



GUIDANCE ON THE
TEMPERATURE
ASPECTS OF
**DRINKING
WATER**



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Other documents developed as part of the Guidelines for Canadian Drinking Water Quality can be found on the [Water Quality—Reports and Publications website](#).



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1.0 INTRODUCTION

The purpose of this document is to summarize how temperature is discussed in the *Guidelines for Canadian Drinking Water Quality* (GCDWQs) and to highlight aspects that may be relevant to drinking water utilities. This document covers temperature aspects from the source through treatment and distribution to in-building plumbing. Water temperature affects all physical, chemical, microbiological, and biochemical processes to some extent. This, in turn, affects treatment efficacy and water quality and can result in issues related to health-based contaminants and/or aesthetics.

All drinking water utilities should implement a risk management approach, such as the source-to-tap or water safety plan approach (CCME, 2004; WHO, 2009, 2012, 2014). These approaches require a system assessment that involves characterizing the water source, describing the treatment barriers that prevent or reduce contamination, highlighting the conditions that can result in contamination, and identifying control measures. Operational monitoring is then established, and operational/management protocols are instituted (e.g., normal operating procedures, corrective actions and incident responses). Compliance monitoring is determined, and other protocols to validate the water safety plan are implemented (e.g., record keeping, consumer satisfaction).

Operator training is required to ensure the effectiveness of the water safety plan at all times. A continuous improvement program should also be in place to optimize system processes for the full range of water quality conditions. Optimization helps water utilities consistently deliver high quality drinking water to all consumers, thereby maximizing consumer satisfaction.

This document does not provide a comprehensive list of measures that should be implemented as part of a source-to-tap or water safety plan approach. It is the responsibility of drinking water utilities to identify and manage the full range of risks that may apply to their systems.

This guidance document replaces the **Guidelines for Canadian Drinking Water Quality: Guideline Technical Document—Temperature**.



1.1 Impacts of a changing climate

Water temperature is forecast to increase as a result of climate change. This may exacerbate other changes expected to occur, such as increased nutrient loading, increased frequency, duration and severity of algal growth and cyanobacterial blooms, increased variability in the quantity and character of runoff, and increased frequency of floods and wildfires. Higher water temperatures may also expand the geographical range of microorganisms that have been associated with waterborne illness in the southern parts of North America (e.g., *Naegleria fowleri*). The GCDWQs do not discuss all the potential climate changes that could impact water utilities because these will vary by region or hydrologic zone. The responsible drinking water authority should be consulted to confirm forecast scenarios that should be considered.

Climate change impacts will heighten the importance of water quality monitoring, proper treatment process selection, day-to-day process control and distribution system operation, and education and outreach programs. Thus, drinking water utilities should integrate the risks associated with climate change into their management strategies to maximize the reliability, robustness and resilience of their drinking water systems. Guidance is available to assist water utilities (AWWA, 2021).

2.0 IMPACTS OF TEMPERATURE

Most guideline and guidance documents of the GCDWQs discuss temperature to some extent because of its diverse impacts. Temperature can influence the physical, chemical, microbiological and biochemical aspects of water. It is important to understand how temperature can produce issues related to health-based contaminants and aesthetics when developing and implementing management strategies. Some important considerations are highlighted below.

2.1 Physical aspects

Temperature can influence a number of physical aspects of drinking water, including density, viscosity, conductivity, boiling and melting points (of the water and dissolved compounds), taste, and odour. Some aspects mentioned in the GCDWQs are noted in Table 1.

