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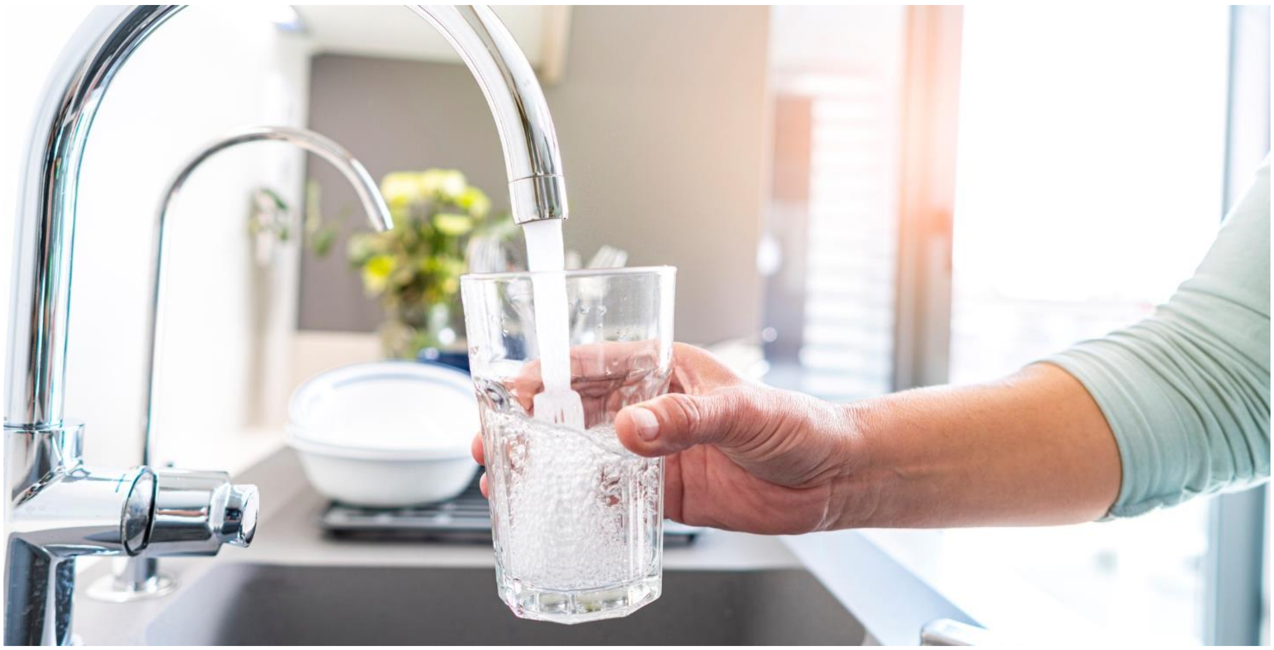
FOCUS ON

Per-and Poly-Fluoroalkyl Substances (PFAS)



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Key Findings

- PFAS (per- and poly-fluoroalkyl substances) are a large group of human-made chemicals, with PFOA (perfluorooctanoic acid) and PFOS (perfluorooctane sulfonate) as the most studied PFAS.
- The unique chemical properties of PFAS has led to their widespread use in a variety of industry and consumer products since the 1940s, but these same properties also result in PFAS persisting in the environment.
- Many PFAS have been phased out from products since the early 2000s, with some exemptions. All Canadians are exposed to some PFAS with average Canadian PFAS serum levels decreasing over time. Some Canadians may be exposed to above average concentrations due to local contamination but the associated health effects are not well known.
- Our understanding of how PFAS behave in the environment and their association with potential human health effects is evolving as new research emerges. Potential human health effects associated with high PFAS exposures include liver effects, adverse pregnancy outcomes, immune responses and some cancers. Effects found in epidemiological studies are generally consistent with findings from animal studies, but overall the human evidence is less robust and the clinical significance of the findings are not clear.

- Where individuals are known to be exposed to above average concentrations of PFAS (such as when PFAS contamination is discovered in a local drinking water source), exposure reduction measures can be taken while health effects research continues. Examples of exposure reduction measures include installing a drinking water treatment system where warranted and making informed consumer choices to purchase PFAS free products.

Introduction

PFAS (per- and poly-fluoroalkyl substances) are a group of human-made chemicals that have been used in a wide variety of industrial and consumer products since the 1940s. However, interest and scientific understanding of how they behave in the environment and their potential human health effects has been increasing more recently and is now a rapidly evolving area. This Focus On does not provide a comprehensive review of PFAS, but rather a general overview to support public health practitioners. This document summarizes the following:

- general description, known sources and concentrations in the environment,
- exposures,
- potential health effects,
- actions that can be taken to reduce exposures, and
- current regulations in Ontario and Canada.

Methods

A rapid grey literature search of public health, environmental health and toxicology resources was conducted to identify information on PFAS, environmental sources, how individuals are exposed to PFAS, how their use is regulated in Canada and Ontario, and practical advice for reducing exposures. Information was generally sourced from reviews of PFAS from regulatory authorities.

A peer-reviewed published literature search was also conducted to obtain recent evidence summaries on human health effects associated with PFAS. Specifically, PHO Library Services conducted a search on September 1, 2022 for systematic reviews and meta-analyses in the Embase and MEDLINE databases on articles related to PFAS and human health. The library search excluded animal studies and limited results to English language articles published between 2012 and 2022, with results screened to identify systematic reviews and meta-analyses published in the last two years. The full library search strategy is available upon request.

What are PFAS?

PFAS are a group of synthetic chemicals with unique chemical properties such as resistance to extreme temperatures, resistance to breakdown/degradation, water and oil repellency and non-stick characteristics.[1–4] These unique properties resulted in their widespread use in a variety of industry and consumer products since the 1940s. There are thousands of PFAS chemicals which can be found in paper and cardboard coatings, leather products, stain-resistant carpet, upholstery, clothing, non-stick coatings on cookware, food packaging, paints, varnishes, sealants, cleaning products, personal care products and cosmetics, aqueous film-forming foam (AFFF) for fire-fighting, and in the production of electronics, plastics and metals.[1,2,4–11]

PFAS can be categorized based on their chemical structure, with PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid) being the most studied to date.[2,8,12] Other PFAS of interest include perfluorohexane sulfonate (PFHxS), a known by-product in the production of PFOS and perfluorobutane sulfonate (PFBS) which is considered a potential replacement for PFOS. Other PFAS, such as perfluorobutanoic acid (PFBA), perfluorohexanoic acid (PFHxA), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnDA), are also sometimes measured in the human population (i.e., in biomonitoring programs).[4]

