEPA (1991) values do.
[2] CT values exceeding the EPA values are in bold font.
[3] Coxsackie virus (CB5).
[4] Echoviruses (E1 and E12).
[5] Poliovirus (PV-1).
All units are mg/L-min.

The Water Research Foundation co-sponsored a project (#3134) titled "Contaminant Candidate List Viruses: Evaluation of Disinfection Efficacy" (Hill and Cromeans, 2010). As part of this project, Cromeans et al. (2010) performed disinfection experiments on several human adenoviruses (AD2, AD40 and AD41), two Coxsackie viruses (CB3 and CB5), two echoviruses (E1 and E11) and murine norovirus (MNV, studied as a surrogate for human norovirus) with 0.2 mg/L of free chlorine and 1 mg/L of monochloramine at pH 7 and 8 in BDF water at 5ºC. The results of the free chlorine inactivation are shown in Exhibit 7.5 (the results for monochloramine are presented in Section 7.4.1). The enteroviruses (e.g., CB5) required the longest times for chlorine inactivation and MNV the least time. CB5 required the longest exposure time, with CT values of 7.4 and 10 for 4-log inactivation at pH 7 and 8, respectively. All the CT values obtained met the EPA values for 2-, 3- and 4-log inactivation, except for CB5 at pH 8.

Exhibit 7.5: CT Values for Virus Inactivation with 0.2 mg/L of Free Chlorine at 5ºC

pH	Log Inactivation	Cromeans et al. (2010)[1,2 3]								USEPA (1991)
		AD2[4]	AD40[4]	AD41[4]	CB3[5]	CB5[5]	E1[6]	E11[6]	MNV[7]	
7	2	0.02	<0.02	0.005	0.97	3.6	0.96	0.82	<0.02	4
	3	0.06	<0.02	0.01	1.4	5.5	1.3	1.0	<0.02	6
	4	0.15	<0.04	ND	2.9	7.4	1.5	1.1	<0.07	8
8	2	0.04	<0.02	<0.02	0.65	4.7	0.99	0.54	<0.02	4
	3	0.12	<0.02	<0.02	1.1	**7.6**	1.3	0.97	<0.02	6
	4	0.27	<0.04	<0.03	1.7	**10**	1.6	1.4	<0.08	8

[1] The Cromeans values do not include a safety factor, whereas the EPA values do.
[2] CT values exceeding the EPA values are in bold font.
[3] ND = no data. The CT value could not be extrapolated due to asymptotic inactivation curves.
[4] Adenoviruses (AD2, AD40 and AD41).
[5] Coxsackie viruses (CB3 and CB5).
[6] Echoviruses (E1 and E11).
[7] Murine norovirus (MNV).
All units are mg/L-min.

7.3.1.4 Effect of Cell Association and Virus Aggregation

Virus particles in water can exist as single particles, as aggregates or clumps (groupings of two or more virus particles) and associated with the host cellular material. Chlorine disinfection relies on the ability of the chemical disinfectants to come into contact with the target organism. Where solid particles are present, disinfection may be impeded because particles interfere with contact between the disinfectant and the target organism (Templeton et al., 2008). There is considerable evidence that most viruses in water are embedded in or associated with suspended solids and that such association often interferes with virus inactivation (Sobsey et al., 1991).

Sobsey et al. (1991) compared inactivation of cell-associated and dispersed HAV by free chlorine and chloramines. Exhibit 7.6 presents the CT values for 4-log inactivation of cell-associated and dispersed HAV from their study. These results indicate that cell-associated HAV was about tenfold more resistant than dispersed HAV to free chlorine at pH 6 and 8 and about fivefold more resistant at pH 10.

Exhibit 7.6: CT Values for 4-Log Inactivation of Cell-Associated and Dispersed HAV at 5ºC

Disinfectant	pH	Sobsey et al. (1991)[1]		CT Ratio of Cell-Associated vs. Dispersed HAV
		Cell-Associated HAV[2]	Dispersed HAV[2]	
Free Chlorine	6	29	2.3	12.6
	8	27	2	13.5
	10	104	19.3	5.4
Chloramines	8	1740	1225	1.4

[1] In 0.01 M phosphate-buffered, halogen-demand-free reagent water.
[2] Hepatitis A virus (HAV).
All units are mg/L-min.

Hill and Cromeans (2010) examined the effect of aggregation on disinfection efficacy for AD2 as it was the only study virus that successfully aggregated and retained a level of aggregation. The CT value for chorine disinfection of aggregated AD2 was twofold that of dispersed AD2 in a river source water (Exhibit 7.7).

Exhibit 7.7: CT Values for Inactivation of Aggregated and Dispersed AD2 at 5ºC and 0.2 mg/L Free Chlorine in a River Source Water

Log Inactivation	Hill and Cromeans (2010)		Ratio of Aggregated vs. Dispersed AD2
	Aggregated AD2	Dispersed AD2	
2	0.16	0.077	2.1
3	ND	0.15	Not applicable
4	ND	0.23	Not applicable

AD2 = Adenovirus.
ND = no data. The CT value could not be extrapolated due to asymptotic inactivation curves.
All units are mg/L-min.

7.3.4.2 Effect of Source Water Quality

Many researchers have performed disinfection studies on inactivation of viruses in purified and BDF, reagent-grade water. Previous studies conducted with natural waters demonstrated both increased and decreased disinfection efficacy of chlorine in these waters compared to purified or buffered waters (Thurston-Enriquez et al., 2003). Since EPA derived the CT values from inactivation experiments using dispersed HAV in BDF water, it is important to examine whether these CT values are sufficient for inactivation of viruses in natural source waters.

Kahler et al. (2010) investigated the effect of source water quality on chlorine inactivation of four viruses—CB5, E1, MNV and AD2—in one untreated groundwater source and two partially treated surface waters (obtained just prior to chemical disinfection). In all source water types, chlorine disinfection was most effective for MNV and least effective for CB5. Inactivation of the study viruses differed significantly between source water types, but there were no clear water

quality characteristics trends that were associated with the lowest or highest disinfection efficacy overall. However, CT values for CB5 in one partially treated river water exceeded the EPA CT values (Exhibit 7.8). The results of this study demonstrate that source water quality plays a substantial role in the inactivation of viruses and that water utilities should consider source water quality in their disinfection practices.

Exhibit 7.8: CT Values for 3-Log Virus Inactivation in a River Source Water with 0.2 mg/L of Free Chlorine

Temp. (ºC)	pH	Kahler et al. (2010)[1,2]				USEPA (1991)
		AD2	CB5	E1	MNV	
5	7	0.099	5.2	0.79	0.020	6
	8	0.12	**7.9**	1.2	0.031	6
15	7	0.063	2.0	0.48	<0.020	3
	8	0.061	**3.6**	0.84	0.020	3

[1] The Kahler et al. 2010 values do not include a safety factor, whereas the EPA values do.
[2] CT values exceeding the EPA values are in bold font.
All units are mg/L-min.
AD2 = Adenovirus, CB5 = Coxsackie virus, E1 = Echovirus, MNV = Murine norovirus.

Page et al. (2009) characterized the effects of pH, temperature and other relevant water quality parameters on the kinetics of AD2 inactivation with free chlorine. Over a pH range of 6.5 to 10, a temperature range of 1ºC to 30ºC and in a variety of water types, free chlorine was highly effective against AD2 (Page et al., 2009). They developed an inactivation model as a function of relevant water quality parameters and disinfectant exposure. The researchers noted that the model provided adequate representation for the free chlorine inactivation of AD2 and comparable results to those reported in the literature for other adenovirus serotypes (Page et al., 2009).

7.3.4.3 Determination of CT Values for CB5 in Recycled Water

In February 2013, the Australian Department of Health (ADOH) published disinfection guidelines for recycled waters, with virus CT values adopted from recent work by the Australia Water Quality Centre (Keegan et al., 2012). Keegan et al. conducted a detailed, comprehensive literature review on virus inactivation in drinking water and wastewater, including the following topics:

- Viruses and viral indicators of interest in wastewater effluents;
- Effects of temperature, pH, ionic strength, virus aggregation and particulates and turbidity on disinfection;
- Relative resistance of viruses to disinfection;
- Matrix effects;
- Use of laboratory versus environmental viruses to derive CT values;
- Virus selection matrix; and
- Methods for data analysis.

Keegan et al. (2012) concluded that while the EPA CT values for viruses were appropriate for drinking water with turbidity of < 1 NTU, research was needed to address a range of factors for recycled waters, such as target virus, resistance, state of the virus, particle protection, turbidity and ionic strength of the water. Therefore, the researchers conducted chlorine experiments with CB5 on secondary treated wastewater with various turbidities (0.2, 2, 5 and 20 NTU) and pH values (7, 8 and 9) at 10ºC (Keegan et al., 2012).

The secondary treated wastewater had undergone primary sedimentation, activated sludge treatment and clarification. The authors diluted the water with ultrapure water by 60 percent to obtain 600 mg/L of total dissolved solids to match Victoria wastewater treatment plant conditions. The authors adjusted the turbidity by either filtering water (0.2 NTU), diluting water (2 NTU), or concentrating water and resuspending particulates in water (5 and 20 NTU). In addition, the authors used BDF water at pH 9 to reproduce published data by Black et al. (2009) (data shown in Exhibit 7.10).

Exhibit 7.9 presents the results of Keegan et al.'s chlorine experiments and the CT values adopted in the Australian guidelines for recycled waters (ADOH, 2013). No safety factor was used to derive the CT values in the ADOH guidelines because of the use of the secondary treated wastewater, not BDF water. As shown in Exhibit 7.9, the CT values for the low turbidity water (<2 NTU) in the ADOH guidelines are similar to the EPA values at pH 7, but much higher at pH 8 and 9. For example, EPA requires a CT value of 8 mg/L-min (including a safety factor of 3) to achieve 4-log inactivation, whereas ADOH requires a CT value of 16 mg/L-min at pH 8 and 27 mg/L-min at pH 9, which are 2 and 3.4 times the EPA value, respectively.

Exhibit 7.9: CT Values for Inactivation of CB5 with Free Chlorine in Recycled Water at 10ºC

pH	Log Inactivation	Keegan et al. (2012)[1,4]			ADOH (2013)[2,4]		USEPA (1991)[3]
		Turbidity (NTU)			Turbidity (NTU)		
		0.2	2	5	<=2	<=5	
7	1	2.05	2.13	2.24	3	3	2
	2	3.29	3.37	3.71	4	4	4
	3	4.41	4.75	4.88	5	5	6
	4	5.44	5.46	5.99	6	7	8
8	1	**5.72**	**6.67**	**7.78**	**7**	**9**	2
	2	**9.6**	**10.32**	**13.16**	**10**	**13**	4
	3	**12.8**	**12.90**	**17.79**	**13**	**18**	6
	4	**15.49**	**15.68**	**21.94**	**16**	**23**	8
9	1	**8.25**	**8.94**	**9.66**	**10**	**10**	2
	2	**14.06**	**15.5**	**16.33**	**16**	**16**	4
	3	**19.10**	**20.88**	**22.03**	**21**	**23**	6
	4	**23.97**	**26**	**27.93**	**27**	**29**	8

[1] Chlorine dosages of 6.5 to 6.9 mg/L were used in the tests. CT values for 20 NTU turbidity tests are not shown because they were not used in the ADOH guideline.
[2] No safety factor was used.
[3] HAV was used for deriving the CT values at 5ºC. A safety factor of three was used.
[4] CT values exceeding the EPA values are in bold font.
All units are mg/L-min.

7.3.4.4 Comparison of CT Values for CB5

Exhibit 7.10 summarizes the CT values for inactivating CB5 at various pH values, as reported by different studies, and lists the key experimental parameters used in these studies. Among the four studies, only Sobsey et al. (1988) reported CT values for pH 6 and 10. In general, the CT values reported in Sobsey et al. (1998) are much higher than in other studies, which could be due to differences in the calculation methods explained later. Comparisons of CT values for pH 7 to 9 are described as follows:

Comparison of CT values for pH 7. The two sets of CT values by Cromeans et al. (2010) and Keegan et al. (2012) are comparable, being below the respective EPA values of 4, 6 and 8 for 2-, 3- and 4-log inactivation.

Comparison of CT values for pH 7.5. Only Black et al. (2009) reported data for this pH. For the rest of the studies, EPA believes the CT values for pH 7.5 were derived by averaging CT values for pH 7 and 8 (*numbers in italic*). All the CT values exceeded the respective EPA values of 4, 6

and 8 for 2-, 3- and 4-log of inactivation. Keegan et al. (2012)'s data are similar to Black et al. (2009).

Comparison of CT values for pH 8. Like for the pH 7.5 data, the Keegan et al. (2012) and the Black et al. (2009) data are similar for pH 8. All the CT values reported for pH 8 exceeded the respective EPA values of 4, 6 and 8 for 2-, 3- and 4-log of inactivation. Keegan's data are 55 percent to 104 percent higher than Cromeans et al. (2010) data.

Comparison of CT values for pH 9. All the CT values reported for pH 9 exceeded the respective EPA values of 4, 6 and 8 for 2-, 3- and 4-log of inactivation. Nonetheless, Keegan et al., (2012)'s two sets of data in different water matrices are very similar to Black et al. (2009)'s. Good correlation was observed between the 2 studies.

Exhibit 7.10: Comparison of CT Values for Inactivation of CB5 with Free Chlorine

pH	Log Inactivation	Sobsey et al. (1988)[1]	Black et al. (2009)	Cromeans et al. (2010)	Keegan et al. (2012)	USEPA (1991)[3]
		CT Values[5]				
6	2	3.5	No data			4
	3	4.4				6
	4	6.6				8
7	2	ND	ND	3.6	3.3	4
	3	ND	ND	5.5	4.4	6
	4	**12**	ND	7.4	5.4	8
7.5	2	ND	**5.4**	***4.2***[2]	***6.4***[2]	4
	3	ND	**8.4**	***6.6***[2]	***8.6***[2]	6
	4	***19.1***[2]	**11.5**	***8.7***[2]	***10.5***[2]	8
8	2	**13**	ND	**4.7**	**9.6**	4
	3	ND	ND	**7.6**	**12.8**	6
	4	**26.2**	ND	**10.0**	**15.5**	8
9	2	ND	**14**	ND	**14.49**	4
	3	ND	**18.7**	ND	**18.30**	6
	4	**54**	**22.9**	ND	**22.13**	8
10	2	**206**	No data			30
	3	ND				44
	4	**413**				60
		Experimental Conditions				

pH	Log Inactivation	Sobsey et al. (1988)[1]	Black et al. (2009)	Cromeans et al. (2010)	Keegan et al. (2012)	USEPA (1991)[3]
Water Matrix		0.01 M phosphate BDF water	0.01 M phosphate BDF water	0.01 M phosphate BDF water	0.01 M phosphate BDF water	NA
Temperature (ºC)		5	5	5	5	NA
Free Chlorine Residual (mg/L)		0.5	1.0	0.2	1.5	NA
Calculation Method		C × T[4]	EFH model	EFH model	Estimated by determining the area under chlorine decay curve of chlorine concentration vs. time	

[1] Data for selected pH and log of inactivation not found in the paper.
[2] EPA estimated data for pH 7.5 using average values of pH 7 and 8.
[3] HAV was used for deriving the CT values at 5ºC. A safety factor of three was used.
[4] EPA estimated the CT value by multiplying the initial chlorine concentration (0.5 mg/L) with time, which could lead to overestimation.
CT values exceeding the EPA values are in bold font.
NA = not applicable, ND = no data available, BDF = buffered, demand-free, EFH = efficiency factor hom.
All units are mg/L-min.

Black et al. (2009) and Cromeans et al. (2010) used the "Efficiency Factor Hom" (EFH) model to calculate CT for virus inactivation in BDF water. The EFH is a mathematical modeling method which uses free available chlorine values determined at the beginning, middle and end of each experiment to extrapolate CT values for viruses that do not achieve 4-log of inactivation in the time frame being tested. In this approach, a single rate constant of chlorine decay is used to calculate the integral. However, Keegan et al. (2012) could not use an EFH model because of the complex decay kinetics of chlorine in wastewater caused by the interaction of chlorine with ammonia, organic amines and other compounds in the wastewater. Therefore, they calculated the CT directly by determining the area under the chlorine decay curve of chlorine concentration versus time.

7.3.5 Information on Virus Inactivation by Chloramines

Systems use monochloramine primarily as a secondary disinfectant to maintain a stable disinfectant residual in the distribution system and to minimize DBP formation and biofilm growth. Chloramines are formed by the reaction of ammonia with aqueous chlorine and contain a mixture of monochloramine, dichloramine and/or trichloramine. The chloramine species distribution is controlled by pH and the chlorine to ammonia ratio. At pH 6 and above, monochloramine predominates. Monochloramine has a slow rate of diffusion through the cell wall; thus, it has been found to be less effective than free chlorine for virus disinfection (Baxter et al., 2007). In contrast to free chlorine, fewer studies have investigated the disinfection kinetics of chloramines for viruses systematically. Some researchers have examined chloramine

disinfection alongside chlorine disinfection and found a greater variation in inactivation rates among different viruses during monochloramine disinfection than during chlorine disinfection (Hill and Cromeans, 2010). This section describes information from the recent studies on virus disinfection by monochloramine.

7.3.5.1 Relative Resistance of Viruses to Monochloramine Disinfection

In the same study as discussed in Section 7.3, researchers obtained CT values for monochloramine disinfection at pH 7 and 8 in BDF water at 5ºC, as shown in Exhibit 7.11 (Hill and Cromeans, 2010; Cromeans et al., 2010). The study viruses each exhibited notable differences in their responses to monochloramine disinfection, both between and within virus types. For example, within virus types, differences in monochloramine 2-log CT values were 2- to 3-fold between CB5 and CB3, 5- to 10-fold between AD2 and AD41 and 110- to 130-fold between E11 and E1. Overall, E1 is the most susceptible to monochloramine disinfection while AD2 and E11 are the most resistant. At pH 8 and 5ºC, CT values for AD2 exceeded the EPA recommended values for 2-, 3- and 4-log of inactivation by 12 percent to 16 percent.

Exhibit 7.11: CT Values for Virus Inactivation with 1 mg/L of Monochloramine at 5ºC

pH	Log Inactivation	Cromeans et al. (2010)[1,2]								USEPA (1991)
		AD2[3]	AD40[3]	AD41[3]	CB3[4]	CB5[4]	E1[5]	E11[5]	MNV[6]	
7	2	600	90	58	270	510	8	**1,000**	26	857
	3	1,000	ND	190	390	710	15	1,300	70	1,423
	4	1,500	ND	ND	500	900	42	1,500	150	1,988
8	2	**990**	360	190	240	670	8	**880**	36	857
	3	**1,600**	ND	ND	330	900	18	1,200	78	1,423
	4	**2,300**	ND	ND	420	1,100	ND	1,400	170	1,988

[1] CT values exceeding the EPA values are in bold font.
[2] ND = no data. The CT value could not be extrapolated due to asymptotic inactivation curves.
[3] Adenoviruses (AD2, AD40 and AD41)
[4] Coxsackie viruses (CB3 and CB5)
[5] Echoviruses (E1 and E11)
[6] Murine norovirus (MNV)
All units are mg/L-min.

Baxter et al. (2007) examined the inactivation of AD2, AD5 and AD41 by UV light, free chlorine and monochloramine. They reported a CT value of 350 to achieve 2.5-log inactivation of AD5 and AD41 by monochloramine at pH 8.5 and 5ºC, whereas Cromeans et al. (2010) reported a CT value of 190 to achieve 2-log inactivation of AD41 at pH 8 and 5ºC (see Exhibit 7.10). Baxter et al. (2007) also reported no observed benefit in applying UV light prior to monochloramine, in terms of enhancing the effectiveness of monochloramine. This was

presumably due to different inactivation mechanisms of UV light (photochemical reaction with deoxyribonucleic acid (DNA)) and monochloramine (e.g., oxidation).

7.3.5.2 Effect of Virus Aggregation

In Hill and Cromeans' study (2010), for monochloramine disinfection on a river source water, the CT values for aggregated AD2 were 1.4 times as high as those for dispersed AD2, as shown in Exhibit 7.12. Sobsey et al. (1991) also reported a 1.4-fold difference between monochloramine CT values for cell-associated and dispersed HAV (Exhibit 7.6). The difference between CT values for cell-associated and dispersed viruses using free chlorine was as much as an order of magnitude, as shown in Exhibit 7.6. Thus, solids association/virus aggregation has a smaller influence on HAV and AD2 inactivation by monochloramine than on inactivation by free chlorine. This may be explained by the extended contact time required for monochloramine, which allows more time for the chemical to permeate the aggregate.

Exhibit 7.12: CT Values for Monochloramine Inactivation of Aggregated and Dispersed AD2 in River Source Water at 5ºC

Log Inactivation	Hill and Cromeans (2010)		Ratio of CT for Aggregated vs. Dispersed AD2
	Aggregated AD2	Dispersed AD2	
2	2,500	1,800	1.4
3	3,700	2,700	1.4
4	4,700	3,600	1.3

AD2 = Adenovirus
All units are mg/L-min.

7.3.5.3 CT Values for Adenoviruses

Although AD2 is one of the most susceptible viruses to chlorine disinfection, it is one of the most resistant viruses to monochloramine disinfection (Hill and Cromeans, 2010). Sirikanchana et al. (2008) performed experiments with a 0.01M buffer (phosphate or borate) solution to investigate the effect of pH, temperature, monochloramine concentration and ammonia-nitrogen -to-chlorine molar ratio on the inactivation kinetics of AD2 with monochloramine. Sirikanchana et al. (2008) found the inactivation kinetics to be independent of monochloramine concentration and ammonia-nitrogen-to-chlorine molar ratio but to have strong pH dependence, with the rate of inactivation decreasing with increasing pH. The kinetics at pH 6 and 8 were consistent with pseudo-first-order kinetics[14], while curves at pH 10 were characterized by a lag phase followed by a pseudo-first-order phase. The rate of inactivation also increased with increasing temperature. The results of this study indicate that monochloramine disinfection might not provide adequate control of adenoviruses in drinking water at high pH and low temperature.

[14] If the concentration of one reactant is in great excess, it can be approximated as a pseudo-first-order reaction (treating the reactant in excess concentration—in this case monochloramine—as a constant).

Inactivation kinetics and pH data for AD2 in Sirikanchana et al. (2008) were also consistent with Hill and Cromeans (2010).

Because recycled water often contains ammonia and preformed chloramines are rapidly formed on addition of chlorine, the EPA chloramines CT values are not applicable to recycled water. Therefore, Keegan et al. (2012) performed disinfection experiments on AD2 at various turbidities and pH values to develop CT values for recycled water (Keegan et al., 2012; ADOH, 2013). Exhibit 7.13 presents the results of their study and the corresponding CT values in the Australian guidelines for recycled water (ADOH, 2013). No safety factors were used to derive the CT values in the ADOH guidelines. Their CT values are significantly higher than the EPA values and those obtained by Sirikanchana et al. (2008), presumably due to the high turbidity and higher chloramine dosage used in the Keegan et al. (2012) study.

Exhibit 7.13: CT Values for Inactivation of AD2 by Chloramines in Recycled Water at 10ºC

pH	Log Inactivation	Keegan et al. (2012)[1,] Turbidity (NTU)		ADOH (2013)[2,4] Turbidity (NTU)		USEPA (1991)[3]
		2	5	<=2	<=5	
7	1	969	1,204	977	1,201	NA
	2	**1,688**	**1,903**	**1,681**	**1,914**	857
	3	**2,393**	**2,638**	**2,386**	**2,628**	1,423
	4	**3,082**	**3,337**	**3,090**	**3,341**	1,988
8	1	1,482	1,590	1,494	1,596	NA
	2	**2,326**	**2,546**	**2,318**	**2,541**	857
	3	**3,160**	**3,490**	**3,141**	**3,486**	1,423
	4	**3,949**	**4,426**	**3,965**	**4,431**	1,988
9	1	2,992	4,364	3,154	4,400	NA
	2	**4,592**	**6,032**	**4,393**	**5,967**	857
	3	**5,716**	**7,511**	**5,631**	**7,535**	1,423
	4	**6,746**	**9,096**	**6,870**	**9,102**	1,988

[1] Chloramine dosage of 15 mg/L was used in the tests. CT values for 20 NTU turbidity tests are not shown because they were not used in the ADOH guideline.

[2] No safety factor was used.

[3] HAV was used for deriving the CT values at 5ºC. No safety factor was used.

[4] CT values exceeding the EPA values are in bold font.

NA = not available.

All units are mg/L-min.

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Six-Year Review 3 Technical Support Document for Microbial Contaminant Regulations: Appendices

List of Appendices

Appendix A. Data Quality Assurance/Quality Control Documentation for SYR3 ICR Microbial Data

As part of the third Six-Year Review (SYR3), the Environmental Protection Agency (EPA) conducted a voluntary data call-in from the states, territories and tribes to obtain the data. The data call resulted in over 47 million compliance and water quality records collected between 2006 and 2011 delivered to EPA. The records within the SYR3 Information Collection Request (ICR) database were collected and analyzed using a rigorous quality assurance and quality control (QA/QC) process, which was designed to closely follow the process outlined in *The Data Management and Quality Assurance/Quality Control Process for the Third Six-Year Review Information Collection Rule Dataset* (USEPA, 2016e). See that report for the full details of the QA/QC process, as well as data acquisition, storage, management and preparation (for analysis).

For the purposes of reviewing the microbial and disinfectant residual data during SYR3, EPA compiled a dataset containing the records for total coliforms (TC), *E. coli* (EC), fecal coliform (FC) and field free and total chlorine residual (referred to as the "SYR3 ICR microbial dataset"). This appendix provides an overview of the data management steps applicable to the SYR3 ICR microbial data, highlighting when different approaches were used as compared to the chemical contaminants regulated under the Chemical Phase Rules and radionuclide contaminants and disinfection byproducts. As described below, a thorough QA/QC process was undertaken to evaluate the microbial dataset. Note that this QA process was not entirely the same as the process used for the Six-Year 2 data reviewed under the Revised Total Coliform Rule (RTCR).

Data Management Steps

A number of data management tasks were necessary to prepare the SYR3 datasets for QA/QC review and, ultimately, for data analysis. Some states/entities submitted their data using the EPA-provided Safe Drinking Water Information System (SDWIS) extract tool and other states/entities submitted their data "as is," in several in different formats. Whenever possible, EPA restructured the data submitted from the non-SDWIS states into the SDWIS state format.[1]

The SDWIS states submitted compliance monitoring data that contained TC/EC results paired with field chlorine residual data collected at the same time and location. With the exception of four tribal datasets (Region 1, Region 9, Navajo Nation and American Samoa), the non-SDWIS states did not submit their microbial data in that format. Many non-SDWIS states/entities did submit TC, EC and FC data but did not include the corresponding chlorine residual data. Other non-SDWIS states submitted their microbial data in summary form (e.g., one summary record for several water samples); these data were not uploaded to the SYR3 ICR database. For more details on these data management steps see USEPA (2016e).

[1] At the time of data collection for SYR3, about 75 percent of all states stored and managed at least portions of their compliance monitoring data in the Safe Drinking Water Information System/State Version (SDWIS/State). In an attempt to make the SYR3 data submittal process as easy for states as possible, EPA developed a SDWIS/State Extract Tool, which ran a customized query to pull the requested data from a SDWIS/State database. Nearly all of the states using SDWIS/State that submitted data to EPA for SYR3 used the SDWIS/State Extract Tool to extract and compile the EPA-requested compliance monitoring data.

SYR3 ICR Database Elements

The SYR3 ICR database includes data collected from states and primacy agencies. There are many different data elements to track items such as laboratory sample results, water system characteristics and QA/QC processes. A more detailed description of the data and collection efforts is available in USEPA (2016e).

For the purposes of conducting occurrence analyses, the data elements were grouped into several tables and combined using queries to create a coherent and usable dataset. The occurrence analyses often differ between Six-Year Review 3 contaminants, and certain elements were used in the SYR3 ICR microbial data analyses that may not be useful or relevant to other contaminants, and vice versa. Exhibit A.1 lists each of the data elements used for conducting microbial/disinfectant residual occurrence analyses, along with a brief description. Any fields that were included in the original datasets but are not listed below were not relevant to conducting the microbial/ disinfectant residual occurrence analyses presented in Chapter 6 of this support document.

Exhibit A.1: List of Primary SYR3 ICR Dataset Elements Used for Microbial and Disinfectant Residual Occurrence Analyses

Field Name	Description
Analyte ID	4-digit SDWIS analyte code
Analyte Name	Analyte name
State Code	Used to identify the state in which a system is located, including tribal systems.
PWSID	Public water system identification number (PWSID).
System Name	Water system name.
System Type	Water system type according to federal requirements. C = Community water system NC = Non-community water system NTNC = Non-transient non-community water system NP = Non-public water system
Retail Population Served	Retail population served by the water system.
Source Water Type	Primary water source for the water system. GU = Ground water under direct influence of surface water GUP = Purchased GU GW = Ground water GWP = Purchased GW SW = Surface water SWP = Purchased SW
Water Facility ID	Unique identifier for each water system facility.
Water Facility Type	Type of the water system facility.

Field Name	Description
	CC = consecutive connection; CH = common headers; CS = cistern; CW = clear well; DS = distribution system; IG = infiltration gallery; IN = intake; NP = non-piped, purchased; OT = other; PC = pressure control; PF = pumping facility; RS = reservoir; SP = spring; SS = sampling station; ST = storage; TM = transmission main (manifold); TP = treatment plant; WH = well head; WL = well; XX = unknown
Sampling Point ID	Unique identifier for each sample point.
Sampling Point Type	Location type of a sampling point. DS = distribution system; EP = entry point; FC = first customer; FN = finished water; LD = lowest disinfectant residual; MD = midpoint in the DS; MR = point of maximum residence; PC = process control; RW = raw water source; SR = source water point; UP = unit process; WS = water system facility point
Source Type	The type of water source, based on whether treatment has taken place. FN = Finished, treated; RW = Raw, untreated; XX = Unknown
Sample Type Code	Sample type code. CO = confirmation; DU = duplicate; FB = field blank; MR = maximum residence time; MS = matrix spike; OT = other; RP = repeat; RT = routine; RW = raw water; SB = shipping blank; SP = special; TE = technical evaluation
Six Year ID	Unique identifier for each sample analytical result. Used as primary key to link multiple tables.
Sample Collection Date	Sample collection date.
Detection Limit Value	Limit below which the specific lab indicated they could not reliably measure results for a contaminant with the methods and procedures used by the lab.
Detection Limit Unit	Units of the detection limit value
Detect	Added by EPA to indicate whether the result was a detection record (1) or a non-detection record (0), based off of the sample analytical result fields in the raw datasets.
Value	Actual numeric (decimal) value of the concentration for the chemical result. This value is equal to zero if the analytical result is less than the contaminant's MRL.
Units	Unit of measurement for the analytical results reported. All DBP records were converted to µg/L for analytical purposes. All TOC and alkalinity records were converted to mg/L for analytical purposes. Added by EPA.
Presence Indicator Code	Indicates whether results of an analysis were positive (P-Presence) or negative (A-Absence).
Field Free Chlorine Residual Measure	Amount of free chlorine residual (mg/L) found in the water after disinfection has been applied. These concentrations were measured in the field at the same time and location as coliform (TC-EC-FC) samples were collected.
Field Total Chlorine Residual Measure	Amount of total chlorine residual (mg/L) found in the water after disinfection has been applied. These concentrations were measured in the field at the same time and location as coliform (TC-EC-FC) samples were collected.

QA/QC Steps

The SYR3 ICR QA/QC effort encountered a range of data quality issues across contaminants and states/entities. Quality control measures were established to identify records that fit certain criteria using a two-step process. The first round of QA/QC was established at the time of data submission, when flags fitting exclusion criteria were run against a state's data submission. These QA/QC steps were applied to all regulated contaminant monitoring data in the SYR3 ICR database. See USEPA (2016e) for complete details on the first round of the SYR3 ICR QA/QC process. Similar to the process for the chemical contaminants, radionuclides and disinfection byproducts, the initial QA/QC steps were conducted on the SYR3 ICR microbial data.

The first round of QA/QC review resulted in the exclusion of any records that met any of the following criteria:

- Records marked with sample type codes other than routine, repeat, or confirmation;
- Records not marked as being for "compliance";
- Records from non-public water systems;
- Records from outside of the SYR3 date range; and
- Records from systems missing inventory information.

The second round of QA/QC procedures allows for the exclusion of records that did not have paired microbial and disinfectant residual data or do not fit within the contaminant's rule requirement context. Additional QA/QC steps were applied that were specific to the SYR3 ICR microbial dataset. The second round of QA/QC review resulted in the exclusion of any records that met any of the following criteria:

- Records from non-SDWIS states. SDWIS states reported field free and/or total chlorine residual data collected at the same time and location as the TC/EC data. TC and EC data from a total of 41 SDWIS and 5 non-SDWIS states were included in the SYR3 ICR database. Only SDWIS states' data (and some tribal data formatted just like the SDWIS states) were included in the final SYR3 ICR microbial dataset because those states submitted "paired" chlorine and coliform data.
- Records marked with a sample type code of confirmation. Only routine and repeat samples were used in the analysis.
- Records from water facility type codes other than distribution systems. Only data where TYPE_CODE = "DS" were included in the analysis.
- Free and/or total chlorine records paired with analytes other than TC/EC/FC. Only free and/or total chlorine records associated with TC, EC, or FC samples were included in the analysis.
- Records where PRESENCE_IND_CODE (presence indicator code) was null or not equal to either "A" (absent) or "P" (present).
- Records with a field free chlorine concentration greater than the total chlorine concentration.
- Records without any field free chlorine or total chlorine data.

- Records from Alabama, Louisiana and South Carolina. These states' data were identified as outliers since most of the TC samples submitted by these states were TC positive (TC+); these data were not considered to be representative of overall TC occurrence rates in Alabama, Louisiana and South Carolina.
- Records with a free chlorine concentration greater than 10 mg/L and records with a total chlorine concentration greater than 20 mg/L. These high values were considered to be potential outliers.
- TC positive (TC+) results without a corresponding EC/FC result and EC/FC results without a corresponding TC+ result. Note that this step was not applied to the disinfectant residual data used in Section 6.2 analyses. However, these TC/EC/FC records were excluded from the Section 6.3 analyses.

After applying the filter protocol to more than 12 million SYR3 ICR microbial data records and almost 9 million free and/or total chlorine records, almost 6 million SYR3 ICR microbial data records remained in the final dataset that was used for conducting occurrence analyses. (Note that a subset of these 6 million records were used for the analyses in Section 6.3). Exhibit A.2 documents the specific counts of records included and excluded in each step for the three contaminants and for the disinfectant residuals.

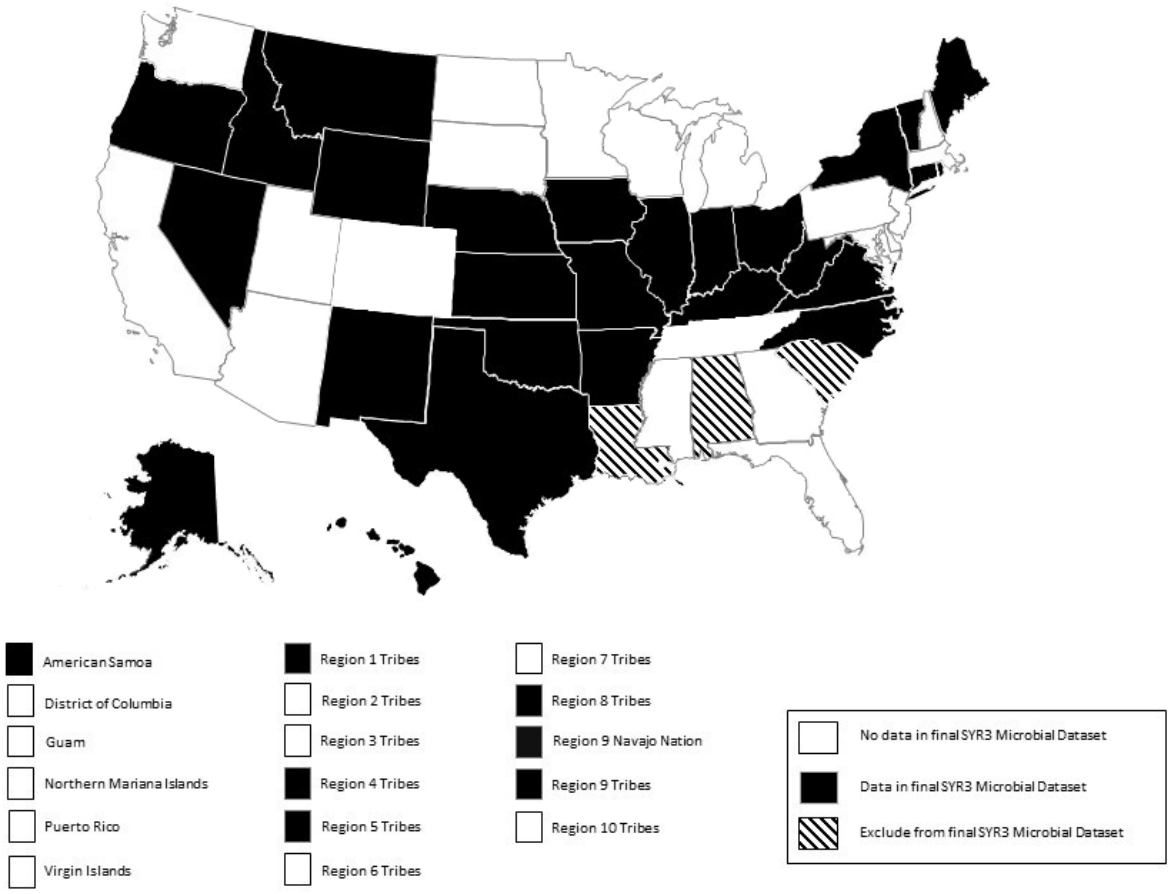
Exhibit A.2: QA Steps for the SYR3 ICR Microbial Data

Step	Total Coliforms		*E. coli*		Fecal Coliform		Field Free Chlorine		Field Total Chlorine	
	Included	Excluded	Included	Excluded	Included	Excluded	Included	Excluded	Included	Excluded
Original Records	9,953,551		1,833,281		281,642		5,273,525		3,489,849	
Step 1: Initial QA (Applied to all SYR3 contaminants)[1]	9,766,686	186,865	1,804,329	28,952	264,090	17,552	5,181,269	92,256	3,451,496	38,353
Step 2: Removal of records from Non-SDWIS states	8,616,753	1,149,933	1,632,695	171,634	113,608	150,482	5,181,269	0	3,451,496	0
Step 3: Removal of records marked with sample type code of "confirmation" (This analysis included "routine" and "repeat" samples.)	8,616,074	679	1,632,093	602	113,608	0	5,181,194	75	3,451,423	73
Step 4: Removal of non-distribution system samples	8,283,060	333,014	1,396,310	235,783	108,452	5,156	4,513,013	668,181	3,217,731	233,692
Step 5: Removal of non-TC/EC/FC samples	8,283,060	0	1,396,310	0	108,452	0	4,172,134	340,879	2,680,319	537,412
Step 6: Removal of records where PRESENCE_IND_CODE (presence indicator code) was null or not equal to either "A" (absent) or "P" (present)	7,984,551	298,509	1,363,400	32,910	103,608	4,844	4,171,861	273	2,679,444	875
Step 7: Removal of records with field free chlorine concentration greater than total chlorine concentration	7,829,837	154,714	1,362,436	964	103,570	38	4,016,145	155,716	2,523,728	155,716
Step 8: Removal of records without any field free or total chlorine data	4,757,381	3,072,456	892,091	470,345	64,335	39,235	4,016,145	0	2,523,728	0
Step 9: Removal of records from AL, LA and SC	4,750,983	6,398	889,683	2,408	64,306	29	4,007,768	8,377	2,521,983	1,745
Step 10: Removal of high free chlorine concentrations > 10 mg/L; Removal of high total chlorine concentrations > 20 mg/L	4,750,432	551	889,570	113	64,304	2	4,007,235	533	2,521,771	212
Final number of records in the SYR3 microbial dataset used for Section 6.2 analyses	**4,750,432**		**889,570**		**64,304**		**4,007,235**		**2,521,771**	
Percent Included for Section 6.2 Analysis	**47.7%**		**48.5%**		**22.8%**		**76.0%**		**72.3%**	
Step 11: Removal of remaining TC positive (TC+) records without a corresponding EC/FC result or EC/FC result without a corresponding TC+ result	4,749,332	1,100	35,889	853,681	3,781	60,523	3,423,730	583,505	2,140,638	381,133
Final number of records in the SYR3 microbial dataset used for Section 6.3 analyses	**4,749,332**		**35,889**		**3,781**		**3,423,730**		**2,140,638**	
Percent Included for Section 6.3 Analysis	**47.7%**		**2.0%**		**1.3%**		**64.9%**		**61.3%**	

[1] The first round of QA/QC included the basic suite of QA/QC steps that were performed on the whole dataset. This QA/QC review resulted in the exclusion of any records that met the following criteria: (1) records marked with sample type codes other than routine, repeat, or confirmation; (2) records not marked as being for “compliance”; (3) records from non-public water systems; (4) records from outside of the SYR3 date range; and (5) records from systems missing inventory information.

