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Water storage and emerging challenges in a changing climate

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Key Messages

- Water storage allows public water systems to function by helping to maintain pressure in distribution pipes, balancing demand, and ensuring continuous potable water access for water customers.
- In small rural, remote, and Indigenous communities without access to a piped supply, water storage practices can differ, with smaller scale storage used for water produced by small treatment plants or wells, or household cisterns for water delivered by truck.
- Ensuring stored water remains safe requires starting with high quality water and taking measures to safeguard it against contamination or degradation until it is needed.
- Stored water quality can be degraded by stagnation, high water age, and environmental conditions that enhance microbiological growth and deplete disinfectant residuals.
- Quality can also be affected by contamination during tank filling, corrosion or leaching of aging tanks, or environmental contamination that enters via poorly sealed lids, holes, cracks, or vents.
- Inadequate inspection that fails to detect problems and inadequate repair and maintenance of tanks further drive the degradation of stored water quality.
- There are significant research gaps in understanding how water storage practices affect health in small rural, remote, and Indigenous communities who are already disproportionately affected by water advisories and water shortages.
- Health concerns include a higher occurrence of gastrointestinal illness and significant psychosocial impacts of living in water-stressed communities, with fewer resources available for managing and maintaining water systems.
- Climate change could increase the challenges to maintaining stored water quality and quantity by changing treatment needs for source water, damaging infrastructure, or causing direct contamination of stored water during flooding or other events.
- Climate change could also increase the demand for safe water storage capacity in communities adapting to more frequent water scarcity events.
- Given the underlying and emerging challenges to maintaining stored water quality, there is a need for increased access among households and communities to the resources and skills needed to inspect, maintain, and repair systems.
- An increase in the frequency of cistern inspection, cleaning, and maintenance practices, preparing to respond to emergency events could also assist in building community resilience.

Introduction

Water storage is an important element of municipal water systems, helping to ensure access to treated water at times of variable demand and to maintain adequate pressure throughout a distribution network. Water storage can add resilience during events such as drought, wildfire, or interrupted water supplies, and can be used to supplement distribution systems during emergencies or disasters. Water storage practices in small systems and private or household settings, however, can differ widely from large municipal systems. Storage systems can range from sophisticated, with automatic monitoring, pumps and additional treatment devices supplying several homes and public buildings or businesses, to basic household cisterns storing water for a single dwelling. For communities and dwellings that are not served by a piped supply, such as those in rural, remote, and Indigenous communities, particularly in Canada's north, water storage may be used to supplement low-yielding wells, or to store hauled water delivered by truck. Communities and households in these locations can face operational and financial challenges in providing safe drinking water, with reduced access to services, trained personnel, and materials.

Building resiliency to ensure long-term and reliable access to safe water requires the ability to protect water supplies from contamination and to readily carry out repairs and maintenance of systems when needed. This includes adapting to changing environmental conditions and responding to and recovering from emergencies and adverse events. These principles are not new. However, they are worth revisiting in light of how climate change could compromise the ability to provide safe drinking water by affecting source water quality,[1-3] cause direct damage or contamination of stored water supplies, or disrupt power, communications, and transportation infrastructure. For households and communities that are already water insecure, increasing resilience requires understanding some of the underlying challenges to maintaining access to safe drinking water, while also identifying where climate-related events could make things worse.[2,4-12] Water storage can be an important part of resilient water systems; however, a better understanding of source water quality, infrastructure, and operations and maintenance practices for small, private, and household water storage, especially in rural and remote locations, can help ensure systems remain resilient in a changing climate.

This review provides an overview of the environmental public health hazards related to water storage and key considerations for maintaining stored water quality in a changing climate, with a focus on small-scale and household systems and lessons learned from larger storage systems.

Note: this review excludes rainwater and greywater harvesting and water stored for non-potable uses.

Methodology

Literature search

We searched the scholarly and grey literature for evidence on current practices in small-scale potable water storage across Canada and evidence of environmental public health hazards that may arise in stored water, particularly in relation to climate-driven events such as wildfire, flooding, drought, extreme heat, and permafrost melting. The following research questions guided the literature search:

- What are the possible effects of climate change on the quality and quantity of water stored in storage tanks or cisterns for small systems or private households?
- What measures have been identified to mitigate climate-related effects and build resilience for communities that rely on stored water?

Ebscohost databases (includes Medline, Cinahl, Academic Search Complete, ERIC, etc.), Google Scholar and Google were scanned for results with no date limit. Jurisdictions in Canada/North America and English language documents were of primary interest. Variants and Boolean operator combination of key search terms were used. Examination of bibliographies and citations of key articles was used to retrieve more extensive information via forward and backward chaining, along with supplemental searches as necessary. Google and the websites of major public health agencies, federal, and provincial ministries were scanned for relevant documents. Retrieved papers were assessed by a single reviewer for inclusion and synthesized narratively. The synthesis was subjected to internal and external review. Full search terms are available upon request.

Expert consultation

Expert advice was sought from persons in different regions of Canada with technical and operational expertise of water storage tanks, experience working directly with communities, and/or knowledge of the public health concerns associated with stored water. Consultees assisted in reviewing this document prior to publication.

Results

Current practice in water storage in Canada

Who stores water?

There is a range of practice in storing water across Canada. Municipal systems use large-scale storage to balance demand, ensure continuous supply, and maintain system pressure, with several thousand storage tanks among publicly owned potable water assets.[13] About 12% of Canadian households do not have access to a piped municipal water supply. Many of these use smaller-scale water tanks and cisterns to store untreated or treated water from a private supply (e.g., primarily well water), and a small percentage store treated water hauled by truck from a municipal system in household cisterns.[14,15]

Cistern use is more prevalent in the prairies, many First Nations communities, and across the North.[14,16-19] In 2011, an estimated 13.5% of homes in First Nation communities (15,451) received trucked water.[20] Inuit Nunangat has the lowest coverage of piped water supply in Canada, with most communities (~80%) relying on trucked water stored in household cisterns. Rural and remote northern households that do not have access to either a piped supply or trucked water, may instead use bottled water, collect treated municipal water from a centralized potable water dispensing unit (PWDU), or gather water from natural sources in portable containers.[21] Natural sources of water are sometimes sought due to reduced trust in public water supplies, poor condition of water storage cisterns, the preferred aesthetic qualities of unchlorinated water, or cultural and spiritual practices of maintaining a connection with natural waters.[16,22-24] Untreated natural water sources, however, can be of variable quality due to environmental or human-caused contamination or if stored in unclean containers.[25-27]

Water storage, whether for water produced by a treatment system or for hauled water, is increasingly being considered as an additional adaptation measure for drought, both at community and household scales. This may increase the future demand for water storage infrastructure and technical and operational knowhow.

How is water stored?

The basic components of a storage tank for small or private systems include the storage vessel or cistern itself, access hatches for inspection and maintenance (e.g., manways or risers), screened air vents to allow air into the tank, overflow pipes, fill ports, and withdrawal or outlet pipes connecting the tank to a household or distribution network. Other features could include floats, pumps, sensors, alarms, or continuous water quality monitoring devices.[28] Some systems may apply additional treatment to water leaving the tank before it reaches the tap, such as water softening, reverse osmosis (RO) or ultraviolet (UV) treatment.

Water storage tanks vary by their size, the materials they are made of, and where they are sited. While large municipal systems can hold thousands of cubic metres, small and private systems are much smaller. Some rural households store water in large cisterns of up to 15,000 L under the home, enough to supply one–three months of water, which may require additional onsite treatment as quality declines over time.[26,28,29] Household or community cisterns for trucked treated water are usually sized to supply a few days to a week (e.g., 700 litres to 2500 gallons) depending on the number of people relying on the cistern, how water is used, and the delivery frequency. Many household cisterns are undersized for the number of users, causing water rationing at times.

Storage tanks and cisterns can be made from concrete, fibreglass, polyethylene, welded or bolted steel, aluminum, or other sturdy, waterproof, and corrosion-resistant material, with most cisterns being constructed of polyethylene, fibreglass, or concrete. Tanks used for potable water storage, and any internal linings or coatings, must be safe for drinking water, meeting the Canadian Standards Association (CSA) B126 Series standards for drinking water tanks to protect health, and constructed of materials that meet NSF/ANSI Standard 61 (*Drinking water system components – health effects*).[30,31] Many household cisterns are polyethylene with Figures 1-4 showing some examples. These may be underground, buried next to, or situated in the basement of a building, or aboveground on an external concrete pad, or housed within an insulated room, shed, or shelter.

Figure 1: Household 2500-gallon cistern for private well water storage. (Credit: A. Eykelbosh)

Figure 2: Water storage tank on concrete plinth supplying a temporary site.

Figure 3: Household cistern for underground use, showing riser. (Credit: Barr Plastics, with permission)

Figure 4: Low profile 2100 imperial gallon cisterns (shown stored on sides). (Credit: Barr Plastics, with permission)

What is the condition of storage tanks in Canada?

The review of the literature found limited reporting on the condition of stored water infrastructure in small and private water systems or households. Some studies have reported on sources of contamination (e.g., animals, waste materials) and inadequate maintenance of household cisterns, leading to concerns among water users about exposure to microbiological hazards.[32,33] Poor conditions can lead some households to avoid using cistern water for potable purposes altogether, or to boil water as a standard practice before use. Others may seek alternative sources such as bottled water for drinking and cooking.[10] High costs or lack of local services or capacity to perform inspection, water testing, cleaning, or repair can compound water quality issues if problems are not readily identified or remedied.[34] Anecdotal information obtained during our expert consultation identified issues such as poor access to household tanks presenting a barrier to inspection and maintenance. In addition, many underground tanks may have poorly sealed manways or risers that can allow contaminants to enter tanks, either from surface water or animals urinating or defecating nearby or on lids. Poorly secured lids can also be tampered with or pose a hazard for children. Further understanding of common condition issues that could arise in water storage assets can be gained by examining those affecting municipal water storage assets. A 2020 inventory assessment of 3,200 storage tanks among publicly owned potable water assets in Canada found that about one-third were in less than good physical condition, with more than 9% reported to be in poor[a] or very poor[b] condition.[13]

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[a] **Poor**: defined as "a failure likely and substantial work required in the short term. Asset barely serviceable. No immediate risk to health or safety. The operating asset has less than 40% of its expected service life remaining."
[b] **Very poor**: defined as "having an immediate need to replace most or all of the asset. Health and safety hazards exist which present a possible risk to public safety or asset cannot be serviced/operated without risk to personnel. Major work or replacement required urgently. The operating asset has less than 10% of its expected service life remaining."