The passing of the *Perfluorooctane Sulfonate Virtual Elimination Act* in 2008 added PFOS and its salts to the Virtual Elimination List under the Canadian Environmental Protection Act (CEPA), 1999.[13] The passing of the *Prohibition of Certain Toxic Substances Regulations, 2012* further restricted the use of PFOS, PFOA and other select PFAS by prohibiting the manufacture, use, sale and import of these substances and products containing them (with some exceptions).[14–17] A proposal is currently underway to revise this regulation to further restrict the use of PFOS and PFOA.[18] While some companies voluntarily phased out the production and use of several PFAS substances in the early 2000s, and measures are in place within North America and Europe to restrict production, existing stocks are still in use and their manufacture continues in other parts of the world.[9,10,19,20] In the United States, the Food and Drug Administration (US FDA) revoked regulations in 2016 which allowed the use of PFOS and PFOA in food packaging.[21] Recently, a number of larger fast-food restaurant chains in Canada and the United States have reportedly committed to voluntarily phasing out packaging containing added PFAS.[22]

PFAS IN THE ENVIRONMENT

Given their widespread use and chemical stability, PFAS have been widely detected in the environment. Major sources of PFAS in the environment include household waste (e.g., landfills), industrial sites where PFAS containing materials have been produced or applied, as well as AFFF firefighting events and training sites.[23–25] These sources contribute PFAS to soil, air and water by leaching into groundwater, discharging to surface water, as well as releases to air and soil through spills and emissions. Once released into the environment, PFAS can remain for prolonged periods either within the water table or partitioning into sediment with a fraction of AFFF becoming airborne during fires as aerosols and diffuse chemicals.[23,25]

PFAS persist in the environment and the body relatively unchanged due to their chemical structures.[1,3–5,7] PFAS are unlikely to degrade or transform under ambient environmental conditions, but laboratory experiments have demonstrated that some physical, chemical and biological processes can change the chemical structure of PFAS under specific conditions. These transformations can result in changes in the form of PFAS within a mixture (e.g. alcohol to aldehyde), or the size of the molecules, potentially changing the toxicity of original mixture.[24,25]

At this time, limited Canadian data with varying trends are available on PFAS concentrations in environmental media. According to Environment and Climate Change Canada, PFOS concentrations in fish (lake trout) showed an overall increase from 1979 to 2000, concentrations then stabilized for a few years before beginning to decrease.[26] This is consistent with a 2022 study that showed that Canadian freshwater concentrations of legacy PFAS (PFOS and PFOA) decreased between 2013 to 2020, while the concentration of other PFAS substances such as perfluoropentanoic acid (PFPeA) and PFBA increased during that timeframe (possibly due to their use as replacement PFAS in consumer products in lieu of PFOS and PFOA).[27] However, trends in specific environmental media and by PFAS chemical may vary, as shown by Gewurtz et al. for certain wildlife, sediment and water samples collected in and around Lake Ontario between the late 1970s and late 2000s.[28]

In general, there is not enough information to predict PFAS trends in concentrations for water, sediment and air, but environmental concentrations, combined with PFAS stability and persistence, can result in bioaccumulation and biomagnification in the ecosystem. Table A in the Appendix shows PFOS levels measured in Canadian water, fish, sediment, and air from 2006 to 2017 as reported by Environment and Climate Change Canada.

PFAS EXPOSURES

All Canadians are exposed to some PFAS due to their persistence in the environment. Exposure to PFAS can occur through food and consumer products, soil, indoor dust and drinking water.[4,9,10,20,29,30] PFAS exposure from drinking water may increase if consuming contaminated drinking water.[10,20,29] The primary route of exposure may also be age-dependent, with oral exposure (via hand-to-mouth activity) to consumer products (e.g., treated fabrics and carpets) as the primary route of exposure for infants, toddlers and children.[4,10,30]

Dietary (Food and Water)

Diet is one way Canadians are exposed to PFOA, PFOS and other PFAS.[3,15,31,32] Food can become contaminated through the growing environment or processing equipment, through animal feed or water, or from food packaging material.[33] PFAS contamination in the growing environment does not necessarily indicate the grown foods will contain detectable levels of PFAS, as this will depend on the amount of PFAS in the growing environment, the type of PFAS present and the type of food/plant species.[33,34] In general, most foods not grown or produced in specific areas with known PFAS contamination do not have detectable levels of PFAS.[34]

An analysis of food samples collected between 1992 to 2004 conducted by Tittlemier et al. estimated an average daily dietary exposure of 250 ng/day using a subset of samples collected as part of the Canadian Total Diet Study.[35] More recent data on PFAS levels in Canadian food are not available, but an ongoing dietary exposure assessment study conducted by the US FDA shows that the majority of food samples analyzed since 2019 do not have measurable concentrations of PFAS.[36]

PFAS have been used in non-stick cookware and in food packaging materials (e.g., fast-food wrappers, microwave popcorn bags, and paperboard take-out containers such as pizza boxes).[21] However, the US FDA indicates the non-stick coating on cookware contains a negligible amount of PFAS capable of migrating into food and Health Canada's Food Research Division found food packaging was not a significant source of PFOA and PFOS.[21,37]

Using an estimated average adult intake rate of 1.4 L/day, Tittlemier et al. (2007) used mean tap water concentrations from Calgary and Vancouver from another study to estimate 0.3 ng/day exposure to total PFAS via drinking water for the general Canadian population.[31,35] A more recent analysis of 226 treated drinking water samples provides drinking water concentrations from 25 drinking water systems in Ontario using river, lake and groundwater sources between 2012 and 2016.[38] Mean and maximum concentrations of a group of ten PFAS were 6.1 ng/L and 20.0 ng/L, respectively. Detection of individual PFAS chemicals was variable, with percent detection ranging from 0 to 73%. Drinking water exposures can be higher in areas where water with elevated PFAS concentrations is relied upon as a drinking water source. Exposures from water during common household activities such as bathing, showering, washing dishes, brushing teeth and laundry are expected to be negligible.[20,29,39]