Table 1. Impact of temperature on select physical aspects of drinking water

Aspect	Comment	Relationship to drinking water
Density	Water is at its densest at approximately 4 °C. As water warms, it becomes less dense.	Water bodies may thermally stratify when an upper heated layer of water of low density floats on a deeper, cooler water layer. The cooler denser layer may become anoxic, leading to the release of undesirable compounds, such as manganese, from sediments. Similarly, when water cools, the densest water sinks, causing lake turnover in the fall. Water storage facilities can also become thermally stratified. The water age of the warmer layer increases, disinfectant residual decreases and biofilm and microbiological growth accelerates.
Viscosity	The viscosity of water is higher at low temperature (e.g., it generates more resistance or drag).	Some particles may not settle at colder temperatures; this may result in particle (turbidity) carry-over from sedimentation to filtration processes; also, filtration processes are less effective at colder temperatures.
Conductivity	As water temperature increases, conductivity (i.e., ionic activity) increases.	Conductivity is a surrogate measure of total dissolved solids which may affect the taste of water, corrosion or mineral deposition. Conductivity measurements should be temperature corrected to 25 °C (known as specific conductance) to facilitate the comparison of results.
Boiling and melting points	Boiling and melting points determine the “state” of matter (e.g., solid, liquid or gas) ^a . In some documents, the vapour pressure or Henry’s law constant is given as a measure of compound volatility (e.g. ability to evaporate from the liquid).	There are a number of points to consider: <ul style="list-style-type: none"> » Boil water advisories—At elevations over 2 000 m, water boils at a slightly lower temperature and should be boiled for at least 2 minutes to ensure all disease-causing microorganisms are inactivated. » Volatility—The vapour pressure of volatile compounds is directly related to water temperature; thus, at higher temperatures, there will be greater water-to-air partitioning. This makes aeration/air stripping treatment technologies more effective at higher temperatures. » Risk assessment methodology—Compound volatility is considered when developing guidelines by assessing the risks from ingestion, as well as inhalation and dermal adsorption during showering or bathing.
Taste	In general, the higher the temperature, the greater the formation of offensive-tasting compounds.	The processes that result in the formation of offensive-tasting compounds are usually chemical (e.g., metals) or biochemical (e.g., metabolites produced by microorganisms).
Odour	In general, the higher the temperature, the greater the formation of odour-causing compounds and/or odour intensity.	Odour-causing compounds can be produced by chemical reactions (e.g., chlorophenols) or by microorganisms (e.g., geosmin). However, it is the physical process of evaporation (e.g., compound volatility) that results in the sensory reaction.

^a The change in “state” of water can have significant impacts (e.g., four- to five-fold increase in natural organic matter during precipitation/snowmelt events, frozen water lines in winter).



2.2 Chemical aspects

Temperature can influence a number of chemical aspects of drinking water, including: pH, solubility and chemical reaction rates. Some chemical aspects mentioned in the GCDWQs are noted in Table 2. A simple relationship between temperature and chemical water quality may not exist because the numerous physical, chemical and biological interactions that occur in a distribution or plumbing system can make effects difficult to predict.

Table 2. Impact of temperature on select chemical aspects of drinking water

Aspect	Comment	Relationship to drinking water
pH	As temperature decreases, the dissociation of water decreases and pH increases. This means that the pH value at which water is considered acidic, neutral or basic varies with temperature: <ul style="list-style-type: none"> » 25 °C Neutral = 7 » 20 °C Neutral = 7.085 » 5 °C Neutral = 7.365 » 0 °C Neutral = 7.5 	There are a number of points to consider: <ul style="list-style-type: none"> » pH meters should include a temperature compensation device; pH should be measured as soon as possible after sample collection to minimize the impact of temperature. » A solution with pH of 7 at 5 °C is acidic because its pH is lower than the neutral value of 7.365 at this temperature (i.e., there is an excess of hydrogen ion [H⁺] versus hydroxide ion [OH⁻]). » Treatment plants coagulating at acidic pH operate farther from neutral pH at 5 °C compared to 25 °C, and significantly less OH⁻ is available to react with the coagulant. Seasonal pH adjustment is suggested to account for lower OH⁻ concentrations during cold water conditions. » Chemically influenced processes in the distribution system, such as corrosion, are pH dependent.
Solubility of solids	The solubility of most solids increases when temperature increases; however there are some notable exceptions, including: <ul style="list-style-type: none"> » calcium carbonate » calcium hydroxide » calcium phosphate » magnesium silicate » sodium hydroxide 	There are a number of points to consider: <ul style="list-style-type: none"> » The solubility of metals generally increases with temperature; thus, only cold tap water should be used for drinking, cooking and preparing baby formula. » A change in temperature can cause material to precipitate and form deposits or it can cause previously deposited material to dissolve and release co-precipitated contaminants. » The effect is difficult to predict and can vary from one system to another because the solubility of many compounds is also pH dependent.