As described above, EPA deemed the current QA/QC process to be sufficient for a dataset of this size. The QA/QC process excluded records that were identified as not being appropriate for this analysis, yielding a final dataset to be used as a basis for analysis. The final SYR3 ICR microbial dataset consists of compliance monitoring data received from 34 states/primacy agencies representing a large sample of paired TC/EC and disinfectant residual data. Exhibit A.3 presents a map of the 34 states/entities with data in the final SYR3 ICR microbial dataset.

Exhibit A.3: States/Entities with Data in SYR3 ICR Microbial Dataset



The final SYR3 ICR microbial dataset includes almost 6 million records of paired coliform and disinfectant residual data from 34 states over a six-year period. Data from both surface water systems and ground water systems are included, as well as all three system types (i.e., community water systems, non-transient non-community water systems and transient water systems) and all system sizes. The 34 states with data are distributed across the entire United States. The final SYR3 ICR microbial dataset enabled the analyses to be conducted with

different stratifications, such as by source water type, system size, system type, etc. An exploration of potential annual, seasonal and geographic trends was also possible using these data.

A few limitations of the final SYR3 ICR microbial dataset are noted. An initial evaluation of the completeness of these data exposed a large degree of variability in the number of records provided by water systems from state to state. The number of records range from one record from the State of Maine to almost 900,000 records from the State of Illinois. For the State of Maine, only one record (from 2008) passed all of the QA/QC steps when preparing the final SYR3 ICR microbial dataset. Very few TC/EC records from Maine had paired chlorine residual data in the SYR3 ICR database. Other states' data were similar to Maine (i.e., the state provided a large amount of TC/EC data but only a small portion of those data were paired with chlorine residual concentrations). Furthermore, there are also many states and some regions of the U.S. whose data are missing from the analysis. As discussed previously, only the data from SDWIS states were included in the final SYR3 ICR microbial dataset. The SDWIS states provided TC/EC data in a usable format that were also paired with disinfectant residual data.

Appendix B. Additional Analyses on the Disinfectant Residuals in Distribution Systems

This appendix provides the analytical results for surface water and ground water systems that were not presented within the body of Chapter 6. This appendix also includes an evaluation of the occurrence related to disinfectant residuals in distribution systems relative to system type and system size, as well as seasonal changes, annual trends and geographic distribution.

Exhibit B.1 through Exhibit B.6 present a breakdown of the counts of free and total chlorine data associated with total coliform samples, and the systems providing those data, by source water type, system type and system size for each year of data. These results are presented for the years 2006 through 2011.

Exhibit B.1: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2006

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	1,517	585	14,426	6,659
		101-500	2,322	1,138	25,011	17,017
		501-1,000	847	557	10,835	9,393
		1,001-4,100	1,103	756	30,518	20,061
		4,101-33,000	552	302	65,641	29,432
		33,001-100,000	56	32	31,767	13,255
		>100,000	8	3	7,472	127
		Total GW	**6,405**	**3,373**	**185,670**	**95,944**
	SW	≤100	230	94	2,882	1,946
		101-500	527	337	5,906	5,970
		501-1,000	266	212	3,493	3,962
		1,001-4,100	629	527	18,801	15,343
		4,101-33,000	614	381	77,801	40,298
		33,001-100,000	92	47	52,900	23,466
		>100,000	29	21	33,839	24,266
		Total SW	**2,387**	**1,619**	**195,622**	**115,251**
TNCWSs	GW	≤100	3,114	898	12,654	4,392
		101-500	710	262	3,424	1,117
		501-1,000	79	16	480	74
		1,001-4,100	36	5	562	49
		4,101-33,000	2	0	80	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**3,941**	**1,181**	**17,200**	**5,632**
	SW	≤100	170	31	1,436	253

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		101-500	76	10	676	84
		501-1,000	9	2	97	20
		1,001-4,100	8	0	97	0
		4,101-33,000	5	0	147	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**268**	**43**	**2,453**	**357**
NTNCWSs	GW	≤100	769	172	3,844	1,217
		101-500	573	170	3,244	1,218
		501-1,000	156	37	1,098	345
		1,001-4,100	87	33	1,727	704
		4,101-33,000	6	2	273	56
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**1,591**	**414**	**10,186**	**3,540**
	SW	≤100	40	13	462	120
		101-500	55	18	669	169
		501-1,000	18	8	237	162
		1,001-4,100	19	12	391	189
		4,101-33,000	0	0	0	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**132**	**51**	**1,759**	**640**
Total	GW	≤100	5,400	1,655	30,924	12,268
		101-500	3,605	1,570	31,679	19,352
		501-1,000	1,082	610	12,413	9,812
		1,001-4,100	1,226	794	32,807	20,814
		4,101-33,000	560	304	65,994	29,488
		33,001-100,000	56	32	31,767	13,255
		>100,000	8	3	7,472	127
		Total GW	**11,937**	**4,968**	**213,056**	**105,116**
	SW	≤100	440	138	4,780	2,319
		101-500	658	365	7,251	6,223
		501-1,000	293	222	3,827	4,144
		1,001-4,100	656	539	19,289	15,532
		4,101-33,000	619	381	77,948	40,298
		33,001-100,000	92	47	52,900	23,466
		>100,000	29	21	33,839	24,266
		Total SW	**2,787**	**1,713**	**199,834**	**116,248**

Exhibit B.2: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2007

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	2,108	574	19,777	7,288
		101-500	3,223	1,233	31,136	18,136
		501-1,000	1,061	639	11,328	9,980
		1,001-4,100	1,394	864	32,317	22,033
		4,101-33,000	648	380	65,110	35,168
		33,001-100,000	72	46	31,424	15,282
		>100,000	13	12	5,116	2,424
		Total GW	**8,519**	**3,748**	**196,208**	**110,311**
	SW	≤100	280	101	3,788	1,935
		101-500	626	356	7,272	6,007
		501-1,000	297	234	4,010	3,939
		1,001-4,100	740	579	20,888	15,669
		4,101-33,000	688	426	86,009	44,094
		33,001-100,000	114	66	56,885	26,382
		>100,000	50	38	48,931	25,738
		Total SW	**2,795**	**1,800**	**227,783**	**123,764**
TNCWSs	GW	≤100	3,531	977	13,992	4,167
		101-500	940	265	4,413	1,123
		501-1,000	105	19	585	67
		1,001-4,100	42	5	720	60
		4,101-33,000	2	0	67	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**4,620**	**1,266**	**19,777**	**5,417**
	SW	≤100	173	16	1,460	192
		101-500	83	9	763	57
		501-1,000	15	4	131	29
		1,001-4,100	9	2	141	2
		4,101-33,000	6	1	173	18
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**286**	**32**	**2,668**	**298**
NTNCWSs	GW	≤100	932	168	4,974	1,039
		101-500	776	143	5,073	913
		501-1,000	217	37	1,645	337
		1,001-4,100	127	28	2,484	602
		4,101-33,000	9	1	508	96
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**2,061**	**377**	**14,684**	**2,987**
	SW	≤100	52	8	590	72
		101-500	61	13	698	137
		501-1,000	22	7	281	144
		1,001-4,100	23	10	568	171

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		4,101-33,000	1	0	200	0
		33,001-100,000	1	0	321	0
		>100,000	0	1	0	2
		Total SW	**160**	**39**	**2,658**	**526**
Total	GW	≤100	6,571	1,719	38,743	12,494
		101-500	4,939	1,641	40,622	20,172
		501-1,000	1,383	695	13,558	10,384
		1,001-4,100	1,563	897	35,521	22,695
		4,101-33,000	659	381	65,685	35,264
		33,001-100,000	72	46	31,424	15,282
		>100,000	13	12	5,116	2,424
		Total GW	**15,200**	**5,391**	**230,669**	**118,715**
	SW	≤100	505	125	5,838	2,199
		101-500	770	378	8,733	6,201
		501-1,000	334	245	4,422	4,112
		1,001-4,100	772	591	21,597	15,842
		4,101-33,000	695	427	86,382	44,112
		33,001-100,000	115	66	57,206	26,382
		>100,000	50	39	48,931	25,740
		Total SW	**3,241**	**1,871**	**233,109**	**124,588**

Exhibit B.3: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2008

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	2,122	611	19,635	8,062
		101-500	3,256	1,310	30,325	20,084
		501-1,000	1,097	653	11,357	11,328
		1,001-4,100	1,462	874	32,509	24,211
		4,101-33,000	690	399	66,799	38,883
		33,001-100,000	72	48	30,168	16,525
		>100,000	16	10	5,152	2,932
		Total GW	**8,715**	**3,905**	**195,945**	**122,025**
	SW	≤100	301	98	3,764	2,037
		101-500	664	338	7,370	5,984
		501-1,000	319	226	4,061	4,327
		1,001-4,100	778	539	20,573	16,605
		4,101-33,000	701	441	86,742	48,029
		33,001-100,000	126	69	60,460	27,661
		>100,000	59	43	49,113	29,994
		Total SW	**2,948**	**1,754**	**232,083**	**134,637**
TNCWSs	GW	≤100	3,655	1,133	15,054	5,923
		101-500	1,080	328	4,873	1,594

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		501-1,000	113	20	655	113
		1,001-4,100	40	5	666	62
		4,101-33,000	2	0	9	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**4,890**	**1,486**	**21,257**	**7,692**
	SW	≤100	194	26	1,465	311
		101-500	98	9	866	68
		501-1,000	18	3	163	19
		1,001-4,100	13	0	172	0
		4,101-33,000	7	0	193	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**330**	**38**	**2,859**	**398**
NTNCWSs	GW	≤100	1,011	185	5,332	1,441
		101-500	823	140	5,300	1,314
		501-1,000	224	33	1,669	363
		1,001-4,100	138	31	2,837	809
		4,101-33,000	10	3	735	96
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**2,206**	**392**	**15,873**	**4,023**
	SW	≤100	58	13	566	95
		101-500	67	18	751	199
		501-1,000	23	8	309	127
		1,001-4,100	24	11	579	206
		4,101-33,000	1	0	479	0
		33,001-100,000	1	0	960	0
		>100,000	0	0	0	0
		Total SW	**174**	**50**	**3,644**	**627**
Total	GW	≤100	6,788	1,929	40,021	15,426
		101-500	5,159	1,778	40,498	22,992
		501-1,000	1,434	706	13,681	11,804
		1,001-4,100	1,640	910	36,012	25,082
		4,101-33,000	702	402	67,543	38,979
		33,001-100,000	72	48	30,168	16,525
		>100,000	16	10	5,152	2,932
		Total GW	**15,811**	**5,783**	**233,075**	**133,740**
	SW	≤100	553	137	5,795	2,443
		101-500	829	365	8,987	6,251
		501-1,000	360	237	4,533	4,473
		1,001-4,100	815	550	21,324	16,811
		4,101-33,000	709	441	87,414	48,029
		33,001-100,000	127	69	61,420	27,661
		>100,000	59	43	49,113	29,994
		Total SW	**3,452**	**1,842**	**238,586**	**135,662**

Exhibit B.4: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2009

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	2,533	828	24,830	8,791
		101-500	4,098	1,835	41,508	23,046
		501-1,000	1,494	963	16,806	13,640
		1,001-4,100	2,135	1,371	50,892	31,497
		4,101-33,000	1,028	683	94,543	53,510
		33,001-100,000	88	60	34,748	19,776
		>100,000	17	8	8,032	5,507
		Total GW	**11,393**	**5,748**	**271,359**	**155,767**
	SW	≤100	335	147	4,081	2,675
		101-500	749	481	7,854	6,807
		501-1,000	380	326	4,447	5,151
		1,001-4,100	851	788	20,767	20,754
		4,101-33,000	785	597	85,783	59,941
		33,001-100,000	131	82	62,258	35,915
		>100,000	66	48	54,371	44,898
		Total SW	**3,297**	**2,469**	**239,561**	**176,141**
TNCWSs	GW	≤100	4,121	1,437	18,351	6,789
		101-500	1,407	544	8,458	2,530
		501-1,000	146	51	1,090	319
		1,001-4,100	51	14	936	147
		4,101-33,000	1	0	1	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**5,726**	**2,046**	**28,836**	**9,785**
	SW	≤100	198	49	1,667	373
		101-500	112	15	1,045	107
		501-1,000	21	5	194	55
		1,001-4,100	13	2	202	37
		4,101-33,000	6	0	134	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**350**	**71**	**3,242**	**572**
NTNCWSs	GW	≤100	1,203	317	7,594	2,260
		101-500	1,027	250	7,744	1,923
		501-1,000	270	68	2,292	515
		1,001-4,100	188	63	4,112	1,304
		4,101-33,000	16	5	972	320
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**2,704**	**703**	**22,714**	**6,322**
	SW	≤100	67	20	663	191
		101-500	101	44	1,043	390
		501-1,000	24	11	354	138

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		1,001-4,100	25	11	634	227
		4,101-33,000	3	1	566	72
		33,001-100,000	1	0	958	0
		>100,000	0	1	0	1
		Total SW	**221**	**88**	**4,218**	**1,019**
Total	GW	≤100	7,857	2,582	50,775	17,840
		101-500	6,532	2,629	57,710	27,499
		501-1,000	1,910	1,082	20,188	14,474
		1,001-4,100	2,374	1,448	55,940	32,948
		4,101-33,000	1,045	688	95,516	53,830
		33,001-100,000	88	60	34,748	19,776
		>100,000	17	8	8,032	5,507
		Total GW	**19,823**	**8,497**	**322,909**	**171,874**
	SW	≤100	600	216	6,411	3,239
		101-500	962	540	9,942	7,304
		501-1,000	425	342	4,995	5,344
		1,001-4,100	889	801	21,603	21,018
		4,101-33,000	794	598	86,483	60,013
		33,001-100,000	132	82	63,216	35,915
		>100,000	66	49	54,371	44,899
		Total SW	**3,868**	**2,628**	**247,021**	**177,732**

Exhibit B.5: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2010

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	2,603	975	26,126	10,761
		101-500	4,129	2,062	44,071	27,820
		501-1,000	1,577	1,068	19,086	16,072
		1,001-4,100	2,267	1,606	56,510	40,331
		4,101-33,000	1,175	839	113,404	73,342
		33,001-100,000	103	69	41,646	28,179
		>100,000	16	14	9,805	10,876
		Total GW	**11,870**	**6,633**	**310,648**	**207,381**
	SW	≤100	327	170	4,111	3,711
		101-500	770	530	8,534	8,987
		501-1,000	384	362	4,780	6,065
		1,001-4,100	821	866	22,271	26,151
		4,101-33,000	877	720	105,667	77,859
		33,001-100,000	152	111	78,231	54,877
		>100,000	85	60	84,004	80,354

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		Total SW	**3,416**	**2,819**	**307,598**	**258,004**
TNCWSs	GW	≤100	4,084	1,406	18,796	8,089
		101-500	1,459	598	8,755	3,128
		501-1,000	174	62	1,244	449
		1,001-4,100	71	27	1,222	342
		4,101-33,000	1	0	3	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**5,789**	**2,093**	**30,020**	**12,008**
	SW	≤100	222	99	1,685	492
		101-500	118	24	1,140	319
		501-1,000	25	9	207	104
		1,001-4,100	14	4	240	33
		4,101-33,000	6	1	130	2
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**385**	**137**	**3,402**	**950**
NTNCWSs	GW	≤100	1,238	371	7,764	2,676
		101-500	1,089	336	8,005	2,354
		501-1,000	284	97	2,328	748
		1,001-4,100	211	98	5,066	2,213
		4,101-33,000	16	6	917	307
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**2,838**	**908**	**24,080**	**8,298**
	SW	≤100	70	24	633	409
		101-500	99	49	1,057	495
		501-1,000	21	10	293	144
		1,001-4,100	25	14	806	402
		4,101-33,000	4	1	616	69
		33,001-100,000	1	0	961	0
		>100,000	0	0	0	0
		Total SW	**220**	**98**	**4,366**	**1,519**
Total	GW	≤100	7,925	2,752	52,686	21,526
		101-500	6,677	2,996	60,831	33,302
		501-1,000	2,035	1,227	22,658	17,269
		1,001-4,100	2,549	1,731	62,798	42,886
		4,101-33,000	1,192	845	114,324	73,649
		33,001-100,000	103	69	41,646	28,179
		>100,000	16	14	9,805	10,876
		Total GW	**20,497**	**9,634**	**364,748**	**227,687**
	SW	≤100	619	293	6,429	4,612
		101-500	987	603	10,731	9,801
		501-1,000	430	381	5,280	6,313
		1,001-4,100	860	884	23,317	26,586
		4,101-33,000	887	722	106,413	77,930
		33,001-100,000	153	111	79,192	54,877

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		>100,000	85	60	84,004	80,354
		Total SW	**4,021**	**3,054**	**315,366**	**260,473**

Exhibit B.6: Summary of Free and Total Chlorine Residual Data by Source Water Type, System Type and System Size in 2011

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
CWSs	GW	≤100	2,706	936	28,625	11,300
		101-500	4,204	2,014	47,382	28,496
		501-1,000	1,615	1,052	20,510	16,388
		1,001-4,100	2,278	1,614	61,358	43,850
		4,101-33,000	1,165	851	120,392	80,041
		33,001-100,000	95	67	44,058	30,694
		>100,000	22	14	11,437	12,426
		Total GW	**12,085**	**6,548**	**333,762**	**223,195**
	SW	≤100	319	182	4,221	3,878
		101-500	783	550	8,697	9,540
		501-1,000	379	371	4,824	6,535
		1,001-4,100	833	876	22,269	27,773
		4,101-33,000	883	720	111,969	86,737
		33,001-100,000	160	108	84,968	61,261
		>100,000	77	62	91,970	89,558
		Total SW	**3,434**	**2,869**	**328,918**	**285,282**
TNCWSs	GW	≤100	4,171	1,444	20,440	8,492
		101-500	1,529	620	9,960	3,783
		501-1,000	193	65	1,450	464
		1,001-4,100	79	26	1,336	439
		4,101-33,000	0	0	0	0
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**5,972**	**2,155**	**33,186**	**13,178**
	SW	≤100	229	44	1,931	468
		101-500	115	26	1,200	359
		501-1,000	28	9	233	91
		1,001-4,100	16	1	313	12
		4,101-33,000	6	1	216	1
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total SW	**394**	**81**	**3,893**	**931**
NTNCWSs	GW	≤100	1,277	361	9,019	2,893
		101-500	1,137	329	8,968	2,389
		501-1,000	300	102	2,450	832
		1,001-4,100	213	94	5,308	2,443

System Type	Source Water Type	Population Served Size Category	Number of Systems with Routine TC Samples		Number of Routine TC Samples	
			Free Chlorine	Total Chlorine	Free Chlorine	Total Chlorine
		4,101-33,000	15	6	1,100	346
		33,001-100,000	0	0	0	0
		>100,000	0	0	0	0
		Total GW	**2,942**	**892**	**26,845**	**8,903**
	SW	≤100	71	24	730	524
		101-500	91	48	1,053	564
		501-1,000	21	10	316	143
		1,001-4,100	25	13	837	450
		4,101-33,000	7	2	759	107
		33,001-100,000	1	0	956	0
		>100,000	0	0	0	0
		Total SW	**216**	**97**	**4,651**	**1,788**
Total	GW	≤100	8,154	2,741	58,084	22,685
		101-500	6,870	2,963	66,310	34,668
		501-1,000	2,108	1,219	24,410	17,684
		1,001-4,100	2,570	1,734	68,002	46,732
		4,101-33,000	1,180	857	121,492	80,387
		33,001-100,000	95	67	44,058	30,694
		>100,000	22	14	11,437	12,426
		Total GW	**20,999**	**9,595**	**393,793**	**245,276**
	SW	≤100	619	250	6,882	4,870
		101-500	989	624	10,950	10,463
		501-1,000	428	390	5,373	6,769
		1,001-4,100	874	890	23,419	28,235
		4,101-33,000	896	723	112,944	86,845
		33,001-100,000	161	108	85,924	61,261
		>100,000	77	62	91,970	89,558
		Total SW	**4,044**	**3,047**	**337,462**	**288,001**

[1] There is some overlap between the free chlorine and total chlorine groups (i.e., some TC records were associated with both free and total chlorine residual concentrations). See Section 6.1.1 for a more detailed description about the records that were associated with both free and total chorine residual concentrations and the possible implications on the data analysis.

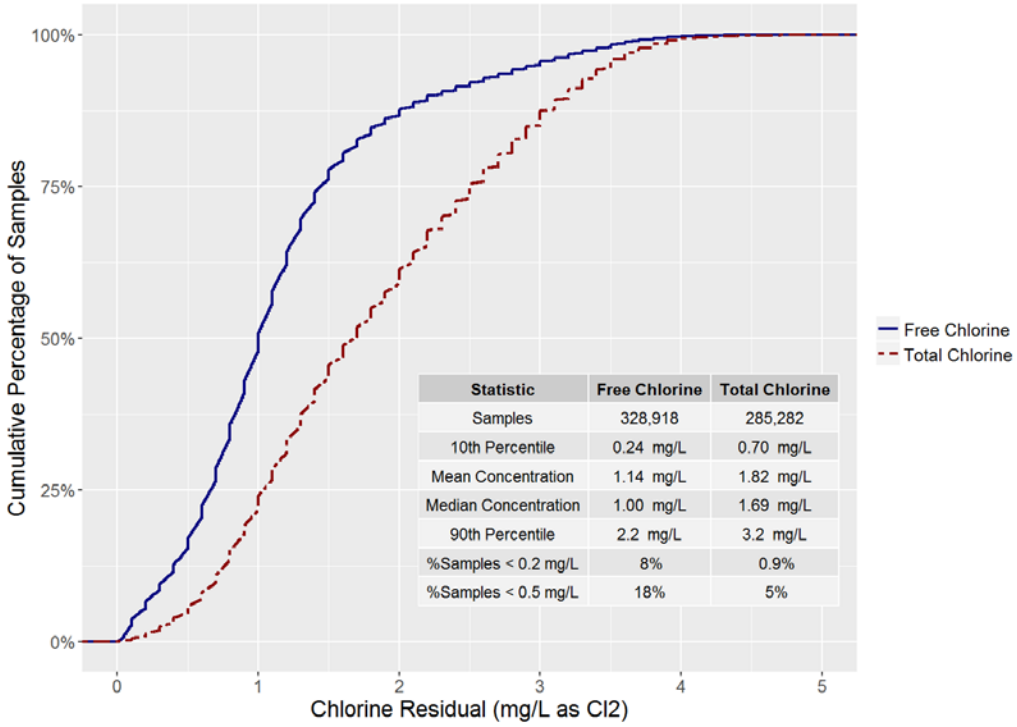
The remaining exhibits of this appendix (Exhibit B.7 through Exhibit B.24) present an evaluation of the occurrence relative to system type, system size, seasonal changes, annual trends and geographic distribution. The majority of these analyses focus on data for the year 2011, primarily for community water systems only.

System Type

Exhibit B.7 and Exhibit B.8 are cumulative distribution plots presenting the free and total chlorine residual concentrations in surface water community water systems and non-community water systems, respectively, for the year 2011. Exhibit B.9 and Exhibit B.10 are cumulative distribution plots presenting the free and total chlorine residual concentrations in ground water community water systems and non-community water systems, respectively, for the year 2011.

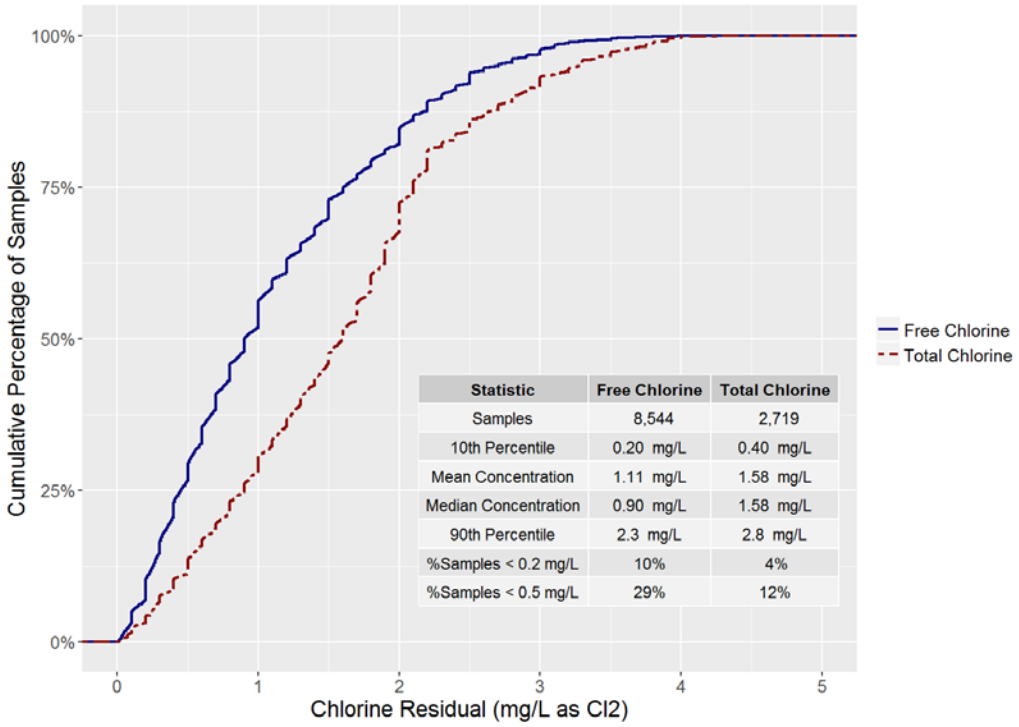
Exhibit B.7 (samples from surface water CWSs) is very similar to the results from all surface water systems (CWSs and NCWS, as shown in Exhibit 6.5), as expected, given that the vast majority of the surface water samples came from CWSs (e.g., 337,462 free chlorine samples from surface water systems with 328,918 of those free chlorine samples coming from surface water CWSs). In general, the mean and median concentrations are similar between CWS and NCWS, but the percent of samples < 0.2 mg/L and < 0.5 mg/L are higher in NCWSs for both free and total chlorine. The results seem unusual since NCWS typically have less spread out distribution systems compared to CWSs, and thus the water should have shorter time in the distribution system and less disinfectant residual decay. The lower values in NCWSs compared to CWSs may reflect different operational strategies, reporting errors, or the fact that the NCWS dataset is so small compared to CWSs.

Exhibit B.7: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Surface Water CWSs (in 2011)



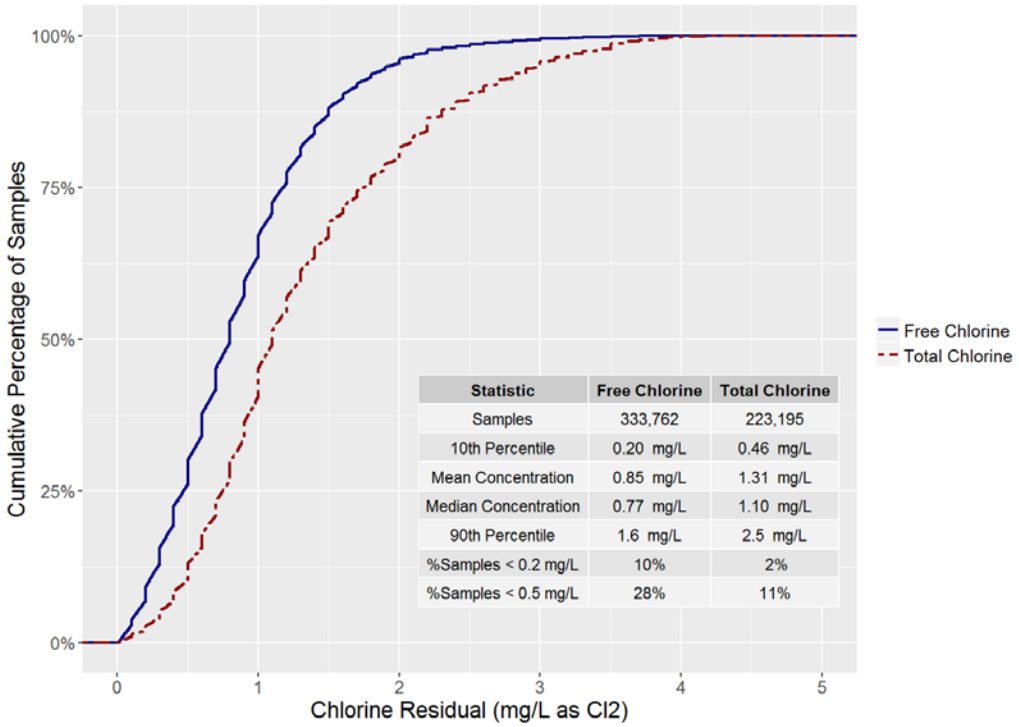
Statistic	Free Chlorine	Total Chlorine
Samples	328,918	285,282
10th Percentile	0.24 mg/L	0.70 mg/L
Mean Concentration	1.14 mg/L	1.82 mg/L
Median Concentration	1.00 mg/L	1.69 mg/L
90th Percentile	2.2 mg/L	3.2 mg/L
%Samples < 0.2 mg/L	8%	0.9%
%Samples < 0.5 mg/L	18%	5%

Exhibit B.8: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Surface Water NCWSs (in 2011)



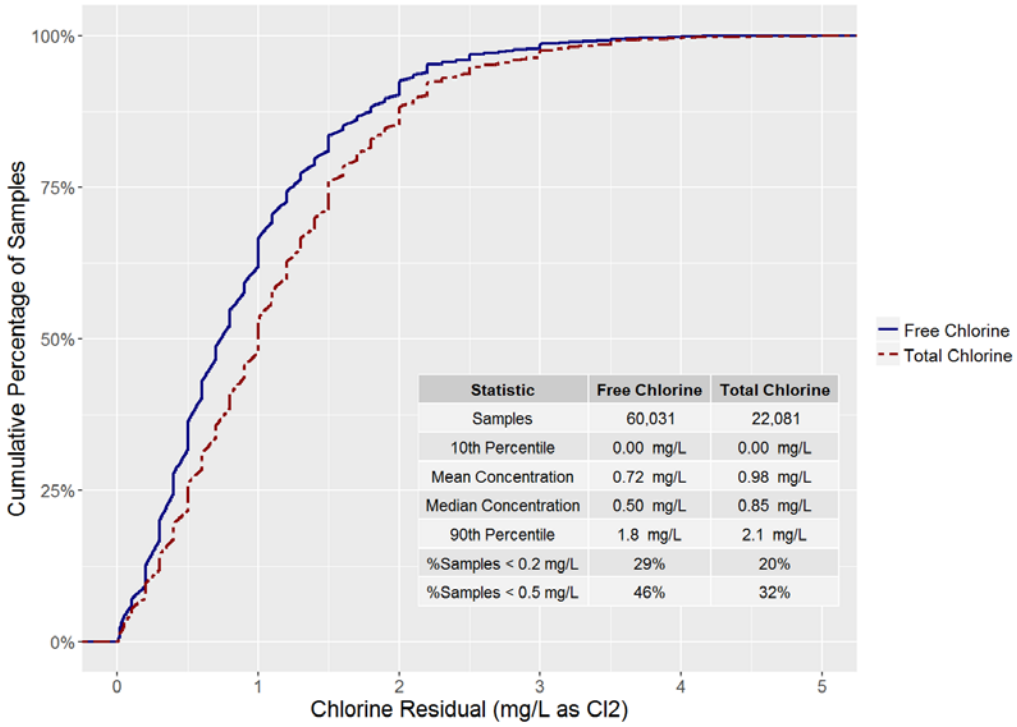
Statistic	Free Chlorine	Total Chlorine
Samples	8,544	2,719
10th Percentile	0.20 mg/L	0.40 mg/L
Mean Concentration	1.11 mg/L	1.58 mg/L
Median Concentration	0.90 mg/L	1.58 mg/L
90th Percentile	2.3 mg/L	2.8 mg/L
%Samples < 0.2 mg/L	10%	4%
%Samples < 0.5 mg/L	29%	12%

Exhibit B.9: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Ground Water CWSs (in 2011)



Statistic	Free Chlorine	Total Chlorine
Samples	333,762	223,195
10th Percentile	0.20 mg/L	0.46 mg/L
Mean Concentration	0.85 mg/L	1.31 mg/L
Median Concentration	0.77 mg/L	1.10 mg/L
90th Percentile	1.6 mg/L	2.5 mg/L
%Samples < 0.2 mg/L	10%	2%
%Samples < 0.5 mg/L	28%	11%

Exhibit B.10: Cumulative Percent of Free and Total Chlorine Residual Concentrations in Ground Water NCWSs (in 2011)



Statistic	Free Chlorine	Total Chlorine
Samples	60,031	22,081
10th Percentile	0.00 mg/L	0.00 mg/L
Mean Concentration	0.72 mg/L	0.98 mg/L
Median Concentration	0.50 mg/L	0.85 mg/L
90th Percentile	1.8 mg/L	2.1 mg/L
%Samples < 0.2 mg/L	29%	20%
%Samples < 0.5 mg/L	46%	32%

System Size

Exhibit B.11 presents summary statistics, by system size, for the free and total chlorine residual data associated with total coliform results in surface water CWSs for the year 2011. Exhibit B.12 presents similar information for ground water CWSs for the year 2011. Summary statistics include: count, 10th percentile, median, average and 90th percentile.

The SW results for free chlorine show that the median concentration is slightly lower for systems serving < 1,000 people, although there is a slight increase in the smallest size category (systems serving < 100 people). The 10th percentile values for SW are highest for systems serving 4,100 – 100,000. The 10th percentile concentrations for the two smallest systems size categories for SW, as well as the largest size category, were less than 0.2 mg/L. Results for total chlorine are similar, with the lowest 10th, median, mean and 90th percentile values generally occurring in systems serving 100 – 1,000 people.

Exhibit B.11: Summary Statistics of Free and Total Chlorine Residual Concentrations in Surface Water CWSs (in 2011), by System Size

System Size (Population Served)	Count	Chlorine Residual Concentration (mg/L)			
		10th Percentile	Median	Average	90th Percentile
Free Chlorine					
≤100	4,221	0.10	0.83	1.05	2.27
101-500	8,697	0.10	0.64	0.77	1.51
501-1,000	4,824	0.20	0.79	0.90	1.80
1,001-4,100	22,269	0.20	0.90	0.95	1.74
4,101-33,000	111,969	0.30	1.00	1.04	1.80
33,001-100,000	84,968	0.34	0.96	1.10	2.10
>100,000	91,970	0.14	1.10	1.38	3.10
Total	**328,918**	**0.24**	**1.00**	**1.14**	**2.20**
Total Chlorine					
≤100	3,878	0.60	1.80	2.01	3.60
101-500	9,540	0.50	1.56	1.73	3.30
501-1,000	6,535	0.30	1.30	1.47	2.90
1,001-4,100	27,773	0.50	1.50	1.60	2.90
4,101-33,000	86,737	0.70	1.54	1.69	2.90
33,001-100,000	61,261	0.65	1.70	1.80	3.20
>100,000	89,558	0.79	2.02	2.05	3.40
Total	**285,282**	**0.70**	**1.69**	**1.82**	**3.20**

Exhibit B.12: Summary Statistics of Free and Total Chlorine Residual Concentrations in Ground Water CWSs (in 2011), by System Size

System Size (Population Served)	Count	Chlorine Residual Concentration (mg/L)			
		10th Percentile	Median	Average	90th Percentile
Free Chlorine					
≤100	28,625	0.00	0.60	0.73	1.51
101-500	47,382	0.10	0.70	0.79	1.58
501-1,000	20,510	0.18	0.74	0.84	1.60
1,001-4,100	61,358	0.20	0.84	0.91	1.68
4,101-33,000	120,392	0.21	0.80	0.87	1.60
33,001-100,000	44,058	0.22	0.70	0.74	1.28
>100,000	11,437	0.24	0.91	1.17	2.60
Total	**333,762**	**0.20**	**0.77**	**0.85**	**1.60**
Total Chlorine					
≤100	11,300	0.20	0.99	1.06	2.05
101-500	28,496	0.30	1.00	1.10	2.00
501-1,000	16,388	0.37	1.00	1.14	2.04
1,001-4,100	43,850	0.43	1.06	1.24	2.30
4,101-33,000	80,041	0.50	1.10	1.34	2.60
33,001-100,000	30,694	0.58	1.20	1.49	2.80
>100,000	12,426	0.88	2.00	1.86	2.80
Total	**223,195**	**0.46**	**1.10**	**1.31**	**2.50**

Temporal/Seasonal Analysis

To assess any potential seasonal variations in the data, EPA calculated the frequency of detection, by month, for the free and total chlorine residual data associated with total coliform results for surface water CWSs in the year 2011. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.13 and Exhibit B.14, respectively): (1) concentrations equal to 0 mg/L; (2) concentrations greater than 0 and less than or equal to 0.2 mg/L; (3) concentrations greater than 0.2 mg/L and less than or equal to 0.5 mg/L; (4) concentrations greater than 0.5 mg/L and less than or equal to 1.0 mg/L; and (5) concentrations greater than 1.0 mg/L.

The free chlorine and total chlorine data (for SW CWSs in 2011) exhibited the same general seasonal patterns. In all months, the higher the chlorine bin, the larger the number of records of free and total chlorine, and consequently the percent of total samples. Also, the proportion of samples in each of the five chlorine bins varied slightly over the course of the year, with a slightly larger percentage of samples in the middle three chlorine bins in the summer and fall

months, and a slightly larger percentage of samples in the largest bin (greater than 1.0 mg/L) in the winter and early spring months.

EPA also calculated the frequency of detection, by month, for the free and total chlorine residual data associated with total coliform results for ground water CWSs in the year 2011. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.15 and Exhibit B.16, respectively).