The types of condition issues that can affect municipal tanks include leaks, corrosion, rusting and pitting of metal tanks, pump failures, deformation following adverse weather events (e.g., heavy winds), contamination of tanks with accumulated sediment, dead animals, and waste materials, failure of external coatings, collapsed roofs, water pooling on roofs, broken overflow pipes, or damaged screens.[35,36]

Figure 5: Large municipal tank indicating leak and surface corrosion. (Credit: N. Elmieh)

Damaged, poorly maintained, or aging[c] storage infrastructure can reduce available water quantity and pose a hazard to water quality[26] via direct contamination, the loss of chlorine residuals, taste and odour issues, or the need to increase chlorine dosing, potentially causing elevated disinfection by-product (DBP) formation.

Public health hazards from stored water

Safe and drinkable water should be free of pathogens and chemical toxins, and have good aesthetic properties (e.g., no colour, taste, or odour). Maintaining safe water quality prioritizes minimizing microbiological hazards using disinfection to reduce the risks of serious acute illnesses.[21,37,38] This is usually achieved by chlorination, ensuring a residual amount of chlorine remains in distributed water until it is consumed. Although some rural households or informal private systems store untreated raw water in tanks, only treated water should enter a storage tank intended to be used for potable purposes, and all measures should be taken to prevent a decline in quality during storage, refilling, cleaning, or treating water.[39] This includes trucked water, which should be treated to maintain a **free chlorine residual** at delivery of 0.2 mg/L to control bacterial regrowth in a storage tank.[40] Maintaining a chlorine residual in storage tanks helps to reduce survival of pathogens and the growth of biofilms; however, stored drinking water quality can be degraded at many points along the source-to-tap pathway. Significantly contaminated source water, damage to infrastructure, direct contamination, lack of turnover (water age), or lack of maintenance of storage tanks can cause the residual to deplete within a tank and can also reduce stored water quality in other ways, as described in Table 1[14,17,38,41-45]

[c]**Aging**: approaching or beyond its expected service life

Table 1: Risks to stored water quality

Cause	Impact on water quality
Source water	• Diffuse or point source contamination of surface and groundwater can introduce turbidity, pathogens, and other contaminants, making water harder to treat to potable standards. • Organic matter (OM) or iron can deplete chlorine residuals. • OM can react with chlorine to form disinfection by-products (DBPs) (e.g., trihalomethanes (THMs)[46,47] or haloacetic acids (HAAs)),[48] which can pose various health hazards.
Tanks and pipes	• Corrosion, damage, accumulation of sediment, or formation of biofilms in pipes or tanks can introduce contamination and deplete chlorine residuals, cause discolouration, taste and odour issues, promote corrosion, or obstruct pipes. • Degraded or damaged tank materials, liners, or sealants can leach chemical contaminants into stored water (e.g., metals, organic contaminants), or affect water pH or aesthetics. • Cross connections can cause backflow from drainage or sanitation pipework. • Tank conditions (e.g., warm, stagnant, presence of biofilms, inadequate disinfection) can promote growth of algae or other microorganisms,[49,50] including opportunistic pathogens, like *Legionella, Mycobacteria, and Pseudomonas* spp.,[50] which can cause infections and disease among susceptible persons exposed to aerosolized water.[49]
Filling	• Delivery trucks and equipment used to fill water tanks or cisterns can be a source of contamination. Fill hoses or cistern lids can become contaminated by unclean hands, animals, dust, or dirt from the ground. Contamination can enter tanks via dirty monitoring equipment, dippers, or containers used to transfer or collect water from a PWDU.[18,27,51,52]
Environmental contamination	• Ingress of groundwater or surface runoff into a tank through missing, damaged, or poorly fitted covers, cracks in cisterns, concave roofs with pooling water, or damaged connections, can introduce contaminants following rainfall or flooding of an exposed tank. This can introduce sewage, animal feces, fuel, pesticides, nutrients, and organic materials, which can support bacterial growth and deplete chlorine residuals.[47] • Holes or poorly covered vents can be an ingress point for airborne contaminants, insects, or animals, which can contaminate tanks with feces or carcasses if they become trapped.
High water age	• Lack of water turnover in a storage tank due to periods of low usage, limited circulation, or stratification based on temperature can increase water age. In high-age water, chlorine residuals dissipate due to volatilization or reaction with surfaces, organic material, or iron allowing bacteria to regrow and biofilms to build up. • High-age water may result in elevated levels of some DBPs[d], such as THMs.[47,55]

Is there evidence of adverse health effects from stored water?

The review found relatively few studies that have assessed the links between water storage practices and health in unregulated and household systems in industrialized countries, indicating a research gap in this area. In the Canadian context, a health survey of First Nations communities found that people relying on

[d] Chloramine as an alternative to chlorine may produce fewer DBPs, but in systems with warming temperatures, could result in elevated growth of ammonia-oxidizing bacteria and potential for nitrification, leading to other water quality changes.[53,54]

trucked water stored in cisterns self-rated their health more negatively than people with access to piped water, and were more likely to have a gastrointestinal (GI) illness and also experience distress associated with poor water quality, inadequate supply of water, and costs of cleaning cisterns.[56] Water-insecure households can face difficult choices on how to use a limited water supply (e.g., cooking, cleaning, bathing, doing laundry etc.) contributing to psychosocial impacts. Other studies have detected total coliforms in cisterns in a minority of households supplied by trucked water, but have not demonstrated causal links to specific health outcomes.[16,23,27] Studies from Labrador, Greenland, and Alaska found that coliforms were detected in about a quarter of the containers used to store gathered water (either from a PWDU or a natural source); but *E. coli* were rarely detected.[21,27,57] These studies identified that water transfer devices (e.g., dippers, cups) were likely the cause of coliform contamination in water held in portable water storage containers, and shared washbasins can often be a source of waterborne illnesses in these settings.[27]

The review of the literature identified examples of waterborne outbreaks or instances of impaired drinking water quality that were caused by defects or contamination of municipal water storage assets, some of which are listed in Table 2. One study of waterborne outbreaks associated with distribution systems in the US (1981-2010) reported that about 7% of outbreaks were due to storage system faults.[42] For municipal systems, animals accessing tanks, improper seals or covers allowing contaminants to enter tanks, or nearby sources of sewage (e.g., septic tanks) leaching into tanks through cracks or defects were common sources of contamination leading to outbreaks.[58-60] Infrastructure damage, delayed maintenance, and infrequent inspection contributed to contamination issues or outbreaks.[61] These systems are subject to higher levels of oversight and monitoring, compared to unregulated or household systems, where faults or contamination may be less frequently detected or illnesses and outbreaks may not be reported or investigated.[59]

Table 2: Examples of outbreaks or drinking water contamination events linked to water storage tanks

Year	Location	Type of contamination	Source of contamination	Outcome
1993-94	Gideon, Missouri, USA	*Salmonella typhimurium*	Wild birds entered a water storage tank through an uncovered roof vent.	Outbreak of >650 cases of diarrhea, 15 hospitalizations, seven deaths.[62]
2008	Alamosa, Colorado, USA	*S. typhimurium*	Cracks in the roof and sides of a large underground water storage tank led to ingress of animal feces via rain or snowmelt and animals gaining access through larger holes. Lack of inspection, draining, and cleaning for many years was a contributing factor.	Outbreak of >1,300 illnesses, 20 hospitalizations, and one death.[63,64]
2008	Northamptonshire, UK	*Cryptosporidium cuniculus*	Defects in two vent covers and a treatment tank access point allowed a rabbit to enter a treated water storage tank, where it died, releasing oocysts as the carcass decayed.	Outbreak of up to 422 cases of cryptosporidiosis.[65]
2015	North Lancashire, UK	*C. hominis* *C. ubiquitum* *C. andersoni*	Structural defects in an underground concrete water storage tank, which had gone undetected due to infrequent use, allowed septic tank effluent and animal waste to seep in.	Boil water notice to 712,000 residents and consumers exposed to the bacterium.[66,67]
2021	Iqaluit, Nunavut, Canada	Fuel	Fuel leaked from a 60-year-old fuel tank buried near a concrete water storage tank, seeping through the concrete into the water supply.	A “Do Not Consume” water advisory issued to the city due to the chemical contamination.[68]
2022	Iqaluit, Nunavut, Canada	Petroleum hydrocarbons	A degraded bitumen-type lining material, used as a water stop inside a water storage tank, leached hydrocarbons into the water. A change in the turbulence in the tank following the 2021 event may have increased the rate of dissociation of the material.	Elevated petroleum hydrocarbons in the municipal water supply.[68]
2023	Camp Richardson, California, USA	*E. coli*	Lack of disinfection of a water storage tank following cleaning resulted in bacterial contamination.	Boil water advisory for multiple businesses.[69]

Climate change and stored water quality

Canada's changing climate is experiencing warming and more frequent extreme weather events, and is projected to change further, based on future emissions scenarios.[70] Weather events such as heavy rainfall, flooding, spring runoff, and warmer temperatures are already known to contribute to waterborne disease outbreaks, and more frequent or intense events could increase the risks to water quality.[5,43,71,72] Concurrent or successive events could compound adverse impacts, such as heavy rainfall following wildfires increasing contaminant loading into surface waters, making water harder to treat and increasing the risk of landslides or debris flows that could damage infrastructure.[25] Alongside threats to source water quality, extreme heat, wildfires, and drought could increase water demand or reduce the availability of source water. Temporary evacuations due to fires or floods could affect stored water quality due to disuse and stagnation causing increased water age and growth of bacteria and biofilms, enhanced by moderate warming.[73]

The availability and treatability of source water, the physical environment in which water is stored or transported, and the potential for contamination of water in tanks will be affected to varying degrees. Table 3 provides an overview of how climate change could contribute to a **decline in source water quality**, **damage to water storage infrastructure**, or **direct contamination or degradation** of stored water quality. While these impacts could affect both large and small systems, including household cisterns, the challenges may differ for small, rural, and remote communities of the North versus larger municipal systems in southern continental climates.[3]