Aspect	Comment	Relationship to drinking water
Solubility of gases	The solubility of dissolved gases decreases as temperature increases (i.e., cold water holds more dissolved gas than warm water). Important dissolved gases relevant to drinking water include ammonia, carbon dioxide and oxygen.	There are a number of points to consider: <ul style="list-style-type: none"> » Ammonia, when present in the raw water, creates a high oxidant demand and decreases disinfection efficacy; it is a nutrient that encourages algal growth in the source and biofilm growth in the distribution system; nitrifying bacteria convert ammonia to nitrite/nitrate. » Carbon dioxide has a significant impact on pH stability; groundwater supplies with dissolved carbon dioxide should use an online pH meter or a headspace-free measuring device for accurate results. » Oxygen has a significant impact on redox conditions. This influences the composition of the microbiological community and redox-state-dependent changes in solubility (e.g., manganese release under anoxic conditions); warmer water temperatures due to climate change are expected to lower dissolved oxygen content and increase the risk of anoxic conditions.
Rates of chemical reactions	In general, every 10 °C increase in temperature doubles the rate of reaction.	There are a number of points to consider: <ul style="list-style-type: none"> » Chemical oxidation and reduction will be more effective at warmer temperatures, which means that temperature is an important factor to be considered when using chemical oxidants for pathogen inactivation. » Decay of the disinfectant residual in the distribution system accelerates at warmer water temperatures. » The rate of formation of disinfection by-products generally increases with warmer temperatures. » Coagulation hydrolysis products form faster at warmer temperatures, making the process more effective. » The hydrolysis of polyphosphates increases with temperature and may release previously sequestered manganese. » The rate of diffusion relates to the movement of molecules and it increases at warmer temperatures (e.g., diffusion of oxygen, metals).



2.3 Microbiological aspects

The impact of temperature on microbiological aspects depends on the microorganism and where it is encountered in the water system. For example, some microorganisms survive better at low temperatures in the source water, while others thrive at warmer temperatures in the distribution system or within residential and building plumbing systems. Table 3 summarizes some of the microbiological aspects mentioned in the GCDWQs.

Table 3. Impact of temperature on select microbiological aspects

Aspect	Comment	Relationship to drinking water
Enteric pathogens (protozoa, viruses and bacteria)	Survival time increases as temperature decreases.	Concentrations can peak at low temperature when filtration and disinfection processes are less effective.
Indicator organisms (<i>E. coli</i> and total coliforms)	Survival time is influenced by a number of physical and biological factors, including temperature.	Monitoring for total coliforms and <i>E. coli</i> is used to indicate potential unsanitary conditions, physical integrity issues, and growth in the distribution system.
Algae and cyanobacteria	The optimal temperature for the growth of toxic cyanobacteria is above 25 °C; other species have adapted to grow at lower temperatures or to over-winter in sediments.	Concentrations can peak at warm temperatures; pH can increase (due to photosynthesis) and may impact filtration and disinfection processes. Blooms can cause other treatment challenges (e.g., cell mass, hydrophilic organic matter) and generate unpleasant tastes/odours.
Biofilm (e.g., bacteria, protozoa, fungi)	Microbial activity increases with temperature, but biofilm can survive and grow at all temperatures encountered in a distribution system (< 4 °C to 30 °C).	Biofilm formation and growth cause numerous water quality issues. For example, biofilms can: <ul style="list-style-type: none"> » harbour pathogens for release at a later time; » consume disinfectant residuals; » generate organic matter (e.g., disinfection by-product precursors); » generate turbidity, colour or unpleasant tastes/odours; » mediate corrosion and the release of metals (e.g., lead, copper).
Nitrifying bacteria	Optimal growth occurs between 20 °C and 30 °C, but nitrifying bacteria can survive and grow at all temperatures encountered in a distribution system (< 4 °C to 30 °C).	In addition to the impacts of biofilms noted above, nitrifying bacteria convert ammonia to nitrite and nitrate.