Exhibit B.13: Free Chlorine Residual - Frequency of Detection in Surface Water CWSs (in 2011), by Month

Free Chlorine Bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of Records												
0	848	841	848	822	840	971	815	846	875	573	624	593
>0 - 0.2	1,566	1,586	1,417	1,418	1,441	1,800	2,011	2,143	2,191	2,115	1,894	1,712
>0.2 - 0.5	2,126	2,200	2,200	2,456	2,564	3,233	3,511	3,625	3,552	3,241	2,819	2,417
>0.5 - 1.0	8,343	8,271	8,729	9,028	9,449	9,730	9,387	9,523	8,950	8,825	8,659	8,565
>1.0	15,301	15,005	15,194	13,860	12,709	11,879	11,647	11,351	11,524	11,989	12,973	13,293
Total	**28,184**	**27,903**	**28,388**	**27,584**	**27,003**	**27,613**	**27,371**	**27,488**	**27,092**	**26,743**	**26,969**	**26,580**
Percent of Total												
0	3.0%	3.0%	3.0%	3.0%	3.1%	3.5%	3.0%	3.1%	3.2%	2.1%	2.3%	2.2%
>0 - 0.2	5.6%	5.7%	5.0%	5.1%	5.3%	6.5%	7.3%	7.8%	8.1%	7.9%	7.0%	6.4%
>0.2 - 0.5	7.5%	7.9%	7.7%	8.9%	9.5%	11.7%	12.8%	13.2%	13.1%	12.1%	10.5%	9.1%
>0.5 - 1.0	29.6%	29.6%	30.7%	32.7%	35.0%	35.2%	34.3%	34.6%	33.0%	33.0%	32.1%	32.2%
>1.0	54.3%	53.8%	53.5%	50.2%	47.1%	43.0%	42.6%	41.3%	42.5%	44.8%	48.1%	50.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Exhibit B.14: Total Chlorine Residual - Frequency of Detection in Surface Water CWSs (in 2011), by Month

Total Chlorine Bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of Records												
0	16	14	20	17	9	12	8	24	11	14	9	11
>0 - 0.2	168	133	160	148	214	334	436	519	544	436	378	331
>0.2 - 0.5	727	652	725	779	959	1,288	1,384	1,650	1,515	1,341	1,098	949
>0.5 - 1.0	3,570	3,372	3,799	4,003	4,289	4,825	4,832	5,003	4,744	4,907	4,517	4,062
>1.0	18,883	18,893	18,449	18,168	17,532	17,346	16,774	17,188	17,517	17,961	18,500	19,115
Total	**23,364**	**23,064**	**23,153**	**23,115**	**23,003**	**23,805**	**23,434**	**24,384**	**24,331**	**24,659**	**24,502**	**24,468**
Percent of Total												
0	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%
>0 - 0.2	0.7%	0.6%	0.7%	0.6%	0.9%	1.4%	1.9%	2.1%	2.2%	1.8%	1.5%	1.4%
>0.2 - 0.5	3.1%	2.8%	3.1%	3.4%	4.2%	5.4%	5.9%	6.8%	6.2%	5.4%	4.5%	3.9%
>0.5 - 1.0	15.3%	14.6%	16.4%	17.3%	18.6%	20.3%	20.6%	20.5%	19.5%	19.9%	18.4%	16.6%
>1.0	80.8%	81.9%	79.7%	78.6%	76.2%	72.9%	71.6%	70.5%	72.0%	72.8%	75.5%	78.1%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Exhibit B.15: Free Chlorine Residual - Frequency of Detection in Ground Water CWSs (in 2011), by Month

Free Chlorine Bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of Records												
0	896	877	914	865	837	803	849	989	980	897	916	803
>0 - 0.2	2,320	2,169	2,287	2,304	2,342	2,546	2,635	2,798	2,738	2,743	2,644	2,502
>0.2 - 0.5	5,220	5,108	4,939	5,316	5,444	5,760	6,115	6,505	6,284	6,059	5,795	5,417
>0.5 - 1.0	9,974	10,105	10,122	9,737	9,461	9,916	9,920	9,973	9,811	10,139	10,007	10,216
>1.0	9,355	9,286	9,143	9,124	8,856	8,646	8,403	7,830	8,494	8,791	8,826	9,011
Total	**27,765**	**27,545**	**27,405**	**27,346**	**26,940**	**27,671**	**27,922**	**28,095**	**28,307**	**28,629**	**28,188**	**27,949**
Percent of Total												
0	3.2%	3.2%	3.3%	3.2%	3.1%	2.9%	3.0%	3.5%	3.5%	3.1%	3.2%	2.9%
>0 - 0.2	8.4%	7.9%	8.3%	8.4%	8.7%	9.2%	9.4%	10.0%	9.7%	9.6%	9.4%	9.0%
>0.2 - 0.5	18.8%	18.5%	18.0%	19.4%	20.2%	20.8%	21.9%	23.2%	22.2%	21.2%	20.6%	19.4%
>0.5 - 1.0	35.9%	36.7%	36.9%	35.6%	35.1%	35.8%	35.5%	35.5%	34.7%	35.4%	35.5%	36.6%
>1.0	33.7%	33.7%	33.4%	33.4%	32.9%	31.2%	30.1%	27.9%	30.0%	30.7%	31.3%	32.2%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Exhibit B.16: Total Chlorine Residual - Frequency of Detection in Ground Water CWSs (in 2011), by Month

Total Chlorine Bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of Records												
0	86	91	83	88	80	77	77	81	98	110	103	84
>0 - 0.2	450	457	412	454	475	545	661	665	650	592	508	480
>0.2 - 0.5	1,724	1,599	1,711	1,702	1,774	1,966	1,981	2,299	2,258	2,140	1,959	1,868
>0.5 - 1.0	5,682	5,469	5,710	5,773	5,707	6,129	6,009	6,228	6,256	6,216	6,157	6,043
>1.0	10,185	10,337	10,520	10,090	9,987	10,009	9,917	10,094	9,736	9,942	10,186	10,425
Total	**18,127**	**17,953**	**18,436**	**18,107**	**18,023**	**18,726**	**18,645**	**19,367**	**18,998**	**19,000**	**18,913**	**18,900**
Percent of Total												
0	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.5%	0.6%	0.5%	0.4%
>0 - 0.2	2.5%	2.5%	2.2%	2.5%	2.6%	2.9%	3.5%	3.4%	3.4%	3.1%	2.7%	2.5%
>0.2 - 0.5	9.5%	8.9%	9.3%	9.4%	9.8%	10.5%	10.6%	11.9%	11.9%	11.3%	10.4%	9.9%
>0.5 - 1.0	31.3%	30.5%	31.0%	31.9%	31.7%	32.7%	32.2%	32.2%	32.9%	32.7%	32.6%	32.0%
>1.0	56.2%	57.6%	57.1%	55.7%	55.4%	53.4%	53.2%	52.1%	51.2%	52.3%	53.9%	55.2%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Annual Trends Analysis

To assess any potential trends over the six years of data in the SYR3 ICR microbial dataset, EPA calculated the frequency of detection, by year, for the free and total chlorine residual data associated with total coliform results for surface water CWSs. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.17 and Exhibit B.18, respectively).

For free chlorine, the number of samples in each bin tended to increase over the six year period, with the largest free chlorine bin (greater than 1.0 mg/L) making up an increasingly larger proportion of all samples over the course of the six years (Exhibit B.17). In the last two years of data (2010 and 2011), nearly twice as many samples were greater than 1 mg/L compared to 37 percent greater than 1 mg/L in 2006. Interestingly, the percent of samples with reported zero free chlorine residual increased in 2009 and 2010 (3.8 percent and 3.4 percent, respectively) compared to 2.7 percent, 2.2 percent, and 2.2 percent for 2006, 2007 and 2008. The percent of samples in the >0 – 0.2 mg/L bin generally decreased, however, from 2006 – 2011.

Exhibit B.17: Free Chlorine Residual - Frequency of Detection in Surface Water CWSs, by Year

Free Chlorine Bin	2006	2007	2008	2009	2010	2011
# Records						
0	5,250	5,025	5,009	9,093	10,560	9,496
>0 - 0.2	16,069	16,277	15,916	18,323	21,117	21,294
>0.2 - 0.5	29,156	30,133	28,510	28,724	33,198	33,944
>0.5 - 1.0	73,428	81,631	77,246	77,141	102,297	107,459
>1.0	71,719	94,717	105,402	106,280	140,426	156,725
Total	**195,622**	**227,783**	**232,083**	**239,561**	**307,598**	**328,918**
% of Total						
0	2.7%	2.2%	2.2%	3.8%	3.4%	2.9%
>0 - 0.2	8.2%	7.1%	6.9%	7.6%	6.9%	6.5%
>0.2 - 0.5	14.9%	13.2%	12.3%	12.0%	10.8%	10.3%
>0.5 - 1.0	37.5%	35.8%	33.3%	32.2%	33.3%	32.7%
>1.0	36.7%	41.6%	45.4%	44.4%	45.7%	47.6%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Similar to the free chlorine data, the percent of samples in the largest total chlorine bin increased slightly between 2006 and 2011 (see Exhibit B.18). In 2010 and 2011, approximately 75 percent of the samples were in the > 1.0 mg/L bin, compared to 65 – 70 percent in the same bin in 2006 - 2008. Unlike the free chlorine data, the percent of total chlorine data in the lowest two bins (0 and >0 – 0.2 mg/L) generally decreased between 2006 and 2011.

Exhibit B.18: Total Chlorine Residual - Frequency of Detection in Surface Water CWSs, by Year

Total Chlorine Bin	2006	2007	2008	2009	2010	2011
# Records						
0	289	447	175	211	260	165
>0 - 0.2	2,547	2,982	3,755	3,597	3,285	3,801
>0.2 - 0.5	7,155	9,030	10,316	10,343	12,218	13,067
>0.5 - 1.0	24,935	28,945	33,211	36,204	49,612	51,923
>1.0	80,325	82,360	87,180	125,786	192,629	216,326
Total	**115,251**	**123,764**	**134,637**	**176,141**	**258,004**	**285,282**
% of Total						
0	0.3%	0.4%	0.1%	0.1%	0.1%	0.1%
>0 - 0.2	2.2%	2.4%	2.8%	2.0%	1.3%	1.3%
>0.2 - 0.5	6.2%	7.3%	7.7%	5.9%	4.7%	4.6%
>0.5 - 1.0	21.6%	23.4%	24.7%	20.6%	19.2%	18.2%
>1.0	69.7%	66.5%	64.8%	71.4%	74.7%	75.8%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

EPA also calculated the frequency of detection, by year, for the free and total chlorine residual data associated with total coliform results for ground water CWSs. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.19 and Exhibit B.20, respectively).

Exhibit B.19: Free Chlorine Residual - Frequency of Detection in Ground Water CWSs, by Year

Free Chlorine Bin	2006	2007	2008	2009	2010	2011
# Records						
0	9,937	10,218	10,815	16,162	11,917	10,626
>0 - 0.2	28,092	29,636	29,625	29,475	29,528	30,028
>0.2 - 0.5	52,970	55,819	54,226	64,209	65,582	67,962
>0.5 - 1.0	64,590	69,679	68,391	88,897	110,544	119,381
>1.0	30,081	30,856	32,888	72,616	93,077	105,765
Total	**185,670**	**196,208**	**195,945**	**271,359**	**310,648**	**333,762**
% of Total						
0	5.4%	5.2%	5.5%	6.0%	3.8%	3.2%
>0 - 0.2	15.1%	15.1%	15.1%	10.9%	9.5%	9.0%
>0.2 - 0.5	28.5%	28.4%	27.7%	23.7%	21.1%	20.4%

Free Chlorine Bin	2006	2007	2008	2009	2010	2011
>0.5 - 1.0	34.8%	35.5%	34.9%	32.8%	35.6%	35.8%
>1.0	16.2%	15.7%	16.8%	26.8%	30.0%	31.7%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Exhibit B.20: Total Chlorine Residual - Frequency of Detection in Ground Water CWSs, by Year

Total Chlorine Bin	2006	2007	2008	2009	2010	2011
# Records						
0	1,488	1,414	1,516	1,578	1,199	1,058
>0 - 0.2	4,446	4,756	5,466	5,509	6,479	6,349
>0.2 - 0.5	18,477	18,614	19,543	19,619	22,394	22,981
>0.5 - 1.0	36,871	43,022	47,662	52,884	67,420	71,379
>1.0	34,662	42,505	47,838	76,177	109,889	121,428
Total	**95,944**	**110,311**	**122,025**	**155,767**	**207,381**	**223,195**
% of Total						
0	1.6%	1.3%	1.2%	1.0%	0.6%	0.5%
>0 - 0.2	4.6%	4.3%	4.5%	3.5%	3.1%	2.8%
>0.2 - 0.5	19.3%	16.9%	16.0%	12.6%	10.8%	10.3%
>0.5 - 1.0	38.4%	39.0%	39.1%	34.0%	32.5%	32.0%
>1.0	36.1%	38.5%	39.2%	48.9%	53.0%	54.4%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Geographic Analysis

To assess any potential geographic trends in the data, EPA calculated the frequency of detection, by state, for the free and total chlorine residual data associated with total coliform results for surface water CWSs in 2011. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.21 and Exhibit B.22, respectively). Similar tables for ground water results are presented in Exhibit B.23 and Exhibit B.24.

Twenty states currently have requirements for minimum free chlorine residual in the distribution system; these requirements apply to systems using free chlorine. Twelve of the 20 states have data in the SYR3 ICR microbial dataset. Illinois and Iowa require a minimum of 0.3 mg/L; and 10 states require a minimum of 0.2 mg/L free chlorine residual (Indiana, Kansas, Kentucky, Missouri, North Carolina, Nebraska, Ohio, Oklahoma, Texas and West Virginia). State requirements for minimum total chlorine residual also vary; the following states require a 1.00 mg/L or higher minimum total chlorine residual (Kansas, Oklahoma, Iowa, Ohio and North

Carolina). Total chlorine residual requirements apply to systems using chloramines, but may also apply to systems using free chlorine.

There is a wide range of records for each state that makes it difficult to make comparisons. As shown in Exhibit B.21, the four states/entities with the largest number of SW CWSs submitting free chlorine data with their total coliform samples in 2011 were North Carolina, Oklahoma, Texas and Virginia. All four states had more than 300 systems with data. Two of these four states also provided the most samples overall for free chlorine (North Carolina and Virginia). There are no free chlorine data from Nebraska and Arkansas, and few data from American Samoa, Hawaii, Kansas, Navajo Nation and Rhode Island. American Samoa reported only 20 results for 5 systems, and all were in the "0 mg/L" bin.

Iowa and Texas had the most samples in the 0 mg/L bin, with 11.5 percent and 42.9 percent respectively. These states also had a high percentage of samples in the > 0 – 0.2 mg/L bin compared to other states. (Currently, the States of Iowa and Texas require a minimum free chlorine residual in the distribution system of 0.3 mg/L and 0.2 mg/L, respectively.) States with a low percentage of samples in the 0 bin but high percent in the > 0 – 0.2 mg/L include Alaska, Iowa, Illinois, Kansas, Missouri, Navajo Nation, Nevada, New York, Rhode Island, Vermont and Region 5 and 8 Tribes. (Four of these states require a minimum free chlorine residual in the distribution system; Iowa and Illinois require a minimum residual of 0.3 mg/L while Kansas and Missouri require a minimum residual of 0.2 mg/L.) The reason for high occurrence of low free chlorine residual sample results in states that have a minimum requirement is unclear. It is possible that the minimum residual requirements came after 2011. It is also possible that systems in those states using chloramines reported free chlorine data along with total chlorine data.

For total chlorine (Exhibit B.22), the four states/entities with the largest number of SW CWSs submitting total chlorine data with their total coliform samples in 2011 were Illinois, Kansas, Texas and West Virginia. All four states had more than 280 systems with data. The three states submitting the most samples overall for total chlorine were Illinois, Ohio and Texas. There were no total chlorine data from Region 4 or Region 5 Tribes, as well as Alaska, American Samoa, Idaho, Navajo Nation, Oregon and Virginia. Several other states/entities provided very few total chlorine residual results.

Within the three states with the most data (IL, OH and TX), the majority of samples (almost 65 percent in IL, more than 71 percent in OH, and almost 95 percent in TX) had total chlorine concentrations that were greater than 1 mg/L. (The State of Ohio requires a minimum total chlorine residual in the distribution system of 1 mg/L.) These states had relatively low percentages of samples in the >0 – 0.2 mg/L bin compared to some other states. New York and Region 8 Tribes had the largest percentage of samples in the > 0 – 0.2 mg/L bin; however, these percentages were based on a low number of samples overall (36 samples and 52 samples for New York and Region 8 Tribes, respectively).

EPA also calculated the frequency of detection, by state, for the free and total chlorine residual data associated with total coliform results for ground water CWSs in 2011. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit B.23 and Exhibit B.24).

Exhibit B.21: Free Chlorine Residual - Frequency of Detection in Surface Water CWSs (in 2011), by State

State[1,2]	No. of Systems	Number of Records Within Each Free Chlorine Bin						Percent of Records Within Each Free Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
AK	110	2,742	4	433	1,278	775	252	100.0%	0.1%	15.8%	46.6%	28.3%	9.2%
AR	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AS	5	20	20	0	0	0	0	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%
CT	58	26,286	207	2,375	5,331	11,274	7,099	100.0%	0.8%	9.0%	20.3%	42.9%	27.0%
HI	3	35	0	0	18	16	1	100.0%	0.0%	0.0%	51.4%	45.7%	2.9%
IA	82	11,148	1,280	2,509	607	3,727	3,025	100.0%	11.5%	22.5%	5.4%	33.4%	27.1%
ID	64	1,754	2	142	435	750	425	100.0%	0.1%	8.1%	24.8%	42.8%	24.2%
IL	260	30,168	471	5,664	4,786	15,349	3,898	100.0%	1.6%	18.8%	15.9%	50.9%	12.9%
IN	53	1,208	0	46	176	558	428	100.0%	0.0%	3.8%	14.6%	46.2%	35.4%
KS	3	7	0	1	0	3	3	100.0%	0.0%	14.3%	0.0%	42.9%	42.9%
KY	187	29,390	2	107	960	7,411	20,910	100.0%	0.0%	0.4%	3.3%	25.2%	71.1%
MO	160	6,243	2	691	631	1,523	3,396	100.0%	0.0%	11.1%	10.1%	24.4%	54.4%
MT	52	3,212	0	46	399	1,648	1,119	100.0%	0.0%	1.4%	12.4%	51.3%	34.8%
NC	321	37,696	37	1,458	2,380	11,406	22,415	100.0%	0.1%	3.9%	6.3%	30.3%	59.5%
NE	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	34	5,950	10	528	1,004	3,202	1,206	100.0%	0.2%	8.9%	16.9%	53.8%	20.3%
NN	7	310	0	32	119	122	37	100.0%	0.0%	10.3%	38.4%	39.4%	11.9%
NV	13	465	0	49	168	213	35	100.0%	0.0%	10.5%	36.1%	45.8%	7.5%
NY	239	3,778	42	409	1,105	1,418	804	100.0%	1.1%	10.8%	29.2%	37.5%	21.3%
OH	236	51,039	19	1,216	3,583	19,003	27,218	100.0%	0.0%	2.4%	7.0%	37.2%	53.3%
OK	366	14,245	388	528	1,489	3,089	8,751	100.0%	2.7%	3.7%	10.5%	21.7%	61.4%
OR	205	21,547	16	493	4,370	12,639	4,029	100.0%	0.1%	2.3%	20.3%	58.7%	18.7%
RI	8	331	1	116	1	68	145	100.0%	0.3%	35.0%	0.3%	20.5%	43.8%
TX	356	16,131	6,924	2,742	837	1,155	4,473	100.0%	42.9%	17.0%	5.2%	7.2%	27.7%
VA	330	54,745	65	808	2,308	7,591	43,973	100.0%	0.1%	1.5%	4.2%	13.9%	80.3%
VT	67	1,965	0	253	575	829	308	100.0%	0.0%	12.9%	29.3%	42.2%	15.7%
WV	71	1,270	0	13	84	425	748	100.0%	0.0%	1.0%	6.6%	33.5%	58.9%
WY	103	5,056	4	445	831	2,214	1,562	100.0%	0.1%	8.8%	16.4%	43.8%	30.9%
Tribes - 01	2	1,091	0	77	166	686	162	100.0%	0.0%	7.1%	15.2%	62.9%	14.8%
Tribes - 04	1	37	0	0	0	11	26	100.0%	0.0%	0.0%	0.0%	29.7%	70.3%

State[1,2]	No. of Systems	Number of Records Within Each Free Chlorine Bin						Percent of Records Within Each Free Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
Tribes - 05	2	25	0	12	3	6	4	100.0%	0.0%	48.0%	12.0%	24.0%	16.0%
Tribes - 08	24	613	2	70	143	140	258	100.0%	0.3%	11.4%	23.3%	22.8%	42.1%
Tribes - 09	12	411	0	31	157	208	15	100.0%	0.0%	7.5%	38.2%	50.6%	3.6%
Total	3,434	328,918	9,496	21,294	33,944	107,459	156,725	100.0%	2.9%	6.5%	10.3%	32.7%	47.6%

[1] This column presents the standard 2-letter state abbreviations with the exception of "AS" for American Samoa and "NN" for Navajo Nation.
[2] All states/entities that provided any free and/or total chlorine data are listed in this table. A few states/entities submitted only free or only total chlorine data; thus, their total number of systems with data in this table is listed as zero.

Exhibit B.22: Total Chlorine Residual - Frequency of Detection in Surface Water CWSs (in 2011), by State

State[1,2]	No. of Systems	Number of Records Within Each Total Chlorine Bin						Percent of Records Within Each Total Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
AK	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AR	268	22,130	3	1,938	4,654	8,878	6,657	100.0%	0.0%	8.8%	21.0%	40.1%	30.1%
AS	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CT	12	3,370	7	290	218	500	2,355	100.0%	0.2%	8.6%	6.5%	14.8%	69.9%
HI	1	9	0	1	1	0	7	100.0%	0.0%	11.1%	11.1%	0.0%	77.8%
IA	89	14,439	0	50	370	2,817	11,202	100.0%	0.0%	0.3%	2.6%	19.5%	77.6%
ID	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
IL	328	36,344	4	267	1,964	10,620	23,489	100.0%	0.0%	0.7%	5.4%	29.2%	64.6%
IN	66	2,091	1	106	260	447	1,277	100.0%	0.0%	5.1%	12.4%	21.4%	61.1%
KS	282	11,428	8	94	159	541	10,626	100.0%	0.1%	0.8%	1.4%	4.7%	93.0%
KY	74	14,836	0	6	122	1,277	13,431	100.0%	0.0%	0.0%	0.8%	8.6%	90.5%
MO	199	15,148	0	29	182	938	13,999	100.0%	0.0%	0.2%	1.2%	6.2%	92.4%
MT	17	1,587	0	70	166	764	587	100.0%	0.0%	4.4%	10.5%	48.1%	37.0%
NC	152	21,656	6	104	243	679	20,624	100.0%	0.0%	0.5%	1.1%	3.1%	95.2%
NE	2	3,703	0	0	0	1	3,702	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
NM	10	3,119	0	43	177	2,227	672	100.0%	0.0%	1.4%	5.7%	71.4%	21.5%
NN	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NV	1	36	0	0	1	29	6	100.0%	0.0%	0.0%	2.8%	80.6%	16.7%

State[1,2]	No. of Systems	Number of Records Within Each Total Chlorine Bin						Percent of Records Within Each Total Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
NY	5	36	1	10	7	18	0	100.0%	2.8%	27.8%	19.4%	50.0%	0.0%
OH	247	54,550	7	114	2,068	13,491	38,870	100.0%	0.0%	0.2%	3.8%	24.7%	71.3%
OK	255	15,852	80	397	1,257	2,591	11,527	100.0%	0.5%	2.5%	7.9%	16.3%	72.7%
OR	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RI	4	14	0	6	4	4	0	100.0%	0.0%	42.9%	28.6%	28.6%	0.0%
TX	495	45,928	44	15	183	2,092	43,594	100.0%	0.1%	0.0%	0.4%	4.6%	94.9%
VA	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VT	42	1,785	0	39	167	392	1,187	100.0%	0.0%	2.2%	9.4%	22.0%	66.5%
WV	293	16,139	2	133	794	3,355	11,855	100.0%	0.0%	0.8%	4.9%	20.8%	73.5%
WY	18	948	0	80	62	192	614	100.0%	0.0%	8.4%	6.5%	20.3%	64.8%
Tribes - 01	1	81	0	8	5	66	2	100.0%	0.0%	9.9%	6.2%	81.5%	2.5%
Tribes - 04	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 05	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 08	7	52	2	1	3	3	43	100.0%	3.8%	1.9%	5.8%	5.8%	82.7%
Tribes - 09	1	1	0	0	0	1	0	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Total	2,869	285,282	165	3,801	13,067	51,923	216,326	100.0%	0.1%	1.3%	4.6%	18.2%	75.8%

[1] This column presents the standard 2-letter state abbreviations with the exception of “AS” for American Samoa and “NN” for Navajo Nation.
[2] All states/entities that provided any free and/or total chlorine data are listed in this table. A few states/entities submitted only free or only total chlorine data; thus, their total number of systems with data in this table is listed as zero.

Exhibit B.23: Free Chlorine Residual - Frequency of Detection in Ground Water CWSs (in 2011), by State

State[1,2]	No. of Systems	Number of Records Within Each Free Chlorine Bin						Percent of Records Within Each Free Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
AK	107	2,381	22	900	673	520	266	100.0%	0.9%	37.8%	28.3%	21.8%	11.2%
AR	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AS	11	1,086	60	130	311	505	80	100.0%	5.5%	12.0%	28.6%	46.5%	7.4%
CT	486	9,115	3,578	947	2,109	2,017	464	100.0%	39.3%	10.4%	23.1%	22.1%	5.1%
HI	37	740	5	206	315	195	19	100.0%	0.7%	27.8%	42.6%	26.4%	2.6%
IA	842	25,882	580	2,580	4,754	10,696	7,272	100.0%	2.2%	10.0%	18.4%	41.3%	28.1%

State[1,2]	No. of Systems	Number of Records Within Each Free Chlorine Bin						Percent of Records Within Each Free Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
ID	270	8,429	425	3,210	3,639	878	277	100.0%	5.0%	38.1%	43.2%	10.4%	3.3%
IL	1,016	59,121	238	5,326	16,732	28,398	8,427	100.0%	0.4%	9.0%	28.3%	48.0%	14.3%
IN	314	5,346	6	462	1,727	2,453	698	100.0%	0.1%	8.6%	32.3%	45.9%	13.1%
KS	7	436	0	1	53	272	110	100.0%	0.0%	0.2%	12.2%	62.4%	25.2%
KY	56	4,491	0	15	123	1,771	2,582	100.0%	0.0%	0.3%	2.7%	39.4%	57.5%
MO	737	22,136	1	2,427	2,591	6,892	10,225	100.0%	0.0%	11.0%	11.7%	31.1%	46.2%
MT	131	2,168	6	239	1,135	594	194	100.0%	0.3%	11.0%	52.4%	27.4%	8.9%
NC	1,332	24,511	395	1,221	4,409	9,676	8,810	100.0%	1.6%	5.0%	18.0%	39.5%	35.9%
NE	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	369	9,566	711	1,236	3,442	3,117	1,060	100.0%	7.4%	12.9%	36.0%	32.6%	11.1%
NN	119	2,284	4	651	711	690	228	100.0%	0.2%	28.5%	31.1%	30.2%	10.0%
NV	92	2,728	60	424	774	1,295	175	100.0%	2.2%	15.5%	28.4%	47.5%	6.4%
NY	509	5,809	280	538	1,890	1,943	1,158	100.0%	4.8%	9.3%	32.5%	33.4%	19.9%
OH	692	35,920	67	1,682	5,104	19,025	10,042	100.0%	0.2%	4.7%	14.2%	53.0%	28.0%
OK	363	7,321	323	642	2,163	2,450	1,743	100.0%	4.4%	8.8%	29.5%	33.5%	23.8%
OR	317	12,825	66	2,071	3,324	4,490	2,874	100.0%	0.5%	16.1%	25.9%	35.0%	22.4%
RI	38	386	261	86	39	0	0	100.0%	67.6%	22.3%	10.1%	0.0%	0.0%
TX	2,804	62,686	2,380	219	4,165	13,656	42,266	100.0%	3.8%	0.3%	6.6%	21.8%	67.4%
VA	660	13,270	623	982	2,675	3,830	5,160	100.0%	4.7%	7.4%	20.2%	28.9%	38.9%
VT	255	3,938	110	1,647	1,485	594	102	100.0%	2.8%	41.8%	37.7%	15.1%	2.6%
WV	52	776	0	4	240	286	246	100.0%	0.0%	0.5%	30.9%	36.9%	31.7%
WY	164	3,108	384	611	985	936	192	100.0%	12.4%	19.7%	31.7%	30.1%	6.2%
Tribes - 01	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 04	9	209	0	0	7	77	125	100.0%	0.0%	0.0%	3.3%	36.8%	59.8%
Tribes - 05	67	1,733	22	566	757	242	146	100.0%	1.3%	32.7%	43.7%	14.0%	8.4%
Tribes - 08	63	1,235	19	272	405	377	162	100.0%	1.5%	22.0%	32.8%	30.5%	13.1%
Tribes - 09	166	4,126	0	733	1,225	1,506	662	100.0%	0.0%	17.8%	29.7%	36.5%	16.0%
Total	12,085	333,762	10,626	30,028	67,962	119,381	105,765	100.0%	3.2%	9.0%	20.4%	35.8%	31.7%

[1] This column presents the standard 2-letter state abbreviations with the exception of “AS” for American Samoa and “NN” for Navajo Nation.

[2] All states that provided any free and/or total chlorine data are listed in this table. A few states submitted only free or only total chlorine data; thus, their total number of systems with data in this table is listed as zero.

Exhibit B.24: Total Chlorine Residual - Frequency of Detection in Ground Water CWSs (in 2011), by State

State[1,2]	No. of Systems	Number of Records Within Each Total Chlorine Bin						Percent of Records Within Each Total Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
AK	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AR	438	22,662	6	2,413	5,536	9,955	4,752	100.0%	0.0%	10.6%	24.4%	43.9%	21.0%
AS	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CT	12	153	13	94	30	15	1	100.0%	8.5%	61.4%	19.6%	9.8%	0.7%
HI	1	4	0	0	2	2	0	100.0%	0.0%	0.0%	50.0%	50.0%	0.0%
IA	872	28,190	156	217	1,504	9,167	17,146	100.0%	0.6%	0.8%	5.3%	32.5%	60.8%
ID	1	12	0	0	11	1	0	100.0%	0.0%	0.0%	91.7%	8.3%	0.0%
IL	861	24,068	28	463	2,376	8,794	12,407	100.0%	0.1%	1.9%	9.9%	36.5%	51.5%
IN	300	7,748	25	524	2,202	3,668	1,329	100.0%	0.3%	6.8%	28.4%	47.3%	17.2%
KS	581	19,392	13	739	1,971	5,594	11,075	100.0%	0.1%	3.8%	10.2%	28.8%	57.1%
KY	9	356	0	0	3	150	203	100.0%	0.0%	0.0%	0.8%	42.1%	57.0%
MO	746	23,669	0	427	1,206	5,397	16,639	100.0%	0.0%	1.8%	5.1%	22.8%	70.3%
MT	34	464	8	37	289	102	28	100.0%	1.7%	8.0%	62.3%	22.0%	6.0%
NC	328	6,573	322	69	372	1,309	4,501	100.0%	4.9%	1.0%	5.7%	19.9%	68.5%
NE	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	129	4,951	43	673	2,260	1,606	369	100.0%	0.9%	13.6%	45.6%	32.4%	7.5%
NN	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NV	16	360	0	3	41	262	54	100.0%	0.0%	0.8%	11.4%	72.8%	15.0%
NY	13	19	14	5	0	0	0	100.0%	73.7%	26.3%	0.0%	0.0%	0.0%
OH	722	35,900	61	170	2,965	16,955	15,749	100.0%	0.2%	0.5%	8.3%	47.2%	43.9%
OK	147	2,755	80	125	518	784	1,248	100.0%	2.9%	4.5%	18.8%	28.5%	45.3%
OR	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RI	18	162	114	41	4	3	0	100.0%	70.4%	25.3%	2.5%	1.9%	0.0%
TX	1,028	40,851	103	86	797	5,696	34,169	100.0%	0.3%	0.2%	2.0%	13.9%	83.6%
VA	2	3	0	1	2	0	0	100.0%	0.0%	33.3%	66.7%	0.0%	0.0%
VT	84	670	57	220	229	106	58	100.0%	8.5%	32.8%	34.2%	15.8%	8.7%
WV	179	4,118	1	30	628	1,778	1,681	100.0%	0.0%	0.7%	15.3%	43.2%	40.8%
WY	4	6	0	0	5	1	0	100.0%	0.0%	0.0%	83.3%	16.7%	0.0%

State[1,2]	No. of Systems	Number of Records Within Each Total Chlorine Bin						Percent of Records Within Each Total Chlorine Bin					
		Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0	Total	0	>0 - 0.2	>0.2 - 0.5	>0.5 - 1.0	>1.0
Tribes - 01	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 04	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 05	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tribes - 08	15	100	14	11	28	28	19	100.0%	14.0%	11.0%	28.0%	28.0%	19.0%
Tribes - 09	8	9	0	1	2	6	0	100.0%	0.0%	11.1%	22.2%	66.7%	0.0%
Total	6,548	223,195	1,058	6,349	22,981	71,379	121,428	100.0%	0.5%	2.8%	10.3%	32.0%	54.4%

[1] This column presents the standard 2-letter state abbreviations with the exception of “AS” for American Samoa and “NN” for Navajo Nation.
[2] All states that provided any free and/or total chlorine data are listed in this table. A few states submitted only free or only total chlorine data; thus, their total number of systems with data in this table is listed as zero.

Appendix C. Additional Analyses on the Occurrence of TC+ and EC+ in Surface Water and Ground Water Systems Compared to Disinfectant Residuals in Distribution Systems

This appendix provides the analytical results for surface water and ground water systems that were not presented within the body of the chapter in Section 6.3, related to the occurrence of TC+ and EC+ results compared to disinfectant residuals in distribution systems. This appendix includes an evaluation of the occurrence relative to system type and system size, as well as seasonal changes, annual trends and geographic distribution. All analyses in this section are based on routine samples taken in the distribution system.

System Type

Exhibit C.1 and Exhibit C.2 present the frequency of detection of total coliforms over the six years of data in community water systems (CWSs) and non-community water systems (NCWSs; includes non-transient non-community and transient non-community water systems), respectively, that were served by surface water. Results were generated separately for five bins of free and total chlorine residual concentrations.

For free chlorine, a higher percentage of samples were TC+ when the residual was 0 and >0 – 0.2 mg/L for NCWSs (1.7 percent and 1.9 percent, respectively), compared to CWSs (0.4 percent and 0.5 percent, respectively). The percent TC+ results for the lower free chlorine bins were obscured by the records that reported zero or very low free chlorine but high total chlorine values (e.g., in a chloramine system) (see Sections 6.3.1 and 6.3.3), particularly for CWSs using surface water. These CWSs are more likely to use chloramines than NCWSs. For total chlorine, percent positive total coliform results were slightly higher for CWSs compared to NCWSs. It is difficult to draw conclusions regarding relative occurrence, however, because of the smaller sample size of the NCWS dataset (see Exhibit C.5).

Exhibit C.1: Total Coliforms - Frequency of Detection in Surface Water CWSs (2006-2011)

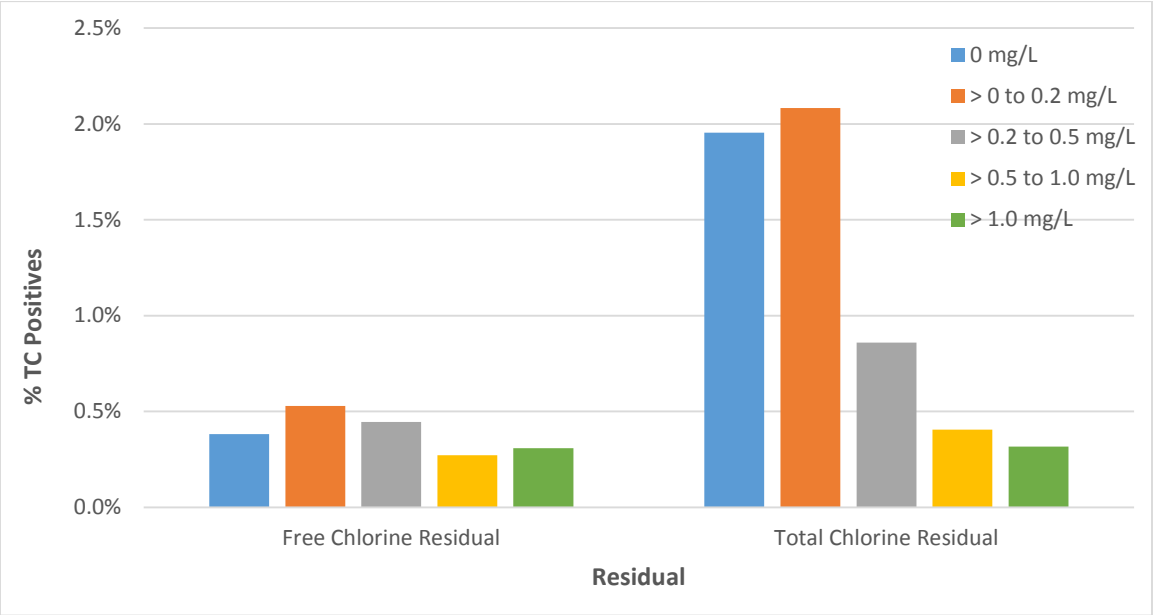


Exhibit C.2: Total Coliforms - Frequency of Detection in Surface Water NCWSs (2006-2011)

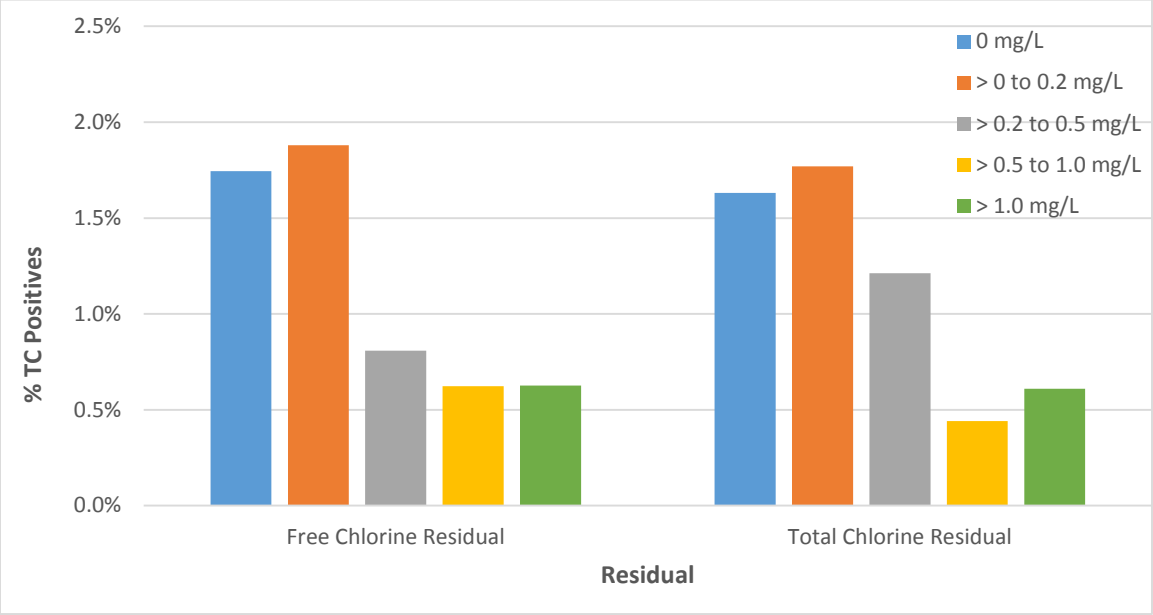


Exhibit C.3 and Exhibit C.4 present the frequency of detection of *E. coli* over the six years of data in surface water CWSs and NCWSs, respectively. For free chlorine, the rate of EC+ was higher for surface water NCWSs compared to CWSs for all disinfectant residual bins. For total chlorine, there were no EC+ sample results in NCWSs when total chlorine was equal to zero (or

"below detection limit"), but 0.35 percent and 0.26 percent EC+ results when total chlorine was greater than 0 – 0.2 mg/L, and greater than 0.2 mg/L – 0.5 mg/L respectively. It is difficult to draw conclusions regarding relative occurrence, however, because of the smaller sample size of the NCWS data (see Exhibit C.5). EC+ rates were higher for NCWSs than for CWSs for all disinfectant residual bins when NCWS data were available.