According to the United States Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR), PFAS can be found in breast milk and the level of exposure to an infant through breastfeeding depends on a number of factors (e.g., level of PFAS in the mother, the amount of PFAS that transfers through milk, the duration of breastfeeding).[5,10,30,40,41] A 2022 study of 664 Canadian breast milk samples found that total PFAS concentrations (sum of seven PFAS) ranged from 3.1 to 603 ng/L, with a median concentration of 106 ng/L.[42] PFOA was the most frequently detected compound and generally contributed the most to the measured PFAS concentrations (approximately 30%).[42] While further research on this potential route of exposure is needed, the CDC/ATSDR and the American Academy of Pediatrics state the benefits of breastfeeding outweigh any potential risks of PFAS exposure through breast milk.[40]

Other

Other potential routes of exposure may include the ingestion of contaminated soil or household dust as well as the inhalation of aerosolized water.[10,30,43–45] However, Health Canada reports that PFAS remain in water, they do not preferentially partition to air (i.e., it does not volatilize) and the primary mechanism for exposure to PFAS in drinking water is via ingestion.[20,29,39] While Health Canada and the United States Environmental Protection Agency (US EPA) recognize that exposures to PFAS by inhaling water aerosols contaminated with PFAS can occur, the total mass of aerosolized water is low and due to its low volatility, PFAS will not concentrate in air, making this route of exposure negligible.[20,29,43] PFAS exposure can also come from use of consumer products such as personal care products, leather products, carpets, upholstery and clothing.[9,10,46,47]

PFAS LEVELS IN THE HUMAN BODY

Population-based biomonitoring data for select PFAS concentrations in human blood plasma are available via the Canadian Health Measures Survey (CHMS). Table 1 summarizes PFAS biomonitoring data from the most recent round of survey data (Cycle 6, 2018-2019) for the Canadian population aged 3-79 years.[46] Complete CHMS biomonitoring results by age group, sex and survey cycle are also available online.

Table 1: PFAS blood plasma levels in the Canadian population aged 3-79 years (2018-2019)[46]

PFAS Chemical	Detection Frequency (%) (95% confidence interval)	Geometric Mean (µg/L) (95% confidence interval)
Perfluorooctane sulfonate (PFOS)	99.3 (98.6–99.7)	2.5 (2.3–2.8)
Perfluorooctanoic acid (PFOA)	100	1.2 (1.1–1.3)
Perfluorohexane sulfonate (PFHxS)	99.6 (99.1–99.9)	0.76 (0.69–0.85)
Perfluorononanoate (PFNA)	98.5 (97.3–99.1)	0.44 (0.41–0.47)
Perfluorodecanoic acid (PFDA)	67.6 (61.4–73.2)	0.12 (0.11–0.14)

Note: Although PFBA, PFHxA, PFUnDa, and PFBS were also measured as part of the CHMS, geometric mean values for concentrations in blood plasma were not reported for these chemicals as >40% of the data were below the limits of detection.

In general, concentrations of PFAS in blood plasma of Canadians aged 12 to 79 (or aged 20 to 79) have decreased over time.[3] Between 2007–2009 and 2018–2019, PFOA concentrations declined by 52%, PFHxS concentrations declined by 64% and PFOS concentrations declined by 67% in Canadians aged 20-79. Between 2009–2011 and 2018–2019, PFNA concentrations declined by 47% and PFDA concentrations declined by 36% in Canadians aged 12-79.[3] Comparisons between age groups found higher blood plasma concentrations among adults versus children, with highest levels reported in the 60 to 79 age group. Blood serum levels in the United States from 2007 to 2016 are similar to Canadian blood plasma levels.[3,48,49]

Human Health Effects

Health Canada reports some PFAS are well absorbed in the body, poorly excreted and not extensively metabolized.[3,4] The potential health risks from exposure to PFAS depends on the level and duration of exposure (i.e., how much and for how long).[39] Toxicological studies involving laboratory animals have found high levels of PFAS are associated with reproductive, developmental, endocrine, liver, kidney and immunological effects.[3,10,50] However, effects observed in animals do not necessarily translate to humans.

The majority of systematic reviews and meta-analyses focused on epidemiological (human) studies published in the last two years have examined human health effects associated with exposure to PFOS and PFOA. As a result, the strength of the evidence for health effects is highest for PFOS and PFOA, as few studies have considered other types of PFAS.

Overall, epidemiological data from cross-sectional studies demonstrate sufficient evidence that elevated exposures to certain PFAS, particularly PFOS and PFOA are associated with increased liver enzymes which may indicate the presence of liver disease or damage.[51]

There is also limited evidence that elevated exposures to certain PFAS are associated with increased risk of select adverse pregnancy outcomes including low birthweight and preterm birth;[52–55] kidney and testicular cancer (particularly with high exposure to PFOA);[56,57] and allergic outcomes in children including exposure to PFOS and atopic dermatitis, and exposure to PFOA and allergic rhinitis.[58] There is limited evidence that PFAS is associated with decreased immune response to diphtheria, tetanus, measles, mumps, and influenza vaccines based on a recent systematic review and meta-analysis.[59] Studies do not consistently show an association between PFAS and other pregnancy outcomes including small for gestational age,[52,55,59] miscarriage,[53–55] pregnancy induced hypertension,[55] as well as reproductive hormones (e.g., testosterone, estradiol)[60] and prostate cancer.[57] Overall, the clinical significance of the epidemiologic findings need further study.

Based on the evidence associated with PFAS exposure, agencies such as the ATSDR and Health Canada have identified that individuals with pre-existing conditions affecting the same systems (e.g., those with compromised liver function or immune systems), pregnant women and young children may be at a higher risk of health effects.[10,31,32]

Our literature search did not identify systematic reviews or meta-analyses that examined the relationship between potential human health effects and PFAS mixtures. The gap in scientific research on how PFAS chemicals behave in mixtures is a challenge for evaluating the potential health effects associated with the mixtures people are actually exposed to.

In 2017, the International Agency for Research on Cancer (IARC) classified PFOA as possibly carcinogenic to humans (Group 2B) due to limited evidence in humans, including the associations observed with cancers of the kidney and testis, and animal studies.[61] A similar evaluation for PFOS has not been completed by IARC.[20]

PFAS Guidelines, Regulations and Exposure Reduction Measures

While the following guidelines and regulations may not be directly applicable to all Ontario settings, they provide context for interpreting environmental measurements and may help indicate when further investigation of potential PFAS contamination could be useful. Many jurisdictions have derived PFAS guidelines for drinking water, while some guidelines for soil and groundwater are also available. Although PFAS are not specifically regulated in food and consumer products, the *Prohibition of Certain Toxic Substances Regulations, 2012* has prohibited the manufacture, use, sale and import of PFAS and PFAS-containing products (with some exceptions).[14]

In general, environmental guidelines are developed to be protective of populations and are based on an assumption of lifetime of exposure to a substance (i.e., protective of chronic exposures). During the guideline development process, it is common to factor in a margin of safety or uncertainty factors such that they are protective of sensitive populations and life stages that may be more susceptible to chemical exposures (e.g., those with chronic conditions or young children).[12,31,32] Derivation of guidelines may also take into account other potential sources of exposure to PFAS (e.g., consideration of total exposures from food, water, air, consumer products).[12] Therefore, short-term exposures to PFAS at concentrations above guideline levels are typically not expected to result in health effects. The potential for health risks resulting from prolonged exposures to high levels of PFAS depend on how much and how long a person was exposed.

