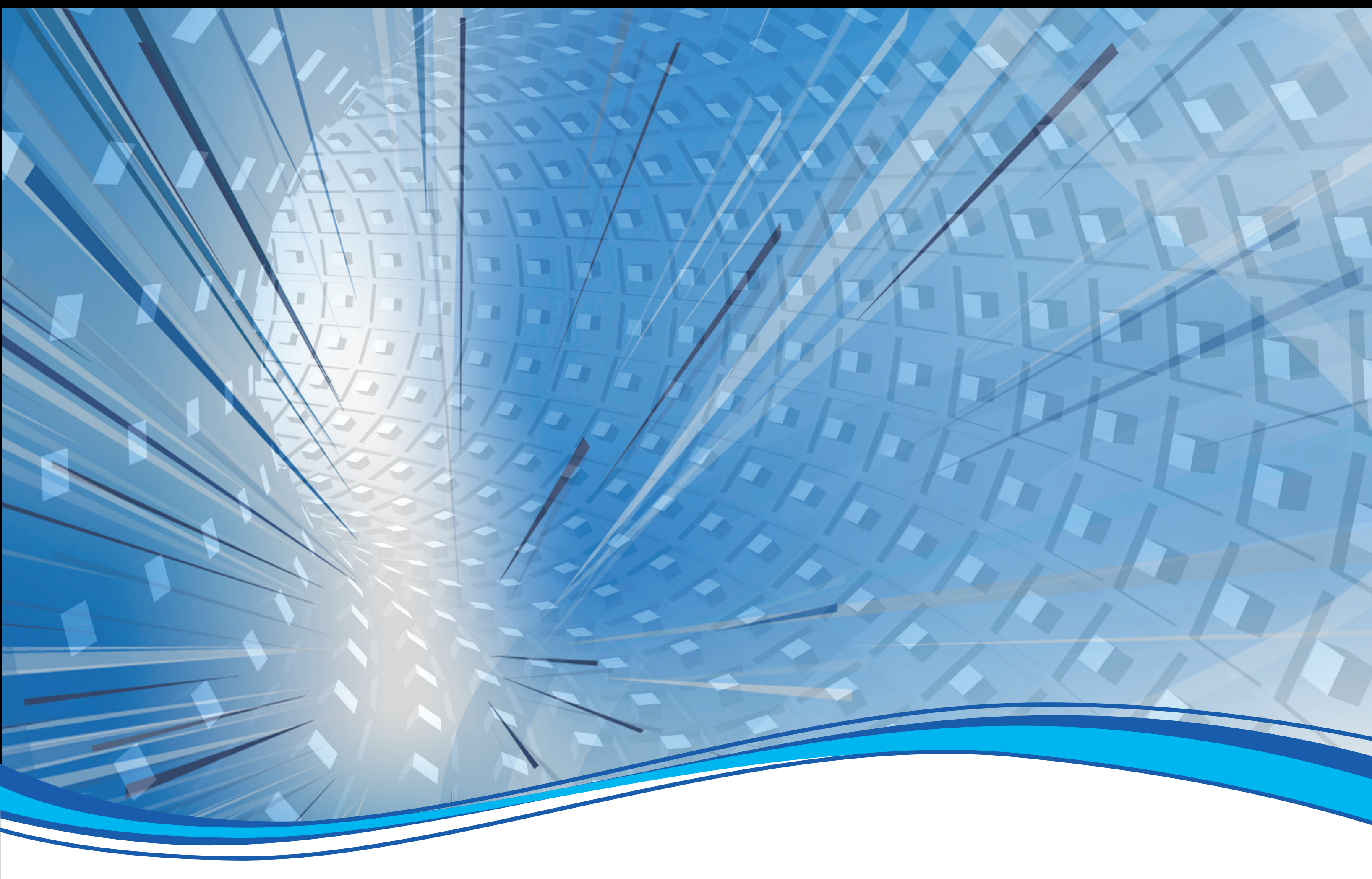
Manual of Water Supply Practices

M68

Water Quality in Distribution Systems



American Water Works Association

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Senior Managing Editor/Project Manager: Melissa Valentine
Cover art: Melanie Yamamoto
Production: Janice Benight
Manuals Specialist: Sue Bach