Table 3: Climate impacts on stored water quality

	Declining source water quality	Damaged infrastructure	Direct contamination of stored water
Higher seasonal temperatures[74]	• Enhanced survival and growth of waterborne pathogens in source waters, making it harder to treat and maintain quality.	• Warping, blistering, or other heat-related damage to tanks, seams, lining, or connectors. • Increased corrosion of metal components. • Increased evapotranspiration and diminished supply.	• Temperature stratification of water in the tank leading to areas of high water age and faster decline of chlorine residual. • Increased survival and growth of bacteria and biofilms inside storage tanks and pipes.
Extreme precipitation & flooding[25,75-78]	• Increased turbidity of surface waters. • Increased mobilization of pathogens and other contaminants, including OM, inorganic (e.g., Fe, Mn) and organic chemical contaminants.	• Damage or displacement due to rising water tables, the force of flood or stormwater, or floating debris. • Destabilized foundations or erosion of soil and backfill covering tanks or pipes. • Corrosion of metal tanks, connections, or electronic components.	• Direct influx of contaminants due to submerged tanks. • Inundation of openings, vents, or overflow pipes with flood waters, allowing for entry of sewage, chemicals, debris, and sediment.
Wildfire[72,78-85]	• Increased turbidity of surface waters due to ash, debris, or sediment runoff following fires and subsequent rainfall, introducing contaminants and OM into source waters.	• Destruction of aboveground storage tanks or housing. • Melting or deformation of plastic tanks, pipe sections, seals, lids, or other components, compromising structural integrity, and increasing the potential for cracks or breaches to occur.	• Infiltration of smoke, ash, and other contaminants through uncovered vents, cracks, or holes, or negative pressure in pipework from destroyed structures drawing in contaminants. • High temperature pyrolysis of plastics and organic materials generating volatile organic contaminants (VOCs) that can diffuse into plastic pipes, liners, or fittings.
Melting permafrost[23,86-90]	• Changes to the hydrology in the north, remobilizing pathogens, legacy chemical contaminants, and OM. • Source waters near northern contaminated sites could become harder to treat.	• Destabilized ground causing shifting or increased stresses on structures, resulting in cracks, leaks, or broken connections. • Damage to roads in and out of communities affecting water deliveries, maintenance, or emergency support.	• Infiltration of contaminants through cracks or broken connections of underground tanks.

	Declining source water quality	Damaged infrastructure	Direct contamination of stored water
More frequent and intense wind and winter storms[91-93]	• Increased turbidity and OM in surface waters due to runoff, meltwaters, and windfall/debris.	• Increased loading on aboveground structures from wind, or heavier and wetter winter snowfall, causing damage or collapse of tanks or housing. • Heavy winds, snowfall, or ice storms causing power failures, disrupting systems due to inability to use pumps, sensors, or treatment equipment.	• Heavy winds generating projectiles, dust, or other airborne debris that can damage or contaminate tanks.
Coastal inundation and sea level rise[94]	• Saltwater intrusion of groundwater or contamination of aquifers, reducing treatability of source water. • Rising water tables and flooding causing sewer overflows to contaminate source waters.	• Displacement of underground tanks due to rising water tables and destabilized foundations. • Corrosion of metal tanks, connections, or electronic components.	• Increased risk of underground tanks being flooded due to rising water tables, or aboveground tanks being inundated during coastal flooding, introducing contaminants into tanks via openings, vents, or overflow pipes.

Declining source water quality, damage to storage infrastructure, and direct internal or external contamination could increase exposures to waterborne pathogens and chemical contaminants and degrade aesthetic quality of stored drinking water. The possible public health concerns include:

- **Declining source water quality:** Surface water and groundwater that is harder to treat increases the operational challenges and costs for water systems and compromises the ability to provide safe water. Systems with limited treatment or monitoring[95] may not detect or remove new or elevated levels of contaminants. This could increase exposure to chemical contaminants and bacteria that cause GI illnesses, or cause a faster decline in stored water quality.[96] Source water with elevated OM depletes chlorine residuals and can impair other treatment processes, such as Fe or Mn removal, or corrosion control for Pb removal.[97] OM can also increase the mobilization of premise plumbing contaminants (e.g., Pb),[98] and high OM reacting with chlorine can increase exposure to DBPs.[99]

- **Damaged infrastructure:** Damaged or destroyed infrastructure can cause an interruption or loss of supply, leading to water rationing and seeking alternative water sources,[100] dehydration, or reduced use of water for cleaning and hygiene.[57] Climate change could affect the asset design life for some structures, which could degrade quicker, presenting a risk to long-term water security.[101] Damaged or blocked roads in and out of communities due to fire, flood, landslide, or permafrost melting could delay water deliveries, maintenance, or emergency support, leaving communities or households vulnerable to water shortages.[89] Damage can also compromise the barriers to contamination (e.g., seals, lids, vents, stresses and cracks in pipes, walls, roofs),[42] allowing for leaks, infiltration of contaminants, animals or insects, or damage to internal linings or sealants, causing corrosion and possible chemical leaching into water and ensuing health effects.[82]

- **Internal and external sources of contamination**: Direct influx of waterborne pathogens or chemical contaminants from outside of the tank (e.g., flood waters or infiltration) increases the risks of GI illness or other health effects. Increased growth and survival of bacteria within stored water tanks, enabled by the growth of biofilms and stagnant water also increases the risk of GI illnesses and exposures to *Legionella*, *Pseudomonas*, or *Mycobacteria,* which can cause a range of minor to more serious illnesses.[49] Corrosion or degradation of linings or sealants,[68] or source water contaminants sorbed to plastic, metal surfaces, biofilms, water softeners, or sediments could later leach back into the water, reintroducing exposures over time.[85,102-104] Degraded stored water quality can reduce aesthetic qualities (e.g., taste, colour, odour), leading to end users seeking less safe or less healthy water alternatives (e.g., bottled drinks), or untreated natural waters, or using less water overall.[22,100]

Climate change could exacerbate many of the existing challenges to maintaining safe and drinkable water as it becomes harder to treat source water to an acceptable standard year-round and store it safely. This could in turn worsen some of the psychosocial effects experienced by water-stressed communities if faced with declining water quality or increased rationing.

For other communities or households that have not been reliant on stored water previously, new or additional water storage capacity could be a means to adapt to changing climate conditions (e.g., persistent drought) or prepare for emergencies.[105] For these communities, it will be important to convey the public health risks from stored water and how to mitigate risks. Climate adaptation plans should thus consider how to mitigate climate risks for existing storage systems and convey best practices in new storage systems to avoid future issues.

Mitigating risks to stored water quality and quantity

Design guidelines for water systems exist at provincial and territorial levels, and for areas of federal jurisdiction. Some recent design guidelines include consideration of the potential impacts of climate change on water systems and provide advice on risk assessment and adaptation.[11,12] Risks can be mitigated by identifying existing vulnerabilities in water systems, including storage, and assessing the likelihood and severity of exposure to hazards, and taking measures to reduce risk such as:

- Selecting tank size, type, and location to suit future needs and possible exposures.
- Reviewing operational, maintenance, and inspection practices considering changing conditions or future adverse events.
- Including water storage assets in emergency preparedness, response, and recovery planning for climate-related events.

While this advice applies to municipal systems and larger storage infrastructure, key considerations can be applied to small and household systems. Communities or households seeking to increase water storage as a climate adaptation measure to drought, declining source water quality or other climate impacts should also consider how to reduce risks to stored water.

Storage tank selection: size, type, and location

Selecting a new tank should ensure assets are appropriate for the conditions they may be placed in, and if modifying an existing storage configuration, systems should be reassessed for risks from emerging climate pressures, and whether current age and condition can sustain future exposures.

Tank size should be appropriate for routine potable (non-emergency) use, considering baseline demand and likelihood of water shortages. Risks exist for both under-sizing and over-sizing of tanks. Undersized tanks can lead to periods of water scarcity and rationing, or the need for more frequent deliveries. Oversized tanks can result in high water age, stratification, and reduced quality over time, due to loss of residual and increased biofilm growth. Flexible systems can help balance variable water demand. Multiple smaller tanks/cells can allow for added capacity when water demand increases or can be taken offline during periods of low use, or for maintenance and cleaning,[83] but should be operated with care between uses.[106]

Tank materials should comply with drinking water standards,[30] but other characteristics may be important depending on the likelihood and severity of exposure to different climate hazards. In areas prone to wildfires or extreme heat, heat-resistant materials such as buried concrete or above ground stainless steel may be preferred to plastic tanks. But in areas subject to ground movements (e.g., due to permafrost melting, flooding, landslides etc.) more flexible materials and fittings may be less prone to cracking (e.g., fibreglass, or plastic as compared with concrete). In areas exposed to saltwater intrusion or rising water tables, underground materials and components should be resistant to corrosion from saltwater or high conductivity groundwater. For aboveground tanks, possible exposure to loading forces from extreme wind or snowstorms could inform choices of more sturdy materials less susceptible to damage or collapse.

Tank location may not be easy to change, but considerations for placement of new tanks or protections of existing tanks can be made for either buried, ground level, or elevated tanks.

- **New tanks** should be placed in areas that minimize exposure to increasing or emerging hazards such as in flood zones or areas at risk of mudslides, flash floods and debris flows (e.g., following a wildfire). New tanks should be sited in an area protected from excessive wind loading.[91,92] Underground tanks are less exposed to fire and temperature spikes but can be more susceptible to impacts of flooding or rising water tables. Tanks should be sited away from sources of animal or human waste, and ground should slope away to prevent pooling water. In areas of melting permafrost, tanks should be sited away from other tanks used for fuel, chemicals, or wastewater.[77]
- **Existing tanks** can be protected from climate exposures in various ways. Buffer zones free of flammable debris or vegetation can be created around tanks or aboveground structures in wildfire zones.[107] Additional insulation or housing can protect from both extreme heat and freezing, or heavy snow falls.[106,108] In flood zones, bunds or barriers can add protection from flood waters, and ensuring vent pipes are above estimated flooding levels can avoid ingress of contaminated flood waters or debris.[109] In areas with rising water tables, anchoring or adding backfill can reduce upward displacement, shifting, or breaches of underground tanks. Elevated tanks exposed to high winds may require anchoring or stiffener rings to prevent buckling under high winds,[77] or seismic restraints may be required in areas prone to ground movement, such as in earthquake zones.