Exhibit C.3: *E. coli* - Frequency of Detection in Surface Water CWSs (2006-2011)

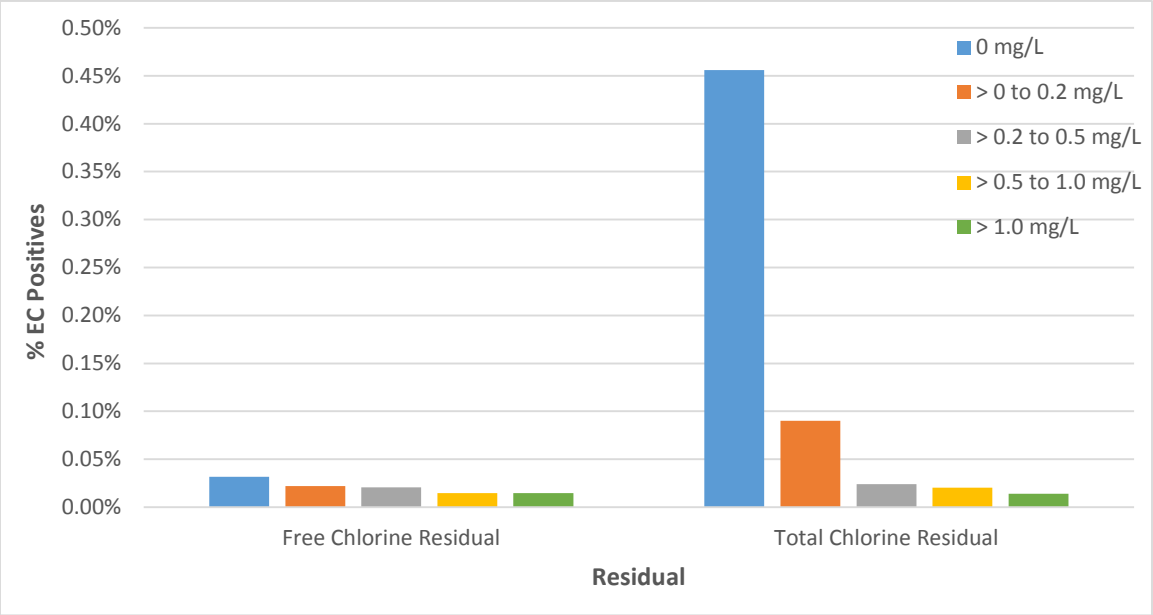


Exhibit C.4: *E. coli* - Frequency of Detection in Surface Water NCWSs (2006-2011)

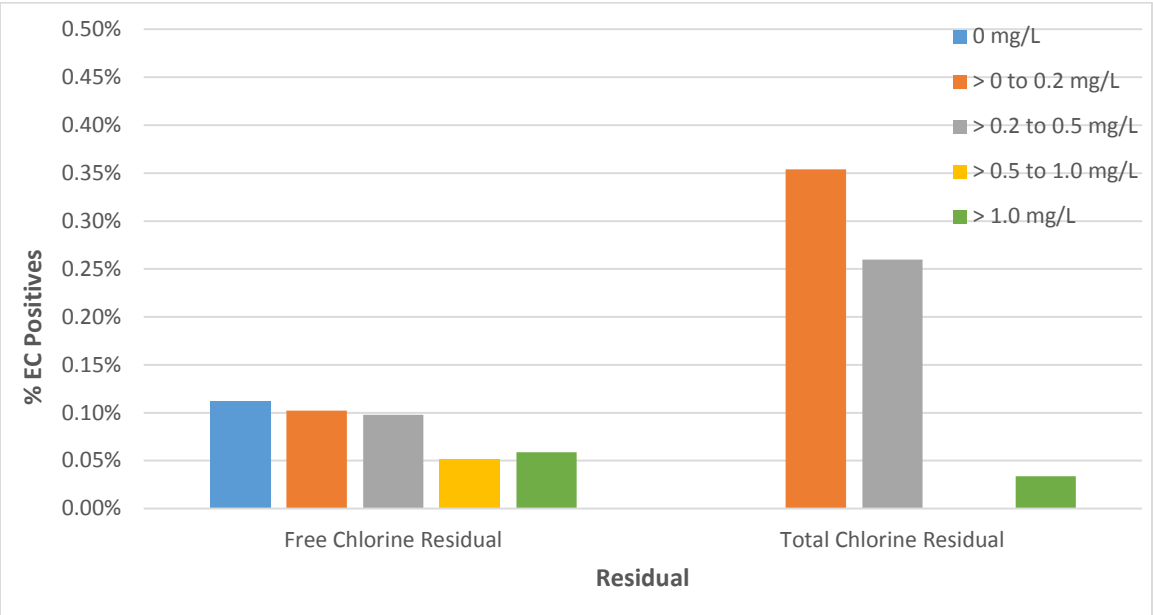


Exhibit C.5: Number of Total Coliform Surface Water Samples Paired with Free and Total Chlorine Data, by System Type (underlying data/denominator for Exhibit C.1, Exhibit C.2, Exhibit C.3 and Exhibit C.4)

System Type	Group	Chlorine Bin	Total Coliforms			*E. coli*	
			% Positive	# Positive Samples	% Positive	# Positive Samples	% Positive
CWSs	**Free Chlorine**	0	44,396	170	0.38%	14	0.03%
		> 0 to 0.2 mg/L	108,975	576	0.53%	24	0.02%
		> 0.2 to 0.5 mg/L	183,651	817	0.44%	38	0.02%
		> 0.5 to 1 mg/L	519,173	1,416	0.27%	77	0.01%
		> 1 mg/L	675,250	2,089	0.31%	98	0.01%
		Total	**1,531,445**	**5,068**	**0.33%**	**251**	**0.02%**
	Total Chlorine	0	1,535	30	1.95%	7	0.46%
		> 0 to 0.2 mg/L	19,966	416	2.08%	18	0.09%
		> 0.2 to 0.5 mg/L	62,127	534	0.86%	15	0.02%
		> 0.5 to 1 mg/L	224,826	910	0.40%	46	0.02%
		> 1 mg/L	784,585	2,489	0.32%	111	0.01%
		Total	**1,093,039**	**4,379**	**0.40%**	**197**	**0.02%**
NCWSs	**Free Chlorine**	0	1,777	31	1.74%	2	0.11%
		> 0 to 0.2 mg/L	4,894	92	1.88%	5	0.10%
		> 0.2 to 0.5 mg/L	8,171	66	0.81%	8	0.10%
		> 0.5 to 1 mg/L	9,640	60	0.62%	5	0.05%
		> 1 mg/L	15,327	96	0.63%	9	0.06%
		Total	**39,809**	**345**	**0.87%**	**29**	**0.07%**
	Total Chlorine	0	184	3	1.63%	0	0.00%
		> 0 to 0.2 mg/L	565	10	1.77%	2	0.35%
		> 0.2 to 0.5 mg/L	1,155	14	1.21%	3	0.26%
		> 0.5 to 1 mg/L	1,811	8	0.44%	0	0.00%
		> 1 mg/L	5,910	36	0.61%	2	0.03%
		Total	**9,625**	**71**	**0.74%**	**7**	**0.07%**

Exhibit C.6 and Exhibit C.7 present the frequency of detection of total coliforms over the six years of data in ground water CWSs and NCWSs, respectively.

Exhibit C.6: Total Coliforms - Frequency of Detection in Ground Water CWSs (2006-2011)

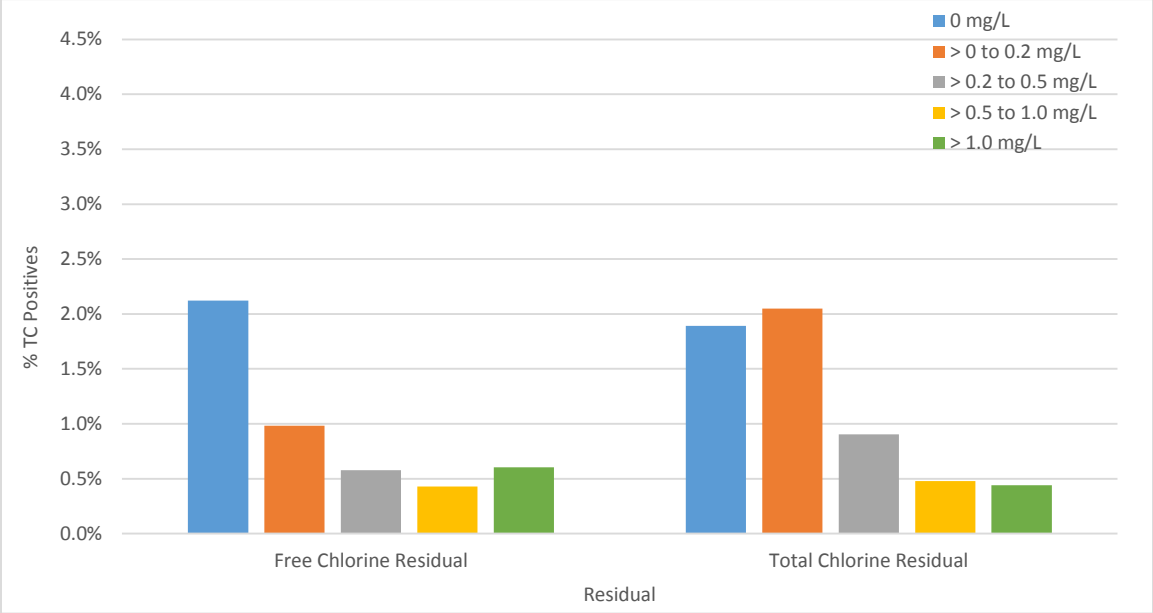


Exhibit C.7: Total Coliforms - Frequency of Detection in Ground Water NCWSs (2006-2011)

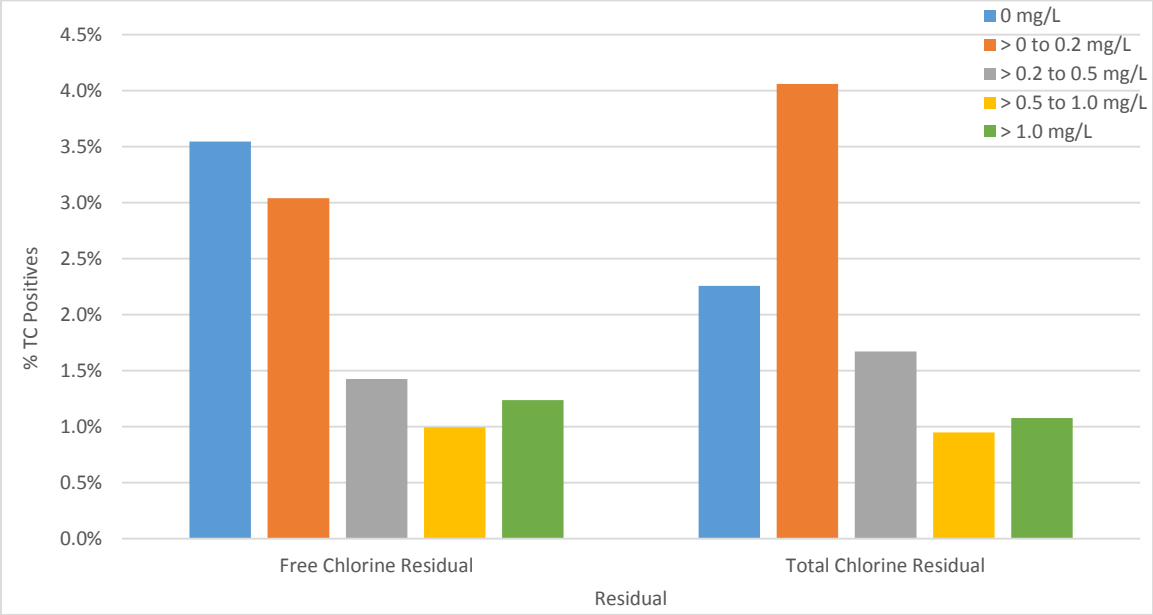


Exhibit C.8 and Exhibit C.9 present the frequency of detection of *E. coli* over the six years of data in ground water CWSs and NCWSs.

Exhibit C.8: *E. coli* - Frequency of Detection in Ground Water CWSs (2006-2011)

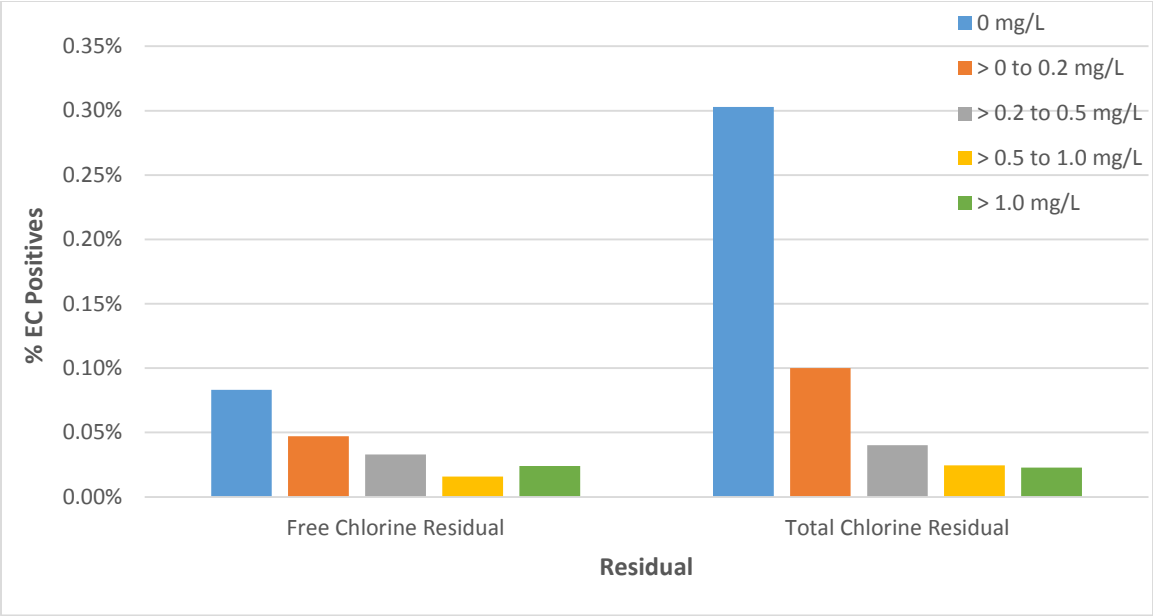


Exhibit C.9: *E. coli* - Frequency of Detection in Ground Water NCWSs (2006-2011)

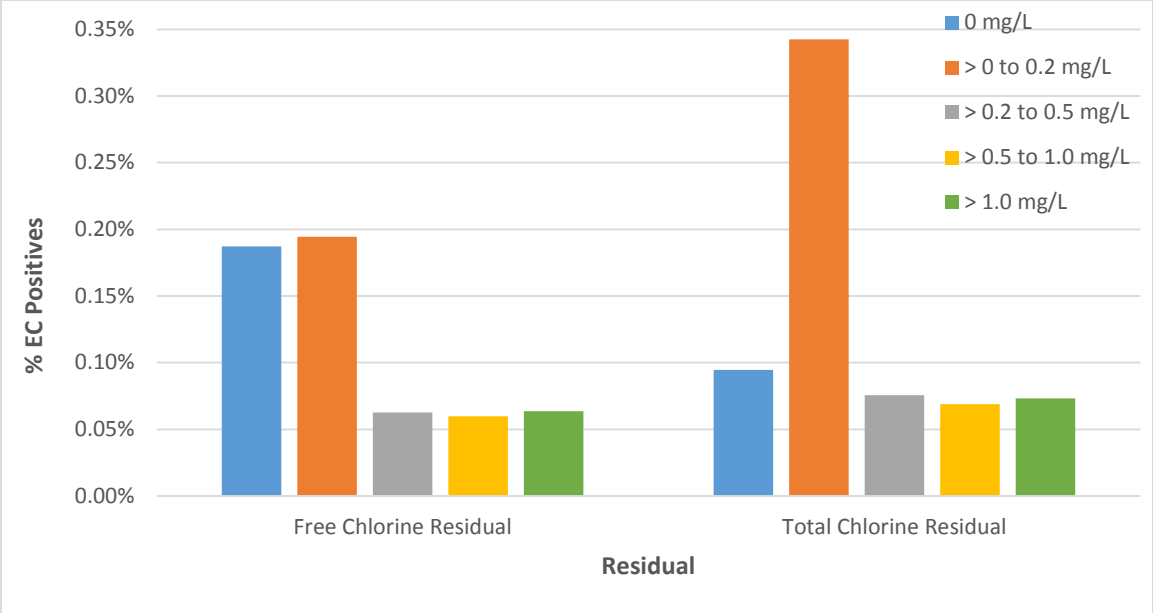


Exhibit C.10: Number of Total Coliform Ground Water Samples Paired with Free and Total Chlorine Data, by System Type (underlying data/denominator for Exhibit C.6, Exhibit C.7, Exhibit C.8 and Exhibit C.9)

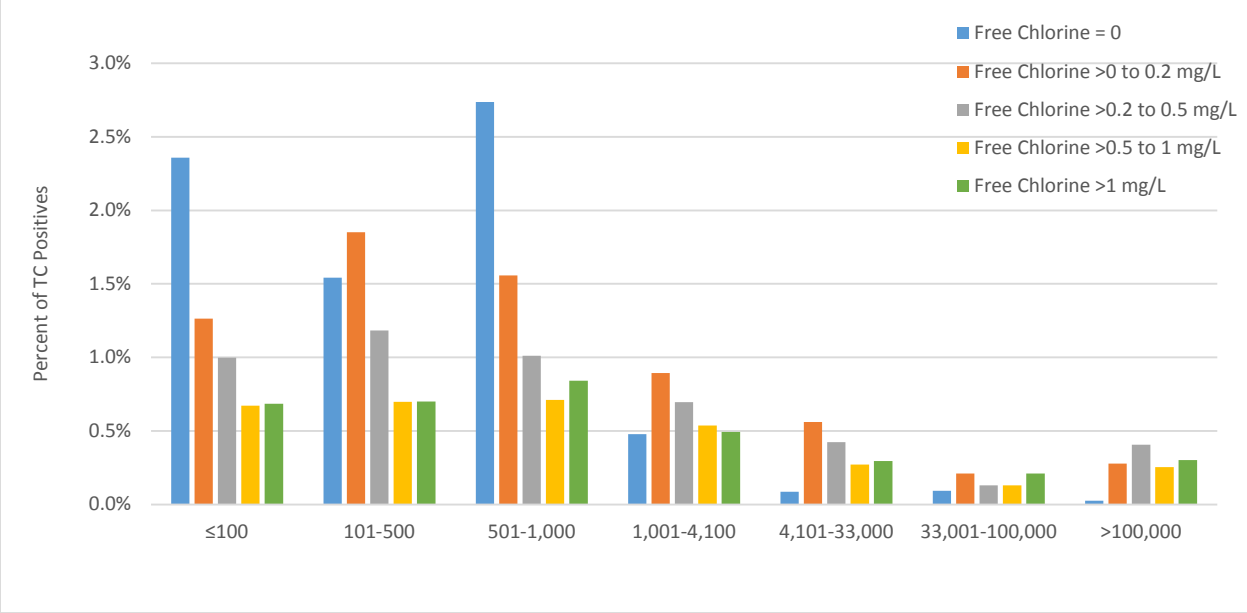
System Type	Group	Chlorine Bin	Total Coliforms			*E. coli*	
			% Positive	# Positive Samples	% Positive	# Positive Samples	% Positive
CWSs	**Free Chlorine**	0	69,658	1,478	2.12%	58	0.08%
		> 0 to 0.2 mg/L	176,170	1,733	0.98%	83	0.05%
		> 0.2 to 0.5 mg/L	360,672	2,088	0.58%	119	0.03%
		> 0.5 to 1 mg/L	521,400	2,243	0.43%	83	0.02%
		> 1 mg/L	365,256	2,210	0.61%	88	0.02%
		Total	**1,493,156**	**9,752**	**0.65%**	**431**	**0.03%**
	Total Chlorine	0	8,252	156	1.89%	25	0.30%
		> 0 to 0.2 mg/L	32,999	676	2.05%	33	0.10%
		> 0.2 to 0.5 mg/L	121,624	1,099	0.90%	49	0.04%
		> 0.5 to 1 mg/L	319,226	1,525	0.48%	78	0.02%
		> 1 mg/L	432,493	1,907	0.44%	99	0.02%
		Total	**914,594**	**5,363**	**0.59%**	**284**	**0.03%**
NCWSs	**Free Chlorine**	0	78,523	2,784	3.55%	147	0.19%
		> 0 to 0.2 mg/L	29,339	892	3.04%	57	0.19%
		> 0.2 to 0.5 mg/L	49,565	706	1.42%	31	0.06%
		> 0.5 to 1 mg/L	53,582	533	0.99%	32	0.06%
		> 1 mg/L	53,551	662	1.24%	34	0.06%
		Total	**264,560**	**5,577**	**2.11%**	**301**	**0.11%**
	Total Chlorine	0	16,932	382	2.26%	16	0.09%
		> 0 to 0.2 mg/L	5,840	237	4.06%	20	0.34%
		> 0.2 to 0.5 mg/L	13,222	221	1.67%	10	0.08%
		> 0.5 to 1 mg/L	20,340	193	0.95%	14	0.07%
		> 1 mg/L	31,437	338	1.08%	23	0.07%
		Total	**87,771**	**1,371**	**1.56%**	**83**	**0.09%**

System Size

To assess any potential variations in the SYR3 ICR microbial data due to system size, EPA calculated the frequency of detection for the total coliform results in surface water systems over the six years for each of seven system size categories presented in the NPDWR Revisions to the Total Coliform Rule: ≤ 100; 101 - 500; 501 - 1,000; 1,001 - 4,100; 4,101 - 33,000; 33,001 - 100,000; and > 100,000. Results were generated separately for five bins of free chlorine residual concentrations for CWSs and NCWSs (Exhibit C.11 and Exhibit C.12, respectively). Results were also generated separately for five bins of total chlorine residual concentrations for CWSs and NCWSs (Exhibit C.16 and Exhibit C.17, respectively).

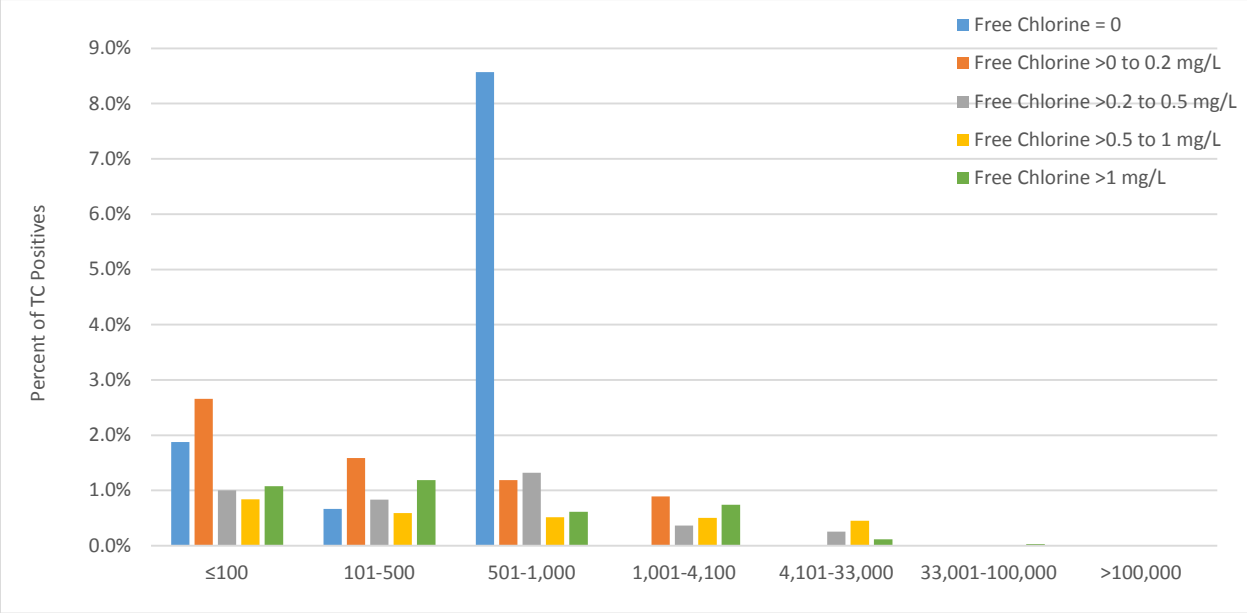
For free chlorine samples, there is a general trend of higher TC+ occurrence in surface water CWSs and NTNCWSs serving 4,100 or fewer compared to larger systems. For surface water CWSs, the percent TC+ is highest in either the 0 mg/L bin or the >0 – 0.2 mg/L bin for surface water CWSs serving 33,000 people or fewer. This relationship does not hold, however, for the medium and large systems, most likely due to the bias of chloramine systems that reported zero or very low free chlorine but high total chorine. Medium and large surface water systems are more likely to use chloramines than small systems. For surface water NCWSs, there is a notable peak in TC+ occurrence in the 0 mg/L bin (8.57 percent). This peak is based on data from 7 systems that comprise the 35 overall samples in this system size category. One of these 7 systems reported the three TC+ samples. The rest of the data in these exhibits show a slight trend in increasing TC+ occurrence with decreasing system size.

Exhibit C.11: Surface Water CWSs: Percent of TC Positives Paired with Free Chlorine Data by System Size (2006-2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the CWS results (in this exhibit) compared to the NCWS results in the next exhibit (Exhibit C.12) to enable a closer look at the CWS results.

Exhibit C.12: Surface Water NCWSs: Percent of TC Positives Paired with Free Chlorine Data by System Size (2006-2011)



EPA also calculated the frequency of detection for the *E. coli* results in surface water systems over the six years for each of seven system size categories. Results were generated separately for five bins of free chlorine residual concentrations for CWSs and NCWSs (Exhibit C.13 and Exhibit C.14, respectively).

The system size trends for EC+ occurrence are similar to, but not exactly the same as, the system size trends for TC+ occurrence. For free chlorine samples in CWSs and NCWSs (Exhibit C.13 and Exhibit C.14, respectively), there is a general trend of higher EC+ occurrence in systems serving 1,000 or fewer compared to larger systems. It is also important to note the small sample size for NCWSs; there were few, if any, samples from NCWSs serving more than 4,100 people.

Exhibit C.13: Surface Water CWSs: Percent of EC Positives Paired with Free Chlorine Data by System Size (2006-2011)

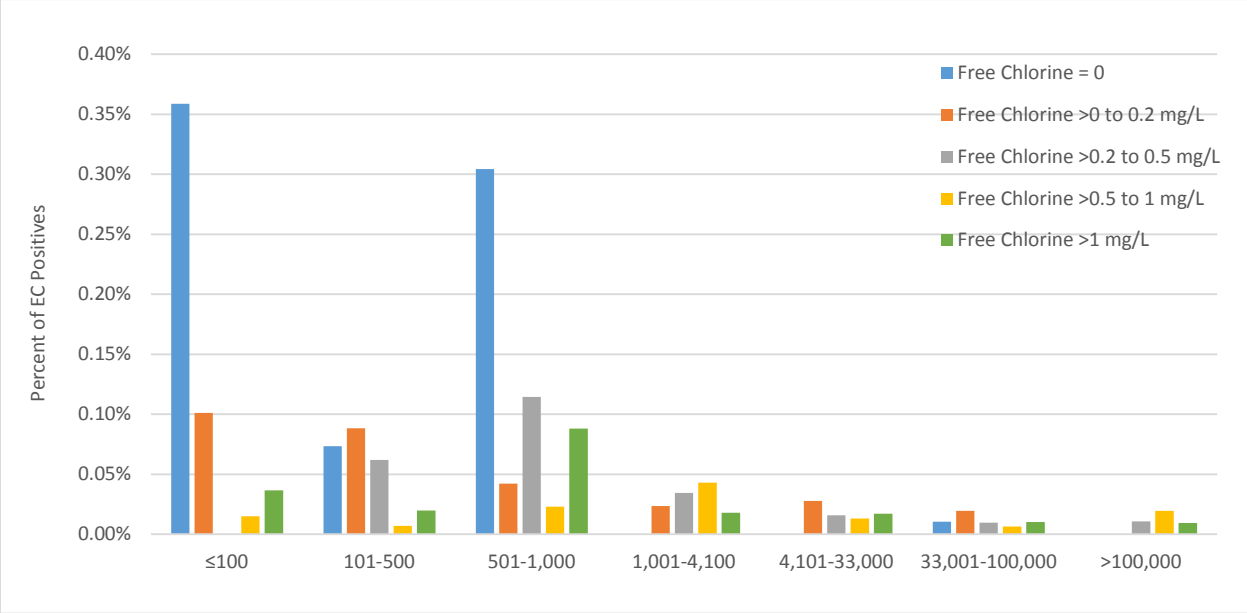
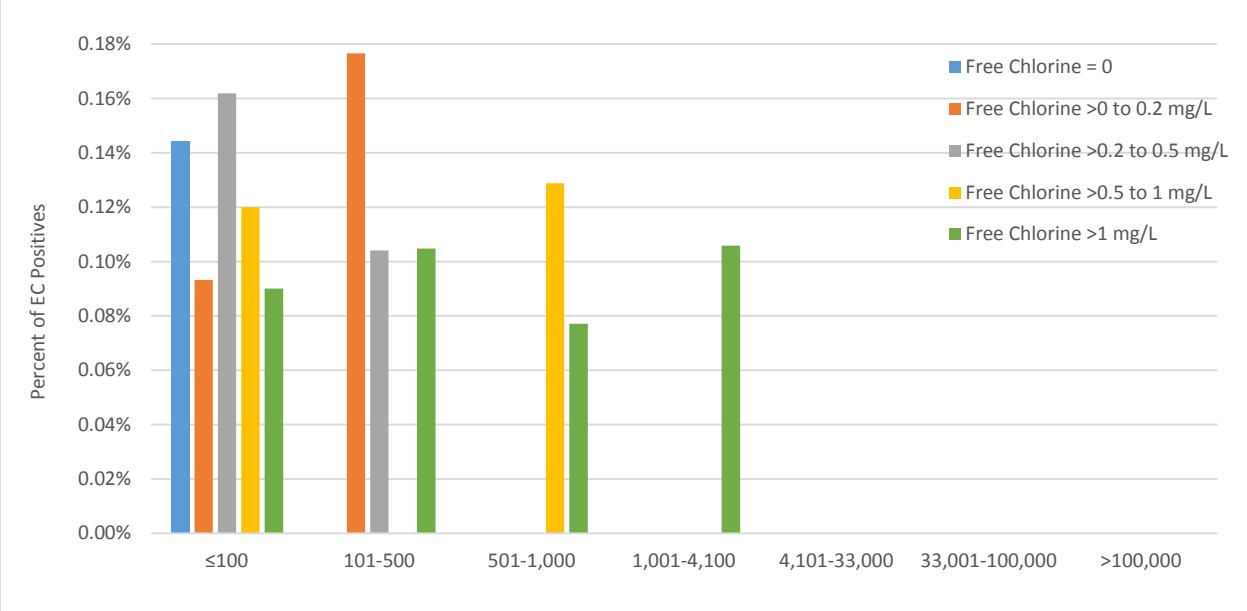


Exhibit C.14: Surface Water NCWSs: Percent of EC Positives Paired with Free Chlorine Data by System Size (2006-2011)[1]



[1] Different scales were used for the Percent of EC Positives (y-axis) for the NCWS results (in this exhibit) compared to the CWS results in the previous exhibit (Exhibit C.13) to enable a closer look at the NCWS results.

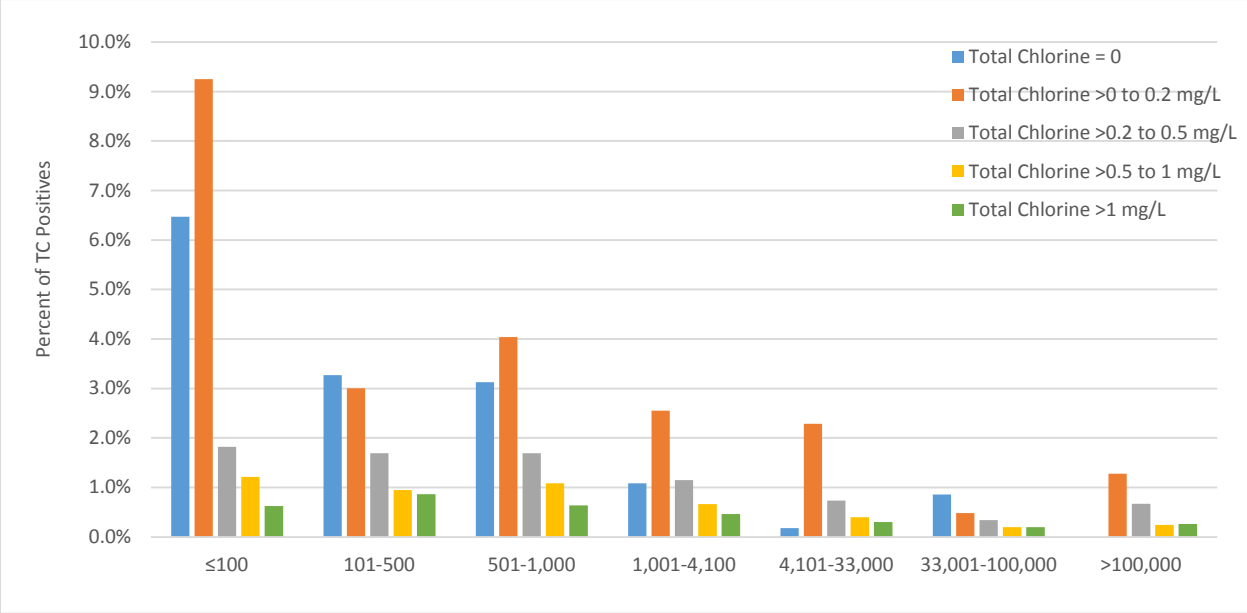
Exhibit C.15: Number of Total Coliform Surface Water Samples Paired with Free Chlorine Data, by System Size and System Type (underlying data/denominator for Exhibit C.11, Exhibit C.12, Exhibit C.13 and Exhibit C.14)

System Size	Total # TC SW Samples Paired with Free Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
CWSs						
≤100	1,951	1,980	4,009	6,702	8,187	22,829
101-500	2,722	6,805	11,317	14,604	10,145	45,593
501-1,000	1,315	2,375	5,239	8,723	7,961	25,613
1,001-4,100	4,822	8,512	20,271	41,809	50,150	125,564
4,101-33,000	12,654	28,935	63,836	197,220	251,292	553,937
33,001-100,000	9,597	25,726	51,180	152,577	156,614	395,694
>100,000	11,335	34,642	27,799	97,538	190,901	362,215
NCWSs						
≤100	1,386	2,145	3,089	3,334	3,331	13,285
101-500	300	1,698	2,884	3,215	2,863	10,960
501-1,000	35	252	455	776	1,297	2,815
1,001-4,100	48	561	1,100	1,382	1,889	4,980
4,101-33,000	6	193	392	440	2,582	3,613
33,001-100,000	2	45	251	493	3,365	4,156
>100,000	0	0	0	0	0	0

Results were also generated separately for five bins of total chlorine residual concentrations for CWSs and NCWSs (Exhibit C.16 and Exhibit C.17, respectively). For total chlorine samples, there is also a general trend of higher TC+ occurrence in systems serving 4,100 or fewer compared to larger systems. The one notable exception is for large surface water NCWSs serving > 100,000; those systems show a very high TC+ occurrence for the two total chlorine residual categories with concentrations greater than 0.5 mg/L. As noted in Exhibit C.20, the NCWS results in this system size category are based on results from a single non-transient non-community purchased surface water system in Texas; the only three total coliform results from this system were TC+.

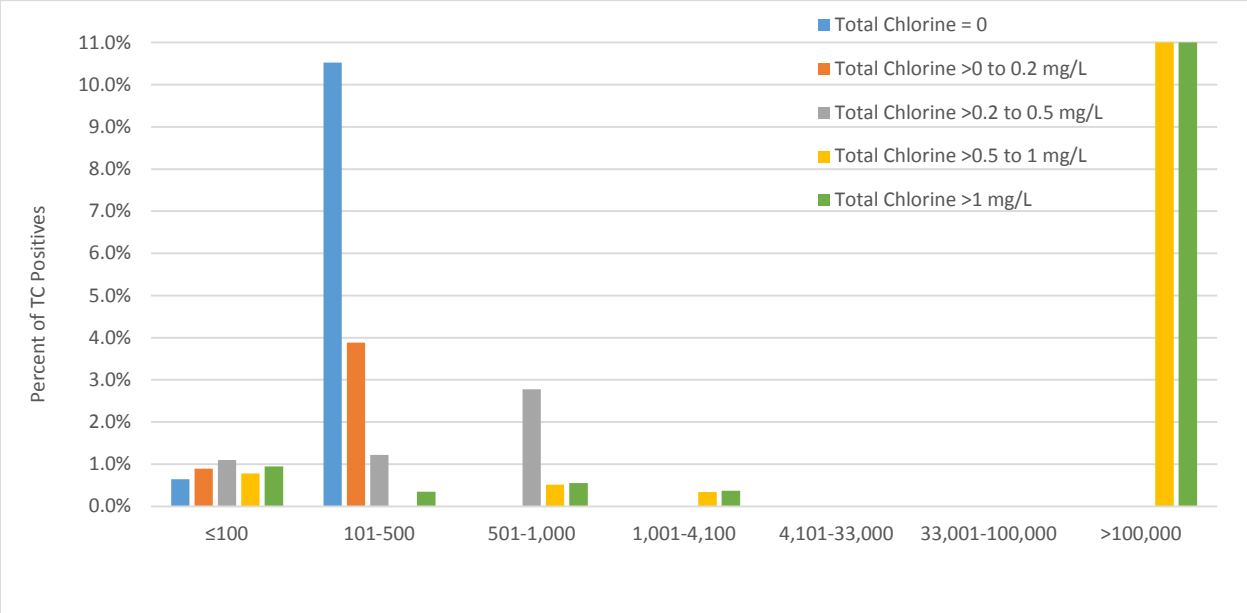
For total chlorine results in surface water CWSs, the highest percent of TC+ samples occurred in either the 0 mg/L bin or the >0 – 0.2 mg/L bin, with a general trending downward of TC+ samples with increasing total chlorine concentrations for all size categories.