Library of Congress Cataloging-in-Publication Data

Names: Smith, Kira S., author. | Slabaugh, Rebecca, author. | American Water Works Association, issuing body.
Title: Water quality in distribution systems / by Kira S. Smith, Rebecca Slabaugh.
Other titles: AWWA manual ; M68.
Description: First edition. | Denver, CO : American Water Works Association, [2017] | Series: AWWA ; M68 | Includes bibliographical references and index.
Identifiers: LCCN 2017028391 | ISBN 9781625762269
Subjects: LCSH: Water quality management. | Water--Distribution.
Classification: LCC TD365 .S62 2017 | DDC 628.1/44--dc23 LC record available at https://lccn.loc.gov/2017028391

Printed in the United States of America

ISBN 978-1-62576-226-9 eISBN-13 978-1-61300-423-4

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Denver, CO 80235-3098
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The AWWA Manual M68 was written through the persistent and dedicated work of the following authors:

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The following individuals provided peer review of this manual. Their knowledge and efforts are gratefully appreciated:

Colleen M. Arnold, Aqua America, Inc., Bryn Mawr, Pa.

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Tarrah Henrie, Corona Environmental, Fremont, Calif.

Randy Moore, Tnemic Company, Saint Louis, Mo.

Lauren Wasserstrom, AWWA, Denver, Colo.

The authors would also like to acknowledge the following individuals who provided editorial and technical comments:

Mike Duer, Tideflex, Carnegie, Penn.

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The following individuals provided peer review of this manual. Their knowledge and efforts are greatly appreciated:

Tim Brown, Albermarle County Service Authority, Charlottesville, Vir.

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This new manual was reviewed and approved by the Distribution System Water Quality Committee. Special thanks to the following committee members during the time of development and for review comments:

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This manual was also reviewed and approved by the Water Quality Technology Division under the Technical and Educational Council and included the following personnel at the time of approval:

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Chapter 1

Introduction

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A drinking water distribution system is a system of pipes that carry potable water from treatment plants or water sources to consumers. It is also the last barrier available to water systems to maintain safe and high-quality water. This manual presents typical distribution system water quality challenges, providing summaries of typical responses and best practices as a "first stop" for drinking water system professionals.

Since each distribution system is unique, this manual is not intended to be all inclusive. Rather, it is a guide that summarizes the issues and actions to be taken when distribution system issues arise and provides references to other industry standards and publications that provide more detail. Additionally, this manual does not delve into treatment process or source water changes that can affect the quality of water that enters the distribution system. Readers are encouraged to familiarize themselves with the American Water Works Association (AWWA) standards and manuals of practice related to water source and treatment. These manuals are available for purchase online at http://www.awwa.org/publications/manuals-of-practice.aspx (accessed May 16, 2016).

For purposes of this manual, distribution systems include pump stations, ground and elevated storage tanks, potable water mains, potable water service lines, and all associated valves, fittings, and meters. Potable water customer service lines are excluded (Texas Commission on Environmental Quality 2015).

The chapters in this manual are organized based on the most common distribution system challenges that water systems face today. These are listed in Table 1-1.

Each chapter provides an introduction and description of a Distribution System Water Quality (DSWQ) Challenge, followed by:

- Discussion and description of the factors associated with each challenge. See text box(es) in each chapter for a summary of Characterizing the DSWQ Challenge;

Table 1-1 M68 chapters and their focus

Chapter	Title
2	Capacity and Water Age
3	Understanding and Managing Biofilm, Coliform Occurrence, and the Microbial Community
4	Infrastructure Integrity and Water Quality
5	Taste, Odor, and Appearance
6	Nitrification
7	Corrosion Control
8	Disinfectants and Disinfection By-products
9	Management of Low Pressure
10	Cross-Connection Control and Backflow Prevention
11	Security Issues

- Summaries of available response actions. See text box(es) in each chapter for a summary of Responding to the DSWQ Challenge; and
- Recommended best practices for optimizing DSWQ. See the table in each chapter that lists DSWQ Best Practices, which are rated as "basic" or "advanced." Some chapters include specific definitions for these terms. Generally, basic practices are the actions all water systems should perform if they have experienced the DSWQ challenge noted. Advanced practices are for water systems that wish to optimize and/or develop a comprehensive program related to the specific DSWQ challenge. Some chapters include an intermediate, or "moderate," rating that is clearly defined within that chapter.