Different jurisdictions may also take different approaches in deriving guidelines for chemicals in the environment. These approaches may consider, to varying degrees, different factors such as benchmark studies, weight of evidence, technical feasibility, background concentrations, and for certain similar chemicals whether to address them individually or as a group.[18,62]

DRINKING WATER

Drinking water guidelines relevant for Ontario and Canada are included in Table B in the Appendix.

Ontario Ministry of the Environment, Conservation and Park's (MECP) interim drinking water guideline

In 2017, following the identification of a 'widespread PFAS release' from firefighting foam that impacted groundwater, the MECP recommended that private drinking water well owners consider treatment if the sum of 11 different PFAS was above 70 ng/L.[63,64]

Health Canada Drinking Water Guidelines

Health Canada has developed maximum acceptable concentration (MAC) guideline values for two PFAS; PFOA (200 ng/L) and PFOS (600 ng/L) which are both based on liver effects observed in laboratory studies involving rats.[31,32] The sum of the ratios of the concentrations of PFOS and PFOA relative to their MACs should not exceed 1 to account for the similar mechanism for toxicological effects of PFOA and PFOS. Drinking water screening values for a number of other PFAS are also available from Health Canada.[39]

MACs and screening values are designed to protect the health of the general public (including children) from lifetime exposures to the substance (i.e., chronic exposures) in drinking water.[39] As substance-specific information is lacking for most PFAS, future development of guideline values may factor in a grouping approach to consider PFAS as a class of chemicals rather than conducting separate evaluations of individual substances.

In April 2021, Health Canada announced their intention to revisit drinking water guidelines for PFAS.[17] Following this announcement, Health Canada released a proposed objective value for total PFAS for public consultation in February 2023.[65] The proposed objective value is 30 ng/L for the sum of total PFAS in drinking water, with total PFAS defined as the full list of substances analyzed under either US EPA Method 533 (25 PFAS) or US EPA Method 537.1 (18 PFAS), or both.[66,67] As an alternative to using US EPA methodology, jurisdictions can also validate and apply an alternate analytical method for total PFAS with a minimum of 18 PFAS included in the validated method.

The proposed objective value takes into consideration the technical feasibility of drinking water treatment using current technologies, the limit of quantification using recognized analytical methods, and environmental concentrations of PFAS reported by Canadian monitoring data.[65] The proposed objective value is not health-based but Health Canada considers available PFAS toxicity data as generally supportive of the proposed objective. The proposed objective value is intended to serve as an interim guideline while a revision of Health Canada's drinking water guidelines for PFAS is underway. This revision is expected to include a comprehensive review of toxicological data and PFAS risk assessments, a review of new analytical and treatment methods for PFAS, and information on how to manage treatment residuals.[65]

United States Environmental Protection Agency Water Health Advisories

The US EPA recently updated their interim drinking water health advisories for PFOA (0.004 ng/L) and PFOS (0.02 ng/L), and also released final drinking water health advisories for PFBS (2000 ng/L) and hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt (known as "GenX" chemicals, 10 ng/L).[68,69] The drinking water health advisories for PFOA and PFOS are based on a developmental immune health outcome (suppression of tetanus and diphtheria vaccine response, respectively) observed in epidemiological studies.[7] The drinking water health advisories for PFBS and HFPO are based on laboratory studies where thyroid effects were observed in newborn mice following gestational exposures in mothers, and liver effects (lesions) were observed in mice, respectively.[7]

The US EPA's health advisories are developed to protect people at all life stages from lifetime (chronic) exposures while accounting for potential exposure sources other than drinking water (e.g., from food, air, consumer products). US EPA's health advisories are not legally enforceable federal standards, but primarily serve to inform drinking water system operators.[70]

It is anticipated that the US EPA will be publishing a set of enforceable National Primary Drinking Water Regulations (NPDWRs) for PFAS by the end of 2023. The proposal includes both a non-enforceable Maximum Contaminant Level Goal (MCLG, or the maximum level of a contaminant at which no known or anticipated adverse health effect would occur) and an enforceable standard, or Maximum Contaminant Level (MCL) or Treatment Technique for PFOA and PFOS. While the MCL is set as close as feasible to the MCLG, considerations for the ability to measure and treat a contaminant and related costs/benefits are incorporated into setting the enforceable standard. The MCLG proposed by US EPA is zero nanograms per litre (0 ng/L) for both PFOA and PFOS while the proposed MCL is 4.0 ng/L for both.[71–73] In addition, PFNA, PFHxS, PFBS and HFPO dimer acid are addressed as a group.[74] Under the proposed regulation, the measured concentrations of these chemicals will be compared against health-based concentrations for each chemical and the sum of the four ratios must not exceed 1.0.[74]

A select number of individual US states have also enacted their own drinking water regulations for PFAS. Currently, a total of 20 states have established drinking water guidelines for PFOS and/or PFOA with some also having guidelines for other PFAS chemicals.[75]

Exposure Reduction Measures for Drinking Water

PFAS are not regularly monitored in drinking water in Canada, but levels are generally expected to be low.[31,32] If a drinking water source is known to be contaminated with PFAS, drinking water system owners can reduce overall exposure by using water treatment, or an alternative water source for drinking, cooking and preparing infant formula. Options can be explored with professionals specialized in water treatment, but examples of treatment processes effective at removing PFAS include adsorption by granular activated carbon (GAC), ion exchange (IX) resin, or high pressure membranes (i.e., nanofilters (NF) and reverse osmosis (RO)).[20,29,76] These can be adapted to suit all sizes of treatment systems. NSF International lists specific water treatment products that have been independently verified to reduce PFOS and PFOA to below 70 ng/L.[77] These will be listed as certified to NSF 53, and/or NSF 58 to specifically include PFOS and PFOA reduction.[77] It is important to follow the manufacturer's recommendations for operation and maintenance of a treatment system (e.g., replacement of filter media).