Exhibit C.16: Surface Water CWSs: Percent of TC Positives Paired with Total Chlorine Data by System Size (2006-2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the CWS results (in this exhibit) compared to the NCWS results in the next exhibit (Exhibit C.17) to enable a closer look at the CWS results.

Exhibit C.17: Surface Water NCWSs: Percent of TC Positives Paired with Total Chlorine Data by System Size (2006-2011)[1]



[1] Due to the small number of records in the >100,000 population size category for NCWSs (a total of 3 samples as can be seen in Exhibit C.20), the percent of TC+ was equal to 100%. However, the upper bound on the y-axis in this plot was set equal to 11 percent to enable a closer look at the other NCWS results.

The EC results paired with total chlorine concentrations are presented in Exhibit C.18 and Exhibit C.19 for CWSs and NCWSs, respectively. For total chlorine samples in SW CWSs (Exhibit C.18), there is not a strong system size trend in EC+ occurrence. For total chlorine samples in SW NCWSs (Exhibit C.19), there are no distinguishable system size trends. As mentioned earlier, it is also important to note the small sample size for NCWSs; there were few, if any, samples from NCWSs serving more than 4,100 people.

For both free and total chlorine data, the trend of higher occurrence in the lower disinfectant residual bins is not as evident in the EC+ dataset compared to the TC+ results.

Exhibit C.18: Surface Water CWSs: Percent of EC Positives Paired with Total Chlorine Data by System Size (2006-2011)

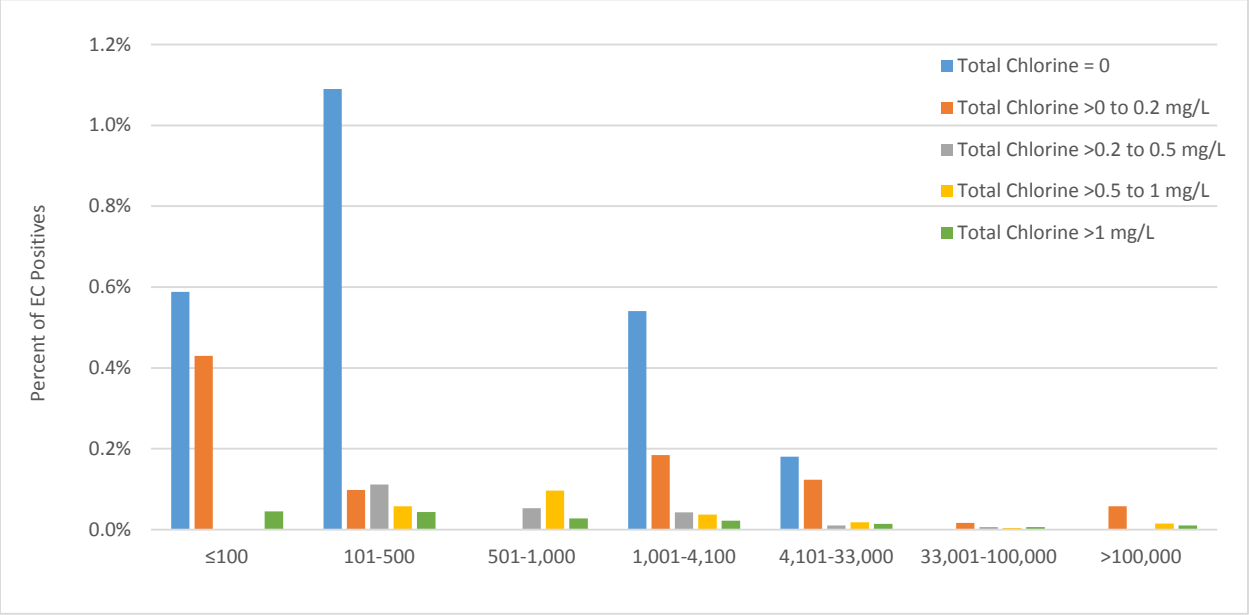
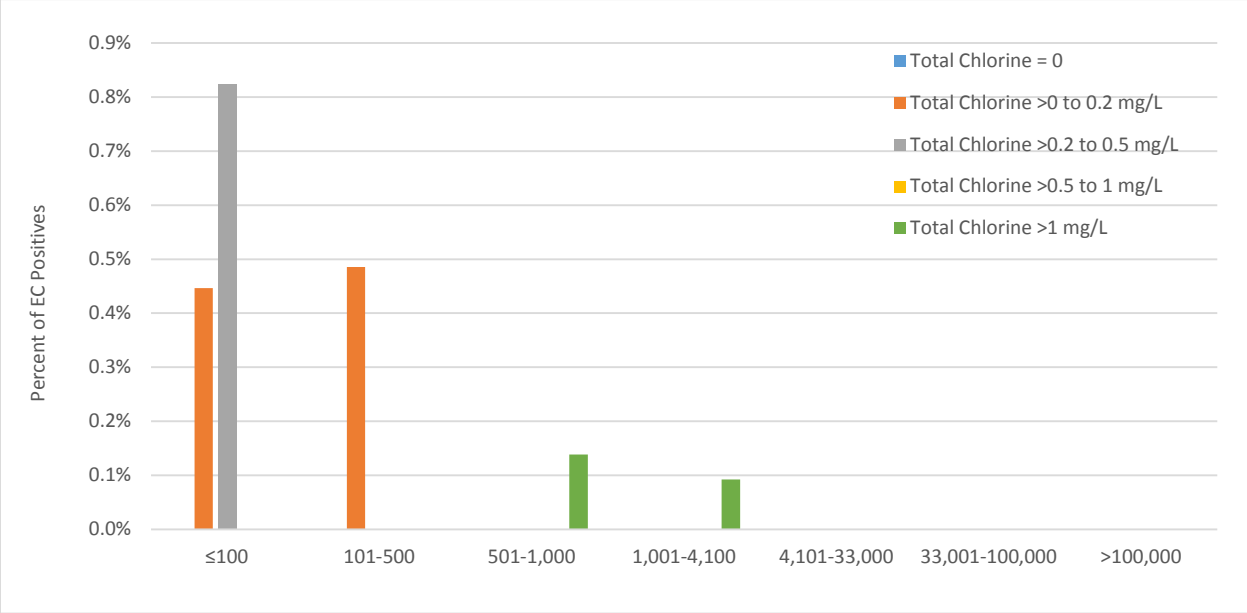


Exhibit C.19: Surface Water NCWSs: Percent of EC Positives Paired with Total Chlorine Data by System Size (2006-2011)[1]



[1] Different scales were used for the Percent of EC Positives (y-axis) for the NCWS results (in this exhibit) compared to the CWS results in the previous exhibit (Exhibit C.18) to enable a closer look at the NCWS results.

Exhibit C.20: Number of Total Coliform Surface Water Samples Paired with Total Chlorine Data, by System Size and System Type (underlying data/denominator for Exhibit C.16, Exhibit C.17, Exhibit C.18 and Exhibit C.19)

System Size	Total # TC SW Samples Paired with Total Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
CWSs						
≤100	170	465	1,263	3,218	11,061	16,177
101-500	367	2,030	4,489	8,652	27,750	43,288
501-1,000	96	1,658	3,781	6,202	18,242	29,979
1,001-4,100	185	3,250	11,573	27,056	80,229	122,293
4,101-33,000	554	4,855	19,807	80,943	250,792	356,951
33,001-100,000	117	5,988	15,078	46,287	162,092	229,562
>100,000	46	1,720	6,136	52,468	234,419	294,789
NCWSs						
≤100	155	224	364	642	2,115	3,500
101-500	19	206	328	667	1,728	2,948
501-1,000	7	37	216	194	722	1,176
1,001-4,100	3	98	247	297	1,084	1,729
4,101-33,000	0	0	0	10	259	269

System Size	Total # TC SW Samples Paired with Total Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
33,001-100,000	0	0	0	0	0	0
>100,000	0	0	0	1	2	3

[1] The NCWS results in this system size category are based on results from a single non-transient non-community water purchased surface water system in Texas that serves more than 200,000 people; the only three total coliform results from this system were TC+.

EPA calculated the frequency of detection for the total coliform results in ground water systems over the six years for each of seven system size categories and presented the results separately for five bins of free chlorine residual concentrations for CWSs and NCWSs (Exhibit C.21 and Exhibit C.22, respectively). Similar results for *E. coli* results in ground water systems are presented for CWSs (Exhibit C.23) and NCWSs (Exhibit C.24).

Exhibit C.21: Ground Water CWSs: Percent of TC Positives Paired with Free Chlorine Data by System Size (2006-2011)

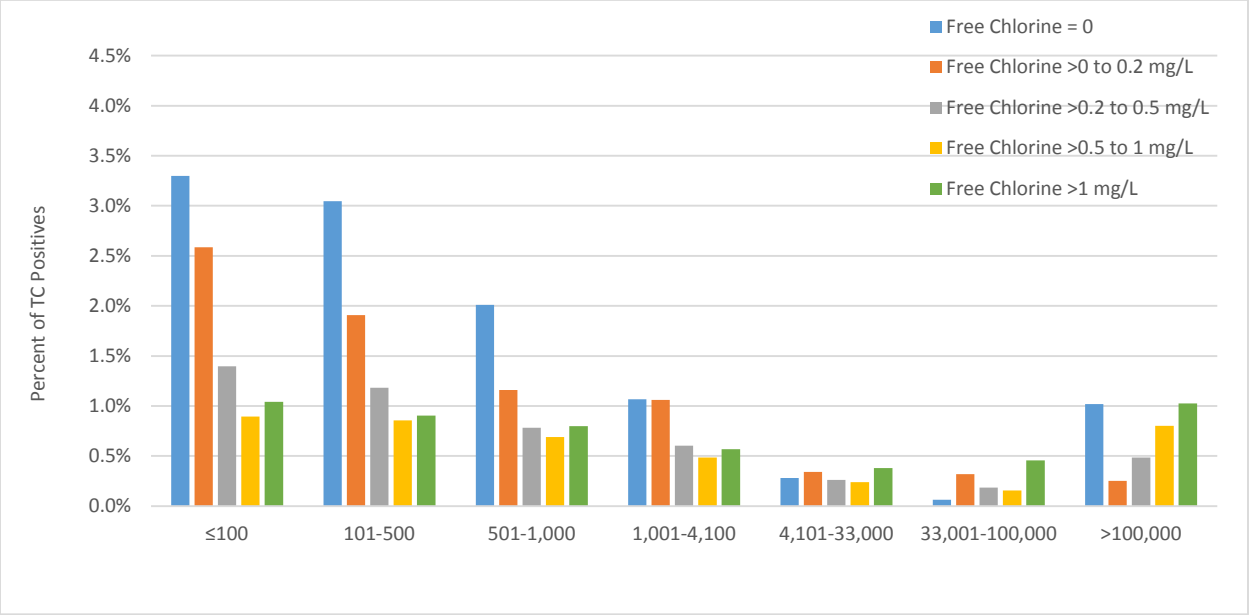


Exhibit C.22: Ground Water NCWSs: Percent of TC Positives Paired with Free Chlorine Data by System Size (2006-2011)

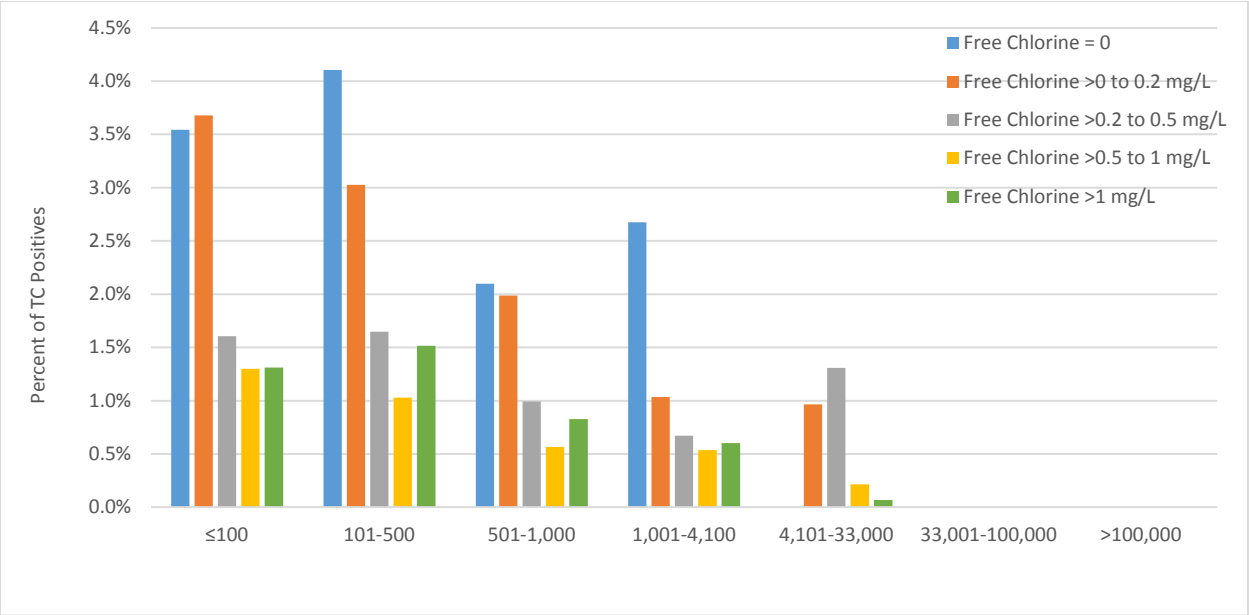


Exhibit C.23: Ground Water CWSs: Percent of EC Positives Paired with Free Chlorine Data by System Size (2006-2011)

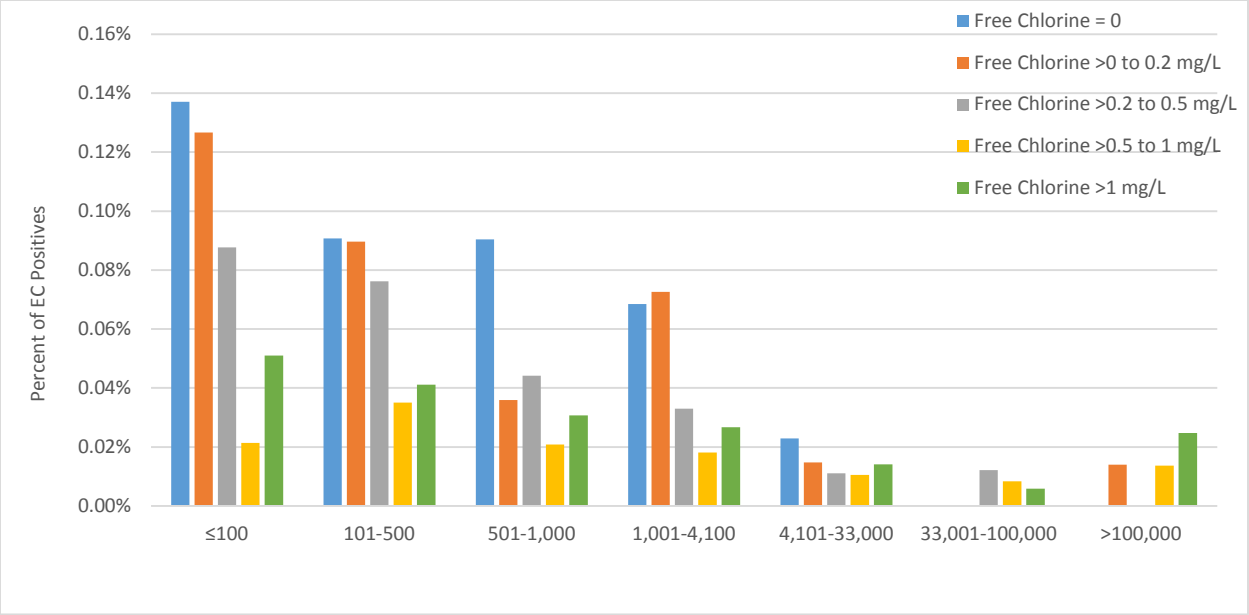


Exhibit C.24: Ground Water NCWSs: Percent of EC Positives Paired with Free Chlorine Data by System Size (2006-2011)

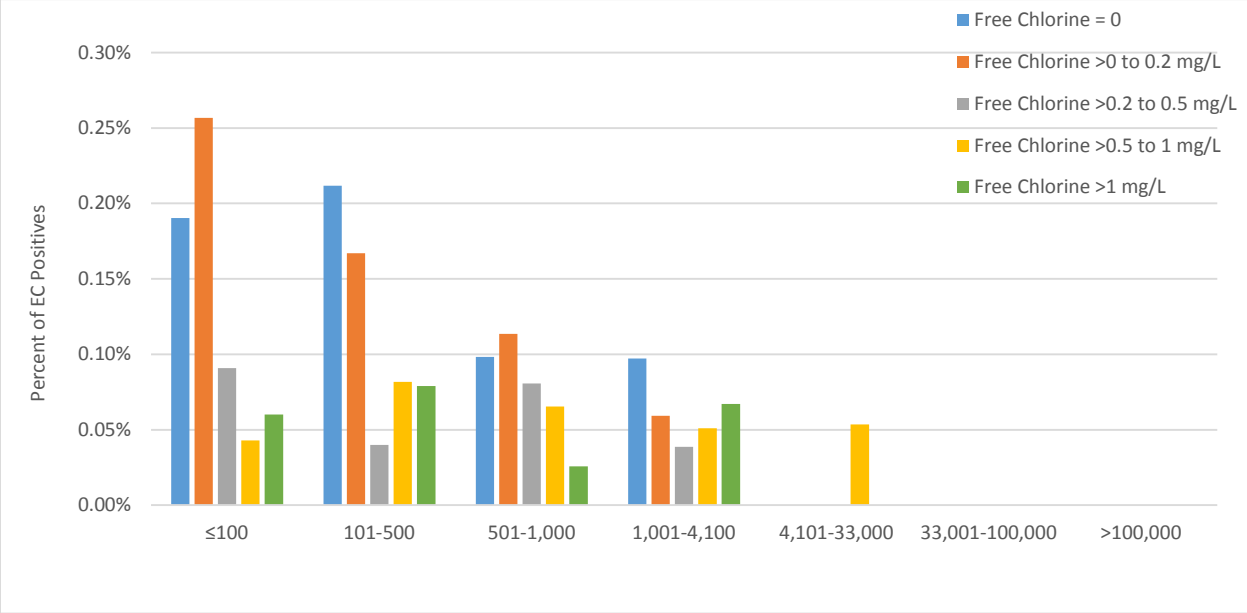
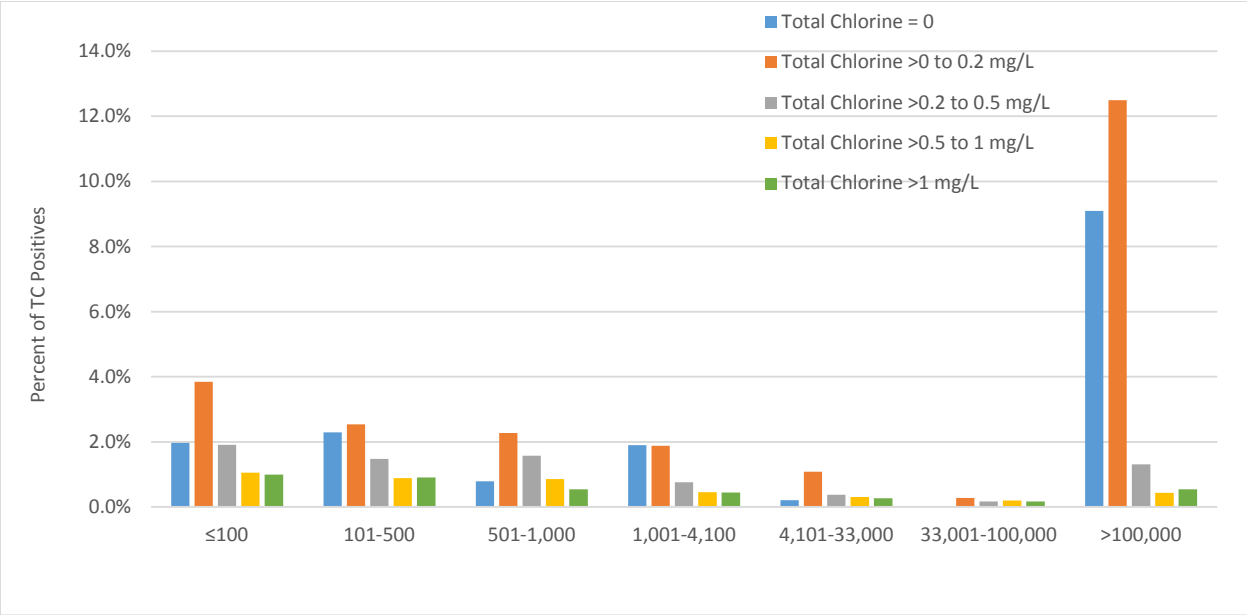


Exhibit C.25: Number of Total Coliform Ground Water Samples Paired with Free Chlorine Data, by System Size and System Type (underlying data/denominator for Exhibit C.21, Exhibit C.22, Exhibit C.23 and Exhibit C.24)

System Size	Total # TC GW Samples Paired with Free Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
CWSs						
≤100	21,156	16,583	30,794	37,393	27,445	133,371
101-500	18,744	30,108	53,828	65,618	51,038	219,336
501-1,000	4,427	11,138	22,651	28,850	22,787	89,853
1,001-4,100	7,306	28,940	60,626	88,287	78,845	264,004
4,101-33,000	13,129	61,175	126,350	190,510	134,630	525,794
33,001-100,000	4,700	21,048	57,573	96,151	34,312	213,784
>100,000	196	7,178	8,850	14,591	16,199	47,014
NCWSs						
≤100	59,359	14,408	19,810	20,937	23,249	137,763
101-500	13,693	9,585	17,538	18,352	19,010	78,178
501-1,000	3,052	1,760	3,722	4,585	3,866	16,985
1,001-4,100	2,056	3,379	7,731	7,841	5,965	26,972
4,101-33,000	363	207	764	1,867	1,461	4,662
33,001-100,000	0	0	0	0	0	0
>100,000	0	0	0	0	0	0

EPA also calculated the frequency of detection for the total coliform results in ground water systems over the six years for each of seven system size categories, presented separately for five bins of total chlorine residual concentrations for CWSs and NCWSs (Exhibit C.26 and Exhibit C.27, respectively). Similar results for *E. coli* results in ground water systems are presented for CWSs (Exhibit C.28) and NCWSs (Exhibit C.29).

Exhibit C.26: Ground Water CWSs: Percent of TC Positives Paired with Total Chlorine Data by System Size (2006-2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the CWS results (in this exhibit) compared to the NCWS results in the next exhibit (Exhibit C.27) to enable a closer look at the CWS results.

Exhibit C.27: Ground Water NCWSs: Percent of TC Positives Paired with Total Chlorine Data by System Size (2006-2011)

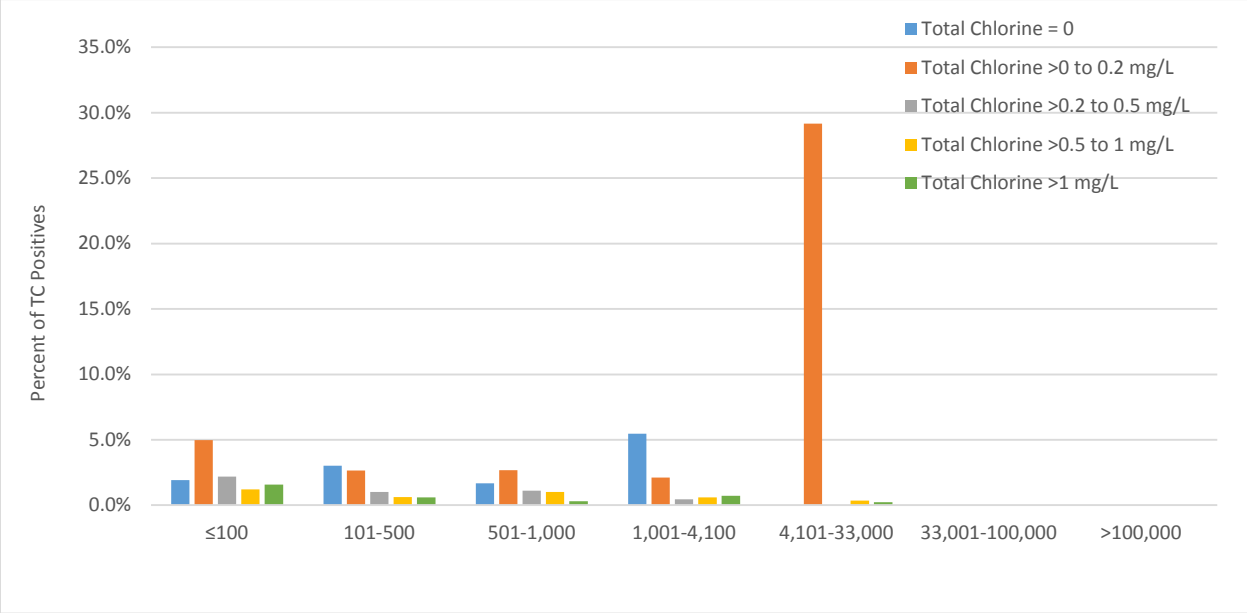


Exhibit C.28: Ground Water CWSs: Percent of EC Positives Paired with Total Chlorine Data by System Size (2006-2011)

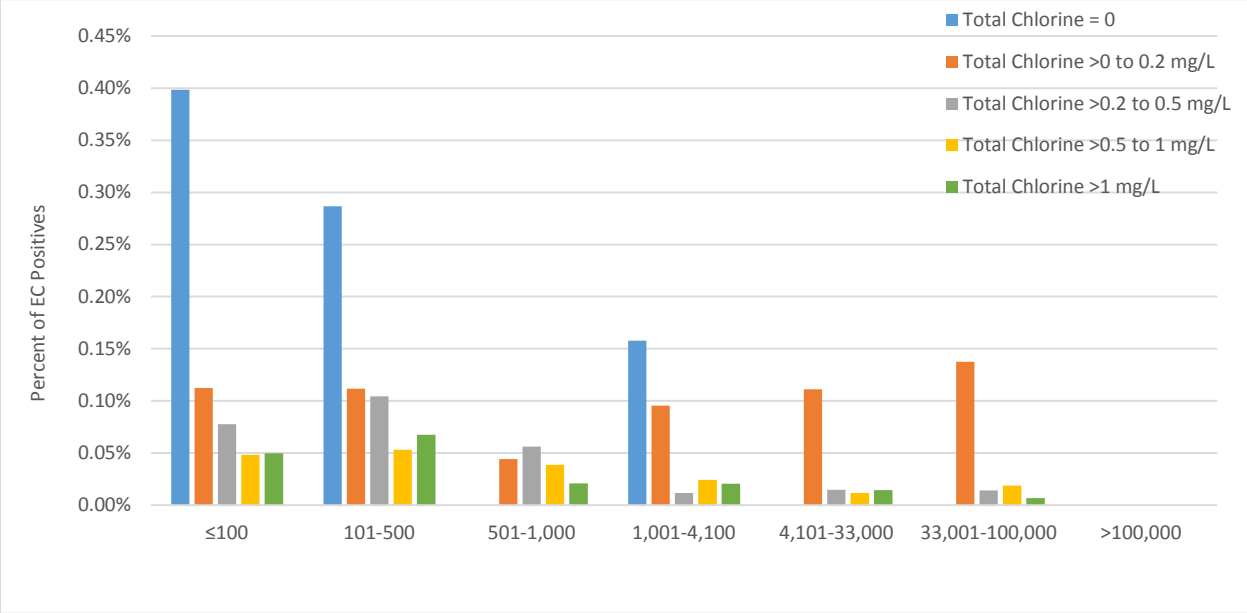


Exhibit C.29: Ground Water NCWSs: Percent of EC Positives Paired with Total Chlorine Data by System Size (2006-2011)

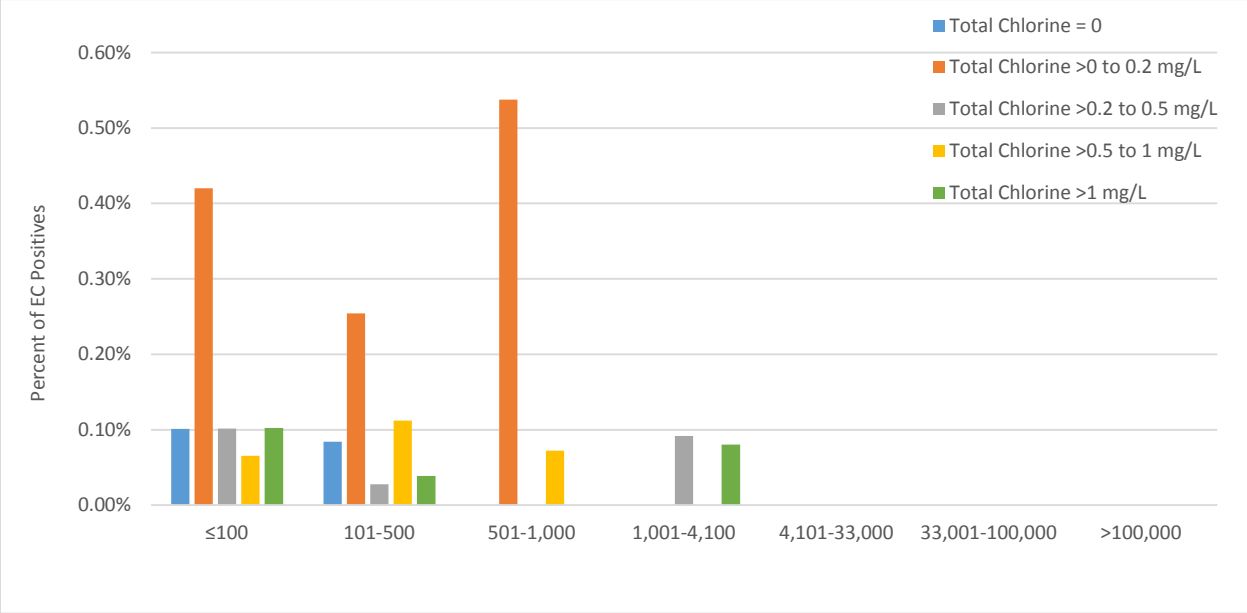


Exhibit C.30: Number of Total Coliform Ground Water Samples Paired with Total Chlorine Data, by System Size and System Type (underlying data/denominator for Exhibit C.26, Exhibit C.27, Exhibit C.28, and Exhibit C.29)

System Size	Total # TC GW Samples Paired with Total Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
CWSs						
≤100	4,267	3,560	10,294	14,582	20,154	52,857
101-500	2,441	8,048	23,007	43,377	57,716	134,589
501-1,000	256	4,538	12,477	25,830	33,695	76,796
1,001-4,100	634	6,294	25,609	65,953	83,488	181,978
4,101-33,000	494	9,000	34,396	113,493	152,990	310,373
33,001-100,000	149	1,455	14,152	48,104	59,849	123,709
>100,000	11	104	1,689	7,887	24,601	34,292
NCWSs						
≤100	11,856	3,334	7,887	10,672	15,616	49,365
101-500	4,755	1,966	3,581	5,358	7,725	23,385
501-1,000	179	186	627	1,382	2,252	4,626
1,001-4,100	128	330	1,089	2,652	4,975	9,174
4,101-33,000	14	24	38	276	869	1,221
33,001-100,000	0	0	0	0	0	0

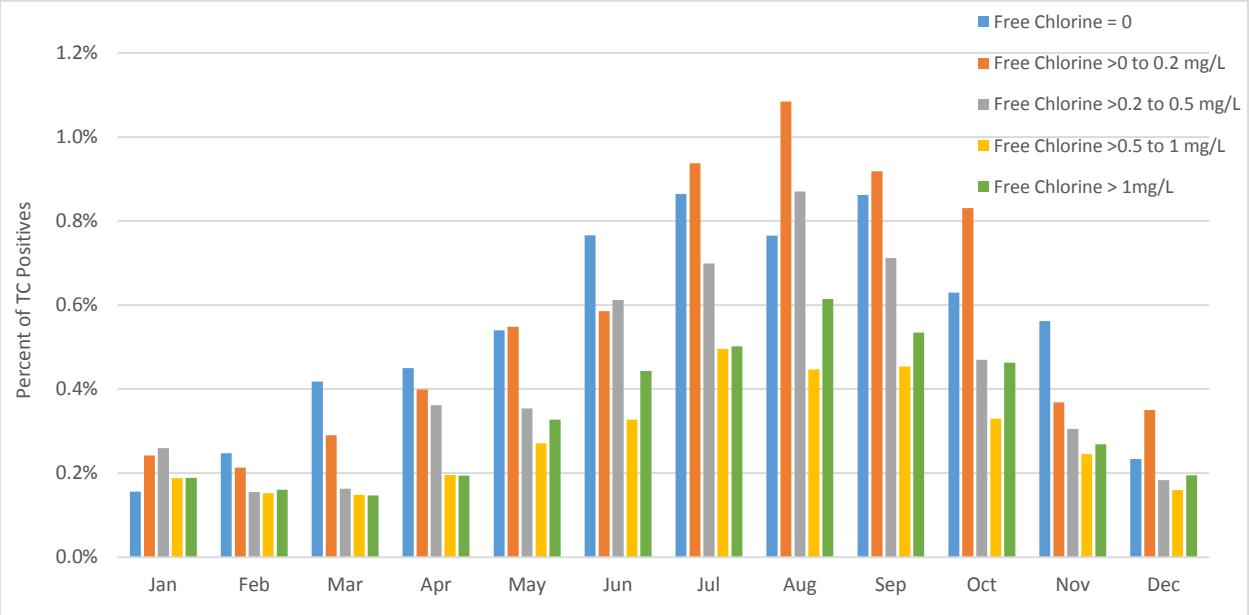
System Size	Total # TC GW Samples Paired with Total Chlorine					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
>100,000	0	0	0	0	0	0

Temporal/Seasonal Analysis

To assess any potential seasonal variations in the SYR3 ICR microbial data, EPA calculated the frequency of detection, by month, for the total coliform results in surface water systems for each calendar month in each year (2006 – 2011). Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.31 and Exhibit C.32, respectively). Note that this analysis does not differentiate between seasonal and non-seasonal systems.

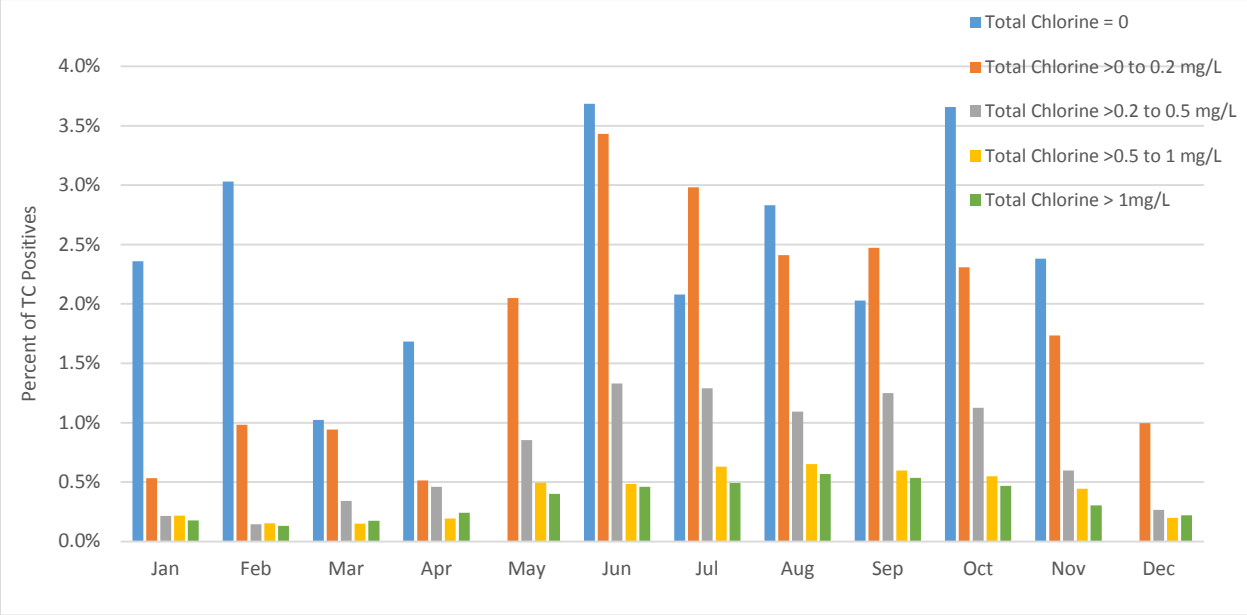
TC+ occurrence was generally higher in warmer months regardless of residual concentration, indicating a strong seasonal trend. The seasonal effect was stronger for free chlorine samples than it was for total chlorine samples. For both free and total chlorine samples, the highest percent of TC+ occurred in either the 0 mg/L bin or the >0 – 0.2 mg/L bin regardless of season (with the exception of free chlorine data in January), with a general trending downward of TC+ samples with increasing residual concentrations, particularly in the total chlorine data (Exhibit C.32).

Exhibit C.31: Surface Water PWSs: Percent of TC Positives Paired with Free Chlorine Data by Month (2006-2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the free chlorine results (in this exhibit) compared to the total chlorine results in the next exhibit (Exhibit C.32) to enable a closer look at the free chlorine results.

Exhibit C.32: Surface Water PWSs: Percent of TC Positives Paired with Total Chlorine Data by Month (2006-2011)



EPA also calculated the frequency of detection, by month, for the *E. coli* results in surface water systems for each calendar month in each year (2006 – 2011). Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.33 and Exhibit C.34, respectively).

EC+ occurrence in surface water systems was generally higher in warmer months regardless of residual concentration, indicating a seasonal trend. Similar to the TC+ results, the seasonal effect was stronger for paired EC+/free chlorine samples than it was for paired EC+/total chlorine samples. As with previous analyses in this section, the trend of higher occurrence in the lower disinfectant residual bins is not as evident in the EC+ dataset (Exhibit C.33 and Exhibit C.34) compared to the TC+ results (Exhibit C.31 and Exhibit C.32).