For both new and used tanks, the safety and ease of access for water haulers, and persons carrying out inspection, maintenance, and cleaning should be considered, especially if these activities may be required more frequently. Poorly sealed and unlocked lids, manways, or risers can present both a safety risk and a contamination risk from surface water, tampering, or animals, particularly if at ground level.

Operational considerations: Inspection and maintenance

The frequency and scope of monitoring and inspection procedures and maintenance protocols may need to be expanded in light of increasing climate pressures to ensure systems are maintained, problems are detected and repaired early, and systems are restored to use quickly following an event.[110] Various provincial, territorial, federal, and international agencies provide advice on water storage tank operation and maintenance to maintain water quality, including inspection checklists, with several examples listed in **Appendix A.**[19,28,29,37,109,111-115]

Inspection checklists may vary depending on the type and design of a storage tank or the type of exposures or damages that may have occurred. Some basic inspection points for the **exterior of the tank** that could be undertaken frequently (e.g., weekly) by a non-professional include:

- **Lids:** Ensure lids close tight, block out light, and prevent animals, insects, or dust from entering the tank. Ensure there is no dirt, debris, ash, or pooling of water. Access hatches should be watertight and secure to prevent contamination and as a safety measure. A locked lid with a good watertight seal can prevent contamination, vandalism, and unintentional entry.
- **Screens:** Ensure screens on vents and overflow outlets remain in place and are undamaged and of small enough mesh size (e.g., #24 mesh) to prevent insects or animals from entering the tank.
- **Roofs or side walls:** Check for evidence of damage such as cracks, leaks, rust, failing sealants, melting or deformation due to heat, fire damage, pooling water, or wind or snow loading.
- **Supports and anchor bolts**: Check for damage, corrosion, or deterioration. Tanks with missing or damaged restraints could be at elevated risk during subsequent events (e.g., floods, earthquakes).
- **Connections to distribution pipes or household**: Check for damage, cracks, or corrosion.

Inspection of the **interior of the tank** by a homeowner may not be feasible, nor safe, and may require a professional trained to work in confined spaces. This may be conducted during filling or cleaning, or following an event where contamination is suspected.

- **Tank walls, floor, and roof:** Check for signs of corrosion, rust, blistering or peeling of lining, failing seals, or buildup of scale or sediment.
- **Water in the tank:** Check for evidence of turbidity, colour, sulphurous smells, floating debris, animals, insects, vegetation, or plant roots.
- **Water level:** Check water levels (e.g., using an external gauge) before and after an event, or during periods of no or low use, to indicate if leaks have occurred or if outside water has infiltrated the tank.

Water quality can be measured frequently at the taps or outlets for basic water quality parameters (e.g., temperature, pH, dissolved solids, free chlorine). Keeping good records can allow changes in water quality to be detected. Low-cost test kits kept onsite can facilitate more frequent testing. A change in quality could prompt inspection and testing for other microbiological or chemical contaminants. More formal water quality testing (e.g., microbiological parameters) may occur less frequently, but can confirm that water remains safe to use.

Maintenance of a cistern or tank can include draining, cleaning, and disinfection at regular intervals, to prevent a decline in stored water quality, but tank cleaning is often neglected due to lack of awareness of appropriate cleaning frequency or methods, cost of cleaning, or lack of available trained personnel.[35,52]

Periodic cleaning is essential to remove sediment, biofilms, or debris. Cleaning is also recommended following construction or repair work, or a period of disuse, or if contamination is detected or suspected. AWWA standard C652-19[116] provides guidance on cleaning and disinfection of storage facilities that are part of public water systems, and additional advice is available from the AWWA for maintaining and repairing assets that are part of public systems.[117] Cleaning or inspection that requires entry into a tank **should only be done by a person trained in working in confined spaces** due to the risks of harmful gasses being present in a tank.

Some small and household systems can be safely cleaned without entering a tank, with the conventional cleaning and chlorination steps listed in **Appendix B.** Conventional cleaning methods require a large amount of potable water and a period of system downtime (up to 24 hours). Therefore, preparation is needed to plan for the potable water demand of the cleaning and disinfection process and to ensure an alternative potable water source is available for drinking, cooking and hygiene until the process is complete. Alternative methods that use other oxidizing substances to degrade biological material, including biofilms and microorganisms may be quicker and use less water. However, these methods are not available everywhere, and may not be suitable for application by non-professionals.

The appropriate cleaning frequency varies based on the source water, tank age and condition, usage patterns, and the results of monitoring or inspection.[118] Most guidance recommends annual cleaning for household cisterns, but in reality, cleaning is often much less frequent, raising concerns of degraded water quality for cistern users.[32,52,56,119] Figures 6 and 7 show images of the condition of cisterns with accumulated sediment, biofilms, and discolouration before and after cleaning.

Figure 6: Image showing a dirty household cistern before and after cleaning. (Credit: Geoffrey Montgomery-Swan, cleancistern.com, with permission)

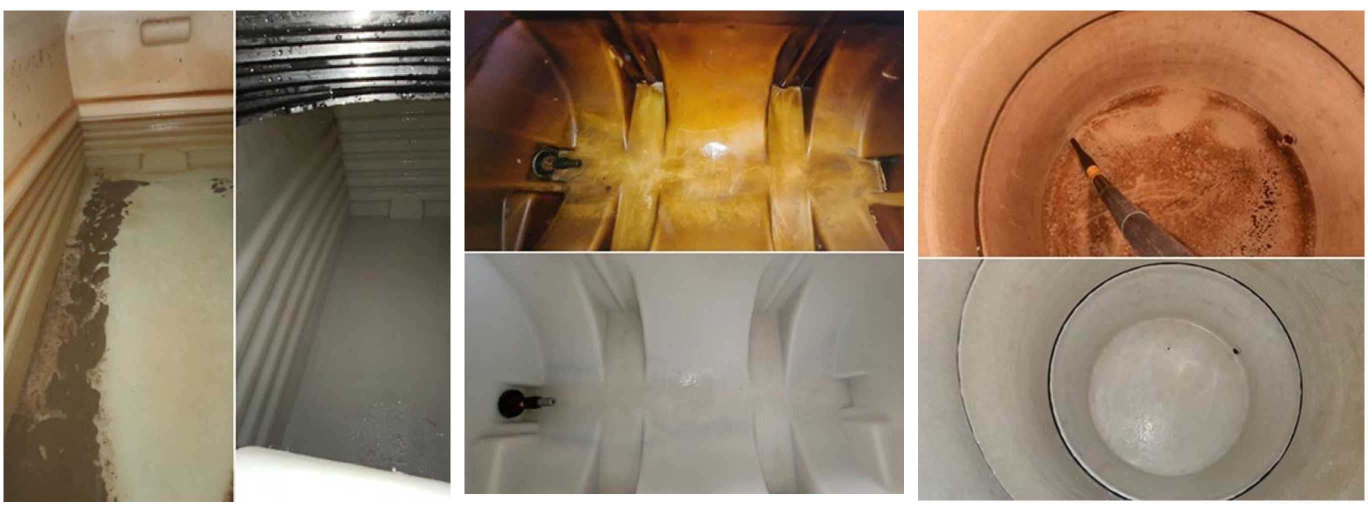

Figure 7: Cisterns before and after cleaning. (Credit: Jon Widney, Dawnix Water Services Inc., with permission)

Maintenance also includes undertaking minor repairs as soon as they are detected, such as patching of holes or damage to screens, vents, or lids. Having basic supplies and the necessary tools on hand, alongside a general awareness of how to do minor repairs to exterior components can help build resilience. Identifying companies or trained personnel in advance who can perform more major repairs, can reduce the risk of extended outages.

Improving preparedness and recovering events

Climate change will affect the quality and treatability of source waters in many areas and could impact communities and households that store water with minimal treatment (e.g., disinfection only). Some systems may require upgraded or additional treatment to remove substances such as turbidity, organic matter, or iron to reduce loss of chlorine residual and prevent the formation of DBPs. In areas where it is becoming more difficult to maintain quality, expert advice can be sought on appropriate devices for in-tank treatments such as aeration or mixing to reduce stagnation and biofilm formation,[39] or additional treatments such as ultrafiltration, biological treatment, reverse osmosis, UV, or granular activated carbon to improve drinking water quality delivered to the tap.[120]

To prepare for more frequent or intense climate related events, communities and households should consider how to include water storage systems in any emergency preparedness and response plans. Some measures that could be included in preparedness plans could include:

- Having a contingency plan in place for events that could temporarily restrict trucked water deliveries or tank maintenance.
- Recording water levels in tanks using an external gauge to identify if there are losses due to leaks, or indications of infiltration or breaches in the tank.[77]
- Ensuring there is a backup power supply and contingency drinking water supply (e.g., bottled water or alternative source).
- Switching off power to pumps, sensors, or other electronic components if evacuating, or in the event of a fire or flood.
- Securing or removing items that could become projectiles during a flood or storm, or flammable materials around tanks during a fire.
- Closing valves, vents, or openings and securing lids to prevent contamination during a flood but considering keeping a vent open during a fire to prevent build up of water vapour.

A **post-event inspection** should check for obvious indications of movement, damage, or infiltration of contaminants through caps, covers, vents or other openings. Any debris, ash, dirt, fire retardants, or other contaminants should be wiped off external surfaces, taking care to prevent materials being washed into tanks. A more detailed external inspection may look for corrosion or weakening of metal bolts or supports, or scorching, melting, warping, or deformation of any pipes, connections, seals, or lids. An internal inspection of a tank could consider visual changes to the water (e.g., turbidity, debris, odour, colour) and whether sensors, pumps, treatment devices or other electrical components need repair or replacement.

An alternative source of water may be needed until the water can be assessed or tested to ensure it is safe to use, or water advisories (e.g., boil water, do not consume, do not use)[121] may be initiated. Public health may be called on to advise on appropriate type and frequency of water quality testing following an event (e.g., microbiological testing for coliforms or *E. coli*), and rehabilitation of systems. Tanks suspected or known to have been contaminated should be drained, cleaned, disinfected, and refilled before use, and may require testing for microbiological parameters and chlorine residual to confirm they are safe to use.[112] Households or water users may also need to flush taps used for drinking, cooking, or bathing, to remove stagnant water before use,[122] and health units may seek to increase health surveillance measures following events to detect any possible outbreaks or health concerns.