GETTING STARTED—HOW TO IDENTIFY A PROBLEM OR CHALLENGE

Understand Baseline Water Quality Conditions

Many water systems have developed acceptable ranges for various water quality parameters in their distribution systems, for example, pH, disinfectant residual, iron, and manganese. These ranges are based on regulatory requirements and specific utility goals. Some have also developed target levels that trigger various responses, such as notifying the water quality manager and taking action (e.g., flushing) to restore water quality to acceptable levels.

AWWA Standard G200-09, *Distribution Systems Operations and Maintenance* (AWWA 2010), provides guidance to help water systems establish the documented programs and practices needed to understand water quality problems in their distribution systems. In addition to meeting regulatory requirements and preparing written sampling plans, the utility should annually review sampling plans and make adjustments based on historical data trends (AWWA 2010). All AWWA standards are available at http://www.awwa.org/publications/standards.aspx (accessed May 16, 2016).

Customer complaint data can also help a utility identify the source and extent of a water quality problem if the complaint information is managed properly and is accessible. Standard G200 recommends that a utility have a system for documenting customer inquiries that includes the date, inquiry type, customer location, sampling results, and resolution (AWWA 2010).

Water systems that wish to take a holistic approach to the improvement of overall distribution system water quality should consider joining AWWA's Partnership for Safe Water. This is a voluntary optimization program that provides various tools and guidance for tracking disinfectant residual, pressure, and main breaks, as well as a self-assessment guide for systems that wish to optimize distribution system operations.

Some water systems have also implemented proactive quality assurance practices by using hazard analysis and critical control points (HACCP) programs in order to ensure higher levels of tap water safety. HACCP is a systematic preventive approach, designed in the 1960s to protect food and beverages from microbiological hazards. For drinking water systems, the HACCP system promotes a "source to tap" philosophy in order to identify the critical points throughout the entire system (i.e., those points within the system or its operation whose disruption or failure would result in a greater public health risk compared to other points) and then to focus resources on these critical locations and processes. This systematic approach helps water systems identify potential hazards that are closer to their source, thus minimizing the occurrence and effects of incidents that degrade water quality and potentially threaten public health (USEPA 2006).

Consider Regulatory and Policy Frameworks

Legislative frameworks should support effective management of drinking water quality. These frameworks vary throughout the world based on constitutional settings. Legislation should define the roles and responsibilities of the primary agencies and entities associated with ensuring the delivery of safe drinking water.

Drinking water quality regulation requires public health and treatment technology expertise, which typically resides within governmental health and/or environmental protection agencies. Local government environmental health officers may also assist in the administration of legislation. Irrespective of the identities of regulators, they need to be given sufficient power to monitor and enforce legislative requirements. In the United States, for instance, the Safe Drinking Water Act (SDWA) provides authority to the US Environmental Protection Agency (USEPA) to set national drinking water regulations, with enforcement potentially including national, regional, and local authorities. Summaries of US and international regulations are provided at the end of this chapter. It is important to note that in the United States, each primacy agency (USEPA region, state, or territory) may have rules and regulations that local public water systems must follow.

In addition to legislation, provision of safe drinking water may be supported by standards and policies that apply to matters such as certification of water operators, water treatment chemicals, and distribution system materials and plumbing. These can take the form of mandatory requirements or recommended practices (Cunliffe 2014).

A summary of current international and US regulatory and standard frameworks associated with distribution systems is included at the end of this chapter. Most have common themes, which include most or all of the following five categories of distribution water quality indicators:

- Microbial activity,
- Disinfectant residuals,
- Disinfection by-products (DBPs),
- Corrosion, and
- Aesthetics.

Microbial activity and disinfectant residuals. Many potential factors associated with microbial activity and loss of disinfectant residual are similar and, therefore, characterized together. Microbial growth in the distribution system can cause changes to drinking water quality that can adversely affect public health. Direct microbiological indicators are generally based on the presence or absence of bacteria, the most common include total coliforms, fecal coliforms, *Escherichia coli*, and heterotrophic plate count bacteria. The presence of these bacteria may indicate the potential existence of a pathogen or issues associated with the treatment process, distribution system integrity, and/or distribution system operations and maintenance. Chapter 3, Managing Biofilm, Coliform Occurrence, and the Microbial Community, provides a summary of the regulatory frameworks associated with these indicators, as well as information on each indicator.