SOIL

Canadian soil quality guidelines for PFOS are available from the Canadian Council of Ministers of the Environment (CCME). The PFOS soil quality guideline for protection of human health is 0.01 mg/kg for all land uses (agricultural, residential/parkland, commercial and industrial).[78] Although CCME did not develop soil guidelines for PFOA, they note that the health effects associated with PFOS and PFOA are similar and additive effects need to be taken into consideration. Similar to the approach taken by Health Canada, the sum of the ratios of the concentrations of PFOS and PFOA relative to the PFOS soil quality guideline should not exceed 1 to account for additive toxicological effects.[78] Given that the CCME soil guidelines were derived using Health Canada's assessment of health effects, these guidelines may be affected following Health Canada's review of PFAS drinking water guidelines.

GROUNDWATER

The CCME has also developed groundwater quality guidelines for PFOS. CCME groundwater quality guidelines are intended to represent concentrations of contaminants in groundwater below which no appreciable human health risk are expected from long-term (chronic) exposure.[79] The PFOS groundwater guideline for the protection of human health is 0.0006 mg/L (equivalent to 0.6 ng/L) and the sum of the ratios of the concentrations of PFOS and PFOA relative to the PFOS groundwater quality guideline should not exceed 1 to account for the additive toxicological effects of PFOA and PFOS.[78] Given that the CCME groundwater guidelines were derived using Health Canada's assessment of health effects, these guidelines may be affected following Health Canada's review of PFAS drinking water guidelines.

Discussion and Conclusions

The unique physical properties of PFAS have resulted in their widespread use in many consumer products and industrial processes such as paper and cardboard coatings, stain-resistant carpet, non-stick coatings on cookware, and aqueous film-forming foam (AFFF) for fire-fighting. However, the same physical properties have also allowed PFAS to persist in the environment raising public and scientific attention in recent years.

Studies have identified landfills, industrial sites and areas where firefighting activities have occurred as sources of PFAS in the environment. Once in the environment, PFAS can enter groundwater and surface water, and may eventually enter the food chain providing multiple sources of potential exposure for the general public. The sources of exposure may include diet, soil, indoor dust and drinking water, in addition to consumer goods and textiles.

Guidelines for PFAS are most commonly available for drinking water though there are some for soil and groundwater. These guidelines are typically developed to protect populations from chronic exposures to PFAS and incorporate margins of safety. Some drinking water regulatory guidelines have recently been lowered as evidence is emerging on potential health effects.

Animal studies on PFAS exposure show an association with increased liver, reproductive, endocrine, kidney and immunological effects. This is supported by an association with elevated liver enzymes particularly for PFOS and PFOA in cross-sectional epidemiological studies, but human data are otherwise limited and further studies are needed on their clinical significance.

Currently, all Canadians are exposed to some PFAS however health effects cannot be clearly attributed. Where individuals are exposed to elevated levels of PFAS over an extended period, actions to reduce exposures can be taken. For example, elevated concentrations above applicable guidelines may result from living in areas of known PFAS contamination, or from occupational exposures in a workplace (e.g., individuals working with AFFF). In these situations, efforts to reduce PFAS exposures are generally recommended by various organizations. Measures such as drinking water treatment systems for homeowners with impacted drinking water wells, making informed consumer choices such as purchasing PFAS free products as indicated and following fish consumption guidance in Ontario can reduce overall exposures until more evidence on the health effects of PFAS are established.[80–84]

References

1. National Collaborating Centre for Environmental Health (NCCEH). Keeping drinking water safe: new guidelines for PFAS in Canada [Internet]. Vancouver, BC: NCCEH; 2019 [cited 2022 Jul 13]. Available from: https://ncceh.ca/content/blog/keeping-drinking-water-safe-new-guidelines-pfas-canada

2. Health Canada. Report on human biomonitoring of environmental chemicals in Canada: results of the Canadian health measures survey cycle 1 (2007-2009). Ottawa, ON: Her Majesty the Queen in Right of Canada, represented by the Minister of Health; 2010. Available from: https://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contaminants/chms-ecms/report-rapport-eng.pdf

3. Health Canada. Per- and polyfluoroalkyl substances (PFAS) in Canadians. Ottawa, ON: Her Majesty the Queen in Right of Canada, represented by the Minister of Health; 2021. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/human-biomonitoring-resources/per-polyfluoroalkyl-substances-canadians.html

4. Health Canada. Second report on human biomonitoring of environmental chemicals in Canada: results of the Canadian health measures survey cycle 2 (2009-2011). Ottawa, ON: Her Majesty the Queen in Right of Canada, represented by the Minister of Health; 2013. Available from: https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/contaminants/chms-ecms-cycle2/chms-ecms-cycle2-eng.pdf

5. Agency for Toxic Substances and Disease Registry (ATSDR). Per- and polyfluoroalkyl substances (PFAS) and your health [Internet]. Boston, MA: ATSDR; 2022 [cited 2022 Jul 13]. Available from: https://www.atsdr.cdc.gov/pfas/index.html

6. Agency for Toxic Substances and Disease Registry (ATSDR). The family tree of per- and polyfluoroalkyl substances (PFAS) for environmental health professionals: names and abbreviations. [Internet]. Boston, MA: ATSDR; 2017 [cited 2023 Mar 22]. Available from: https://www.atsdr.cdc.gov/pfas/docs/PFAS_FamilyTree_EnvHealthPro-508.pdf

7. United States Environmental Protection Agency (USEPA). Technical fact sheet: drinking water health advisories for four PFAS (PFOA, PFOS, GenX chemicals, and PFBS) [Internet]. Washington, DC: USEPA; 2022 [cited 2022 Sep 8]. Available from: https://www.epa.gov/system/files/documents/2022-06/technical-factsheet-four-PFAS.pdf

8. United States Environmental Protection Agency (USEPA). Risk management for per- and polyfluoroalkyl substances (PFAS) under TSCA [Internet]. Washington, DC: USEPA; 2022 [cited 2022 Jul 13]. Available from: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas

9. Lau C, Anitole K, Hodes C, Lai D, Pfahles-Hutchens A, Seed J. Perfluoroalkyl acids: a review of monitoring and toxicological findings. Toxicol Sci. 2007;99(2):366-94. Available from: https://doi.org/10.1093/toxsci/kfm128

10. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological profile for perfluoroalkyls [Internet]. Boston, MA: ATDSR; 2021 [cited 2022 Jul 13]. Available from: https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf

11. Centers for Disease Control and Prevention (CDC). Per- and polyfluoroalkyl substances (PFAS) [Internet]. Atlanta, GA: CDC; 2021 [cited 2022 Sep 8]. Available from: https://www.cdc.gov/niosh/topics/pfas/default.html

12. United States Environmental Protection Agency (USEPA). Drinking water health advisories for PFAS fact sheet for communities [Internet]. Washington, DC: USEPA; 2022 [cited 2022 Jul 13]. Available from: https://www.epa.gov/system/files/documents/2022-06/drinking-water-ha-pfas-factsheet-communities.pdf

13. *Perfluorooctane Sulfonate Virtual Elimination Act*, SC 2008, c 13. Available from: https://laws-lois.justice.gc.ca/eng/acts/p-8.3/page-1.html

14. *Prohibition of Certain Toxic Substances Regulations*, 2012. SOR/2012-285. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-285/FullText.html

15. Walkerton Clean Water Centre (WCWC). PFAS in water systems: a Canadian perspective [Internet]. Wakerton, ON: WCWC; 2021 [cited 2022 Sep 16]. Available from: https://wcwc.ca/wp-content/uploads/2020/12/PFAS-Fact-Sheet-2021-02-23-FINAL-ENG.pdf

16. Environment and Climate Change Canada. Aqueous film-forming foam and the prohibition of certain toxic substances regulation. Ottawa, ON: Her Majesty the Queen in Right of Canada, represented by the Minister of Environment and Climate Change; 2017. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/cepa/5081%20AFFF%20Fact%20Sheet%20_FINAL_EN.pdf

17. Ministerial Condition No. 20614 (Department of the Environment). (2021) C Gaz I, 1696. (Canadian Environmental Protection Act, 1999). Available from: https://gazette.gc.ca/rp-pr/p1/2021/2021-04-24/pdf/g1-15517.pdf

18. Prohibition of certain toxic substances regulations, 2022 (Department of the Environment; Department of Health). (2022) C Gaz I, 2365. (Canadian Environmental Protection Act, 1999). Available from: https://www.gazette.gc.ca/rp-pr/p1/2022/2022-05-14/pdf/g1-15620.pdf

19. Awad E, Zhang X, Bhavsar SP, Petro S, Crozier PW, Reiner EJ, et al. Long-term environmental fate of perfluorinated compounds after accidental release at Toronto airport. Environ Sci Technol. 2011;45(19):8081-9. Available from: https://doi.org/10.1021/es2001985

20. Health Canada. Perfluorooctane sulfonate (PFOS) in drinking water [Internet]. Ottawa, ON: Government of Canada; 2016 [modified 2016 Jun 15; cited 2022 Jul 13]. Available from: https://www.canada.ca/en/health-canada/programs/consultation-perfluorooctane-sulfonate-pfos-in-drinking-water/document.html

21. Food & Drug Administration (FDA). Authorized uses of PFAS in food contact applications [Internet]. Silver Spring, MD: FDA; 2022 [cited 2022 Sep 16]. Available from: https://www.fda.gov/food/chemical-contaminants-food/authorized-uses-pfas-food-contact-applications

22. Restaurants Brands International (RBI). Packaging & recycling [Internet]. Toronto, ON: RBI; 2020 [cited 2022 Sep 16]. Available from: https://www.rbi.com/English/sustainability/packaging-and-recycling/default.aspx

23. Chen Y, Zhang H, Liu Y, Bowden JA, Tolaymat TM, Townsend TG, et al. Concentrations of perfluoroalkyl and polyfluoroalkyl substances before and after full-scale landfill leachate treatment. Waste Manag. 2022;153:110-20. Available from: https://doi.org/10.1016/j.wasman.2022.08.024

24. Panieri E, Baralic K, Djukic-Cosic D, Buha Djordjevic A, Saso L. PFAS molecules: a major concern for the human health and the environment. Toxics. 2022;10(2):44. Available from: https://doi.org/10.3390/toxics10020044

25. Interstate Technology Regulatory Council (ITRC). Environmental fate and transport for per- and polyfluoroalkyl substances [Internet]. Washington, DC: ITRC; 2020 [cited 2023 Mar 23]. Available from: https://pfas-1.itrcweb.org/fact_sheets_page/PFASFact_Sheet_Fate_and_Transport_April2020.pdf

26. Environment and Climate Change Canada. Canadian environmental sustainability indicators: perfluorooctane sulfonate in fish and water. Gatineau, QC: Her Majesty the Queen in Right of Canada, represented by the Minister of Environment and Climate Change; 2019. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/cesindicators/pfos-fish-water/2019/PFOS-in-fish-and-water-en.pdf

27. Lalonde B, Garron C. Perfluoroalkyl substances (PFASs) in the Canadian freshwater environment. Arch Environ Contam Toxicol. 2022;82(4):581-91. Available from: https://doi.org/10.1007/s00244-022-00922-x

28. Gewurtz SB, Backus SM, De Silva AO, Ahrens L, Armellin A, Evans M, et al. Perfluoroalkyl acids in the Canadian environment: multi-media assessment of current status and trends. Environ Int. 2013;59:183-200. Available from: https://doi.org/10.1016/j.envint.2013.05.008

29. Health Canada. Perfluorooctanoic acid (PFOA) in drinking water [Internet]. Ottawa, ON: Government of Canada; 2016 [cited 2022 Jul 13]. Available from: https://www.canada.ca/en/health-canada/programs/consultation-perfluorooctanoic-acid-pfoa-in-drinking-water/document.html

30. Agency for Toxic Substances and Disease Registry (ATSDR). An overview of the science and guidance for clinicians on per- and polyfluoroalkyl substances (PFAS) [Internet]. Boston, MA: ATDSR; 2019 [cited 2022 Jul 25]. Available from: https://www.atsdr.cdc.gov/pfas/docs/clinical-guidance-12-20-2019.pdf

31. Health Canada. Guidelines for Canadian drinking water quality: guideline technical document : perfluorooctanoic acid (PFOA). [Internet]. Ottawa, ON: Her Majesty the Queen in Right of Canada, as represented by the Minister of Health; 2018 [cited 2022 Jul 20]. Available from: https://publications.gc.ca/collections/collection_2018/sc-hc/H144-13-8-2018-eng.pdf