Exhibit C.33: Surface Water PWSs: Percent of EC Positives Paired with Free Chlorine Data by Month (2006-2011)

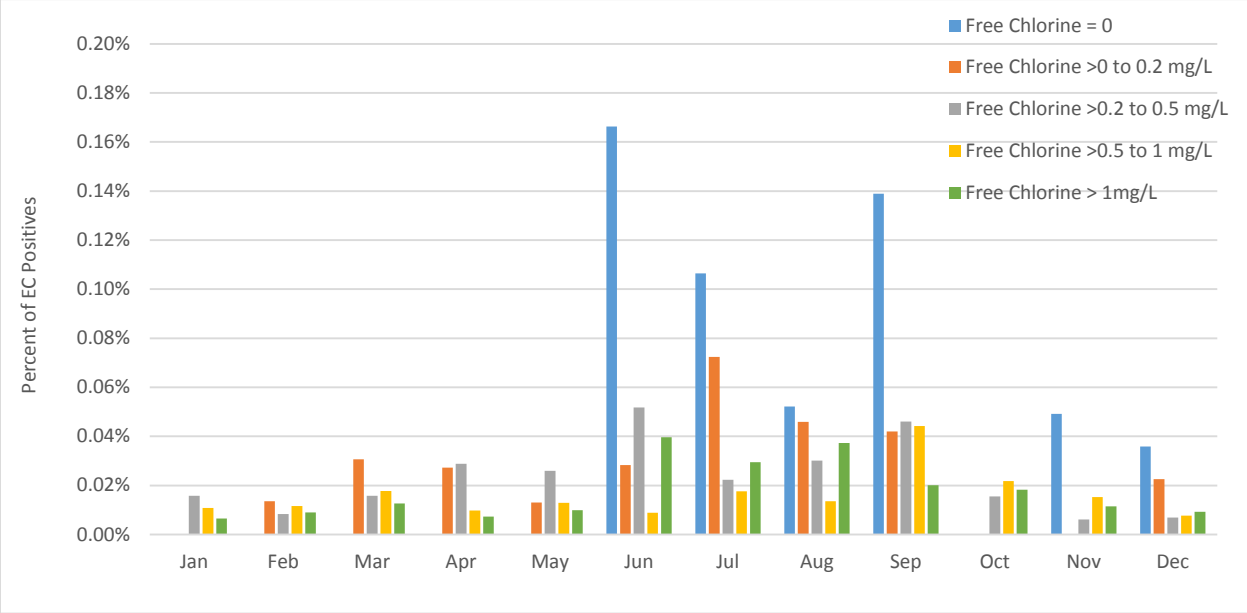


Exhibit C.34: Surface Water PWSs: Percent of EC Positives Paired with Total Chlorine Data by Month (2006-2011)

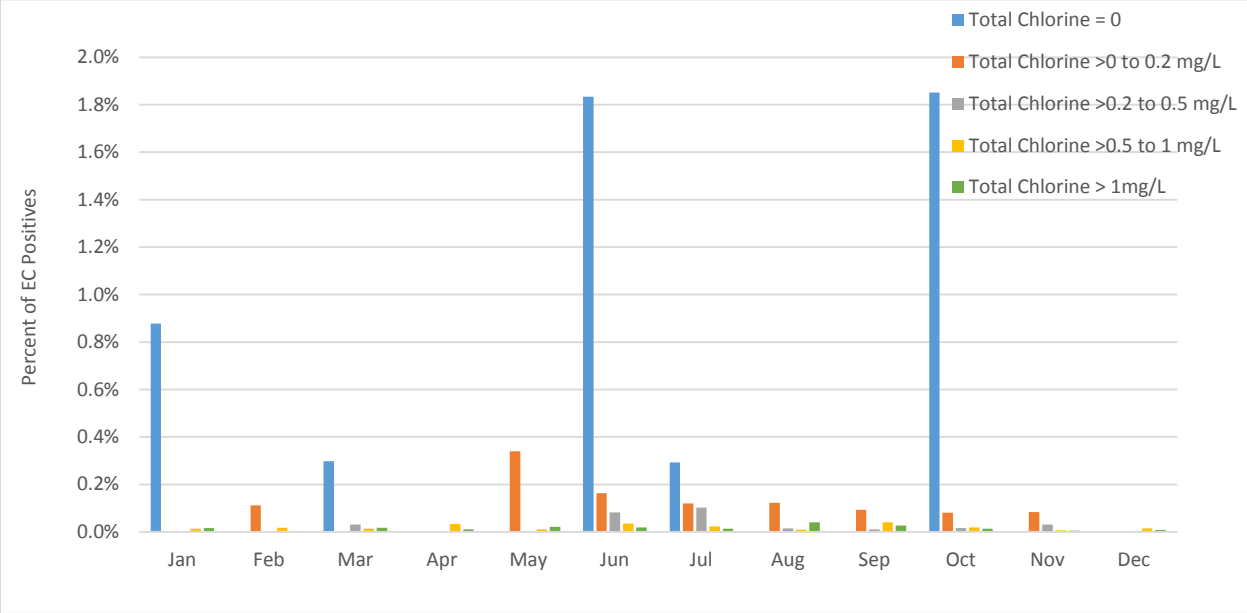


Exhibit C.35: Number of Total Coliform Samples in Surface Water Paired with Free and Total Chlorine Data, by Month (underlying data/denominator for Exhibit C.31, Exhibit C.32, Exhibit C.33 and Exhibit C.34)

Month	Total # TC SW Samples Paired					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
Free Chlorine						
Jan	3,967	8,004	12,559	40,661	61,063	126,254
Feb	3,480	7,562	12,262	40,651	62,031	125,986
Mar	3,844	7,437	12,913	42,002	61,597	127,793
Apr	3,797	8,281	14,192	44,804	59,392	130,466
May	4,169	8,938	15,264	46,445	56,057	130,873
Jun	4,091	10,291	17,697	46,986	53,907	132,972
Jul	3,869	11,068	19,175	46,229	53,429	133,770
Aug	4,152	11,651	19,782	46,000	52,327	133,912
Sep	4,045	11,163	19,337	44,592	53,722	132,859
Oct	3,611	10,866	18,529	44,157	55,441	132,604
Nov	3,584	9,763	16,396	43,299	58,700	131,742
Dec	3,564	8,845	13,716	42,987	62,911	132,023
Total Chlorine						
Jan	151	1,038	3,443	15,986	64,615	85,233
Feb	118	810	3,265	15,591	64,332	84,116
Mar	127	838	3,544	16,438	66,089	87,036
Apr	134	1,030	3,969	17,856	65,849	88,838
May	128	1,239	5,013	19,192	64,877	90,449
Jun	148	1,793	6,059	20,467	63,316	91,783
Jul	179	2,452	6,786	20,718	61,999	92,134
Aug	185	2,730	7,440	21,521	65,211	97,087
Sep	160	2,617	7,222	20,638	65,528	96,165
Oct	128	2,434	6,545	20,643	67,588	97,338
Nov	110	2,066	5,511	19,272	69,217	96,176
Dec	151	1,484	4,485	18,315	71,874	96,309

EPA calculated the frequency of detection, by month, for the total coliform results in ground water systems for each calendar month in each year (2006 – 2011). Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.36 and Exhibit C.37, respectively).

Exhibit C.36: Ground Water PWSs: Percent of TC Positives Paired with Free Chlorine Data by Month (2006-2011)

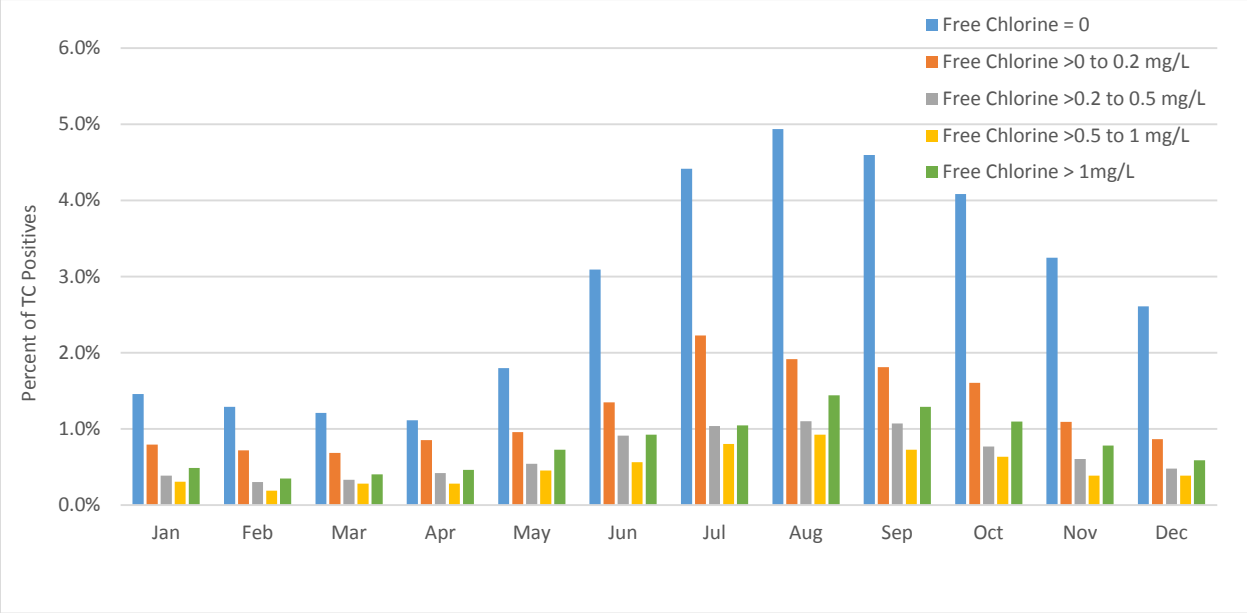
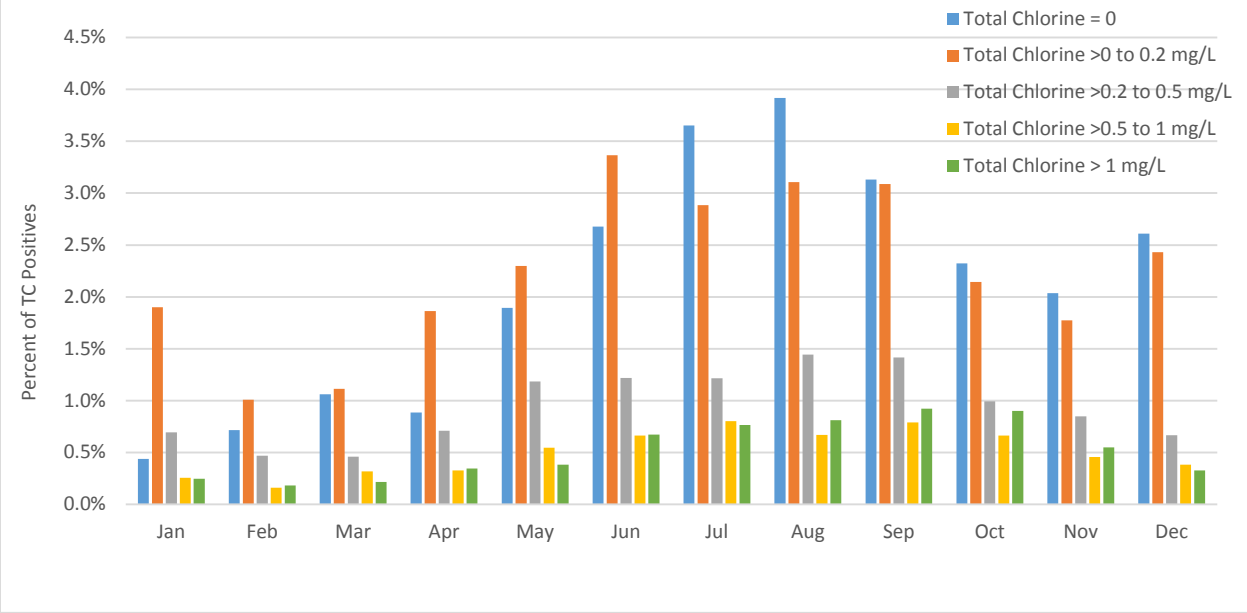


Exhibit C.37: Ground Water PWSs: Percent of TC Positives Paired with Total Chlorine Data by Month (2006-2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the total chlorine results (in this exhibit) compared to the free chlorine results in the previous exhibit (Exhibit C.36) to enable a closer look at the total chlorine results.

EPA calculated the frequency of detection, by month, for the *E. coli* results in ground water systems for each calendar month in each year (2006 – 2011). Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.38 and Exhibit C.39, respectively).

Exhibit C.38: Ground Water PWSs: Percent of EC Positives Paired with Free Chlorine Data by Month (2006-2011)

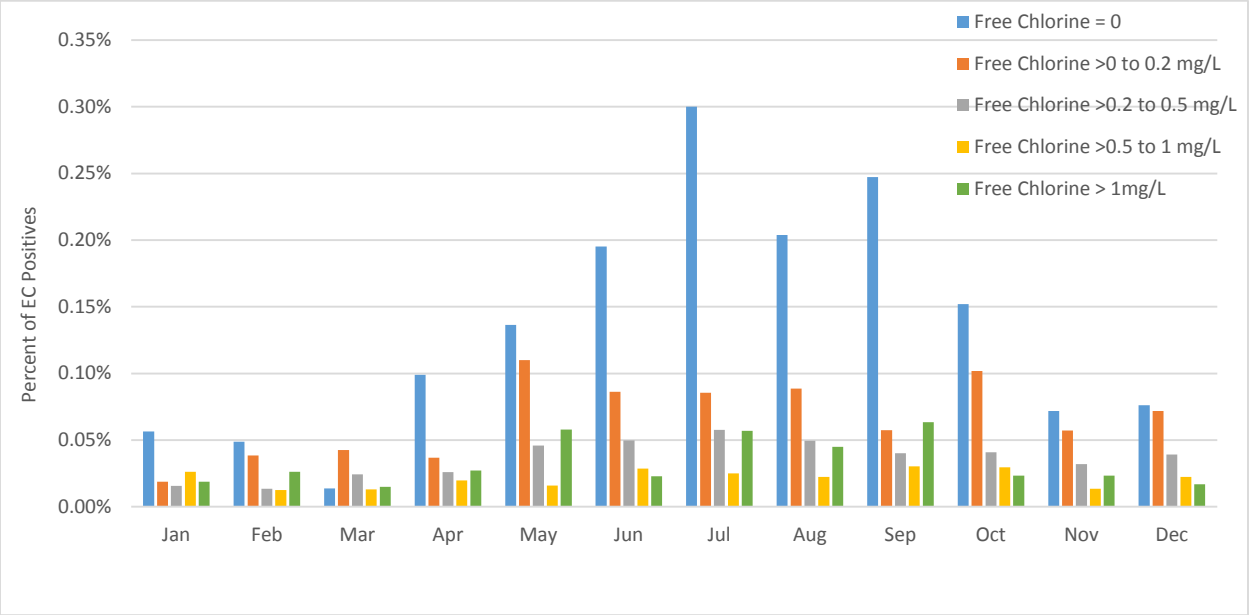


Exhibit C.39: Ground Water PWSs: Percent of EC Positives Paired with Total Chlorine Data by Month (2006-2011)

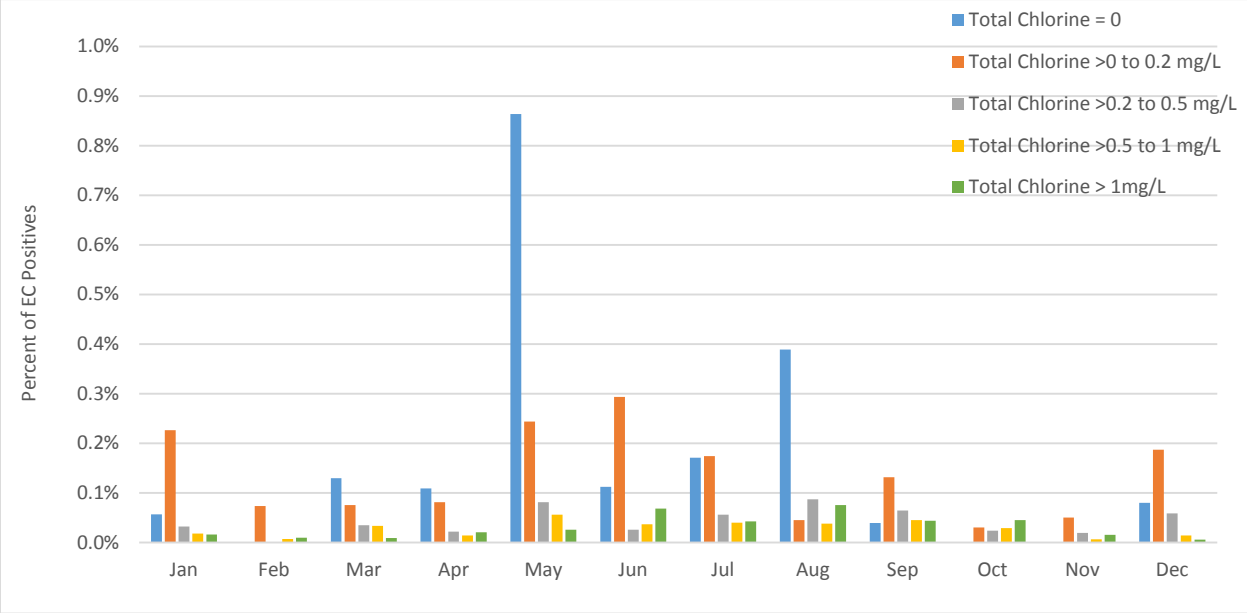


Exhibit C.40: Number of Total Coliform Samples in Ground Water Paired with Free and Total Chlorine Data, by Month (underlying data/denominator for Exhibit C.36, Exhibit C.37, Exhibit C.38 and Exhibit C.39)

Month	Total # TC GW Samples Paired					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
Free Chlorine						
Jan	12,262	15,562	31,367	46,128	33,860	139,179
Feb	10,639	15,263	31,090	47,354	35,088	139,434
Mar	11,378	15,788	31,603	47,546	34,791	141,106
Apr	12,660	16,293	32,779	47,922	34,861	144,515
May	11,887	16,414	33,326	47,221	33,817	142,665
Jun	12,672	17,439	34,708	47,552	33,479	145,850
Jul	12,692	18,425	36,527	48,235	33,582	149,461
Aug	13,258	18,914	37,484	48,546	33,540	151,742
Sep	14,184	18,927	37,577	48,711	34,961	154,360
Oct	13,689	18,413	36,787	49,006	36,763	154,658
Nov	11,309	17,457	34,429	47,914	36,704	147,813
Dec	11,551	16,614	32,560	48,847	37,361	146,933
Total Chlorine						
Jan	2,074	2,719	9,921	25,977	35,657	76,348
Feb	1,614	2,687	9,412	25,555	37,114	76,382

Month	Total # TC GW Samples Paired					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
Mar	1,856	2,819	9,780	26,714	38,736	79,905
Apr	2,260	2,960	10,321	27,653	37,862	81,056
May	1,891	3,174	10,971	27,949	38,181	82,166
Jun	2,053	3,366	11,503	28,492	37,754	83,168
Jul	2,478	3,571	12,331	29,186	37,602	85,168
Aug	1,997	3,924	13,155	29,899	39,250	88,225
Sep	2,532	3,713	12,888	29,860	39,423	88,416
Oct	2,636	3,561	12,535	30,218	40,025	88,975
Nov	1,825	3,353	11,379	29,327	40,506	86,390
Dec	1,968	2,992	10,650	28,736	41,820	86,166

Annual Trends Analysis

To assess any potential yearly trends over the six years of data in the SYR3 ICR microbial data, EPA calculated the frequency of detection for the total coliform results in surface water systems. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.41 and Exhibit C.42, respectively).

For free chlorine, the data show a general trend of higher TC+ occurrence in 2007 and 2008, with a general trending downward of the data in 2009 through 2011. The trend of increasing TC+ occurrence with decreasing free chlorine residual is also stronger in 2006 – 2008 than it is for 2009 – 2011. For total chlorine, the results are opposite with higher overall occurrence happening in the last two years of the dataset (2010 and 2011) compared to 2006 – 2009. Total chlorine results show a more consistent trend in TC+ occurrence and disinfectant residual concentration, with higher TC+ occurrence in the 0 mg/L or the >0 – 0.2 mg/L bin for all years, and a general trending down off occurrence in the higher residual bins.

Exhibit C.41: Surface Water PWSs: Percent of TC Positives Paired with Free Chlorine Data by Year (2006 - 2011)

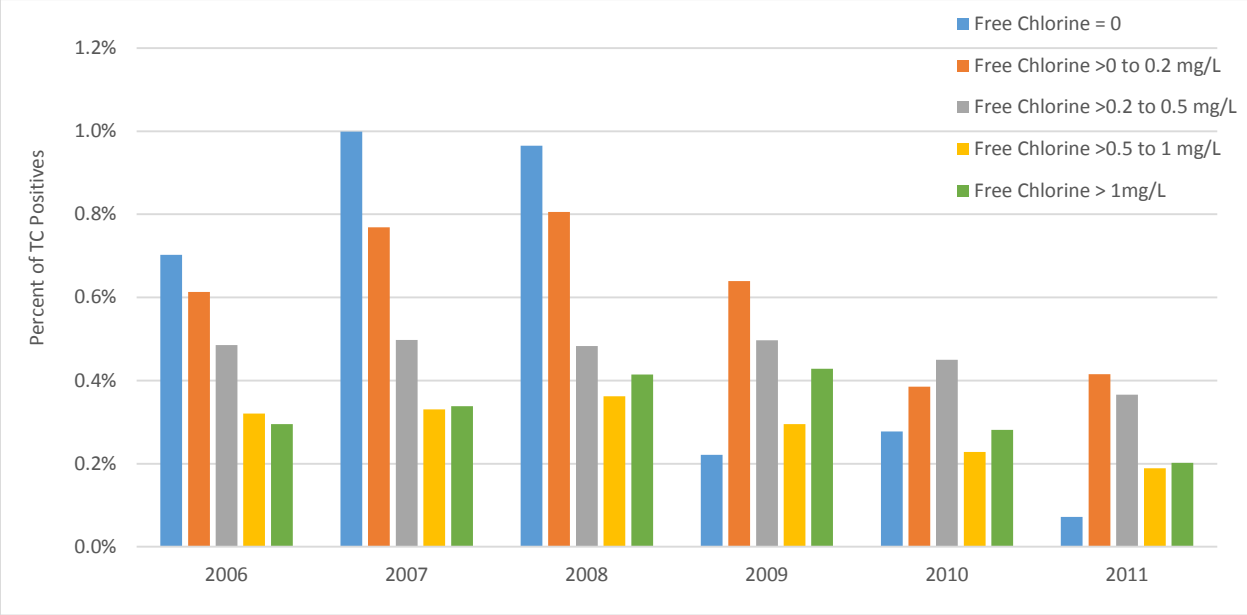
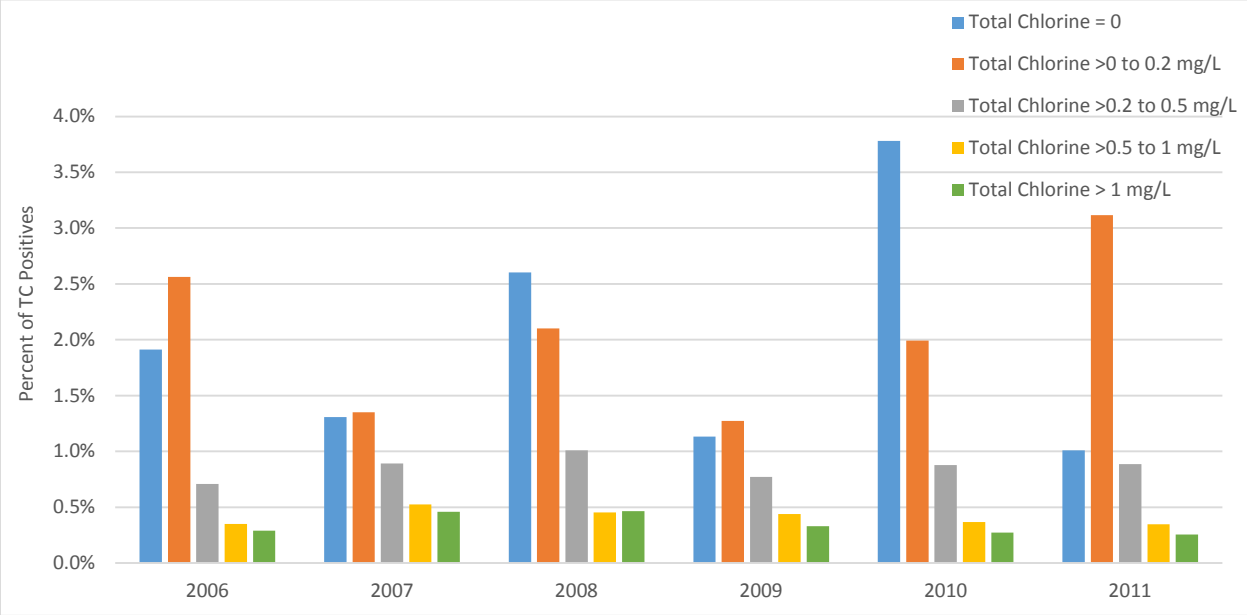


Exhibit C.42: Surface Water PWSs: Percent of TC Positives Paired with Total Chlorine Data by Year (2006 - 2011)



EPA also calculated the frequency of detection for the *E. coli* results in surface water systems. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.43 and Exhibit C.44, respectively). Exhibit C.43 and Exhibit C.44 do not show a

uniform trend in percent EC+ in surface water from 2006 to 2011, with each of the two residual type bins for free and total chlorine showing different trends and peak years.

Exhibit C.43: Surface Water PWSs: Percent of EC Positives Paired with Free Chlorine Data by Year (2006 - 2011)

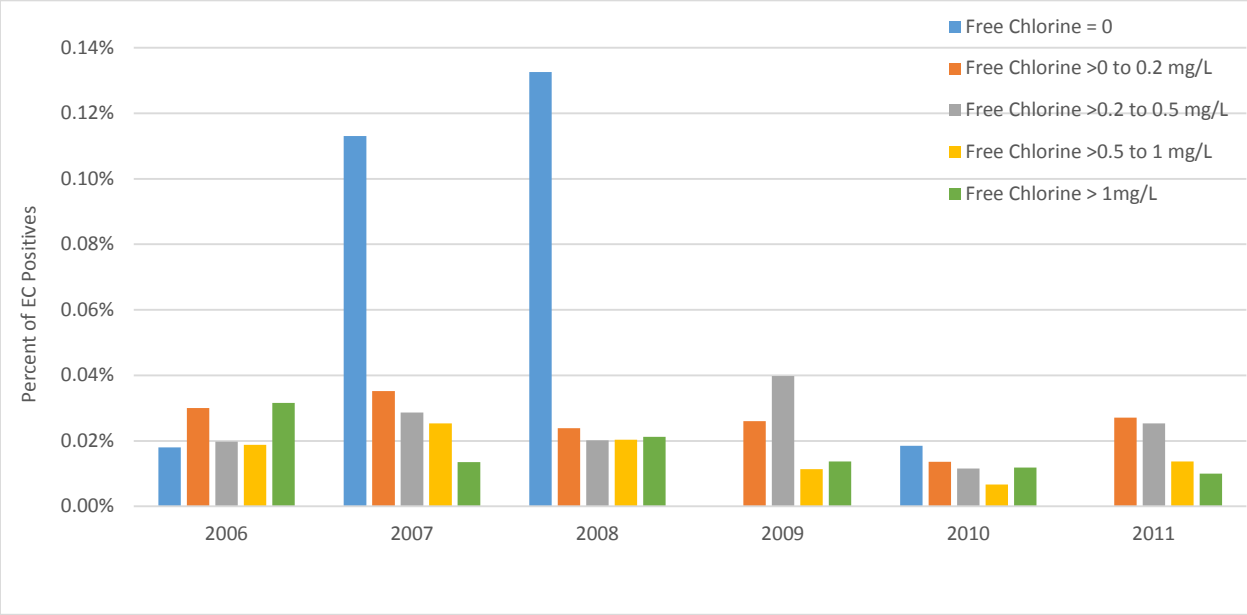
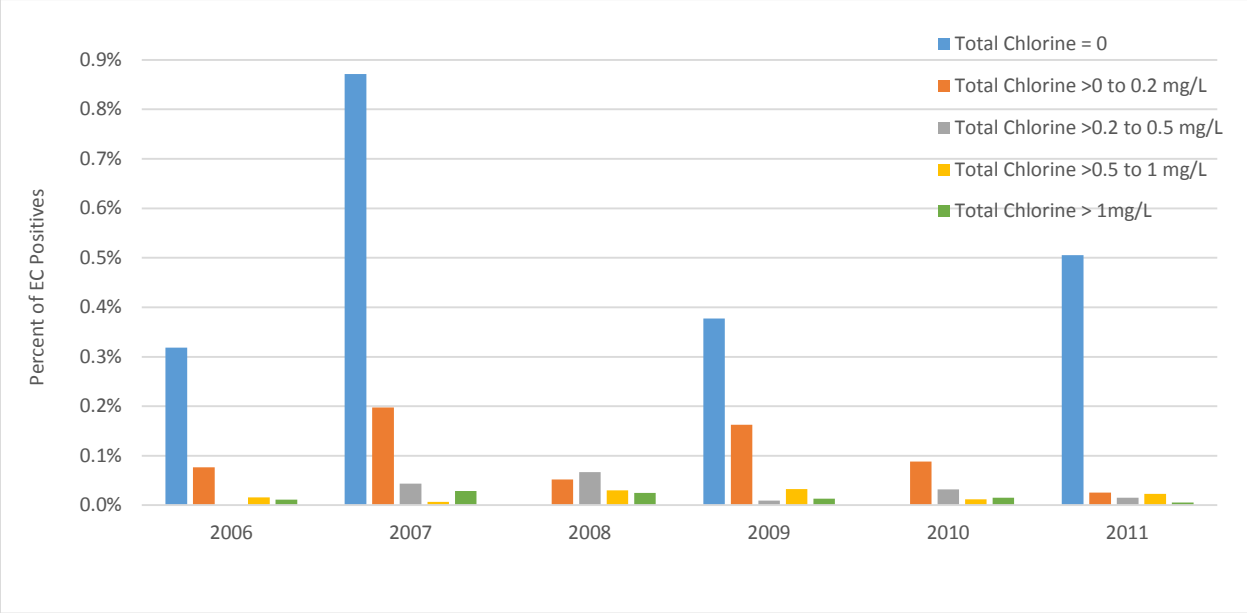


Exhibit C.44: Surface Water PWSs: Percent of EC Positives Paired with Total Chlorine Data by Year (2006 - 2011)



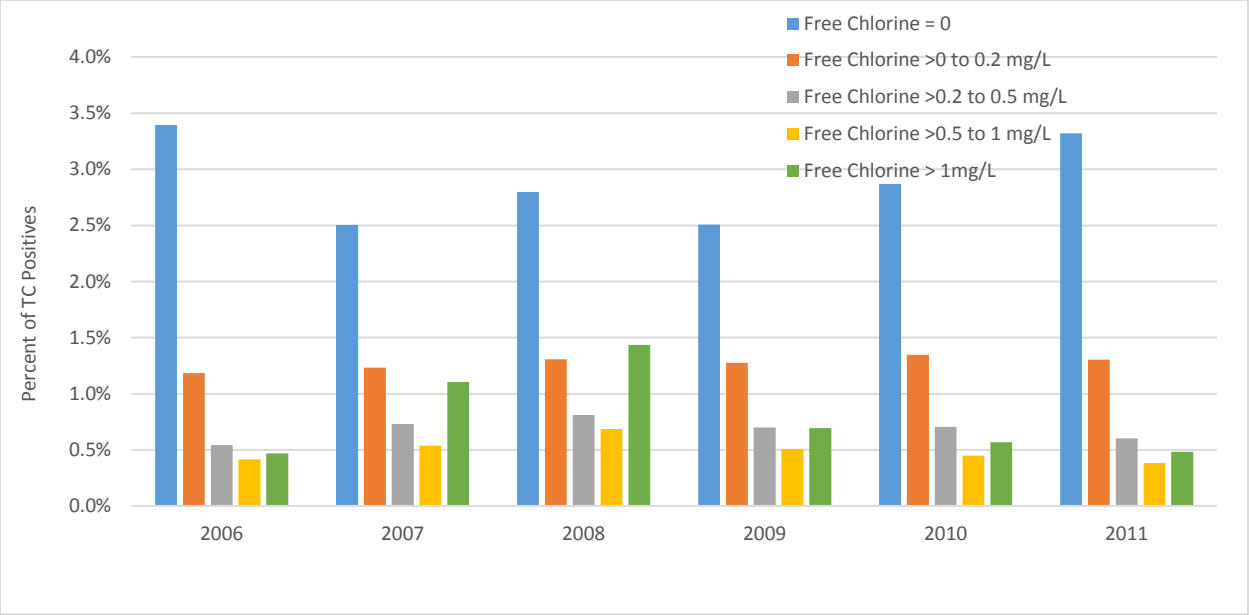
[1] Different scales were used for the Percent of EC Positives (y-axis) for the total chlorine results (in this exhibit) compared to the free chlorine results in the previous exhibit (Exhibit C.43) to enable a closer look at the total chlorine results.

Exhibit C.45: Number of Total Coliform Samples in Surface Water Paired with Free and Total Chlorine Data, by Year (underlying data/denominator for Exhibit C.41, Exhibit C.42, Exhibit C.43 and Exhibit C.44)

Year	Total # TC SW Samples Paired					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
Free Chlorine						
2006	5,553	16,634	30,298	74,514	72,823	199,822
2007	5,306	17,047	31,352	82,933	96,456	233,094
2008	5,282	16,759	29,806	78,654	108,073	238,574
2009	9,479	19,226	30,163	78,864	109,277	247,009
2010	10,813	22,048	34,692	104,195	143,587	315,335
2011	9,740	22,155	35,511	109,653	160,361	337,420
Total Chlorine						
2006	314	2,615	7,329	25,159	80,823	116,240
2007	459	3,039	9,201	29,105	82,778	124,582
2008	192	3,857	10,496	33,419	87,694	135,658
2009	265	3,693	10,508	36,541	126,725	177,732
2010	291	3,411	12,424	50,045	194,284	260,455
2011	198	3,916	13,324	52,368	218,191	287,997

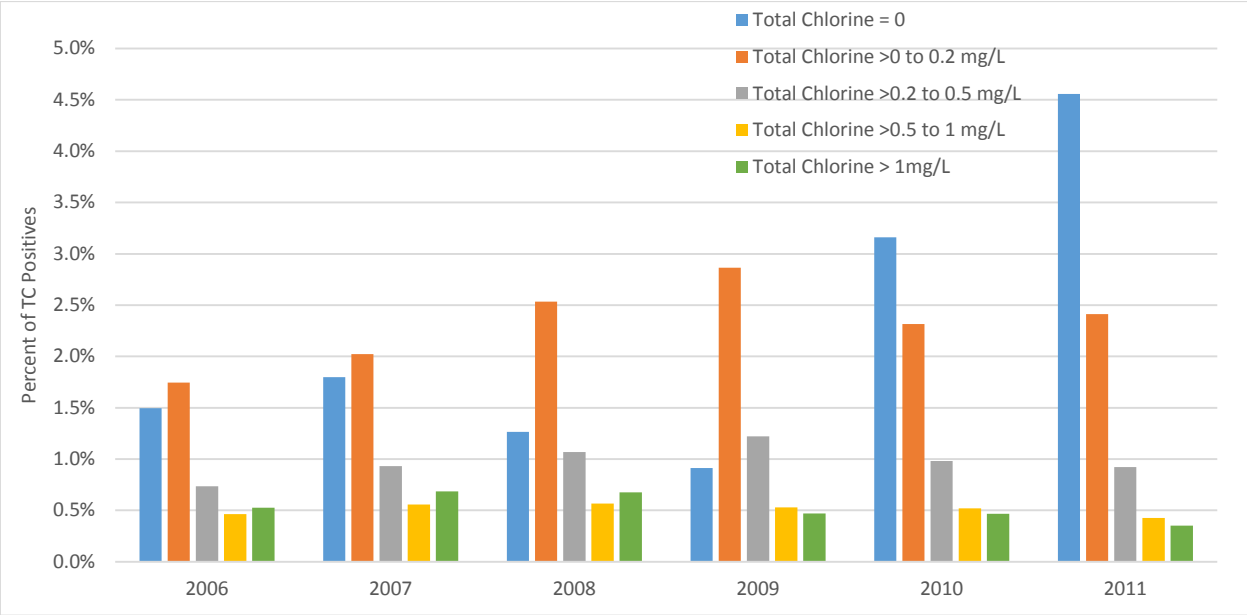
EPA calculated the frequency of detection, by year, for the total coliform results in ground water systems. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.46 and Exhibit C.47, respectively).

Exhibit C.46: Ground Water PWSs: Percent of TC Positives Paired with Free Chlorine Data by Year (2006 - 2011)[1]



[1] Different scales were used for the Percent of TC Positives (y-axis) for the free chlorine results (in this exhibit) compared to the total chlorine results in the next exhibit (Exhibit C.47) to enable a closer look at the free chlorine results.

Exhibit C.47: Ground Water PWSs: Percent of TC Positives Paired with Total Chlorine Data by Year (2006 - 2011)



EPA calculated the frequency of detection, by year, for the *E. coli* results in ground water systems. Results were generated separately for five bins of free and total chlorine residual concentrations (Exhibit C.48 and Exhibit C.49, respectively).