Summary

Water storage is an important part of water systems across Canada, and essential in communities and households that do not have access to piped systems and depend on trucked or gathered water. Small-scale storage may also become an important measure to build resilience to drought events. While most storage tanks across public water systems are in good or very good condition, up to one third are in less than good condition,[13] and many studies have highlighted issues with storage tanks and cisterns in unpiped communities that rely on trucked water. Climate-related events increase the potential for stored water quality to decline or supplies to be interrupted, posing a range of public health concerns. This could exacerbate some of the existing water inequities in Canada, particularly in rural, remote, northern, and Indigenous communities that do not have access to a piped water supply, potentially confounding some of the psychosocial impacts experienced in water-stressed communities.[123]

Current approaches to storing water, and the possible impacts of climate change will vary across Canada, and the approaches to building resilience may be site and system specific, from optimizing storage capacity to protecting stored water supplies and equipping households and communities with the skills and tools needed to inspect, maintain, and repair systems as needed. Building resilience could include raising awareness on how best to mitigate public health risks from stored water, such as improved cistern inspection, cleaning, and maintenance practices, and how to prepare and respond to emergency events.[23] For communities or households newly considering water storage as an adaptation measure, advice on selecting appropriate tank types and locations, and understanding the appropriate operational, inspection, and maintenance requirements in the context of changing climate hazards is needed.

This review identified knowledge gaps in understanding the role of water storage in the provision of safe and drinkable water in Canada. There is limited research on the current use and condition of small-scale water storage across Canada for small or private systems and household cisterns. Further study, ensuring a decolonizing approach to research, on the quality of water in household cisterns and the barriers to monitoring, maintenance, and repair, warrant further study.[16] There are also opportunities for policy interventions to better equip unpiped communities to improve household cistern condition through support for inspection and maintenance of systems.

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Appendix A. Guidance on water storage tank and cistern operation, maintenance, and inspection

Organization	Guidance on operation, maintenance, and inspection of water storage tanks and cisterns
Gov't of Alberta	• The public health guidelines for non-municipal drinking water [112] • Maintaining your cistern[111]
Gov't of Saskatchewan	• Cleaning and disinfection guideline for private cisterns after a drinking water advisory • Disinfection guideline for bulk water haulers
Manitoba Health	• Water storage tanks (cisterns)[28] • Bulk water hauling guidelines
Gov't of Ontario	• Drinking water haulage guidelines • Providing safe drinking water to cisterns at non-residential drinking water systems serving designated facilities
Nova Scotia Environment & Climate Change	• The drop on water (Cisterns)
Gov't of Newfoundland & Labrador	• Operation & maintenance of a water storage tank
Gov't of the Northwest Territories	• Good engineering practice for northern water and sewer systems[124]
Agriculture & Agri-Food Canada	• Maintaining safe domestic water quality with on-farm cisterns and water tanks
Interdepartmental Water Quality Training Board	• Drinking water storage tanks
Yukon River Inter-Tribal Watershed Council	• Safe drinking water and sanitary practices manual FY 19[125]
US Environmental Protection Agency	• How to conduct a sanitary survey of drinking water systems. A learner's guide [109] • Finished water storage tank inspection/cleaning checklist
US Centers for Disease Control & Prevention	• Cisterns before and after a disaster
Rural Community Assistance Partnership	• Water quality in storage facilities (Video)
Colorado Dept of Public Health & Environment	• Drinking water Storage Tank Rule checklists and templates
WaterRegsUK	• Cold water storage cisterns (guidance on installation and maintenance)

Appendix B: Cleaning a cistern

Cleaning steps for cisterns that do not require a person to enter the tank

Some smaller and easily accessible tanks can be safely cleaned from the outside. Several public agencies provide detailed advice on procedures and safety information, and many companies can provide cistern cleaning services. Preparation for cistern cleaning or disinfection should include appropriate risk assessment to identify physical and chemical safety hazards, planning for water needs during the process, and safe disposal of wash and disinfection water.

The conventional approach to cistern cleaning involves the following basic steps:

DRAIN — Drain to remove stagnant water and sediment, using a bottom drain, pump, or wet/dry vacuum. Disconnecting treatment devices, water softeners, etc.

SCRUB — Physically remove grime, sediment, and biofilms using scrubbers or a pressure-washer.

RINSE — Rinse scrubbed surfaces with potable water using a garden hose or pressure washer and inspecting for leaks or holes in need of repair.

DRAIN — Drain the rinse water, assisted by a pump or wet/dry vacuum, rinsing and draining more than once if needed.

CHLORINATE — Fill the cistern with potable water and add/mix in household unscented bleach (5-6% hyperchlorite) to achieve a **20 to 50 mg/L** chlorine solution. This equates to roughly 400 mL per 1000L or 1L per 1000L of tank capacity respectively. Run the solution through associated plumbing and leave in the tank and pipes for **six to 24 hours** depeding on the chlorine concentration.

DRAIN — Drain the chlorine solution, away from sensitive plants, trees, natural waterways, septic tanks, or septic fields that could be adversely affected.

REFILL — Refill the cistern with potable water from a treated supply, flushing through taps, and testing for chlorine residual (>0.2 mg/L free chlorine). Reconnect treatment devices and water softeners and collect a sample for microbiological testing if required (*E. coli*).

For further information, including appropriate chlorine concentrations, application, and contact time, refer to advice provided by governmental and other agencies in Appendix A.[28,29,108,111,126-128]

References

1. Guzman Herrador BR, de Blasio BF, MacDonald E, Nichols G, Sudre B, Vold L, et al. Analytical studies assessing the association between extreme precipitation or temperature and drinking water-related waterborne infections: a review. Environ Health. 2015 Mar 27;14(1):29. Available from: https://doi.org/10.1186/s12940-015-0014-y.
2. Cann KF, Thomas DR, Salmon RL, Wyn-Jones AP, Kay D. Extreme water-related weather events and waterborne disease. Epidemiol Infect. 2013;141(4):671-86. Available from: https://doi.org/10.1017/S0950268812001653.
3. Leveque B, Burnet JB, Dorner S, Bichai F. Impact of climate change on the vulnerability of drinking water intakes in a northern region. Sustain Cities Soc. 2021 Mar;66:102656. Available from: https://doi.org/10.1016/j.scs.2020.102656.
4. Levy K, Woster AP, Goldstein RS, Carlton EJ. Untangling the impacts of climate change on waterborne diseases: a systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. Environ Sci Technol. 2016 May 17;50(10):4905-22. Available from: https://doi.org/10.1021/acs.est.5b06186.
5. Thomas KM, Charron DF, Waltner-Toews D, Schuster C, Maarouf AR, Holt JD. A role of high impact weather events in waterborne disease outbreaks in Canada, 1975 – 2001. Int J Environ Health Res. 2006 Jun;16(3):167-80. Available from: https://doi.org/10.1080/09603120600641326.
6. Lulham N, Warren FJ, Walsh KA, Szwarc J. Canada in a changing climate: synthesis report. Ottawa, ON: Government of Canada; 2023. Available from: https://changingclimate.ca/synthesis/?hsid=8cbe5d3b-f49a-41ce-bce3-fa8c9668381e.
7. Lyle ZJ, VanBriesen JM, Samaras C. Drinking water utility-level understanding of climate change effects to system reliability. ACS ES&T Water. 2023 Jul;3(8):2395-406. Available from: https://doi.org/10.1021/acsestwater.3c00091.
8. Duffy D. Water storage systems. WaterWorld. 2018 Apr 11. Available from: https://www.waterworld.com/drinking-water/article/14070808/water-storage-systems.
9. Hayward J, Johnston L, Jackson A, Jamieson R. Hydrological analysis of municipal source water availability in the Canadian arctic territory of Nunavut. Arctic. 2021;74(1):30-41. Available from: https://www.jstor.org/stable/27088554.
10. Elash A, Walker C. This First Nation produces clean water. So why are so many residents afraid to drink it? CBC News. 2019 Jan 9. Available from: https://www.cbc.ca/news/indigenous/garden-hill-first-nations-drinking-water-1.4907864.
11. Atlantic Canada Water and Wastwater Association. Atlantic Canada water supply guidelines. Halifax, NS: ACWWA; 2022 May. Available from: https://www.acwwa.ca/resources/water-wastewater-guidelines/kmp/design-guidelines/267-atlantic-canada-water-supply-guidelines-may-2022/file.html.
12. British Columbia Ministry of Health. Design guidelines for drinking water systems in British Columbia. Drinking water officers' guide. Victoria, BC: Government of BC; 2023 Mar. Available from: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/how-drinking-water-is-protected-in-bc/dwog_part_b_-_17_design_guidelines_for_drinking_water.pdf.