Disinfectants in drinking water are used to control microbial growth and the potential hazards associated with that growth. Chlorine-based disinfectant residuals have both minimum and maximum regulatory limits. Chapter 8, Disinfectants and Disinfection By-products, discusses these types of disinfectants and summarizes the regulatory frameworks associated with them.

Chapters 3 and 8 provide information on the indicators and possible hazards associated with these indicators. These chapters should be used as starting points for water systems in the detection of microbial indicators and/or loss of disinfectant residuals. However, the contributing factors or root causes for the presence of these indicators can be found in other chapters of this manual. Table 1-2 summarizes potential contributing factors for the presence of microbiological indicators and loss of disinfectant residual in the distribution system, as well as other chapters that provide more information on these factors.

Disinfection by-products. DBPs are chemicals that form when disinfectants/oxidants react with organic and inorganic substances in the water. Several DBPs are currently regulated based on potential health effects, and water systems should focus on controlling the levels of these regulated compounds. Chapter 8, Disinfectants and Disinfection By-products, provides information on these currently regulated DBPs, as well as emerging compounds, in terms of the regulatory framework and health effects. Chapter 8 also provides information on the DBPs that are associated with different types of disinfectants used by water systems. Table 1-3 lists the chapters that include information on changing DBP levels in distribution systems.

Lead, copper, and other corrosion indicators. USEPA promulgated the Lead and Copper Rule (LCR) in 1991 to reduce consumer exposures to lead and copper in drinking water (56 FR 26460; *Federal Register* 1991). The purpose of the LCR framework is to protect public health by minimizing lead and copper levels in drinking water, primarily by reducing water corrosivity (USEPA 2004). Health Canada's Water Quality and Health Bureau also has developed guidelines for lead and copper. Table 1-4 lists the chapters that include information on internal corrosion challenges.

Aesthetics. In the United States, the USEPA sets secondary standards related to constituents that cause unpleasant aesthetic conditions in distribution systems. Customer complaints are an initial indicator for aesthetic issues. These are typically related to color, taste, odor, particles, pressure, and sometimes perceived or actual sickness. AWWA Standard G200 recommends use of action plans to address color and staining, as well as taste and odor inquiries (AWWA 2010). Many customer complaints can be attributed to the factors listed in Table 1-5.

Table 1-2 Chapters on microbial activity and disinfectant residual challenges

Potential Contributing Factor	Relevant Chapter(s)
Microbial growth, pathogen presence	Chapter 3, Understanding and Managing Biofilm, Coliform Occurrence, and the Microbial Community
Disinfectant residual	Chapter 8, Disinfectants and Disinfection By-products
Aged water	Chapter 2, Capacity and Water Age
Main breaks	Chapter 4, Infrastructure Integrity and Water Quality
	Chapter 9, Management of Low Pressure
Nitrification	Chapter 6, Nitrification
Unprotected cross-connections	Chapter 10, Cross-Connection Control and Backflow Prevention
Contamination	Chapter 11, Security Issues

Table 1-3 Chapters on disinfection by-products challenges

Potential Contributing Factor	Relevant Chapter(s)
Changes in disinfectant and/or source water organic content	Chapter 8, Disinfectants and Disinfection By-products
Aged water	Chapter 2, Capacity and Water Age

Table 1-4 Chapters on internal corrosion challenges

Potential Contributing Factor	Relevant Chapter(s)
Inadequate corrosion control	Chapter 7, Corrosion Control
Contamination event evidenced by pH/alkalinity variations	Chapter 10, Cross-Connection Control and Backflow Prevention
	Chapter 11, Security Issues
Change in disinfectant or treatment	Chapter 8, Disinfectant and Disinfection By-products
Microbial-induced corrosion	Chapter 3, Understanding and Managing Biofilm, Coliform Occurrence, and the Microbial Community
	Chapter 6, Nitrification

Table 1-5 Customer complaint issues

Potential Contributing Factor	Relevant Chapter(s)
Corrosion	Chapter 7, Corrosion Control
Secondary and other constituents that cause aesthetic issues	Chapter 5, Taste, Odor, and Appearance
Main breaks	Chapter 4, Infrastructure Integrity and Water Quality
	Chapter 9, Management of Low Pressure
Microbial growth	Chapter 3, Understanding and Managing Biofilm, Coliform Occurrence, and the Microbial Community
	Chapter 6, Nitrification
Changes in disinfectants	Chapter 8, Disinfectants and Disinfection By-products