Aspect	Comment	Relationship to drinking water
Legionella	Optimal growth occurs between 25 °C and 45 °C, but Legionella can survive and grow outside this range.	Legionella can survive and grow in biofilms and inside the free-living protozoa found in distribution and plumbing systems; they are resistant to commonly used chemical disinfectants.
<i>Mycobacterium avium</i> complex	Optimal growth occurs between 15 °C and 45 °C, but mycobacteria can survive and grow outside this range.	Mycobacteria can survive and grow in biofilms and inside the free-living protozoa found in distribution and plumbing systems; they are very resistant to commonly used chemical disinfectants.

2.4 Biochemical aspects

Some of the physical and chemical aspects noted above may be strongly influenced by microbial activity. As microbiological survival and growth are impacted by water temperature, drinking water utilities should be aware of the combined effects of physical, chemical and biological interactions on water quality. This is particularly important when organic and inorganic nutrients are present (e.g., organic matter, iron, manganese, nitrogen, phosphorus, sulphate).

Cyanobacterial blooms may be associated with water quality issues due to the potential presence of cyanobacterial toxins or odorous compounds. Algal and cyanobacterial blooms also comprise a source of nitrogen-rich organic matter (e.g., disinfection by-product precursors).

Other microorganisms accelerate oxidation-reduction processes involving sulphur or nitrogen. Sulphate-reducing bacteria may be involved in the tuberculation of metal pipes. The hydrogen sulphide produced by these bacteria also generates unpleasant tastes and/or odours and may increase corrosion in both metal and concrete pipes. Nitrifying bacteria convert ammonia to nitrite/nitrate as noted above. Other bacteria can both oxidize and reduce iron and manganese. This, in turn, leads to the growth of biofilms and the accumulation of deposits in the distribution system. Health-based contaminants (e.g., arsenic, manganese) can accumulate in these deposits and be released when water quality conditions change (e.g., temperature or pH). These releases are also generally associated with discolouration or turbidity.



Other microorganisms are involved in metabolism and decay (i.e., biodegradation). Biodegradable compounds mentioned in the GCDWQs include natural organic matter, some haloacetic acids and some pesticides. While the net effect of biodegradation may be decreased concentrations for some compounds, biodegradable organic matter encourages biofilm growth in the distribution system.

Microbial activity in the distribution systems can lower the pH due to biofilm respiration which produces carbon dioxide. This can lead to corrosion and the release of metals (e.g., lead, copper). Warmer water temperatures may exacerbate this issue.

3.0 MEASUREMENT AND SAMPLING PROTOCOLS

Water temperature can be measured with any standard liquid-in-glass or electronic thermometer with an analog or digital readout. The use of mercury-filled thermometers should be avoided to prevent the possible release of mercury in the event of breakage of the thermometer (APHA et al., 2017). Instruments are available for online measurement of temperature in water treatment applications.

Temperature specifications apply for various parameters to ensure that the sample is representative (e.g., at the time of collection, as well as during sample transport and storage). Drinking water utilities should confirm temperature specifications with the laboratory for the parameters in their monitoring plans. Commercial devices are available to verify that temperature specifications are achieved during sample transport and storage. During the summer and winter months, additional steps may be required to maintain the optimal temperature of samples while in transport.

Temperature may also be an important factor to consider when establishing sampling frequencies. For example, a raw water temperature of 20 °C may trigger monitoring for cyanobacteria and/or their toxins. Distribution system water temperatures of 15 °C may trigger an increase in sampling frequency from weekly to daily for some parameters.

4.0 EFFICACY OF TREATMENT PROCESSES

In order to ensure that guidelines are achievable, the GCDWQs include information on effective treatment technologies. Temperature affects all physical, chemical and biological treatment processes to some extent, including disinfection, coagulation, sedimentation, filtration, aeration/air stripping and corrosion control. Thus, it is important to understand seasonal trends. Process adjustments or additional processes may be required to manage the impacts of temperature and effectively treat water throughout the year.