Exhibit C.48: Ground Water PWSs: Percent of EC Positives Paired with Free Chlorine Data by Year (2006 - 2011)

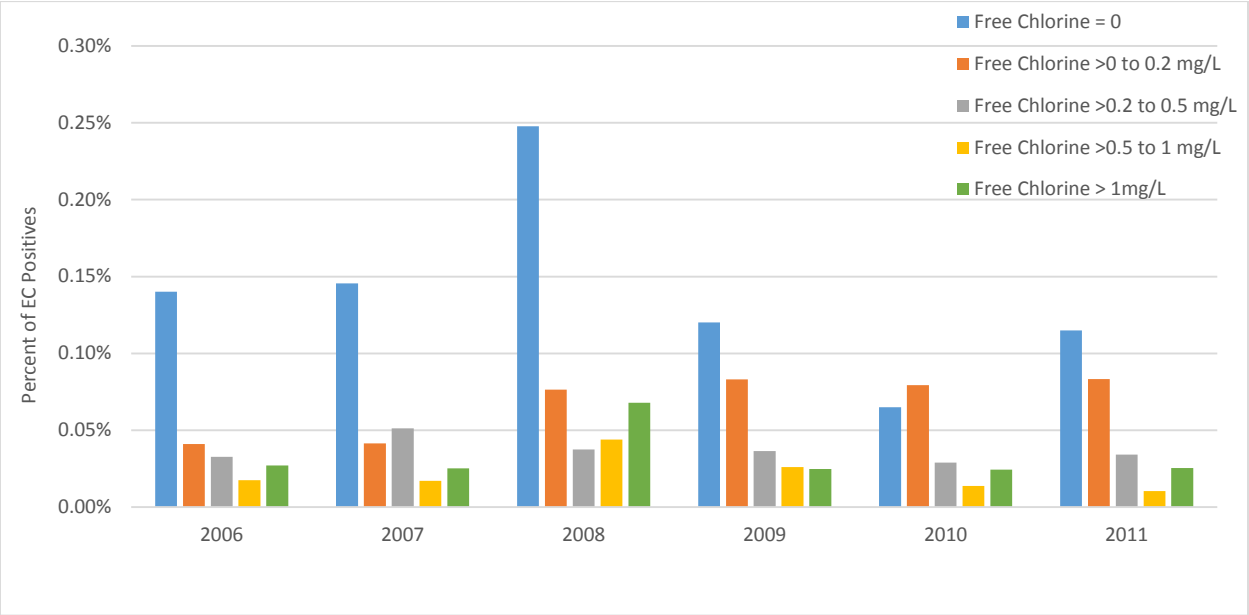


Exhibit C.49: Ground Water PWSs: Percent of EC Positives Paired with Total Chlorine Data by Year (2006 - 2011)

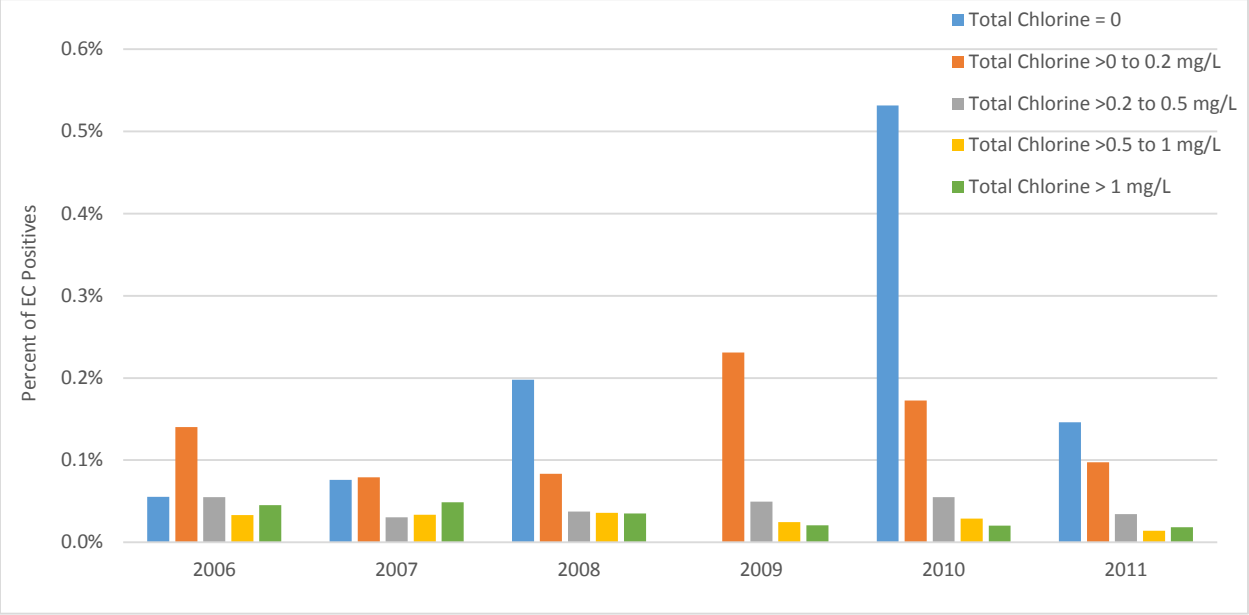


Exhibit C.50: Number of Total Coliform Samples in Ground Water Paired with Free and Total Chlorine Data, by Year (underlying data/denominator for Exhibit C.46, Exhibit C.47, Exhibit C.48 and Exhibit C.49)

Year	Total # TC GW Samples Paired					
	0	> 0 to 0.2 mg/L	> 0.2 to 0.5 mg/L	> 0.5 to 1 mg/L	> 1 mg/L	Total
Free Chlorine						
2006	22,134	31,605	57,915	68,311	33,038	213,003
2007	23,348	33,785	62,516	75,457	35,484	230,590
2008	24,624	33,991	61,121	74,992	38,255	232,983
2009	29,960	34,859	73,936	99,620	84,445	322,820
2010	24,641	35,249	75,647	122,993	106,101	364,631
2011	23,474	36,020	79,102	133,609	121,484	393,689
Total Chlorine						
2006	3,609	4,988	20,023	38,897	37,594	105,111
2007	3,947	5,043	19,773	44,780	45,165	118,708
2008	5,056	5,996	21,258	50,196	51,218	133,724
2009	4,704	6,495	22,158	56,811	81,704	171,872
2010	3,765	8,114	25,503	72,378	117,916	227,676
2011	4,103	8,203	26,131	76,504	130,333	245,274

Geographic Analysis

To assess any potential geographic trends in the SYR3 ICR microbial data, EPA calculated the frequency of detection, by state, for the total coliform results in surface water, ground water and all systems. Results for all five bins of free and total chlorine residual concentrations were combined; the percent of TC+ for all systems (SW and GW) are presented in Exhibit C.51.

A total of 34 states/entities provided TC data for surface water and/or ground water systems. Twenty-eight of those states/entities provided sample data with TC positives. States in the upper three categories of TC+ measures are located in all parts of the United States. However, a potential geographic pattern of occurrence is obscured by the lack of data from 23 states. For example, there are very limited data for the southern Rockies and no data for the Upper Midwest or the southeast portion of the country. The seven states with the highest occurrence of TC positives in all systems (SW and GW systems) are Arkansas, Connecticut, Nevada, New York, Rhode Island, Texas and Vermont. Of these seven states, Texas is the only one that requires a minimum free chlorine residual in the distribution system; that minimum requirement is equal to 0.2 mg/L. Eight of the 12 states with minimum free chlorine requirements that have data in the SYR3 ICR microbial dataset were positive for TC in less than 0.5 percent of samples. Refer to the geographic analysis section of Appendix B for a list of the states with minimum requirements for free and total chlorine residual in the distribution system.

Exhibit C.51: All PWSs (SW + GW): Percent of TC Positives (2006 - 2011)

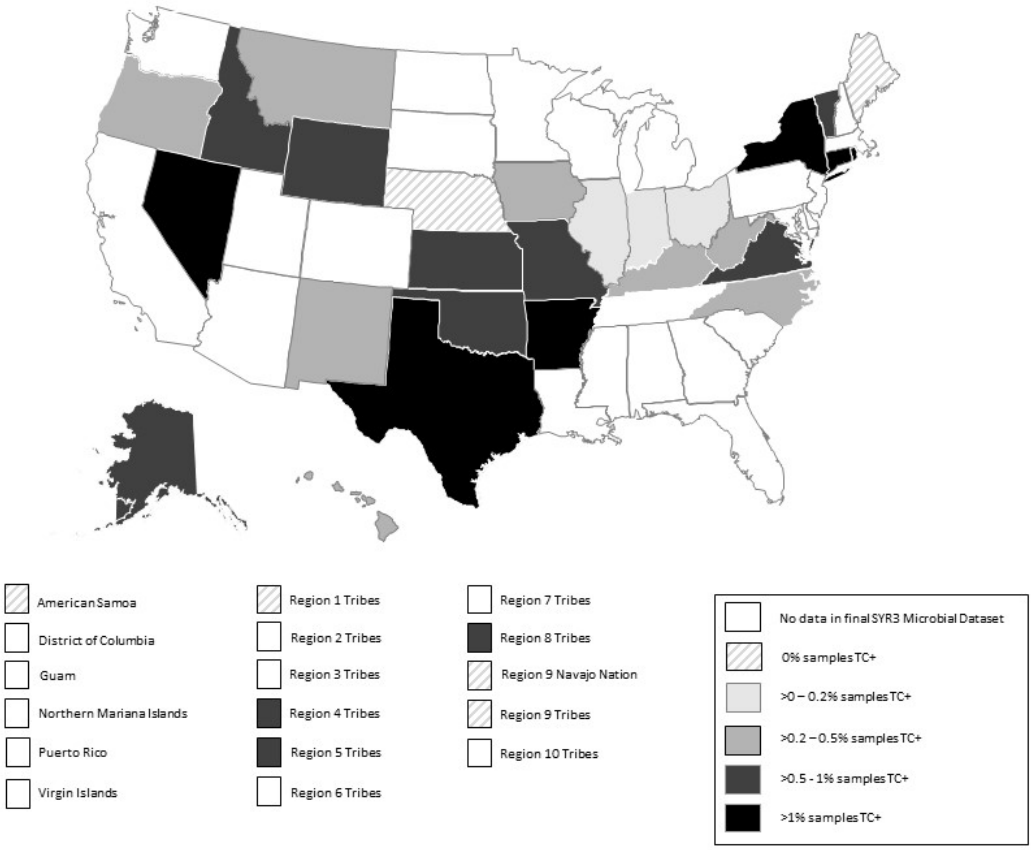


Exhibit C.52: Number of TC Samples and Percent of TC+, by State (underlying data for Exhibit C.51)

State/ Region	All Systems (SW + GW)			Surface Water Systems			Ground Water Systems		
	Total # TC Samples	# TC+ Samples	% TC+ Samples	Total # TC Samples	# TC+ Samples	% TC+ Samples	Total # TC Samples	# TC+ Samples	% TC+ Samples
AK	35,396	183	0.52%	19,760	113	0.57%	15,636	70	0.45%
AR	259,507	3,165	1.22%	120,999	1,131	0.93%	138,508	2,034	1.47%
AS	2,241	0	0.00%	0	0	0.00%	2,241	0	0.00%
CT	266,775	3,122	1.17%	156,547	192	0.12%	110,228	2,930	2.66%
HI	8,773	33	0.38%	886	0	0.00%	7,887	33	0.42%
IA	269,118	967	0.36%	88,576	151	0.17%	180,542	816	0.45%
ID	76,066	576	0.76%	16,035	72	0.45%	60,031	504	0.84%
IL	799,476	1,597	0.20%	354,102	499	0.14%	445,374	1,098	0.25%
IN	47,764	72	0.15%	9,218	20	0.22%	38,546	52	0.13%
KS	200,874	1,788	0.89%	69,318	586	0.85%	131,556	1,202	0.91%
KY	296,791	866	0.29%	259,455	669	0.26%	37,336	197	0.53%
ME	1	0	0.00%	1	0	0.00%	0	0	0.00%
MO	107,306	576	0.54%	37,327	119	0.32%	69,979	457	0.65%

State/ Region	All Systems (SW + GW)			Surface Water Systems			Ground Water Systems		
	Total # TC Samples	# TC+ Samples	% TC+ Samples	Total # TC Samples	# TC+ Samples	% TC+ Samples	Total # TC Samples	# TC+ Samples	% TC+ Samples
MT	43,519	142	0.33%	27,425	46	0.17%	16,094	96	0.60%
NC	323,550	1,584	0.49%	144,120	518	0.36%	179,430	1,066	0.59%
NE	21,785	0	0.00%	21,785	0	0.00%	0	0	0.00%
NM	115,640	462	0.40%	34,475	55	0.16%	81,165	407	0.50%
NN	15,403	0	0.00%	1,734	0	0.00%	13,669	0	0.00%
NV	17,446	253	1.45%	3,393	43	1.27%	14,053	210	1.49%
NY	68,342	890	1.30%	23,428	411	1.75%	44,914	479	1.07%
OH	167,129	292	0.17%	97,530	54	0.06%	69,599	238	0.34%
OK	253,936	2,403	0.95%	185,230	1,185	0.64%	68,706	1,218	1.77%
OR	205,086	954	0.47%	121,722	277	0.23%	83,364	677	0.81%
RI	6,957	426	6.12%	2,230	33	1.48%	4,727	393	8.31%
TX	449,773	5,873	1.31%	130,763	1,826	1.40%	319,010	4,047	1.27%
VA	327,504	1,780	0.54%	236,258	696	0.29%	91,246	1,084	1.19%
VT	40,616	529	1.30%	14,528	92	0.63%	26,088	437	1.68%
WV	137,475	549	0.40%	101,569	295	0.29%	35,906	254	0.71%
WY	56,240	338	0.60%	32,446	86	0.27%	23,794	252	1.06%
Region 1 Tribes	2,310	0	0.00%	2,303	0	0.00%	7	0	0.00%
Region 4 Tribes	2,192	13	0.59%	208	1	0.48%	1,984	12	0.60%
Region 5 Tribes	10,642	62	0.58%	285	1	0.35%	10,357	61	0.59%
Region 8 Tribes	9,153	89	0.97%	3,127	13	0.42%	6,026	76	1.26%
Region 9 Tribes	24,422	0	0.00%	2,254	0	0.00%	22,168	0	0.00%
Total	**4,669,208**	**29,584**	**0.63%**	**2,319,037**	**9,184**	**0.40%**	**2,350,171**	**20,400**	**0.87%**

EPA also calculated the frequency of detection, by state, for the *E. coli* results in surface water, ground water and all systems. Results for all five bins of free and total chlorine residual concentrations were combined; the percent of EC+ for all systems (SW and GW) are presented in Exhibit C.53.

A total of 34 states/entities provided TC data in surface water and/or ground water for this analysis. Twenty-seven of those states/entities provided sample data identified EC positives. States in the upper three categories of EC+ measures are located in all parts of the United States. However, a potential geographic pattern of occurrence is obscured by the lack of data from 23 states. For example, there are very limited data for the southern Rockies and no data for the Upper Midwest or the southeast portion of the country. The four states with the highest occurrence of EC positives are Connecticut, Kansas, New York and Rhode Island and. Of these four states, Kansas is the only one that requires a minimum free chlorine residual in the distribution system; that minimum requirement is equal to 0.2 mg/L. Seven of the 12 states with minimum requirements that have data in the SYR3 ICR microbial dataset were positive for EC in less than 0.02 percent of samples.

Exhibit C.53: All PWSs (SW + GW): Percent of EC Positives (2006 - 2011)

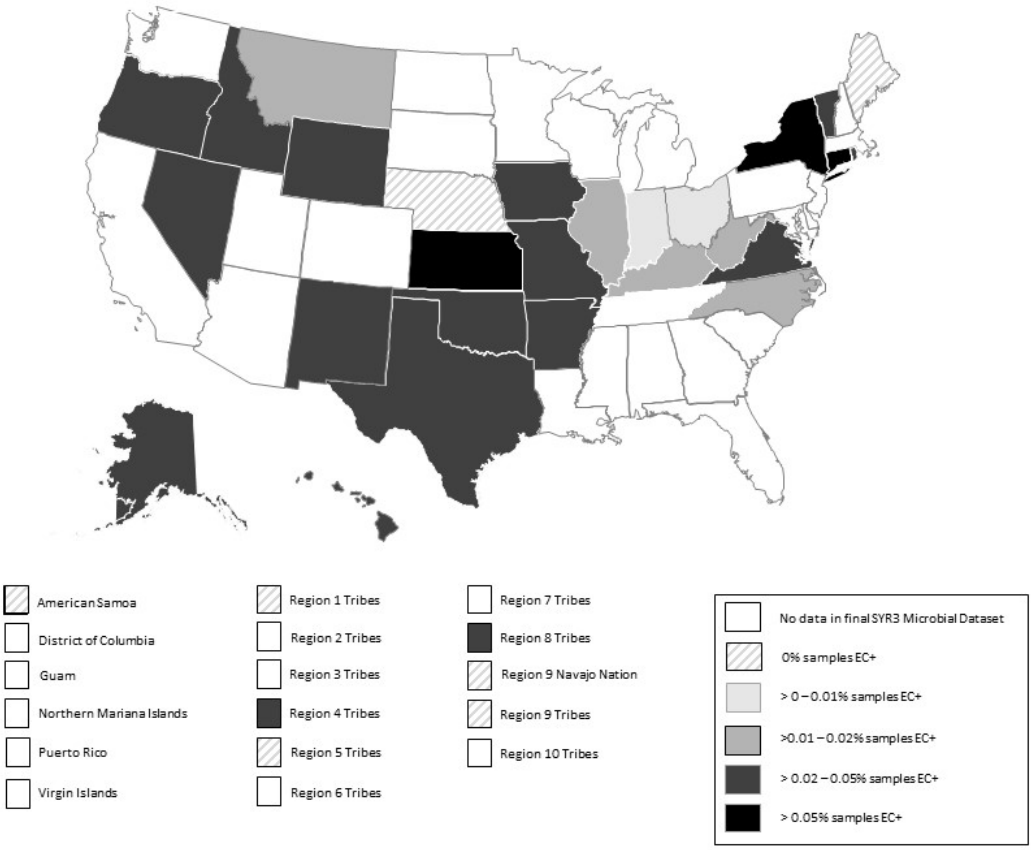


Exhibit C.54: Number of TC Samples and Percent of EC+, by State (underlying data for Exhibit C.53)

State/ Region	All Systems (SW + GW)			Surface Water Systems			Ground Water Systems		
	Total # EC Samples	# EC+ Samples	% EC+ Samples	Total # EC Samples	# EC+ Samples	% EC+ Samples	Total # EC Samples	# EC+ Samples	% EC+ Samples
AK	35,396	12	0.03%	19,760	11	0.06%	15,636	1	0.01%
AR	259,507	119	0.05%	120,999	41	0.03%	138,508	78	0.06%
AS	2,241	0	0.00%	0	0	0.00%	2,241	0	0.00%
CT	266,775	172	0.06%	156,547	19	0.01%	110,228	153	0.14%
HI	8,773	3	0.03%	886	0	0.00%	7,887	3	0.04%
IA	269,118	102	0.04%	88,576	17	0.02%	180,542	85	0.05%
ID	76,066	24	0.03%	16,035	4	0.03%	60,031	20	0.03%
IL	799,476	86	0.01%	354,102	41	0.01%	445,374	45	0.01%
IN	47,764	4	0.01%	9,218	1	0.01%	38,546	3	0.01%
KS	200,874	136	0.07%	69,318	39	0.06%	131,556	97	0.07%
KY	296,791	46	0.02%	259,455	35	0.01%	37,336	11	0.03%

State/ Region	All Systems (SW + GW)			Surface Water Systems			Ground Water Systems		
	Total # EC Samples	# EC+ Samples	% EC+ Samples	Total # EC Samples	# EC+ Samples	% EC+ Samples	Total # EC Samples	# EC+ Samples	% EC+ Samples
ME	1	0	0.00%	1	0	0.00%	0	0	0.00%
MO	107,306	27	0.03%	37,327	14	0.04%	69,979	13	0.02%
MT	43,519	6	0.01%	27,425	2	0.01%	16,094	4	0.02%
NC	323,550	52	0.02%	144,120	14	0.01%	179,430	38	0.02%
NE	21,785	0	0.00%	21,785	0	0.00%	0	0	0.00%
NM	115,640	27	0.02%	34,475	1	0.00%	81,165	26	0.03%
NN	15,403	0	0.00%	1,734	0	0.00%	13,669	0	0.00%
NV	17,446	6	0.03%	3,393	2	0.06%	14,053	4	0.03%
NY	68,342	79	0.12%	23,428	30	0.13%	44,914	49	0.11%
OH	167,129	13	0.01%	97,530	1	0.00%	69,599	12	0.02%
OK	253,936	91	0.04%	185,230	46	0.03%	68,706	45	0.07%
OR	205,086	60	0.03%	121,722	20	0.02%	83,364	40	0.05%
RI	6,957	14	0.20%	2,230	1	0.05%	4,727	13	0.28%
TX	449,773	206	0.05%	130,763	55	0.04%	319,010	151	0.05%
VA	327,504	76	0.02%	236,258	35	0.02%	91,246	41	0.04%
VT	40,616	14	0.03%	14,528	5	0.03%	26,088	9	0.03%
WV	137,475	26	0.02%	101,569	10	0.01%	35,906	16	0.04%
WY	56,240	17	0.03%	32,446	4	0.01%	23,794	13	0.05%
Region 1 Tribes	2,310	0	0.00%	2,303	0	0.00%	7	0	0.00%
Region 4 Tribes	2,192	1	0.05%	208	0	0.00%	1,984	1	0.05%
Region 5 Tribes	10,642	0	0.00%	285	0	0.00%	10,357	0	0.00%
Region 8 Tribes	9,153	4	0.04%	3,127	1	0.03%	6,026	3	0.05%
Region 9 Tribes	24,422	0	0.00%	2,254	0	0.00%	22,168	0	0.00%
Total	**4,669,208**	**1,423**	**0.03%**	**2,319,037**	**449**	**0.02%**	**2,350,171**	**974**	**0.04%**

Appendix D. Producing a Reduced Dataset for Undisinfected Ground Water Systems

Total Coliform (TC), *E. coli* (EC) and Fecal Coliform (FC) data, as received, included records for individual samples. To better understand how TC and fecal indicator (either EC or FC) positive rates varied by system size, system type, sample type and disinfection practice, EPA needed to identify which systems were using ground water without disinfection. Then, to simplify statistical modeling of the TC and EC positives[2] rates, the data for each system and month were reduced to a small number of summary counts: (a) the total number of routine samples assayed, (b) the number of routine samples testing positive for TC, (c) the total number of TC positive routine samples tested for EC and (d) the number of routine samples testing positive for EC. This appendix summarizes the processes for identifying undisinfected ground water systems and producing summary counts for small undisinfected ground water systems. EPA analyzed the occurrence of total coliforms in PWSs using undisinfected ground water and presented the results in Section 6.4 and Appendix F of this document.

Identification of Undisinfected Ground Water Systems

Ground water systems may use disinfectants in different ways. Many do not disinfect at all. Some may add a disinfectant, typically free chlorine or UV, at the source to achieve 4-log virus treatment under the Ground Water Rule (GWR). Others may provide this level of treatment but do not monitor to qualify for 4-log treatment under the GWR. Some may add some chlorine at the source to oxidize then remove iron and manganese. Other ground water systems may use chlorine (or, less frequently, chloramines) as a residual disinfectant to provide some public health protection and improve water quality in the distribution system. Individual ground water sources within a system may receive different levels of treatment.

EPA conducted an analysis to evaluate the possible differences in coliform occurrence between disinfected and undisinfected ground water systems. The SYR3 ICR microbial dataset does not contain a simple data field that identifies the disinfection status of ground water systems. EPA developed an approach for categorizing the ground water systems from SDWIS states with total coliforms as disinfected or undisinfected systems. The steps in this process are described below.

1. Identify the subset of GW systems from the SDWIS states with total coliform data.

   A total of 83,535 systems (from SDWIS states) submitted total coliform results (2006 to 2011) that passed the list of initial QA/QC checks.[3] Of those, 72,582 are GW systems.

[2] There are some systems that take a fecal coliform (FC) sample following a TC+ result rather than an EC sample; thus, FC counts were also included.

[3] These initial QA/QC checks included the identification of the following: (1) records marked with sample type codes other than routine, repeat or confirmation; (2) records marked as not being for compliance; (3) records from non-public water systems; (4) records from outside of the SYR3 date range; and (5) records from systems missing inventory information. All of these data were excluded from the process of identifying undisinfected GW systems.

2. Use the treatment process data in the SYR3 ICR dataset, as well as SDWIS, to identify disinfected GW systems.

    a. Assume any systems listing 4-log treatment of viruses in the treatment table are disinfected GW systems.
    b. Assume any additional systems that do not report 4-log treatment of viruses but report that they are disinfected and report chlorine, chloramines, UV, chlorine dioxide are also disinfected GW systems.

3. Of the remaining systems that were not identified as disinfected GW systems in step 2, evaluate field free and total chlorine data.

    a. Assume any systems with at least one free or total chlorine record > 0.1 mg/L are disinfected GW systems.
    b. Assume the remaining systems with no field disinfectant residual data and no disinfected information in their treatment type are undisinfected GW systems. (Note that the list of GW systems identified as undisinfected may include systems with free or total chlorine records < 0.1 mg/L.)

Data Reduction

The SYR3 ICR dataset contains TC, EC, and FC data from 2006 through 2011 for 46 states (41 SDWIS and 5 non-SDWIS states[4]). The basic suite of QA/QC steps were conducted on the TC, EC, and FC data. For more details on these QA/QC steps, refer to USEPA (2016e), *The Data Management and Quality Assurance/Quality Control Process for the Third Six-Year Review Information Collection Rule Dataset*. This QA/QC review resulted in the exclusion of any records that met the following criteria:

- records marked with sample type codes other than routine, repeat, or confirmation;
- records not marked as being for "compliance";
- records from non-public water systems;
- records from outside of the SYR3 date range; and
- records from systems missing inventory information.

Additional QA/QC steps were applied that were specific to TC, EC, and FC.[5] All records identified as follows were excluded from the analysis:

[4] About 75% of all states currently store and manage at least portions of their compliance monitoring data in the Safe Drinking Water Information System/State Version (SDWIS/State). The majority of states using SDWIS/State that submitted data to EPA used a SDWIS Query Extract Tool, developed and provided by EPA, to extract and compile the EPA-requested compliance monitoring data. The states not using SDWIS/State submitted their compliance monitoring data "as is," resulting in a variety of formats of datasets submitted to EPA. Furthermore, not all of the requested data from the non-SDWIS states was in a format usable to EPA for the SYR3 analyses.

[5] Note that a detailed QA was not conducted to ensure that all repeat samples had a corresponding routine sample.

- Records where PRESENCE_IND_CODE (presence indicator code) was null or not equal to either "A" (absent) or "P" (present);
- TC positive (TC+) results without a corresponding EC or FC result;[6]
- EC and FC results without a corresponding TC+ result; and
- Records from facility type codes other than distribution systems (i.e., only data where TYPE_CODE = "DS" were included in the analysis).

Rather than including a record for each sample assayed, the reduced dataset includes, for each water system and month, counts of the routine and repeat samples assayed and found to be positive for TC, EC and FC. Field names for these counts all begin with "#" as shown in Exhibit D.1.

Exhibit D.1: Descriptions of Field Names in the Undisinfected Ground Water Systems Reduced Dataset

Field Name	Description
PWSID	Public water system identification number (PWSID)
Month	Month (1 through 12)
Year	Year (2006 through 2011)
Retail Population Served	Retail population served by the water system
System type	Water system type according to federal requirements C = Community water system NTNC = Non-transient non-community water system NC = Transient non-community water system
Source Water Type	Water source for the water system. GW = Ground Water (included in this category were systems using GW or Purchased GW [GWP]) SW = Surface Water (included in this category were systems using SW, Purchased SW [SWP], Ground water Under Direct Influence of Surface Water [GU], and Purchased GU [GUP])
Disinfecting?	An indication if the system disinfects its water (Y = Yes; blank = No). All systems with a source water type = "SW" were assumed to be disinfecting. Note: An explanation of the determination of the ground water systems' disinfection status is included on pages 2 and 3 of this document.
# TC Samples (routine)	The count of routine total coliform (TC) samples
# TC+ Samples (routine)	The count of routine TC positive samples
# EC Samples (routine)	The count of routine *E. coli* (EC) samples
# EC+ Samples (routine)	The count of routine EC positive samples
# FC Samples (routine)	The count of routine fecal coliform (FC) samples
# FC+ Samples (routine)	The count of routine FC positive samples
# TC Samples (repeat)	The count of repeat TC samples
# TC+ Samples (repeat)	The count of repeat TC positive samples

[6] TC+ results were linked with EC and FC samples if they had the same water system ID, water system facility ID, sample point ID, sample collection date, lab assigned ID, and sample ID. Only the SDWIS states had data in all of these fields to enable this linkage between TC+ and EC/FC data.

Field Name	Description
# EC Samples (repeat)	The count of repeat EC samples
# EC+ Samples (repeat)	The count of repeat EC positive samples
# FC Samples (repeat)	The count of repeat FC samples
# FC+ Samples (repeat)	The count of repeat FC positive samples

In the final "reduced" dataset, there are data for a total of 80,692 water systems located in 39 states. Exhibit D.2 provides an extract of the information included in the final "reduced" dataset. Note that not all systems have results for all 12 months of each year. Furthermore, there were some repeat samples that occurred in a different month than their corresponding routine sample; thus, some system/month/year combinations have counts of repeat samples but no routine samples.

Exhibit D.2: Extract of Reduced Data for Three Systems

PWSID	Month	Year	Population Served (Retail)	System type	Source Water Type	Disin-fecting?	#TC Samples (RT)	#TC+ Samples (RT)	#EC Samples (RT)	#EC+ Samples (RT)	#FC Samples (RT)	#FC+ Samples (RT)	#TC Samples (RP)	#TC+ Samples (RP)	#EC Samples (RP)	#EC+ Samples (RP)	#FC Samples (RP)	#FC+ Samples (RP)
CT0640011	4	2006	388,700	C	SW	Y	218	6	6				18					
CT0640011	4	2007	388,700	C	SW	Y	214	3	3				9					
CT0640011	4	2008	388,700	C	SW	Y	260	1	1				3					
CT0640011	4	2009	388,700	C	SW	Y	196	3	3				9					
CT0640011	4	2010	388,700	C	SW	Y	201	1	1				3					
CT0640011	4	2011	388,700	C	SW	Y	208											
IA3353088	6	2006	6,415	C	GW	Y	7											
IA3353088	6	2007	6,415	C	GW	Y	7											
IA3353088	6	2008	6,415	C	GW	Y	7											
IA3353088	6	2009	6,415	C	GW	Y	7											
IA3353088	6	2010	6,415	C	GW	Y	7											
IA3353088	6	2011	6,415	C	GW	Y	7											
SC1720001	1	2006	15,141	C	GW		1	1			1		1					
SC1720001	5	2006	15,141	C	GW		2	2			2		5					
SC1720001	7	2007	15,141	C	GW		2	2			2		6					
SC1720001	8	2010	15,141	C	GW		1	1	1				4					
SC1720001	9	2007	15,141	C	GW		1	1			1		3					
SC1720001	9	2008	15,141	C	GW		1	1			1		3					
SC1720001	10	2009	15,141	C	GW		1	1			1		3					

Appendix E. Analysis of the Generalized Estimating Equation (GEE) and Generalized Linear Mixed Models (GLMM) as used to Estimate the Relative Rate of Highly Credible Gastrointestinal Illness (HCGI) by Colford et al. (2009)

Summary of the Colford et al. (2009) Results

The goal of the Colford et al. paper "was to estimate the efficacy of an in-home water filter to reduce the risk of highly credible gastrointestinal illness (HCGI) among older adults living in a community whose tap water met or exceeded current US drinking water standards."

Colford et al. reported that they found a 12% mean reduction in gastrointestinal illness episodes per year among an elderly population in households using a filter. This finding is based on the GEE model estimate of the device (active filter v sham filter) rate ratio to be 0.88, with 95% confidence interval (0.77, 1.00). Hence, the 95% confidence interval for the estimated reduction is (0%, 23%). It should be noted that the upper bound of this wide confidence interval suggests the plausibility that filter use has no reduction (i.e., 0%).

The paper also presents results from the GLMM model which estimates the device rate ratio of episodes per year to be 0.85, with 95% confidence interval (0.76, 0.94). Exhibit E.1 compares the GEE and GLMM device rate ratio confidence intervals, and shows the similarity of the two intervals, despite the GEE upper confidence limit attaining the value 1.00 while the GLMM upper confidence limit does not. Such consistency between the two models is expected as the two models have similar specifications (both models have the same relationship between predictor variables and gastrointestinal illness, differing essentially only in the way variability is formulated in the regressions). Colford et al. note, as in Diggle et al (1994), GEE provides 'a marginal, population-averaged inference' and GLMM provides 'an individual-specific inference.' This distinction is not important since, as in Hubbard et al (2010), in certain linear and log-linear (e.g. Poisson as used in Colford et al.) models the parameter estimates from the GEE and GLMM Poisson regression have equivalent interpretation towards individual averages and population averages.

The study collected self-reported occurrences of gastrointestinal illness which was then used to define highly credible gastrointestinal illness (HCGI).

Summary of the Colford et al. (2009) Statistical Approach and Assumptions

The study goal was to estimate the efficacy of an in-home water filter (device) to reduce the risk of highly credible gastrointestinal illness (HCGI). Each household was to use an active device in one cycle (6 months) and a sham device in another cycle; the name cross-over study is applied to such designs where the household is exposed to various treatments in consecutive periods. GEE and GLMM models were developed with device as the only predictor variable (unadjusted models). Models were also developed that adjust for a set of covariates, namely, gender, age,

self-reported health, number of medications, irritable bowel syndrome at baseline, diarrhea at baseline, and daily water consumption (adjusted models).

The GEE and GLMM both model the same mathematical relationship shown in Equation (1), where *y* represents either the episodes of HCGI or the days of HCGI, *t* represents the time (or person-days) within a cycle, x' represents the predictor variables (in this case, device, cycle, gender, age, self-reported health, number of medications, irritable bowel syndrome at baseline, diarrhea at baseline, and daily water consumption), and β represents the corresponding parameter estimates for these predictors.

$$log(E(y)) - log(t) = x'\beta \qquad (1)$$

GEE and GLMM differ in their expression and estimation of the statistical variation in the data. The statistical variation in GLMM is modeled as three variance components, 1) residual (each person/cycle randomly varies), 2) person, and 3) household. The statistical variation in GEE is modeled as a correlation structure among the residuals (e.g. residuals among persons within a household will be correlated while persons in different households will be uncorrelated). Both GEE and GLMM apply a Poisson regression to episodes or days of HCGI. Without going into detail, loosely GLMM uses maximum likelihood to solve for the mathematical relationship and variance components, while GEE uses weighted least squares to solve for the mathematical relationship and correlation structure. In any event, the similarities of the two methodologies dictates that the corresponding results are expected to be consistent.

The paper initially focuses on 8 analyses; combinations of 1) episodes and days of HCGI, 2) GEE and GLMM, and 3) unadjusted and adjusted (for additional covariates) analyses. The Davenport Study (Colford et al. 2005) and other studies have found the duration of an HCGI episode to be reasonably short and constant, hence days of HCGI is highly correlated with episodes of HCGI. The study states episodes to be the 'primary outcome' and prevalence (i.e. days) to be the 'secondary outcome, presumably since days, instead of episodes, adds an extra dimension of variability. Further, literature on longitudinal data suggests adjusting for covariates related to the outcome will explain more of the between person variation, and result in smaller standard error estimates for the parameter estimates. Hence, the paper's focus is further narrowed to the adjusted GEE and GLMM models. The results of these two models has been extracted from the paper and presented in Exhibit E.8.

The study goal is addressed by the device parameter estimates in Exhibit E.8 and depicted in Exhibit E.1. The GEE model estimates the rate ratio to be 0.88, with 95% confidence interval (0.77, 1.00). The interpretation of this rate ratio, as discussed previously in the study summary, is an expected 12% reduction in HCGI episodes in households using a filter. The GLMM model estimates the rate ratio to be 0.85, with 95% confidence interval (0.76, 0.94). The point estimates, 0.88 and 0.85, do not differ greatly, nor do the respective lower confidence limits and upper confidence limits. Hence, the GEE and GLMM findings are consistent with one another, despite the GEE upper confidence limit attaining the value 1.00 while the GLMM upper confidence limit does not.

Review of Modeling

The rationale for presenting GEE and GLMM models in Colford et al. could be questioned. While the findings of the GEE and GLMM models are consistent with one another, a reader may question why both are presented and which is the more appropriate.

The literature is rich with comparisons of the GEE and GLMM methodologies. Generally, the two methods are found to achieve similar results and only occasionally is one method highly recommended over the other. Exhibit E.3 through Exhibit E.7 show results of several studies where the GEE and GLMM models have been compared. These studies, like Colford et al., show the GEE and GLMM findings to be consistent with one another.

Colford et al. correctly assert that GEE provides 'a marginal, population-averaged inference' and that GLMM provides 'an individual-specific inference'. Diggle et al. (1994) and other papers espouse on this distinction. This distinction is important for logistic regression, but not so for Poisson regression as in this study. The parameter estimates from the GEE and GLMM Poisson regression have equivalent interpretation towards individual averages and population averages.

One often noted distinction between GEE and GLMM models is that the GEE methodology is more robust than the GLMM methodology. Specifically, Hubbard et al. (2010) and several other papers note that even if the correlation structure modeled in GEE is wrong, the standard error estimates can be valid. Further, the GEE approach does not require distributional assumptions concerning the variance components. The person and household random effects in the GLMM models of Colford et al. are assumed to follow a normal distribution. This normality assumption can be difficult to dispute or verify. Thus Colford et al. show some preference to the GEE model due to its robustness.

The random effects in a GLMM model, when substantiated, can result in much smaller standard error estimates for the parameter (Park 1993). In Exhibit E.6, the GLMM slope standard error estimate (0.033) is half the magnitude of the GEE slope standard error estimate (0.065). This is not the case for the Colford et al. analysis, so no preference towards the GLMM model may be conferred. More specifically, if the variance component assumption for GLMM correctly modeled HCGI among individual within households, then the standard errors estimates for the parameter estimates would likely be much smaller in the GLMM models than in the GEE models. Since estimates from Colford et al. are not much smaller, this cast some doubt on the validity of the normality assumptions for GLMM.

How well the model explains the observed data can be assessed by goodness-of-fit statistics, such as Akaike's information criterion (AIC). Such statistics are useful to compare two GLMM models or two GEE models, but have limited utility in comparing a GEE model to a GLMM model. The reason being most such statistics are designed to measure the improvement of fit between incremental changes in a given model form. There is no 'incremental' difference between GEE and GLMM. Alternatives such as cross-validation and Bayesian methods, could be applied to address whether the GEE or GLMM significantly explains the data better.

Carrière and Bouyer (2002) conclude GEE models are 'easy to implement and represent a first solution' and that GLMM 'although more complex, uses all available data and are more suitable for explicative studies.' Feng et al. (2001) states 'GLMM works well but requires full distributional assumptions, GEE is too liberal'. Several papers also note that GLMM is less restrictive concerning missing data; the statistical nomenclature is that GEE requires a missing completely at random (MCAR) assumption, while GLMM requires only missing at random (MAR). Colford et al. note that over 80% of households completed both cycles of the study. However, they also note data from 157 households were discarded due to mislabeled devices.

Colford et al. only present the findings from the GEE model in the Discussion section of their paper. While not specifically noted in the paper, the robustness of the GEE approach may be the reason for their preference of GEE over GLMM. Because there is nothing in the GLMM model results that indicate that it would be preferred and because the two approaches are consistent with one another, emphasizing the GEE results seems reasonable.

Their conclusion is an expected 12% reduction in HCGI episodes among an elderly population of households using a filtration device compared to an elderly population of households using no device. However, the sample size of the study is small (557 households) and the 95% confidence interval for the estimated reduction includes 0%, so we cannot definitively conclude that there is a reduction based on the GEE results. Further, in their subgroup analysis, the reduction was estimated as negligible in cycle 1 and 25% in cycle 2 (possibly indicating the device effect is a surrogate for some other effect). Moreover, the cycle effect is much larger in magnitude than the device effect (i.e., the GEE model finding is that there is 45% more HCGI in cycle 1 compared to cycle 2, whereas the device effect is only 12%). The authors note that such a cycle effect has been reported by others. This cycle effect could possibly be described as a Hawthorne effect (i.e., that knowledge of being in a study has an effect). In addition to the GEE model parameter estimate, this Hawthorne effect is evident in Exhibit E.2. Exhibit E.2 clearly shows decreasing incidence of HCGI over time on study. Alternative analyses are suggested in the next section.

Other effects that are larger than the device effect in the GEE results include gender, irritable bowel syndrome at baseline and diarrhea at baseline.

Suggestions for Further Analyses/Research

Further analysis of this rich dataset could provide additional insights. For example, Exhibit E.2 below shows a clear effect due to time on study. The GEE model crudely incorporates time on study using the variable cycle. A more elaborate relationship between time on study and HCGI could be postulated. Additionally, there is a possible seasonal effect (i.e. drinking water in winter or during drought is maybe more likely to cause HCGI). Modeling such temporal effects would be of interest. It may also be possible to abstract additional covariates. For example, Beaudeau et al. (2014) consider the turbidity of the drinking water supply at a point in time as a potential predictor of HCGI, though it may not be possible to obtain such past data for the Sonoma water system in the Colford et al. study.

The GEE and GLMM models in this paper each use one of the many variance structures available. Alternative variance structures could be tested. Also, there are alternative modeling

approaches; including Bayesian methods, transition models, and survival analysis. Diggle et al. has some discussion relating these approaches. Just as GEE and GLMM have common themes, there are common themes among most of the alternative modeling approaches, hence it seems likely the alternatives would shed little new light.

Colford et al. models both episodes and days of HCGI. The correlation of episodes and days indicates the length of HCGI episodes is likely reasonably constant. Regardless, an analysis with length of HCGI episode seems interesting. It may be that HCGI episodes are shorter in households using a filtration device, or other hypotheses could be contemplated.

Summary Responses to the Questions Posed in the Technical Direction from EPA

The following provides summary responses to the four EPA questions based on the discussion presented above:

What role doe the GEE and GLMM mathematical models have in estimating HCGI attributable incidence to drinking water?