SUMMARY OF STANDARDS AND REGULATIONS

US Regulations

In the United States, Congress established the SDWA to protect the quality of drinking water throughout the nation. This law focuses on all waters actually or potentially designed for drinking use, whether from above ground or underground sources. SDWA authorizes USEPA to establish minimum standards to protect tap water and requires all owners or operators of public water systems to comply with these primary (health-related) standards (USEPA 2015). The 1996 amendments to the SDWA require that USEPA consider a detailed risk and cost assessment and best available peer-reviewed science when these standards are developed (USEPA 2015). USEPA also encourages attainment of secondary standards (nuisance-related; USEPA 2015).

The USEPA regulations that are based on the SDWA and its amendments are listed in Title 40 of the Code of Federal Regulations (CFR), which can be found at www.ecfr.gov (accessed April 26, 2016).

The SDWA, like most environmental regulations, is typically implemented through primacy agencies, where individual states or territories establish and enforce requirements that are at least as stringent as the federal requirements. Prior to the SDWA, states adopted US Public Health Service standards as regulations or guidelines (USEPA 1999). However, a 1970 survey of community water supplies revealed that 79 percent of systems were not being surveyed by state or local health departments (US Department of Health, Education, and Welfare 1970). The SDWA establishes and authorizes USEPA to allow states to assume primary oversight and enforcement, or primacy, for public water systems (Tiemann 2014).

According to Title 40 CFR regulations, primacy agencies have special requirements beyond implementation of the SDWA, which include ensuring that water systems are appropriately designed, constructed, and have appropriately certified operators based on water system size and water type.

Several SDWA requirements apply to the quality of water that enters distribution systems. There are also rules that apply to distribution systems, including the Total Coliform Rule, Surface Water Treatment Rules, Disinfectants/Disinfection Byproduct Rules, and Lead and Copper Rule. USEPA develops these regulations by setting acceptable public health standards based on the best available peer-reviewed science and what is feasible for water systems. To ensure these levels are met, USEPA regulations also set minimum monitoring requirements. Table 1-6 summarizes the current USEPA regulations that are associated with distribution systems, the public health requirement associated with distribution system levels, and required monitoring. Some chapters in this manual contain more detailed information on regulations as related to specific DSWQ challenges.

Additionally, it is important to note that the USEPA released its third Six-Year Review (Six-Year Review 3) in December 2016. The SDWA requires the USEPA to review each national primary drinking water regulation at least once every six years and to revise them, if appropriate. As part of the Six-Year Review 3, USEPA identified the following eight contaminants as candidates for regulatory revision: chlorite, cryptosporidium, haloacetic acids, heterotrophic bacteria, giardia lamblia, legionella, total trihalomethanes, and viruses. Many of these contaminants are related to distribution system challenges and are reflected in chapters of this manual. The reader is encouraged to reference the USEPA website on the Six-Year Review 3 for the most current information (USEPA 2016).

Table 1-6 Summary of USEPA distribution system regulatory requirements and monitoring

Regulation	Distribution System Requirement	Monitoring
TCR and RTCR (USEPA 2014)	No more than 5 percent of samples positive for total coliform and no fecal contamination or *Escherichia coli*; RTCR requires assessments for exceedances	Collect monthly samples at sites representative of the distribution system and population served
Surface Water Treatment Rules (USEPA 2004a)	At least 95 percent of distribution samples in water originating from a surface water source must have detectable residual*	Check residual disinfectant concentration at entry points to the distribution system and at TCR/RTCR routine sites
Disinfectant/Disinfection Byproduct Rules (USEPA 2006a)	Chlorine maximum residual disinfectant level (MRDL) = 4.0 mg/L; TTHMs and HAA5 locational running annual average maximum contaminant levels = 80 and 60 μg/L, respectively	Check residual disinfectant concentration at TCR/RTCR routine sites; measure TTHM and HAA5 quarterly in distribution system
Lead and Copper Rule (USEPA 1999a)	Lead levels must be <15 μg/L and copper levels must be <1.3 mg/L in 90 percent of samples†	First-draw tap samples for lead and copper every 6 months, annually, or every 3 years; alkalinity, pH, and corrosion inhibitor (if appropriate) monitoring every six months or annually

Abbreviations: HAA5, group of five haloacetic acids; TCR, Total Coliform Rule; TTHM, total trihalomethanes; RTCR, Revised Total Coliform Rule.