13. Statistics Canada. Inventory distribution of publicly owned potable water assets by physical condition rating, Infrastructure Canada. Ottawa, ON: Government of Canada; 2022 Jul 26. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410019601.
14. Daley K, Truelstrup Hansen L, Jamieson RC, Hayward JL, Piorkowski GS, Krkosek W, et al. Chemical and microbial characteristics of municipal drinking water supply systems in the Canadian Arctic. Environ Sci Poll Res. 2018 Nov;25(33):32926-37. Available from: https://doi.org/10.1007/s11356-017-9423-5.
15. Statistics Canada. Households and the environment survey, dwelling's main source of water. Ottawa, ON: Government of Canada; 2021 Oct 19. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810027401.
16. Bradford LEA, Bharadwaj LA, Okpalauwaekwe U, Waldner CL. Drinking water quality in Indigenous communities in Canada and health outcomes: a scoping review. Int J Circumpolar Health. 2016 Jan;75(1):32336. Available from: https://doi.org/10.3402/ijch.v75.32336.
17. Gora SL, Anaviapik Soucie T, McCormick NE, Ontiveros CC, L'Hérault V, Gavin M, et al. Microbiological water quality in a decentralized Arctic drinking water system. Environ Sci: Wat Res Technol. 2020 May;6(7):1855-68. Available from: http://dx.doi.org/10.1039/D0EW00019A.
18. Patrick RJ, Grant K, Bharadwaj L. Reclaiming Indigenous planning as a pathway to local water security. Water. 2019;11(5):936. Available from: https://doi.org/10.3390/w11050936.
19. Baird JM, Summers R, Plummer R. Cisterns and safe drinking water in Canada. Can Water Resour J. 2013 Jun;38(2):121-34. Available from: https://doi.org/10.1080/07011784.2013.780790.
20. Neegan Burnside Ltd. National assessment of First Nations water and wastewater systems – national roll-up report. Ottawa, ON: Government of Canada; 2011 Apr. Available from: https://www.sac-isc.gc.ca/eng/1313770257504/1533829250747.
21. Wright CJ, Sargeant JM, Edge VL, Ford JD, Farahbakhsh K, Shiwak I, et al. Water quality and health in northern Canada: stored drinking water and acute gastrointestinal illness in Labrador Inuit. Environ Sci Poll Res. 2018 Nov;25(33):32975-87. Available from: https://doi.org/10.1007/s11356-017-9695-9.
22. Ratelle M, Spring A, Laird BD, Andrew L, Simmons D, Scully A, et al. Drinking water perception and consumption in Canadian subarctic Indigenous communities and the importance for public health. FACETS. 2022;7:343-59. Available from: https://doi.org/10.1139/facets-2021-0094.
23. Martin D, Bélanger D, Gosselin P, Brazeau J, Furgal C, Déry S. Drinking water and potential threats to human health in Nunavik: adaptation strategies under climate change conditions. Arctic. 2007 Jun;60(2):195-202. Available from: http://www.jstor.org/stable/40513135.
24. Eichelberger L. Household water insecurity and its cultural dimensions: preliminary results from Newtok, Alaska. Environ Sci Poll Res. 2018 Nov;25(33):32938-51. Available from: https://doi.org/10.1007/s11356-017-9432-4.
25. Finlayson-Trick E, Barker B, Manji S, Harper SL, Yansouni CP, Goldfarb DM. Climate change and enteric infections in the Canadian Arctic: do we know what's on the horizon? Gastrointest Disord. 2021 Aug;3(3):113-26. Available from: https://doi.org/10.3390/gidisord3030012.
26. Inuit Tapiriit Kanatami. Access to drinking water in Inuit Nunangat. Ottawa, ON: Inuit Tapiriit Kanatami; 2020 Nov. Available from: https://www.itk.ca/wp-content/uploads/2020/12/ITK_Water_English_07.pdf.
27. Maréchal JYA, Hansen LT, Jensen PE. Water quality in rural Greenland - acceptability and safety. Hyg Environ Health Adv. 2023 Sep;7:100065. Available from: https://doi.org/10.1016/j.heha.2023.100065.

28. Manitoba Conservation and Water Stewardship. Water storage tanks (cisterns). Winnipeg, MB: Government of Manitoba; 2014. Available from: https://www.gov.mb.ca/sd/pubs/water/drinking_water/water_factsheet_cisterns.pdf.
29. Scott E, Corkal D. Maintaining safe domestic water quality with on-farm cisterns and water tanks. Ottawa, ON: Agriculture and Agri-Food Canada; 2006 Feb. Available from: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/wqe11319/$FILE/cisternstorage.pdf.
30. The NSF Joint Committee on Drinking Water Additives. NSF/ANSI 61-2016: Drinking water system components – health effects. Ann Arbor, MI: NSF International; 2016 Accessed Dec 11 2023. Available from: https://d2evkimvhatqav.cloudfront.net/documents/NSF-ANSI_61_watemarked.pdf?v=1594929800.
31. Health Canada. Products and materials that come into contact with drinking water. Ottawa, ON: Government of Canada; 2015 Oct 15. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/water-quality/drinking-water/products-materials-that-come-into-contact-drinking-water.html.
32. Spicer NC. An examination of drinking water in two Indigenous communities in Canada: University of Alberta; 2020. Available from: https://era.library.ualberta.ca/items/540f3657-371b-4294-8f41-e4cbcfc5ed46/view/285599e6-2a31-4ee9-b70c-49b8640c27f1/Spicer_Neal_202004_MSc.pdf.
33. Harper R, O'Gorman M. The most precious gift: the right to clean water in First Nations. CREATE-H20 Conference; 2017 Jun 2; Winnipeg MB. Available from: https://create-h2o.ca/pages/annual_conference/presentations/2017/O'Gorman_water_conf.pdf.
34. Office of the Auditor General of Canada. Access to safe drinking water in First Nations communities— Indigenous Services Canada. Ottawa, ON: Auditor General of Canada; 2021. Available from: https://www.oag-bvg.gc.ca/internet/English/parl_oag_202102_03_e_43749.html.
35. Government of Newfoundland & Labrador. Evaluation of potable water storage tanks in Newfoundland and Labrador and their effect on drinking water quality St. John's, NL: Government of Newfoundland & Labrador; 2011 Jul. Available from: https://www.gov.nl.ca/ecc/files/waterres-reports-drinking-water-tank-report-july-12-2011.pdf.
36. Government of Nunavut. RFP 2017-63 feasibility study - Rankin Inlet water infrastructure-treatment. Rankin Inlet, NU: Government of Nunavut; 2017 Oct 12. Available from: https://assembly.nu.ca/sites/default/files/TD-18-5(2)-EN-Feasibility-Study-Rankin-Inlet-Waster-Infrastructure-Treatment.pdf.
37. Rural Communicty Assistance Partnership. Water quality in storage facilities (Video). Urbana-Champaign, Illinois: WaterOperator.org; 2017 Feb 10. Available from: https://wateroperator.org/blog/featured-video-water-quality-in-storage-facilities
38. World Health Organization. Water safety planning for small community water supplies: step-by-step risk management guidance for drinking-water supplies in small communites. Geneva, Switzerland: WHO; 2012. Available from: https://iris.who.int/handle/10665/75145.
39. U.S. Environmental Protection Agency, Water Research Foundation. Summary document: state of research on high-priority distribution system issues. Washington, DC: US EPA; 2016 Jun. Available from: https://www.epa.gov/sites/default/files/2016-07/documents/ricp_report_final_508v5.pdf.
40. Indigenous Services Canada. Draft updates to the protocol for centralised drinking water systems in First Nations communities. Ottawa, ON: Government of Canada; 2023 Jun. Available from: https://www.sac-isc.gc.ca/eng/1689939603075/1689939693020.

41. Health Canada. Guidance for providing safe drinking water in areas of federal jurisdiction. Ottawa, ON: Government of Canada; 2021 Dec 24. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-providing-safe-drinking-water-areas-federal-jurisdiction-version-3.html.
42. Renwick DV, Heinrich A, Weisman R, Arvanaghi H, Rotert K. Potential public health impacts of deteriorating distribution system infrastructure. J Am Water Works Assoc. 2019 Feb 4;111(2):42-53. Available from: https://doi.org/10.1002/awwa.1235.
43. Schuster CJ, Ellis AG, Robertson WJ, Charron DF, Aramini JJ, Marshall BJ, et al. Infectious disease outbreaks related to drinking water in Canada, 1974-2001. Can J Public Health. 2005 Jul-Aug;96(4):254-8. Available from: https://doi.org/10.1007/BF03405157.
44. Health Canada. Guidelines for Canadian drinking water quality: guideline technical document - total coliforms. Ottawa, ON: Government of Canada; 2020 Jun. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-total-coliforms.html.
45. Environment and Climate Change Canada. Boil water advisories. Ottawa, ON: Environment and Climate Change Canada,; 2022 Jun 29. Available from: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/boil-water-advisories.html.
46. Health Canada. Guidelines for Canadian drinking water quality: guideline technical document - trihalomethanes. Ottawa, ON: Government of Canada; 2006 May. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-trihalomethanes.html.
47. Amarawansha G, Zvomuya F, Tomy G, Farenhorst A. Trihalomethanes in drinking water from three First Nation reserves in Manitoba, Canada. Environ Monit Assess. 2023 Jan;195(2):341. Available from: https://doi.org/10.1007/s10661-022-10694-5.
48. Health Canada. Guidelines for Canadian drinking water quality: guideline technical document – haloacetic acids. Ottawa, ON: Government of Canada; 2008 Jul. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-haloacetic-acids.html.
49. O'Keeffe J. Climate change and opportunistic pathogens (OPs) in the built environment. Environ Health Rev. 2022;65(3):69-76. Available from: https://doi.org/10.5864/d2022-016.
50. Lu J, Struewing I, Yelton S, Ashbolt N. Molecular survey of occurrence and quantity of Legionella spp., Mycobacterium spp., Pseudomonas aeruginosa and amoeba hosts in municipal drinking water storage tank sediments. J Appl Microbiol. 2015;119(1):278-88. Available from: https://doi.org/10.1111/jam.12831.
51. Ministry of Health and Long-Term Care. Drinking water haulage guidance document. Toronto, ON: Province of Ontario; 2008 Dec. Available from: https://collections.ola.org/mon/23007/293935.pdf.
52. Bradford L, Waldner C, McLaughlin K, Zagozewski R, Bharadwaj L. A mixed-method examination of risk factors in the truck-to-cistern drinking water system on the Beardy’s and Okemasis First Nation Reserve, Saskatchewan. Can Water Resour J. 2018 Oct;43(4):383-400. Available from: https://doi.org/10.1080/07011784.2018.1474139.