32. Health Canada. Guidelines for Canadian drinking water quality: guideline technical document : perfluorooctane sulfonate (PFOS). [Internet]. Ottawa, ON: Her Majesty the Queen in Right of Canada, as represented by the Minister of Health; 2018 [cited 2022 Jul 20]. Available from: http://publications.gc.ca/collections/collection_2018/sc-hc/H144-13-9-2018-eng.pdf

33. European Food Safety Authority (EFSA). PFAS in food: EFSA assesses risks and sets tolerable intake [Internet]. Parma: EFSA; 2022 [cited 2022 Sep 16]. Available from: https://www.efsa.europa.eu/en/news/pfas-food-efsa-assesses-risks-and-sets-tolerable-intake

34. Food & Drug Administration (FDA). Questions and answers on PFAS in food [Internet]. Silver Spring, MD: FDA; 2022 [cited 2022 Sep 12]. Available from: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food

35. Tittlemier SA, Pepper K, Seymour C, Moisey J, Bronson R, Cao XL, et al. Dietary exposure of Canadians to perfluorinated carboxylates and perfluorooctane sulfonate via consumption of meat, fish, fast foods, and food items prepared in their packaging. J Agric Food Chem. 2007;55(8):3203-10. Available from: https://doi.org/10.1021/jf0634045

36. Food & Drug Administration (FDA). Analytical results of testing food for PFAS from environmental contamination [Internet]. Silver Spring, MD: FDA; 2022 [cited 2023 Mar 22]. Available from: https://www.fda.gov/food/process-contaminants-food/analytical-results-testing-food-pfas-environmental-contamination

37. Health Canada. Questions and answers on perfluorinated chemicals in food [Internet]. Ottawa, ON: Government of Canada; 2014 [modified 2014 Jul 29; cited 2022 Sep 16]. Available from: https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants/perfluorinated-chemicals-food/questions-answers-perfluorinated-chemicals-food-environmental.html

38. Kleywegt S, Raby M, McGill S, Helm P. The impact of risk management measures on the concentrations of per- and polyfluoroalkyl substances in source and treated drinking waters in Ontario, Canada. Sci Total Environ. 2020;748:141195. Available from: https://doi.org/10.1016/j.scitotenv.2020.141195

39. Health Canada. Water talk - perfluoroalkylated substances in drinking water [Internet]. Ottawa, ONN: Government of Canada; 2019 [cited 2022 Jul 13]. Available from: https://www.canada.ca/en/services/health/publications/healthy-living/water-talk-drinking-water-screening-values-perfluoroalkylated-substances.html

40. Agency for Toxic Substances and Disease Registry (ATSDR). Per- and polyfluoroalkyl substances (PFAS) and your health: PFAS and breastfeeding [Internet]. Boston, MA: ATSDR; 2021 [cited 2022 Jul 14]. Available from: https://www.atsdr.cdc.gov/pfas/health-effects/pfas-breastfeeding.html

41. Agency for Toxic Substances and Disease Registry (ATSDR). Per- and polyfluoroalkyl substances (PFAS) and your health: how can I be exposed [Internet]. Boston, MA: ATDSR; 2022 [cited 2022 Jul 13]. Available from: https://www.atsdr.cdc.gov/pfas/health-effects/exposure.html

42. Rawn DFK, Dufresne G, Clément G, Fraser WD, Arbuckle TE. Perfluorinated alkyl substances in Canadian human milk as part of the Maternal-Infant Research on Environmental Chemicals (MIREC) study. Sci Total Environ. 2022;831:154888. Available from: https://doi.org/10.1016/j.scitotenv.2022.154888

43. Environmental Protection Agency (EPA). Our current understanding of the human health and environmental risks of PFAS [Internet]. Washington, DC: EPA; 2022 [cited 2022 Jul 13]. Available from: https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas

44. Oklahoma State University. Contaminant of emerging concern: per- and polyfluroalkyl substance (PFAS) [Internet]. [cited 2022 Sep 16]. Available from:

https://extension.okstate.edu/programs/solid-waste-management/contaminant-of-emerging-concern-per-and-polyfluroalkyl-substance-pfas.html

45. Michigan Department of Environment, Great Lakes and Energy. Frequently asked questions on air quality related issues Air Quality Workgroup – Michigan PFAS Action Response Team (MPART) [Internet]. 2019 [cited 2022 Sep 30]. Available from: https://www.michigan.gov/-/media/Project/Websites/pfasresponse/documents/MPART/Workgroup/Air-Quality/FAQ-Air-Quality-Related-Issues.pdf?rev=2e8807a55c32424696cad59e4b47ede2

46. Health Canada. Sixth report on human biomonitoring of environmental chemicals in Canada: results of the Canadian Health Measures Survey Cycle 6 (2018–2019) [Internet]. 2021. Available from: https://www.canada.ca/content/dam/hc-sc/documents/services/environmental-workplace-health/reports-publications/environmental-contaminants/sixth-report-human-biomonitoring/pub1-eng.pdf

47. Xia C, Diamond ML, Peaslee GF, Peng H, Blum A, Wang Z, et al. Per- and polyfluoroalkyl substances in North American school uniforms. Environ Sci Technol. 2022;56(19):13845-57. Available from: https://doi.org/10.1021/acs.est.2c02111

48. Agency for Toxic Substances and Disease Registry (ATSDR). PFAS in the US population [Internet]. Boston, MA: ATSDR; 2022 [cited 2023 Feb 8]. Available from: https://www.atsdr.cdc.gov/pfas/health-effects/us-population.html

49. Centers for Disease Control and Prevention (CDC). Biomonitoring data tables for environmental chemicals [Internet]. Silver Spring, MD: CDC; 2022 [cited 2023 Feb 8]. Available from: https://www.cdc.gov/exposurereport/data_tables.html

50. Agency for Toxic Substances and Disease Registry (ATSDR). Per- and polyfluoroalkyl substances (PFAS) and your health: what are the health effects of PFAS? [Internet]. Boston, MA: ATDSR; 2022 [cited 2022 Jul 13]. Available from: https://www.atsdr.cdc.gov/pfas/health-effects/index.html

51. Costello E, Rock S, Stratakis N, Eckel SP, Walker DI, Valvi D, et al. Exposure to per- and polyfluoroalkyl substances and markers of liver Injury: a systematic review and meta-analysis. Environ Health Perspect. 2022;130(4):046001. Available from: https://doi.org/10.1289/EHP10092