* Several states have rules regarding disinfectant residual requirements in distribution systems. Check with local primacy agencies for specific requirements.

† At the time this chapter was written, USEPA's National Drinking Water Advisory Council work group had finalized and made recommendations to revise the Lead and Copper Rule (LCR). These recommendations include proactive lead service line replacement, stronger public education, improved corrosion control treatment, tap sampling modifications, expanded water quality parameter monitoring, a household action level for lead, and separate requirements for copper. For more information on these recommendations and any subsequent proposed LCR changes, visit http://www.epa.gov/dwreginfo/lead-and-copper-rule (accessed April 26, 2016).

World Health Organization

The World Health Organization (WHO), an agency of the United Nations responsible for public health, developed a comprehensive set of guidelines related to drinking water quality that are intended to assist policymakers around the world to ensure sound drinking water practice. These nonenforceable guidelines have been established for various microbial, chemical, radiological, and aesthetic-based contaminants (WHO 2011). The WHO has also formalized a HACCP management approach, known as Water Safety Plans (WSPs; WHO 2009).

Australia

The National Health and Medical Research Council in collaboration with the National Resource Management Ministerial Council developed the Australian Drinking Water Guidelines in order to provide individual communities and regulatory agencies with a structure for proper treatment and management of drinking water supplies. The guidelines propose limits for microbial, physical, and chemical parameters in drinking water to ensure supplies are safe for human consumption. In addition, the guidelines include recommendations for selecting and monitoring the effectiveness of various treatment processes. These are nonenforceable standards. Each state or territory may choose to implement any or all of the guidelines. Readers are advised to consult the individual state or territory for additional information on drinking water requirements (NHMRC, NRMMC 2011).

Canada

Health Canada's Water Quality and Health Bureau, on behalf of the Federal–Provincial–Territorial Committee on Drinking Water, is the federal organization responsible for developing the Guidelines to Canadian Drinking Water Quality (Health Canada 2014). Similar to maximum contaminant levels established in the United States, these guidelines are designed to protect public health by establishing maximum acceptable concentrations (MACs) for microbiological, physical, chemical, and radiological parameters in drinking water (Health Canada 2014). These are nonenforceable federal standards. In Canada, the establishment of drinking water legislation is the responsibility of the individual provinces and territories (Health Canada 2014).

Each province or territory may choose to adopt a portion or all of the MACs established under the Guidelines to Canadian Drinking Water Quality or to establish new levels. To date, only 2 of the 12 provinces and territories (Alberta and Nova Scotia) have adopted the Guidelines to Canadian Drinking Water Quality in their entirety as enforceable drinking water regulations (Health Canada 2014). In addition, each province or territory is responsible for developing a set of drinking water requirements related to treatment, monitoring, and reporting (Health Canada 2014). Alberta has also regulated the need for drinking water safety plans for each system, which follows the WHO's WSP management approach (Government of Alberta 1995–2015).

While the individual requirements vary across Canada, the overarching nationwide goal is to use a multibarrier approach to protect public drinking water by reducing or preventing contamination at the source, during treatment, and throughout the distribution system (Health Canada 2014). Table 1-7 summarizes some of the Health Canada guidelines that apply to distribution systems (Health Canada 2014).

Table 1-7 Summary of Health Canada distribution system guidelines and monitoring

Guideline	Maximum Acceptable Concentration (MAC)	Recommended Monitoring
Total coliform/ *Escherichia coli*	None detectable in a 100-mL sample leaving the treatment plant and in nondisinfected water leaving the well	For systems that serve up to and including 5,000 people: monitor water leaving pump house or treatment plant and at representative locations in the distribution system four times per month; no consecutive samples from the same site or not more than 10 percent of samples should show the presence of total coliform bacteria*
Chlorine	None required	Free and/or total chlorine residuals should be tested when bacteriological samples are taken*
Monochloramine	3.0 mg/L	Free and/or total chlorine residuals should be tested when bacteriological samples are taken*
Lead	0.010 mg/L	Option 1: two-tier protocol; tier 1, annual first draw, if 10 percent >0.015 mg/L, then tier 2: four consecutive 1-L sampling in highest 10 percent locations Option 2: lead service line residences; four consecutive 1-L sampling; site average <MAC in >90 percent of locations†
Trihalomethanes	0.10 mg/L for the sum of chloroform, chlorodibromomethane, bromodichloromethane, and bromoform	For systems that use chemical disinfection, monitor every three months to compute a locational running annual average of quarterly samples*
Haloacetic acids	0.08 mg/L as low as reasonably achievable; for the sum of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid	For systems that use chemical disinfection, monitor every three months to compute a locational running annual average of quarterly samples*