53. Zheng S, Li J, Ye C, Xian X, Feng M, Yu X. Microbiological risks increased by ammonia-oxidizing bacteria under global warming: the neglected issue in chloraminated drinking water distribution system. Sci Total Environ. 2023 May;874:162353. Available from: https://doi.org/10.1016/j.scitotenv.2023.162353.
54. US Envrionmental Protection Agency. Nitrification. Washington, DC: US EPA; 2002 Accessed Jan 12 2024. Available from: https://www.epa.gov/sites/default/files/2015-09/documents/nitrification_1.pdf.
55. Roberts T, Reckhow D, Kumpel E, Chavarria KA. Disinfection byproducts in intermittent piped water supplies. ACS ES&T Water. 2023 Nov;3(12):3767-81. Available from: https://doi.org/10.1021/acsestwater.3c00401.
56. Dupont D, Vespa M, McKay S, Anthony R, Islam K, Harper R, et al. Water and sanitation in First Nations communites: economic analysis Winnipeg, MB: Centre for Human Rights Research; 2016. Available from: https://chrr.info/wp-content/uploads/2016/11/Fact_sheet15-1.pdf.
57. Mattos K, Eichelberger L, Warren J, Dotson A, Hawley M, Linden K. Household water, sanitation, and hygiene practices impact pathogen exposure in remote, rural, unpiped communities. Environ Eng Sci. 2021 May:355-66. Available from: http://doi.org/10.1089/ees.2020.0283.
58. Karanis P, Kourenti C, Smith H. Waterborne transmission of protozoan parasites: a worldwide review of outbreaks and lessons learnt. J Water Health. 2006;5(1):1-38. Available from: https://doi.org/10.2166/wh.2006.002.
59. Pons W, Young I, Truong J, Jones-Bitton A, McEwen S, Pintar K, et al. A systematic review of waterborne disease outbreaks associated with small non-community drinking water systems in Canada and the United States. PLoS ONE. 2015;10(10):e0141646. Available from: https://doi.org/10.1371/journal.pone.0141646.
60. Means SP. Magna's tap water under a boil water order - because of a dead raccoon. Salt Lake Tribune. 2020 Apr 9. Available from: https://www.sltrib.com/news/2020/04/09/magna-tap-water-under/.
61. Bagenstose K. Dead snakes and mice, toxic sludge: how pathogens go unnoticed in America's water towers. USA Today. 2021 Updated Jun 1. Available from: https://www.usatoday.com/in-depth/news/investigations/2021/05/21/infrastructure-neglect-water-towers-add-millions-illnesses/6769259002/.
62. Angulo F, Tippen S, Sharp D, Payne B, Collier C, Hill J, et al. A community waterborne outbreak of salmonellosis and the effectiveness of a boil water order. Am J Public Health. 1997;87(4):580-4. Available from: https://doi.org/10.2105/ajph.87.4.580.
63. Ailes E, Budge P, Shankar M, Collier S, Brinton W, Cronquist A, et al. Economic and health impacts associated with a Salmonella typhimurium drinking water outbreak−Alamosa, CO, 2008. PLoS ONE. 2013 Mar 18;8(3):e57439. Available from: https://doi.org/10.1371/journal.pone.0057439.
64. Falco R, Williams S. Waterborne Salmonella outbreak in Alamosa, Colorado March and April 2008: outbreak identification, response, and investigation. Denver, CO: Colorado Department of Public Health and Environment; 2009 Nov. Available from: http://www.cdphe.state.co.us/wq/drinkingwater/pdf/AlamosaInvestRpt.pdf.
65. Puleston RL, Mallaghan CM, Modha DE, Hunter PR, Nguyen-Van-Tam JS, Regan CM, et al. The first recorded outbreak of cryptosporidiosis due to Cryptosporidium cuniculus (formerly rabbit genotype), following a water quality incident. J Water Health. 2014;12(1):41-50. Available from: https://doi.org/10.2166/wh.2013.097.

66. BBC. United utilities fined £300,000 for water bug contamination. London, UK: BBC; 2017 [updated Oct 11]; Available from: https://www.bbc.com/news/uk-england-lancashire-41565873.
67. Drinking Water Inspectorate. Report of the drinking water inspectorate's investigation into the cryptosporidium contamination of Franklaw Treatment Works in August 2015. London, UK: DWI; 2017 Oct 25. Available from: https://cdn.dwi.gov.uk/wp-content/uploads/2020/11/03162328/Cryptosporidium-Contamination-of-Franklaw-Treatment-Works-in-August-2015.pdf.
68. City of Iqaluit. Water quality emergency final investigation report to council. Iqaluit, NU: City of Iqaluit; 2022 May 5. Available from: https://www.iqaluit.ca/news/water-quality-emergency-final-investigation-report-council.
69. Tahoe Daily Tribune. E.coli found in water near Camp Richardson; boil water advisory in affect. Tahoe Daily Tribune. 2023 Sep 9. Available from: https://www.tahoedailytribune.com/news/e-coli-found-in-water-near-camp-richardson-boil-water-advisory-in-affect/.
70. Bush E, Lemmen D, eds. Canada's changing climate report. Ottawa, ON: Government of Canada; 2019. Available from: https://changingclimate.ca/CCCR2019/.
71. Moghaddam-Ghadimi S, Tam A, Khan UT, Gora SL. How might climate change impact water safety and boil water advisories in Canada? FACETS. 2023;8:1-21. Available from: https://doi.org/10.1139/facets-2022-0223.
72. Harper SL, Edge VL, Schuster-Wallace CJ, Berke O, McEwen SA. Weather, water quality and infectious gastrointestinal illness in two Inuit communities in Nunatsiavut, Canada: potential implications for climate change. Ecohealth. 2011 Mar;8(1):93-108. Available from: https://doi.org/10.1007/s10393-011-0690-1.
73. Calero Preciado C, Soria-Carrasco V, Boxall J, Douterelo I. Climate change and management of biofilms within drinking water distribution systems. Front Environ Sci. 2022 Oct 3;10. Available from: https://doi.org/10.3389/fenvs.2022.962514.
74. Roshani E, Kleiner Y, Colombo A, Salomons E. Water distribution systems: climate change risks and opportunities. Ottawa, ON: National Research Council Canada; 2022 Jan 10. Available from: https://nrc-publications.canada.ca/eng/view/ft/?id=18abf323-32d7-479a-bba8-c7dad4c5480b.
75. Semenza JC, Ko AI. Waterborne diseases that are sensitive to climate variability and climate change. New Engl J Med. 2023 Dec 7;389:2175-87. Available from: http://doi.org/10.1056/NEJMra2300794.
76. Wols BA, van Thienen P. Modelling the effect of climate change induced soil settling on jointed drinking water distribution pipes. Comput Geotech. 2015 Oct;70:106-15. Available from: https://doi.org/10.1016/j.compgeo.2015.07.007.
77. U.S. Environmental Protection Agency. Underground storage tank flood guide. Washington, DC: US EPA; 2020 Aug. Available from: https://www.epa.gov/sites/default/files/2014-03/documents/ustfloodguide.pdf.
78. National Environmental Health Association. Wildfire response. Guide for environmental public health professionals. Denver, CO: NEHA; 2023. Available from: https://www.neha.org/Images/resources/2023-Wildfire-Guide_Digital.pdf.
79. Robichaud PJL, Padowski JC. Drinking water under fire: water utilities' vulnerability to wildfires in the Pacific Northwest. J Am Water Resour Assoc. 2023 Nov 10:1-13. Available from: https://doi.org/10.1111/1752-1688.13174.

80. Emmerton CA, Cooke CA, Hustins S, Silins U, Emelko MB, Lewis T, et al. Severe western Canadian wildfire affects water quality even at large basin scales. Water Res. 2020 Sep;183:116071. Available from: https://doi.org/10.1016/j.watres.2020.116071.

81. Fischer EC, Wham BP, Metz A, editors. Contaminant migration from polymer pipes to drinking water under high temperature wildfire exposure. American Society of Civil Engineers Lifelines Conference; 2022 Jan 31-Feb 11; Los Angeles, CA. Available from: https://ascelibrary.org/doi/abs/10.1061/9780784484432.060.

82. Jankowski C, Isaacson K, Larsen M, Ley C, Cook M, Whelton AJ. Wildfire damage and contamination to private drinking water wells. AWWA Water Sci. 2023 Feb 15;5(1). Available from: https://doi.org/10.1002/aws2.1319.

83. Whelton AJ, Seidel C, Wham BP, Fischer EC, Isaacson K, Jankowski C, et al. The Marshall fire: scientific and policy needs for water system disaster response. AWWA Water Sci. 2023;5(1):e1318. Available from: https://doi.org/10.1002/aws2.1318.

84. Draper WM, Li N, Solomon GM, Heaney YC, Crenshaw RB, Hinrichs RL, et al. Organic chemical contaminants in water system infrastructure following wildfire. ACS ES&T Water. 2022 Feb;2(2):357-66. Available from: https://doi.org/10.1021/acsestwater.1c00401.

85. Proctor CR, Lee J, Yu D, Shah AD, Whelton AJ. Wildfire caused widespread drinking water distribution network contamination. AWWA Water Sci. 2020;2(4):e1183. Available from: https://doi.org/10.1002/aws2.1183.

86. Langer M, von Deimling TS, Westermann S, Rolph R, Rutte R, Antonova S, et al. Thawing permafrost poses environmental threat to thousands of sites with legacy industrial contamination. Nat Commun. 2023 Mar;14(1):1721. Available from: https://doi.org/10.1038/s41467-023-37276-4.

87. Miner KR, D'Andrilli J, Mackelprang R, Edwards A, Malaska MJ, Waldrop MP, et al. Emergent biogeochemical risks from Arctic permafrost degradation. Nat Clim Change. 2021 Oct;11(10):809-19. Available from: https://doi.org/10.1038/s41558-021-01162-y.

88. Wiebe AJ, McKenzie JM, Hamel E, Rudolph DL, Mulligan B, de Grandpré I. Groundwater vulnerability in the Yukon and Northwest Territories, Canada. Hydrogeol J. 2023 Oct. Available from: https://doi.org/10.1007/s10040-023-02720-8.

89. Warren JA, Berner JE, Curtis T. Climate change and human health: infrastructure impacts to small remote communities in the north. Int J Circumpolar Health. 2005 Dec;64(5):487-97. Available from: https://doi.org/10.3402/ijch.v64i5.18030.

90. Department of Environment. Flooding & severe weather events: mitigating risk to underground petroleum storage tanks. Halifax, NS: Province of Nova Scotia; 2020 Aug. Available from: https://novascotia.ca/nse/water/docs/CC_petrol_storage_underground.pdf.

91. World Bank. Resilient water infrastructure desing brief. New York, NY: World Bank; 2020. Available from: https://openknowledge.worldbank.org/entities/publication/709788c9-b5e2-5190-8845-b757f33ac7d4.

92. Mishra V, Sadhu A. Towards the effect of climate change in structural loads of urban infrastructure: a review. Sustain Cities Soc. 2023 Feb 1;89:104352. Available from: https://doi.org/10.1016/j.scs.2022.104352.