GEE and GLMM are both viable methods to estimate incidence of HCGI (both use Poisson regression, but modified to account for the longitudinal dataset). Both models provide incidence rate ratio estimates for device use, which translate into estimates of potential reduction in HCGI for households using filters.

Why are both models presented; and what are the strengths and weaknesses of each? and what assumptions are used in the models?

While 8 analyses (combinations of episodes and days of HCGI, GEE and GLMM, and unadjusted and adjusted) are presented by Colford et al. (Table 3 in the paper), unadjusted models should not be considered for policy inference since important covariates are not accounted for. Models with days of HCGI can be discounted since days and episodes of HCGI are correlated and using days essentially only adds another level of variation to modeling. GEE estimation of variation is more robust than GLMM. The study goal was to assess filter use impact on an elderly population, and GEE is designed to provide inference on a population. GLMM is designed to provide individual inference, but for Poisson regression, GLMM parameters have both a population and individual interpretation. These slight advantages of GEE may make it the preferred model to be used for policy inference.

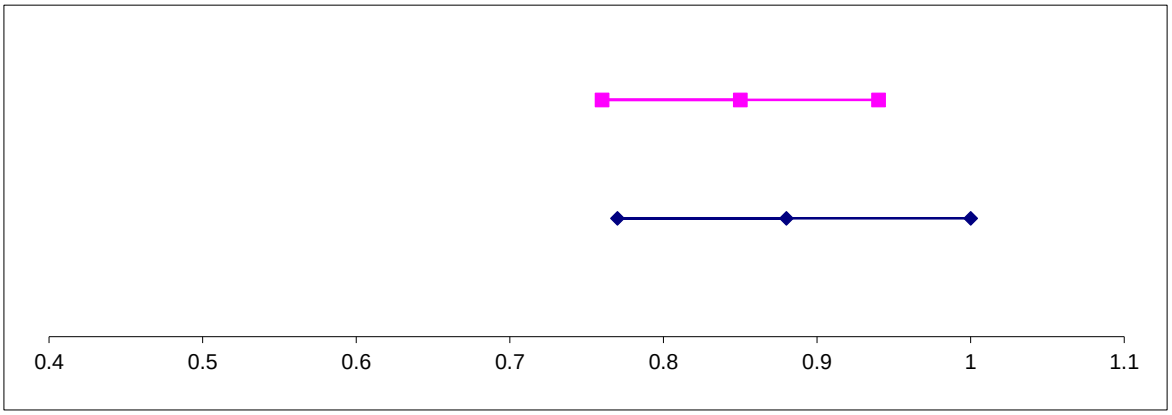
Goodness-of-fit statistics to compare GEE and GLMM were not available. Even if they were available, they would not indicate statistical superiority of one model over the other. Other methods, such as cross-validation or Bayesian methods, would be unlikely to statistically demonstrate superiority of one model over the other.

Assuming that models are used to address factors not specifically accounted for by the study design, what are the specific factors and are there ways other than the use of GEE and GLMM that could be used to better understand the health diary data?

Both GEE and GLMM point estimates of device effect on HCGI are not adversely affected by factors not specifically accounted for by the study design. The standard errors may be reduced (and the corresponding confidence intervals tighter) if the study design could incorporate additional important factors. Plausible other factors include water quality measures (e.g., turbidity) or weather measures (e.g., heat waves or rainy season may effect HCGI incidence). Future study designs should identify and measure covariates more specifically that might relate to HCGI due to other sources than drinking water.

Other statistical models (e.g., survival analysis) also model incidence, but would not be expected to yield any better understanding. Finally, time on study is modeled as simply cycle 1 (first 6 month period using one device) and cycle 2 (next 6 month period using the other device). Improved measures of time on study are suggested, thereby accounting for the Hawthorne effect. However, it is unclear whether substantial improvements to the results from the two models used by Colford et al. would be achieved.

Exhibit E.1: GEE and GLMM point estimates and 95% confidence intervals for device effect



Note: Pink squares are GLMM, and blue diamonds are GEE. Colford et al. 2009.

Exhibit E.2: Weekly changes in the number of episodes (per person-year) of highly credible gastrointestinal illness during the Sonoma Water Evaluation Trial, 2001- 06. Colford et al. 2009

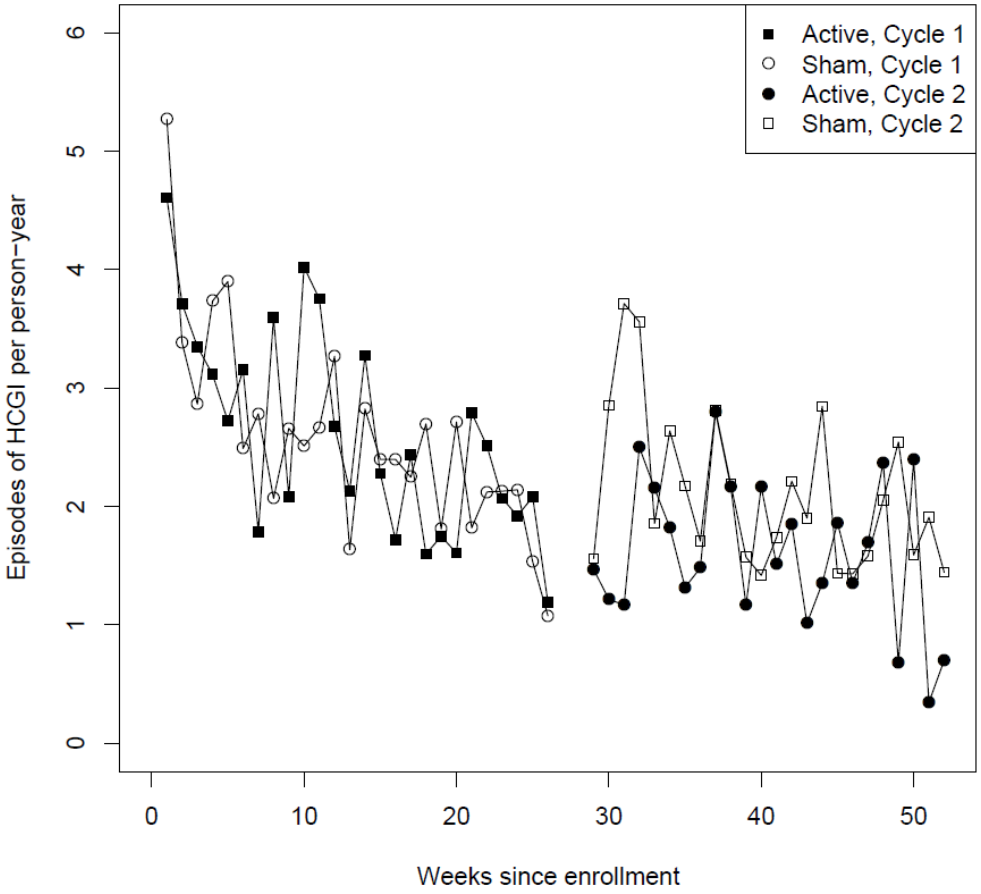


Exhibit E.3: GEE and GLMM model of Thall & Vail (1990) data

	GEE	GLMM
	β (s.e.)	β (s.e.)
intercept	1.35 (0.16)	1.00 (0.15)
time	0.11 (0.12)	0.11 (0.05)
treatment	0.027 (0.22)	-0.023 (0.20)
interaction	-0.10 (0.21)	-0.10 (0.07)

Note: Poisson regression of seizure counts for 59 patients on treatment (placebo or progabide) at 4 time points.

Exhibit E.4: GEE and GLMM model of Pothoff &Roy data (Verbeke and Molenberghs 2000)

	GEE	GLMM
	β (s.e.)	β (s.e.)
intercept girls	17.18 (1.25)	17.18 (1.29)
intercept boys	16.21 (1.04)	16.25 (1.07)
slope girls	0.49 (0.10)	0.49 (0.10)
slope boys	0.80 (0.09)	0.80 (0.09)

Note: Poisson regression of growth data for 11 girls and 16 boys at 4 ages.

Exhibit E.5: GEE and GLMM model of Chroidal Neovascularization Prevention Trial data (Ying & Liu 2006)

	GEE	GLMM
	β (s.e.)	β (s.e.)
intercept	-1.00 (0.23)	-1.27 (0.21)
laser treatment	0.054 (0.32)	0.054 (0.23)

Note: Poisson regression of visual acuity for 156 patients with one eye laser treated and other eye control over 4 years.

Exhibit E.6: GEE and GLMM model of Sly et al data (Burton et al 1998)

	GEE	GLMM
	β (s.e.)	β (s.e.)
intercept	57.2 (27.1)	59.2 (26.2)
slope time	0.247 (0.065)	0.247 (0.033)

Normal regression of peak expiratory flow measured daily for 12 asthmatic boys over 3 months.

Exhibit E.7: GEE, GLMM, and Bayesian GLMM model of Community Hypertension Assessment Trial (Ma et al 2009)

	GEE	GLMM	Bayesian GLMM
	Odds Ratio (95% CI)	**Odds Ratio (95% CI)**	**Odds Ratio (95% CI)**
intervention v. control	1.14 (0.72, 1.80)	1.10 (0.65, 1.86)	1.12 (0.64, 1.95)

Note: logistic regression of normal blood pressure (v. high) for 1540 elderly patients randomized to intervention or control over 1 year.

Exhibit E.8: Model results for episodes of highly credible gastrointestinal illness using GEE and GLMM analysis for an active vs. a sham device in the Sonoma Water Evaluation Trial, 2001-06

	GEE		GLMM	
Outcome / Model Specification	**RR ***	**(95% CI)†**	**RR ***	**(95% CI)‡**
Episodes of highly credible gastrointestinal illness				
Adjusted Estimate				
Device (Active vs. Sham)	0.88	(0.77, 1.00)	0.85	(0.76, 0.94)
Cycle (1 vs 2)	1.45	(1.29, 1.66)	1.47	(1.32, 1.64)
Male (vs female)	0.76	(0.60, 0.98)	0.64	(0.51, 0.79)
Age (per 10 years)	0.93	(0.83, 1.06)	0.88	(0.75, 1.03)
Self-reported health (vs. Excellent)				
Good	0.74	(0.53, 1.03)	0.68	(0.54, 0.86)
Fair	0.87	(0.54, 1.41)	0.81	(0.52, 1.27)
Poor	0.87	(0.52, 1.45)	1.49	(0.64, 3.48)
Number of medications	1.09	(1.05, 1.13)	1.10	(1.06, 1.15)
Irritable bowel syndrome at baseline	1.49	(1.08, 2.06)	1.80	(1.24, 2.61)
Diarrhea at baseline	2.58	(1.93, 3.45)	4.62	(3.69, 5.80)
Total water consumption (per 8-ounce glass)	1.03	(0.98, 1.07)	1.02	(0.97, 1.06)

* RR : Rate ratio (episodes of illness)
† 95% Confidence Intervals for GEE models estimated using exchangeable correlation & robust SEs
‡ 95% Confidence Intervals. All GLMM specifications include random intercepts for individual and household.
Note: Extracted from Table 3 of Colford et al. 2009 paper.

Appendix F. Occurrence of Total Coliforms / *E. coli* in Small PWSs Using Undisinfected Ground Water

F.1. Data Source and Groups

The total coliform/*E. coli* (TC/EC) data used in this analysis originated as part of a data extraction effort for a large suite of contaminants compiled into a database and provided to EPA that included the year 2011. Previously, EPA had similarly analyzed TC/EC data from the year 2005 and reported the results in the Revised Total Coliform Rule (RTCR) Economic Analysis (EA) (USEPA, 2012). EPA has extracted TC/EC data from the 2011 dataset. The TC/EC data were compiled from PWS or state reports (states often perform TC/EC assays for PWSs). Some states did not follow uniform procedures in building the TC/EC database. For example, some states may have only entered total coliform positive data into the database. Data from these states (i.e., Louisiana, Alabama, and South Carolina) with anomalous record keeping procedures were removed from this dataset.

Data provided to EPA by most states did not include a data field to indicate disinfection. However, there typically is a data field for ancillary information such as chlorine residual in the distribution system. For the 2011 data, EPA developed a multi-step decision tree to identify undisinfected systems by a process of elimination, using this ancillary information. (See Appendix D of this document for a description of this process.) Undisinfected PWSs in the 2005 data may have been identified or verified by merging two differing state and national datasets, a costly step not undertaken for the 2011 data. After applying the decision tree to arrive at a set of undisinfected systems, EPA did not test the results to evaluate the decision tree result. In comparing the 2005 and 2011 datasets, EPA observed small differences in ancillary information in 2005 versus 2011. Also, there is not complete overlap between the 2005 and 2011 data (i.e., the same states do not report the same data in the same way in both years).

The complete dataset used in this analysis consists of TC records from about 38,000 undisinfected systems for 2011 (note that the 2005 data analyzed in the RTCR EA included TC records from about 60,000 undisinfected systems). For modeling purposes, these data were divided into 27 basic subsets of systems (3 system types, 3 water types and 3 size ranges).

Exhibit F.1: Undisinfected Small Ground Water Systems from SYR3 ICR Dataset Used for TC Analyses

Size Ranges	Community Water Systems	Non-Transient Non-Community Water Systems	Transient Non-Community Water Systems
<101 people served	2,262	2,246	18,538
101 – 1,000 people served	2,450	2,378	9,539
1,001 – 4,100 people served	492	182	143

This section discusses data from all three system types and size ranges and one water type—undisinfected ground water (Exhibit F.1).

EPA assumed that each system has four detection rates: 1) TC detection rates in routine samples; 2) TC detection rates in repeat samples, 3) EC detection rates, given TC detection, in routine samples and 4) EC detection rates, given TC detection, in repeat samples. In the following analysis, EPA analyzed only routine samples.

F.2. Data Analysis

This analysis addresses only PWSs that use undisinfected ground water. Because the disinfection barrier is absent, any public health benefit might be greatest in unprotected undisinfected PWSs. The purpose of this data analysis is to identify and characterize the groups of PWSs that have high TC detection rates.

The limited amount of data for the individual small PWSs prevented us from precisely estimating any particular system's detection rate, but such data from a large number of systems supported estimation of distributions of detection rates. To estimate the distributions of detection rates, EPA assumed that each system has two unobserved detection rates: 1) TC detection rates in routine samples; and 2) EC detection rates, given TC detection in routine samples. For each system, the observed fraction (number of detects/number of assays) is an imprecise estimate of the unobserved detection rate.

Routine TC detection rates vary from system to system, even among systems of the same type and size. The beta distribution serves well to describe these varying rates. EPA did not directly observe the system-specific detection rates or their distributions, but instead estimated the parameters of these distributions using the data, summarized as the number of routine TC assays (N) and the number of routine TC positives (K) for each system. Assuming that the assays for a particular system are each independent, identically distributed Bernoulli trials, the number of TC detections for the system is a binomial random variable with parameters N and the unobserved detection rate, p. For example, if a system were to assay 12 routine TC samples and find 2 to be positive, the ratio K / N = 1 / 6 would be an imprecise estimate of the detection probability. In modeling, EPA used the counts K and N, rather than their ratio to inform the likelihood function. Likelihood is a function of the data (expressed in terms of K and N for each system) and the beta distribution parameters α and β. Below, in Equation 1, log likelihood (LL) is expressed as a function of the data from NSys systems and beta distribution parameters α and β. NSys is the number of systems with data and i is an index for systems. Log likelihood is the sum of the NSys system-specific log likelihoods. Logarithms were used to avoid computational overflow/underflow issues.

Equation 1

$$LL(\alpha,\beta) := \sum_{i=1}^{NSys} \ln\left[\int_0^1 \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\cdot\Gamma(\beta)}\cdot p^{\alpha-1}\cdot(1-p)^{\beta-1}\cdot\frac{N_i!}{K_i!\cdot(N_i-K_i)!}\cdot p^{K_i}\cdot(1-p)^{N_i-K_i}\,dp\right]$$

In Equation 1, α and β are model parameters, Γ is the gamma function, p is the unobserved probability of a TC-positive, K_i is the number of TC-positive assay results, N_i is the number of TC assays, and $N_i - K_i$ is the number of negative assay results for system i. The integral is evaluated for each of the NSys systems having data. The integral simplifies to the result shown in parentheses in Equation 2:

Equation 2

$$LL(\alpha,\beta) := C + \sum_{i=1}^{NSys} \ln\left(\frac{\Gamma(\alpha+\beta)\cdot\Gamma(\alpha+K_i)\cdot\Gamma(\beta+N_i-K_i)}{\Gamma(\alpha+\beta+N_i)\cdot\Gamma(\alpha)\cdot\Gamma(\beta)}\right)$$

C is a constant that depends only on the data, as shown in Equation 3.

Equation 3

$$C := \sum_{i=1}^{NSys} \ln\left(\frac{\Gamma(N_i+1)}{\Gamma(K_i+1)\cdot\Gamma(N_i-K_i+1)}\right)$$

Equation 2 can be expressed in terms of function lbeta (the natural logarithm of the beta function), as shown in Equation 4:

Equation 4

$$LL(\alpha,\beta) := C + \sum_{i=1}^{NSys} \left(\text{lbeta}(\alpha+K_i,\beta+N_i-K_i) - \text{lbeta}(\alpha,\beta)\right)$$

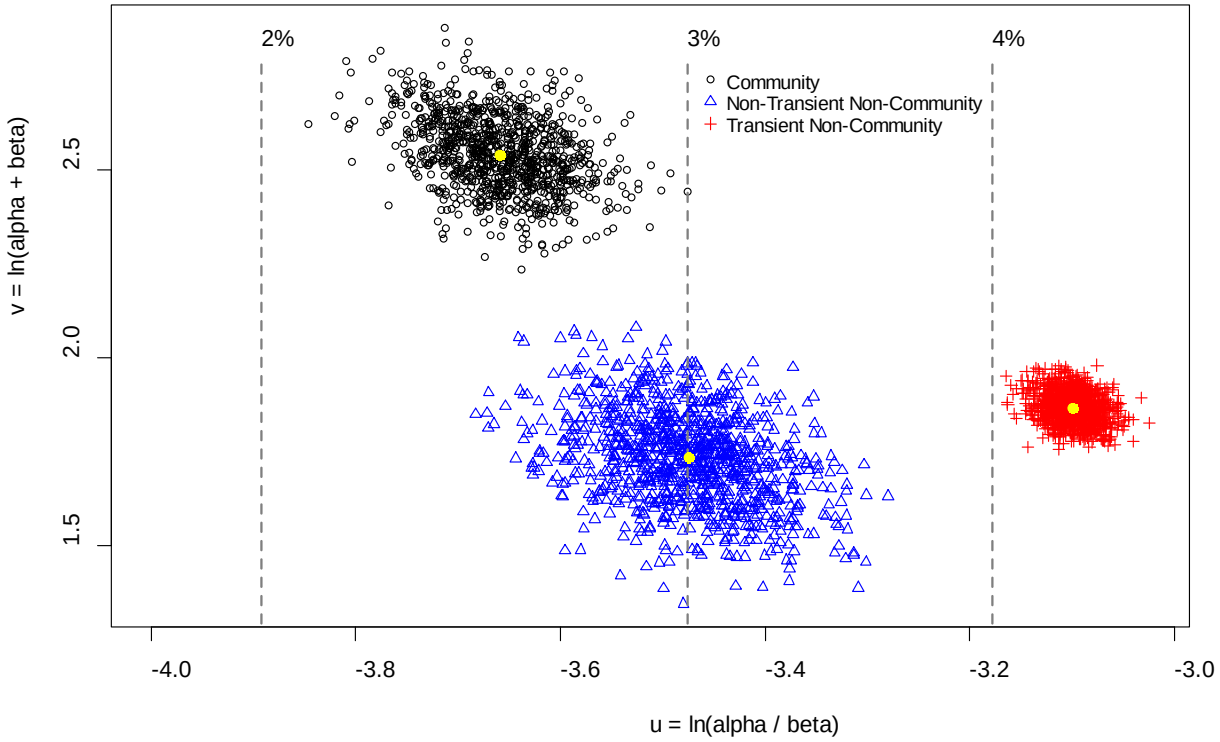
Parameterizing the beta distribution as $u = \ln(\alpha / \beta)$ and $v = \ln(\alpha + \beta)$, and using a wide flat prior over u and v, these new parameters were estimated in a Bayesian framework using the above likelihood function. Markov Chain Monte Carlo (MCMC) samples of parameter pairs were produced using R (The R Foundation for Statistical Computing, http://www.r-project.org/foundation/main.html), using the "LearnBayes" package simcontour function (Albert, 2007). Results were checked by generating independent MCMC samples using R and OpenBUGS (Lunn et al., 2009).

F.3 Results

Parameter Estimation

Some of the results are shown below to illustrate the data, data analysis, statistical modeling and results. To best illustrate the differences between the three system types, Exhibit F.2 displays only results for the smallest systems: those serving 25 to 100 people.

Exhibit F.2: MCMC Samples Predicting TC Detection in PWS Subsets: Three PWS Types Serving Smallest Populations (25 – 100 People)



The exhibit shows three MCMC samples, each MCMC sample consisting of 1,000 pairs of parameters u and v. Each plotted point is a parameter pair (u, v) describing a realistic beta distribution of TC detection rates that is consistent with the data. The X-axis (u) is log odds for mean TC positive detection probability. The mean TC positive detection probability (mean(p)) can be derived from u as follows:

$$\text{mean}(p) = \alpha / (\alpha + \beta) = e^u / (1 + e^u)$$

Three of these mean values (2 percent, 3 percent, and 4 percent) are shown as vertical dashed lines in Exhibit F.2. Log odds associated with these percentages are negative because the values are less than 0.5. For example, the log odds associated with 2 percent is the natural logarithm of 0.02 / 0.98, which is -3.89. The Y-axis (v) is a precision parameter. In terms of the conventional parameters (α and β), u is the log of the mean odds (α / β) and v is the log of the sum $\alpha + \beta$. The conventional parameters can be determined from u and v as follows:

$$\alpha = e^{u+v} / (1 + e^u)$$

$$\beta = e^v / (1 + e^u)$$

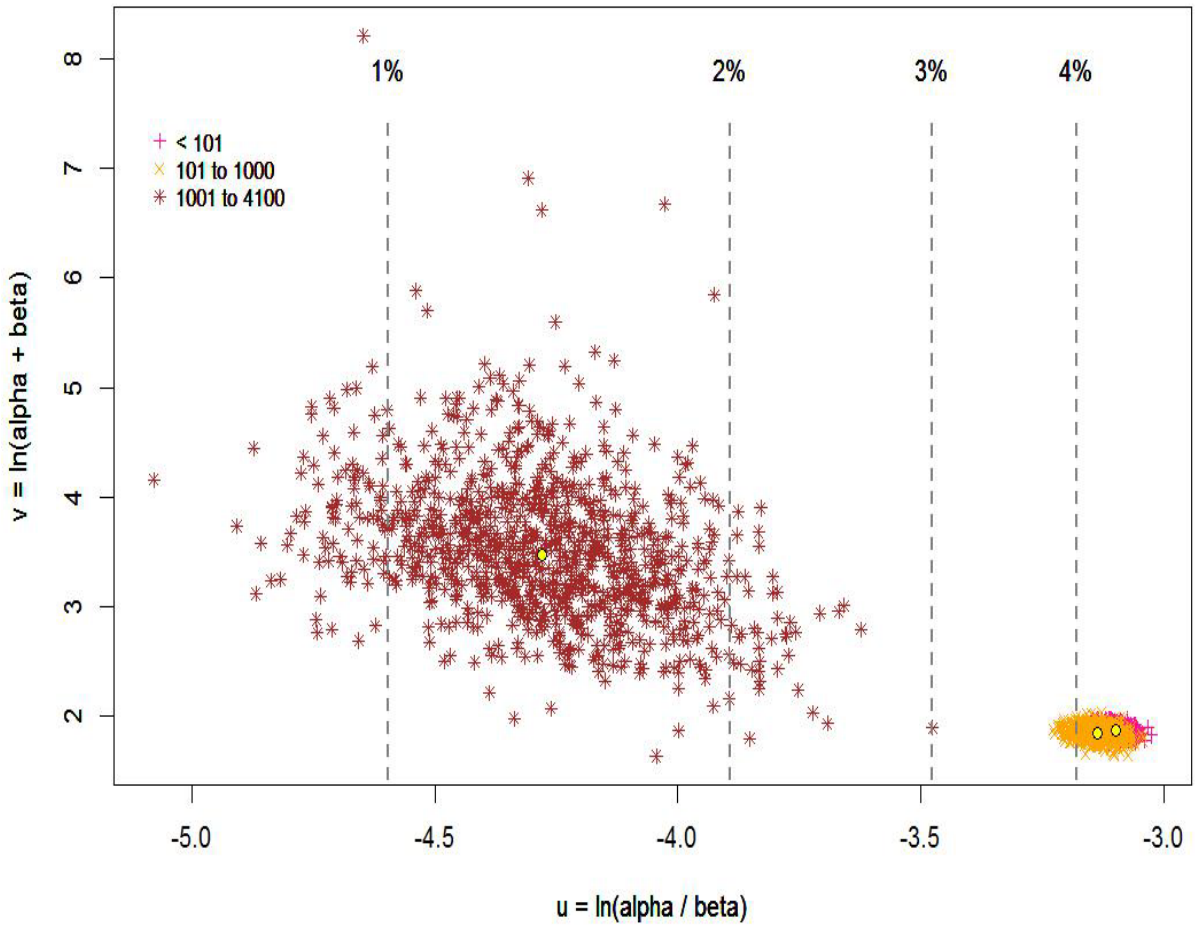
A wide scatter of points indicates large uncertainty, due to having fewer data to support the estimate. A tight set of plotted points indicates smaller uncertainty due to a larger dataset (i.e., many systems, assays and PWSs with multiple assays). The filled circle in the center of each cluster is the sample mean of u and v for the cluster. The means for parameter u correspond to an average detection rate of 2.5 percent for community water systems, 3.0 percent for non-transient water systems, and 4.3 percent for transient non-community water systems. Vertical dashed lines correspond to log odds for average TC detection rates of 2 percent, 3 percent and 4 percent. For example, the tight cluster of beta distributed probabilities for the transient systems (plus signs) all have average TC detection rates above 4 percent.

Exhibit F.2 shows the following:

- The most precise parameter estimates are for the transient PWSs, as they have the tightest cluster of points in the figure. This is not surprising, given the large number of transient PWSs (see Exhibit F.1).
- The least precise parameter estimates are for the non-transient PWSs, as they have the greatest scattering of points. The numbers of non-transient PWSs and community PWSs are similar, but monitoring tends to be more frequent for community PWSs and as a result, there are more data, supporting a more precise estimate for community PWSs.
- On average, the highest TC detection rates are for transients, followed by non-transient and community PWSs.
- Community PWSs have the lowest between-system variance (greatest between-system precision). Transient PWSs and non-transient PWSs have greater between-system variance, v, suggesting that these groups have more PWSs with detection rates much greater than the means.

Exhibit F.3 is a similar display showing clusters of beta-distributed probabilities for TC detection rate distributions of all three size groupings of undisinfected transient PWSs. The figure shows that, among these PWSs, smaller systems have higher average TC detection rates than larger systems. A similar result was reported by EPA (USEPA, 2012) for PWSs that use disinfected ground water or surface water.

Exhibit F.3: MCMC Samples Predicting TC Detection in PWS Subsets: Transient PWS Types Serving Three Small Population Subsets



In Exhibit F.3, estimates for the largest transient PWSs (serving 1,001 to 4,100 people) are widely dispersed due to the small number of systems in this subset. The exhibit shows that the average detection rate for the larger systems is low (between 1 percent and 2 percent), compared to the smaller transient PWSs. MCMC samples for the two smallest subsets overlap and are precise (tightly clustered) due to the large numbers of systems in these subsets. MCMC sample means are displayed as small open circles. Based on the mean of u, the average detection rates are 4.3 percent for systems serving fewer than 101, 4.1 percent for those serving 101 to 1,000 people, and 1.3 percent for systems serving 1,001 to 4,100 people.

Exhibit F.4 and Exhibit F.5 show estimates for community and non-transient PWSs. Again, the effect of system size is shown. Smaller systems have greater average detection rates and more between-system variability.

Exhibit F.4: MCMC Samples Predicting TC Detection in PWS Subsets: Community PWS Types Serving Three Small Population Subsets

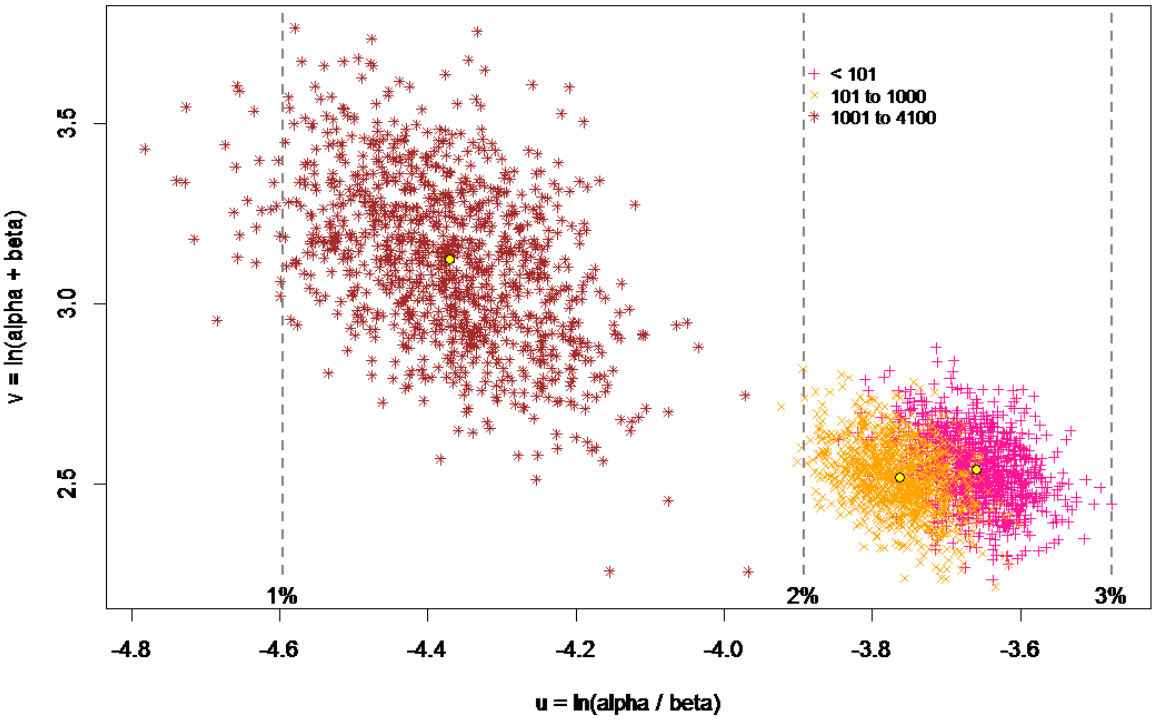
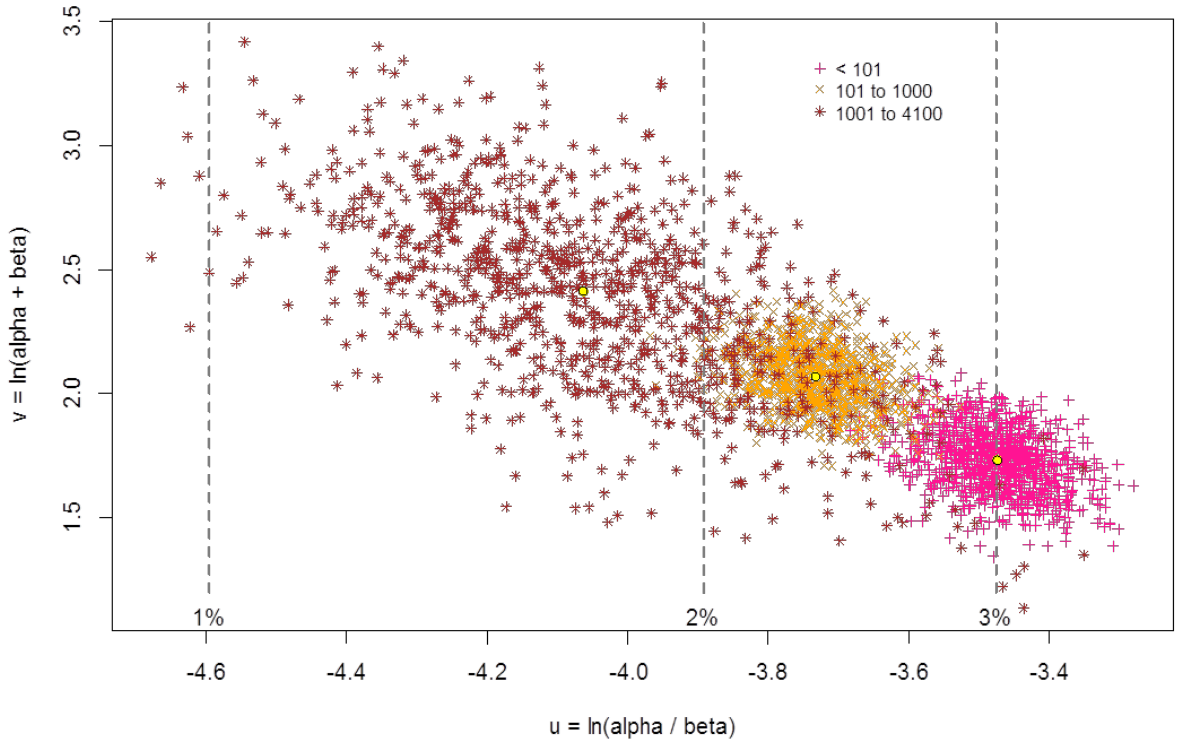


Exhibit F.5: MCMC Samples Predicting TC Detection in PWS Subsets: Non-Transient PWS Types Serving Three Small Population Subsets



F.4 Detection Rates and Risk

The public health significance of TC detection is uncertain. However, TC detection has utility as a relative risk marker, perhaps indicating infiltration of recent precipitation. Even within sets of PWSs with low average detection rates, individual PWSs can have detection rates in the upper tail of the distribution, and much greater than the average detection rate. Thus, EPA hypothesized that public health hazard is high for PWSs having high TC detection rates.

To illustrate the relative hazard, Exhibit F.6 and Exhibit F.7 show the distribution of routine TC detection rates for the smallest of the community, non-transient and transient PWSs using undisinfected ground water. The cumulative distribution functions shown are based on MCMC sample mean parameter values (u and v). Exhibit F.6 shows that, among the three PWS types, transient PWSs have the largest percentage with high TC detection rates (e.g., above 15 percent or any other potential hazard marker percentage).

Exhibit F.6: Detection Rate Distribution Functions for Small (<101) PWSs Based on MCMC Sample Mean Parameter Values

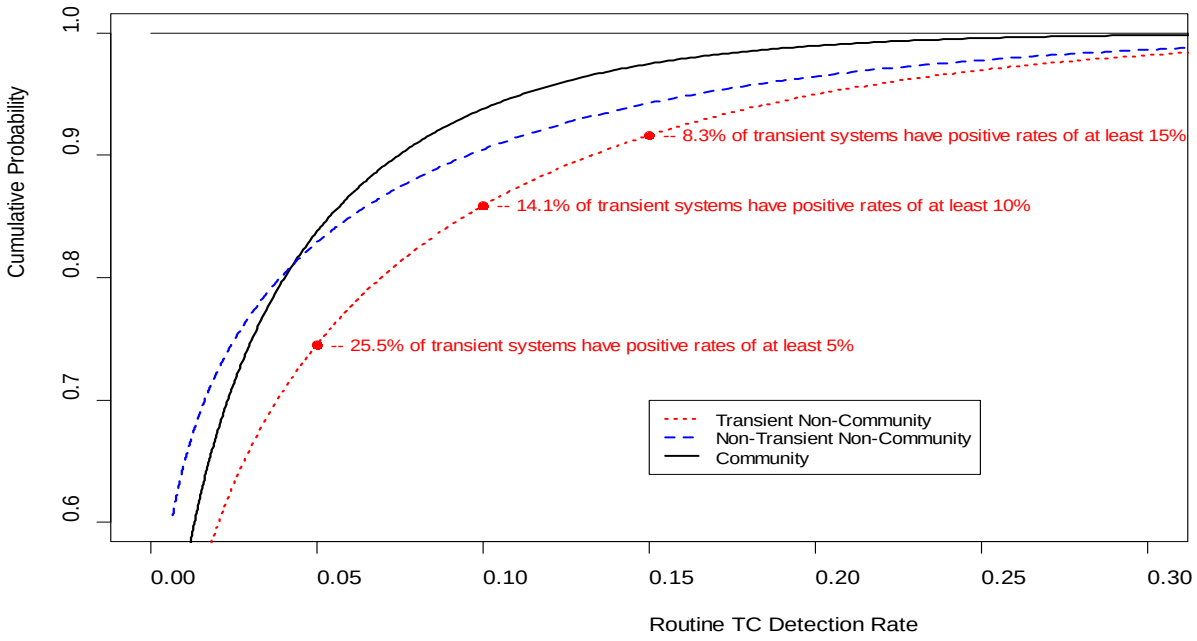


Exhibit F.7 shows the fraction of PWSs having routine TC detection rates above selected values. A significant fraction of smaller systems have high TC detection rates. For example, 5 percent of transient non-community systems serving populations fewer than 101 individuals (about 2,500 undisinfected systems) have TC detection rates of at least 20 percent.

The smallest rate in Exhibit F.7 (5 percent) is of special interest because observing 5 percent or more positives in a month triggers an assessment under the RTCR in systems that assay 40 or more samples per month (larger PWSs). For the smaller PWSs that assay fewer than 40 samples per month, two TC positive samples trigger an assessment. Notice that about one in four of the smallest transient non-community systems are estimated to have positive rates of 5 percent or more.

Exhibit F.7: Routine Total Coliform Detection Rates in Undisinfected PWS Systems Serving < 101 People

Detection Rate	Community	Non-Transient Non-Community	Transient Non-Community
5% or more	16% of systems	17% of systems	25% of systems
10% or more	6.5% of systems	9.5% of systems	14% of systems
15% or more	2.5% of systems	5.7% of systems	8.3% of systems
20% or more	1.0% of systems	3.5% of systems	5.0% of systems
30% or more	0.16% of systems	1.4% of systems	1.8% of systems

EPA re-analyzed the 2005 TC data and analyses (60,000 wells from a slightly differing set of states, with undisinfected wells determined by merged databases, using the same analytical solution used for the 2011 data). EPA found that, for the 2005 data, the maximum likelihood estimate of the average TC detection rate was 6 percent, as compared with 5 percent for the 2011 data, for the transient PWSs serving populations less than 101 individuals. For this same grouping of PWSs, in re-examining the tail of the distribution, EPA found 4.6 percent (for 2005 data) versus 5 percent (for 2011 data) of PWSs had a TC detection rate of 20 percent or more.

In the 2011 data, about 5 percent of TC detections were positive for *E. coli*. This rate appears relatively unchanged between 2005 and 2011. However, the response to an *E. coli* detection has changed due to the promulgation of the Ground Water Rule and RTCR. As a result, an *E. coli* detection may require a corrective action to find the fecal contamination source and end the contamination. Treatment, such as installing disinfection may be required by the state. Because the number of *E. coli* detections is small as compared with TC detections, EPA was unable to determine precise estimates of *E. coli* detection rate distributions. EPA found no significant differences in the average EC detection rates across PWS sizes and types.