* Health Canada Guidance for Providing Safe Drinking Water in Areas of Federal Jurisdiction, Version 2. Accessed May 16, 2016. http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-federal-eau/index-eng.php.

† Health Canada Guidance on Controlling Corrosion in Drinking Water Distribution Systems. Accessed May 16, 2016. http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-corrosion-eau/index- eng.php.

Emirate of Abu Dhabi

In 2009, the Regulation and Supervision Bureau for the Water, Wastewater, and Electricity Sector in the Emirate of Abu Dhabi developed the Water Quality Regulations to ensure that safe drinking water is provided to all customers throughout the Emirate of Abu Dhabi. The regulations establish maximum limits for select microbial, inorganic, and organic contaminants in drinking water based on WHO guidelines. The regulations include requirements for monitoring and recordkeeping for water suppliers. While the regulations do not directly discuss treatment or disinfection, they do state that "the water does not contain any element, organism or substance at a concentration or value which would be detrimental to public health" and contain limits for various DBPs (Regulation and Supervision Bureau 2009).

European Union

In 1998, the European Union (EU) issued Directive 98/83/EC, which established minimum standards for water intended for human consumption for EU Member States. Although disinfection is not explicitly required, the directive includes limits for microbiological parameters and DBPs that are similar to the WHO guidelines. Member States are also encouraged to minimize DBP formation, but not at the expense of disinfection. Member States may adopt stricter standards as well as limits for additional parameters. In general, most Member States require disinfection of surface waters using chlorine, chlorine dioxide, ozone, or ultraviolet light but do not require disinfection of groundwater supplies. Only some Member States require that a minimum disinfectant residual be maintained at all times in the distribution system. Other Member States, such as the Netherlands, apply strategies that include the use of only high-quality water supplies and biologically stable distribution system materials in addition to distribution system operational strategies such as flushing to minimize the potential for bacterial regrowth (EU Council 1998).

In October 2015, the European Commission adopted a directive to revise Directive 98/83/EC to include an option to perform monitoring in a more flexible way, provided a risk assessment is performed to ensure full protection of public health. It follows the principle HACCP and the WHO's WSP approach (European Commission 2015).

New Zealand

The New Zealand Water Quality Guidelines were developed based on WHO guidelines and include recommended maximum values for microbial, radiological, and chemical parameters, including DBPs. The guidelines are enforceable and apply to all drinking water providers regardless of source, treatment type, or distribution system size. The guidelines require that some form of disinfection be provided for all surface or spring water sources. The guidelines also include requirements for monitoring disinfection efficiency at treatment plants and in the distribution system in addition to reporting and corrective action requirements (Ministry of Health 2008).

Republic of South Africa

The South African Water Quality Guidelines were established in 1996 and provide target water quality ranges for various microbial, physical, chemical, and aesthetic parameters. The guidelines recommend disinfection via chlorination or chloramination and that an adequate residual be maintained to minimize any bacterial regrowth or biological corrosion (Department of Water Affairs and Forestry 1996).

Drinking water must also comply with the requirements set forth in the South African National Standard (SANS) 241 Drinking Water Specification. The specification establishes maximum allowable concentrations for select parameters monitored at the "pointe of delivery." Values have been established based on WHO guidelines (Department of Water Affairs and Forestry 1996).

Singapore

Recently, the Singapore Government promulgated the Environmental Public Health Act, which established standards for the quality of drinking water in piped systems. The act also includes information on development of sampling and safety plans. Although the act does not plainly require disinfection, the Public Utilities Board, which is the national water agency in Singapore, provides disinfection of its water supplies prior to distribution (Government of Singapore 2008).