The efficacy of a treatment process will depend both on source-specific water quality and the treatment goal. As a result, source-specific treatability studies, including bench- and/or pilot-scale testing, are recommended to determine the most effective treatment option(s) and to assess unintended consequences for the full range of water quality conditions. Treatability studies should:

- » be conducted for both cold (<10 °C) and warm (>10 °C) water conditions;
- » assess impacts on biological and chemical stability in the distribution system using pipe specimens harvested from the system; and
- » evaluate approaches to mitigate any observed adverse responses.

The lack of a source-specific treatability study may result in:

- » the selection of inappropriate treatment;
- » an increase in disinfection by-product concentrations following the implementation of treatment;
- » an increase in corrosion potential following the implementation of treatment;
- » biologically or chemically unstable water quality; or
- » other unintended consequences.



Chemicals used during treatment may also require special precautions to minimize the formation of harmful by-products. In particular, hypochlorite solutions should be stored in a cool, dry location out of direct sunlight. When these solutions are stored at higher temperatures, the chemical decomposition of hypochlorite speeds up (e.g., less available chlorine) and chlorate and perchlorate form. Every 5 °C increase in storage temperature approximately doubles the rate of perchlorate formation. Bromate is also present in these solutions. The lower available chlorine necessitates an increase in dose to maintain disinfection targets. This, in turn, results in higher bromate, chlorate and perchlorate concentrations in the treated water. ANSI/AWWA Standard B300 recommends a verification program to confirm that hypochlorite treatment chemicals meet specifications, particularly for available chlorine.

5.0 DISTRIBUTION SYSTEM WATER QUALITY

Water temperature can change as water flows through the extensive network of water mains, valves, hydrants and storage facilities that make up the distribution system. Thus, drinking water utilities should develop a strategy to both understand and manage these changes. This typically involves operational monitoring to assess trends with the goal of preventing or correcting water quality issues. Some best practices for managing the impacts of temperature that are mentioned in the GCDWQs include optimizing storage facility turn-over rates and installing mixers to prevent thermal stratification. Other important elements include maintaining stable biological and chemical water quality conditions and minimizing physical and hydraulic disturbances.

It is important to note that a distribution system with a residence time of 7 days and temperature of > 15 °C *will likely require* a different management strategy than one with a residence time of 3 days and temperature of < 15 °C. Monitoring water temperature in the distribution system is helpful to understand general water quality trends, establish relationships with other parameters (e.g., disinfectant residual) and develop appropriate management strategies.

6.0 RESIDENTIAL AND BUILDING PLUMBING SYSTEMS

Drinking water utilities should have education and outreach programs to make consumers aware of how water quality can deteriorate within residential and building plumbing systems. Key elements include maintaining the temperature of hot and cold water systems outside of the ideal range for microorganism growth (i.e., cold water < 20 °C and hot water > 60 °C).

7.0 MANAGEMENT STRATEGIES

Temperature is a critical parameter for many drinking water aspects, and drinking water utilities should endeavour to appropriately manage its impacts. To do so requires a good understanding of the following:

- » how temperature changes seasonally in the water source;
- » how this impacts water treatment processes;
- » how temperature changes through the distribution system;
- » how this impacts water quality at the point of consumption (i.e., tap);
- » whether any of these changes lead to health, aesthetic or operational issues;
- » what operational and management protocols are necessary;
- » what education and outreach programs are necessary;
- » what climate change adaption plans are necessary.



As temperature impacts every aspect of drinking water, drinking water utilities should develop management strategies for normal operating conditions, corrective actions and incident responses, as well as when planning the following:

- » switching or introducing a new water source;
- » treatment process changes;
- » distribution system modifications;
- » revisions to sampling plans and protocols.

Management strategies will be unique to each system depending on its design, size and complexity, as well as on regulatory requirements. Seasonal adjustments may be required to effectively manage the impacts of temperature throughout the year.

8.0 REFERENCES

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9.0 FURTHER READING

Temperature is a key factor in most GCDWQs and has significant impacts on many drinking water aspects (e.g., treatment, distribution, sampling protocols). It is recommended that readers refer to the guideline or guidance document to obtain specific information related to a parameter of interest. Readers can find guidelines and guidance documents on the [Water Quality—Reports and Publications website](#).

APPENDIX A: LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
AWWA	American Water Works Association
GCDWQs	Guidelines for Canadian drinking water quality