93. Indigenous Services Canada. Emergency response plan for drinking water systems in First Nations communities. Ottawa, ON: Government of Canada; 2014 Accessed 8 Dec 2023. Available from: https://www.sac-isc.gc.ca/eng/1398341765198/1533667912163.
94. Wade T, ClimAtlantic. Health risks associated with sea level rise. Vancouver, BC: National Collaborating Centre for Environmental Health; 2022 Nov. Available from: https://ncceh.ca/resources/evidence-reviews/health-risks-associated-sea-level-rise.
95. Thurton D. Fort McMurray seeing big spike in water-treatment costs: CBC News; 2017 Feb 9. Available from: https://www.cbc.ca/news/canada/edmonton/fort-mcmurray-wildfire-water-treatment-costs-contaminants-1.3973249.
96. Harper SL, Wright C, Masina S, Coggins S. Climate change, water, and human health research in the Arctic. Water Secur. 2020 Aug;10:100062. Available from: https://doi.org/10.1016/j.wasec.2020.100062.
97. Anderson LE, DeMont I, Dunnington DD, Bjorndahl P, Redden DJ, Brophy MJ, et al. A review of long-term change in surface water natural organic matter concentration in the northern hemisphere and the implications for drinking water treatment. Sci Total Environ. 2023 Feb;858:159699. Available from: https://doi.org/10.1016/j.scitotenv.2022.159699.
98. Gora SL, Trueman BF, Anaviapik-Soucie T, Gavin MK, Ontiveros CC, Campbell J, et al. Source water characteristics and building-specific factors influence corrosion and point of use water quality in a decentralized arctic drinking water system. Environ Sci Technol. 2020 Feb 18;54(4):2192-201. Available from: https://doi.org/10.1021/acs.est.9b04691.
99. Cool G, Delpla I, Gagnon P, Lebel A, Sadiq R, Rodriguez MJ. Climate change and drinking water quality: predicting high trihalomethane occurrence in water utilities supplied by surface water. Environ Model Software. 2019 Oct;120:104479. Available from: https://doi.org/10.1016/j.envsoft.2019.07.004.
100. Harper SL, Edge VL, Ford J, Thomas MK, Pearl DL, Shirley J, et al. Acute gastrointestinal illness in two Inuit communities: burden of illness in Rigolet and Iqaluit, Canada. Epidemiol Infect. 2015 Oct;143(14):3048-63. Available from: https://doi.org/10.1017/S0950268814003744.
101. Orcesi A, O'Connor A, Bastidas-Arteaga E, Stewart MG, Imam B, Kreislova K, et al. Investigating the effects of climate change on material properties and structural performance. Struct Eng Int. 2022 Oct;32(4):577-88. Available from: https://doi.org/10.1080/10168664.2022.2107468.
102. Chong NS, Abdulramoni S, Patterson D, Brown H. Releases of fire-derived contaminants from polymer pipes made of polyvinyl chloride. Toxics. 2019 Nov 11;7(4). Available from: https://doi.org/10.3390/toxics7040057.
103. Mao F, Ong SK, Gaunt JA. Modeling benzene permeation through drinking water high density polyethylene (HDPE) pipes. J Water Health. 2015 Sep;13(3):758-72. Available from: https://doi.org/10.2166/wh.2015.183.
104. Jankowski CM, Gustafson LA, Isaacson KP, Del Real KR, Noh Y, Ehde AB, et al. Residential water softeners release carbon, consume chlorine, and require remediation after hydrocarbon contamination. Environ Sci Technol. 2023 Jun 13;57(23):8750-9. Available from: https://doi.org/10.1021/acs.est.3c00700.
105. Dilling L, Daly ME, Travis WR, Ray AJ, Wilhelmi OV. The role of adaptive capacity in incremental and transformative adaptation in three large U.S. urban water systems. Global Environ Change. 2023 Mar;79:102649. Available from: https://doi.org/10.1016/j.gloenvcha.2023.102649.

106. WaterRegsUK. Cold water storage cisterns. Gwent, UK: Water Regs UK Ltd; 2024. Available from: https://www.waterregsuk.co.uk/guidance/installation/installation-specifi/specific-installatio/how-should-cold-wate/.
107. Washington State Department of Ecology. Sustainable remediation: climate change resiliency and green remediation. Olympia, WA: State of Washington; 2023 Jan. Available from: https://apps.ecology.wa.gov/publications/documents/1709052.pdf.
108. Interdepartmental Water Quality Training Board. Drinking water storage tanks. Ottawa, ON: Government of Canada; 2009. Available from: https://www.waterqualitytraining.ca/files/Cistern_Accompanying_Document_V2_3.pdf.
109. U.S. Envrionmental Protection Agency. How to conduct a sanitary survey of drinking water systems. A learner's guide. Washington, DC: US EPA; 2019 Aug. Available from: https://www.epa.gov/sites/default/files/2019-08/documents/sanitary_survey_learners_guide_508_8.27.19.pdf.
110. Klasic M, Fencl A, Ekstrom JA, Ford A. Adapting to extreme events: small drinking water system manager perspectives on the 2012–2016 California Drought. Climatic Change. 2022 Feb;170(3):26. Available from: https://doi.org/10.1007/s10584-021-03305-8.
111. Alberta Environment and Parks. Maintaining your cistern. Edmonton, AB: Government of Alberta; 2019 Aug. Available from: https://open.alberta.ca/dataset/9f7989ed-d363-4dfe-8823-7d16f7185d0c/resource/b94ee071-43e9-42b3-9f82-6ca610c77e78/download/aep-ww-fs13-cisterns-2019-08.pdf.
112. Alberta Health. Public health guidelines for non-municipal drinking water. Edmonton, AB: Government of Alberta; 2021 Jul. Available from: https://open.alberta.ca/dataset/b9d0c516-4849-44af-8010-0a30a51a4316/resource/e2523472-bb43-4462-8ad4-b261eb2ba138/download/health-public-health-guidelines-non-municipal-drinking-water-2021.pdf.
113. Colorado Department of Public Health & Environment. Storage tank comprehensive inspection checklist. Denver, CO: State of Colorado; 2016. Available from: https://cdphe.colorado.gov/dwtank.
114. U.S. Environmental Protection Agency. Finished water storage tank inspection/cleaning checklist. Washington, DC: US EPA; 2020 Dec 8. Available from: https://www.epa.gov/region8-waterops/finished-water-storage-tank-inspectioncleaning-checklist.
115. Government of Newfoundland and Labrador. Operation & maintenance of a water storage tank. St. John's NL: Government of Newfoundland and Labrador; 2020 Oct. Available from: https://www.gov.nl.ca/ecc/files/waterres-training-operator-onsite-training-tanks-sop.pdf.
116. American Water Works Association. AWWA C652-19 Disinfection of water-storage facilities. Denver, CO: AWWA; 2020. Available from: http://dx.doi.org/10.12999/AWWA.C652.19.
117. Stein G. AWWA standards and manuals support water storage tank inspection and cleaning. Journal AWWA. 2020 Nov;112(11):80-2. Available from: https://doi.org/10.1002/awwa.1617.
118. Ministry of the Environment Conservation and Parks. Providing safe drinking water to cisterns at non-residential drinking water systems serving designated facilities. Toronto, ON: Government of Ontario; 2023 Mar 9. Available from: https://www.ontario.ca/page/providing-safe-drinking-water-cisterns-non-residential-drinking-water-systems.

119. Papineau I, Barbeau B. Water tank cleaning in Nunavik: a pilot study. Montreal, QC: École Polytechnique de Montréal; 2009 Jul. Available from: https://keac-ccek.org/wp-content/uploads/2015/09/eaupotables3-anglais.pdf.
120. State Water Resources Control Board. Information to water customers regarding water quality in buildings located in areas damaged by wildfire. Sacramento, CA: Government of California; 2019. Available from: https://www.waterboards.ca.gov/drinking_water/programs/documents/benzenecustomeradvisoryfinal.pdf.
121. Indigenous Services Canada. About drinking water advisories. Ottawa, ON: Government of Canada; 2021 Feb 19. Available from: https://www.sac-isc.gc.ca/eng/1538160229321/1538160276874.
122. First Nations Health Authority. Returning to your home after wildfires. West Vancouver, BC: FNHA; 2017. Available from: https://www.fnha.ca/Documents/FNHA-Returning-to-Your-Home-After-Wildfires.pdf.
123. Government of Canada. Canada's national adaptation strategy. Ottawa, ON: Government of Canada; 2023. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/national-adaptation-strategy/full-strategy.html#toc11.
124. Government of the Northwest Territories. Good engineering practice for northern water and sewer systems. Yellowknife, NWT: Government of the Northwest Territories; 2017 Dec. Available from: https://www.maca.gov.nt.ca/sites/maca/files/resources/goodengpractice2ed.pdf.
125. The Yukon River Intertribal Watershed Council. Safe drinking water and sanitary practices manual. Anchorage, AK: Yukon River Inter-Tribal Watershed Council; 2019 Accessed Jan 15 2024. Available from: https://www.yritwc.org/_files/ugd/dcbdaf_72a5124b393b445188708a731c89bc47.pdf.
126. Saskatchewan Ministry of Health. Cleaning and disinfection guideline for private cisterns after a drinking water advisory. Saskatoon, SK: Government of Saskatchewan; 2014. Available from: https://www.saskhealthauthority.ca/sites/default/files/2021-06/Guideline-2014-11-01-RRPL-PrivateCisternsAfteraDrinkingWaterAdvisory-vo1.pdf.
127. Godfrey S, Reed B. Cleaning and disinfecting water storage tanks and tankers. Geneva, Switzerland: World Health Organization; 2013 Jul. Available from: https://cdn.who.int/media/docs/default-source/wash-documents/who-tn-03-cleaning-and-disinfecting-water-storage-tanks-and-tankers.pdf?sfvrsn=394020f2_4.
128. US Centers for Disease Control and Prevention. Cleaning and disinfecting water cisterns after floods and heavy rains. Atlanta, GA: US Department of Health & Human Services; 2022. Available from: https://www.cdc.gov/healthywater/emergency/drinking/disinfection-cisterns.html.

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