52. Gui SY, Chen YN, Wu KJ, Liu W, Wang WJ, Liang HR, et al. Association between exposure to per- and polyfluoroalkyl substances and birth outcomes: a systematic review and meta-analysis. Front Public Health. 2022;10:855348. Available from: https://doi.org/10.3389/fpubh.2022.855348

53. Yang Z, Liu HY, Yang QY, Chen X, Li W, Leng J, et al. Associations between exposure to perfluoroalkyl substances and birth outcomes: a meta-analysis. Chemosphere. 2022;291(Pt 2):132909. Available from: https://doi.org/10.1016/j.chemosphere.2021.132909

54. Deji Z, Liu P, Wang X, Zhang X, Luo Y, Huang Z. Association between maternal exposure to perfluoroalkyl and polyfluoroalkyl substances and risks of adverse pregnancy outcomes: a systematic review and meta-analysis. Sci Total Environ. 2021;783:146984. Available from: https://doi.org/10.1016/j.scitotenv.2021.146984

55. Gao X, Ni W, Zhu S, Wu Y, Cui Y, Ma J, et al. Per- and polyfluoroalkyl substances exposure during pregnancy and adverse pregnancy and birth outcomes: a systematic review and meta-analysis. Environ Res. 2021;201:111632. Available from: https://doi.org/10.1016/j.envres.2021.111632

56. Bartell SM, Vieira VM. Critical review on PFOA, kidney cancer, and testicular cancer. J Air Waste Manag Assoc. 2021;71(6):663-79. Available from: https://doi.org/10.1080/10962247.2021.1909668

57. Steenland K, Winquist A. PFAS and cancer, a scoping review of the epidemiologic evidence. Environ Res. 2021;194:110690. Available from: https://doi.org/10.1016/j.envres.2020.110690

58. Luo Y, Deji Z, Huang Z. Exposure to perfluoroalkyl substances and allergic outcomes in children: a systematic review and meta-analysis. Env Res. 2020;191:110145. Available from: https://doi.org/10.1016/j.envres.2020.110145

59. Zhang X, Xue L, Deji Z, Wang X, Liu P, Lu J, et al. Effects of exposure to per- and polyfluoroalkyl substances on vaccine antibodies: a systematic review and meta-analysis based on epidemiological studies. Environ Pollut Barking Essex. 2022 Aug 1;306:119442. Available from: https://doi.org/10.1016/j.envpol.2022.119442

60. Petersen KU, Larsen JR, Deen L, Flachs EM, Hærvig KK, Hull SD, et al. Per- and polyfluoroalkyl substances and male reproductive health: a systematic review of the epidemiological evidence. J Toxicol Env Health B Crit Rev. 2020;23(6):276-91. Available from: https://doi.org/10.1080/10937404.2020.1798315

61. International Agency for Research on Cancer (IARC). Some chemicals used as solvents and in polymer manufacture: IARC monographs on the evaluation of carcinogenic risks to humans, volume 110. Geneva: World Health Organization (WHO); 2017. Available from: https://publications.iarc.fr/547

62. Environmental Protection Agency (USEPA). Per- and polyfluoroalkyl substances (PFAS) [Internet]. Washington, DC: EPA; 2022 [cited 2023 Mar 22]. Available from: https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

63. North Bay Parry Sound District Health Unit. Perfluoroalkylated substances in water: Medical Officer of Health report and recommendations [Internet]. Parry Sound, ON: North Bay Parry Sound District Health Unit; 2017 [cited 2023 Mar 22]. Available from: https://www.myhealthunit.ca/en/community-data-and-reports/resources/Reports-Statistics--Geographic-Profiles/Environmental-health/PFAS-MOH-Report-and-Recommendations-2017-08-15.pdf

64. Ontario. Ministry of the Environment, Conservation and Parks. Minister’s annual report on drinking water (2022) [Internet]. Toronto, ON: King's Printer for Ontario; 2022 [updated 2022 Dec 19; cited 2023 Feb 15]. Available from: http://www.ontario.ca/page/ministers-annual-report-drinking-water-2022

65. Health Canada. Draft objective for per- and polyfluoroalkyl substances in Canadian drinking water. [Internet]. Ottawa, ON: Government of Canada; 2023 [cited 2023 Feb 10]. Available from: https://www.canada.ca/en/health-canada/programs/consultation-draft-objective-per-polyfluoroalkyl-substances-canadian-drinking-water/overview.html

66. Environmental Protection Agency (EPA). Method 533: determination of per- and polyfluoroalkyl substances in drinking water by isotope dilution anion exchange solid phase extraction and liquid chromatography/tandem mass spectrometry [Internet]. Washington, DC: EPA; 2019 [cited 2023 Feb 15]. Available from: https://www.epa.gov/sites/default/files/2019-12/documents/method-533-815b19020.pdf

67. Environmental Protection Agency (EPA). Method 537.1: determination of selected per- and polyfluorinated alkyl substances in drinking water by solid phase extraction and liquid chromatography/tandem mass spectrometry [Internet]. Washington, DC: EPA; 2020 [cited 2023 Feb 15]. Available from: https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=343042&Lab=NERL

68. Environmental Protection Agency (EPA). Drinking water health advisories for PFOA and PFOS [Internet]. Washington, DC: EPA; 2022 [cited 2023 Mar 22]. Available from: https://www.epa.gov/sdwa/drinking-water-health-advisories-pfoa-and-pfos

69. Environmental Protection Agency (EPA). Drinking water health advisories for GenX chemicals and PFBS [Internet]. Washington, DC: EPA; 2022 [cited 2023 Mar 22]. Available from: https://www.epa.gov/sdwa/drinking-water-health-advisories-genx-chemicals-and-pfbs

70. Environmental Protection Agency (EPA). Drinking water health advisories (HAs) [Internet]. Washington, DC: EPA; 2022 [cited 2023 Mar 22]. Available from: https://www.epa.gov/sdwa/drinking-water-health-advisories-has

71. Environmental Protection Agency (EPA). Per- and polyfluoroalkyl substances (PFAS): proposed PFAS national primary drinking water regulation [Internet]. Washington, DC: EPA; 2023 [cited 2023 Mar 16]. Available from: https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

72. Environmental Protection Agency (EPA). Public comment draft toxicity assessment and proposed maximum contaminant level goal for perfluorooctanoic acid (PFOA) in drinking water [Internet]. Washington, DC: EPA; 2023 [cited 2023 Mar 16]. Available from: https://www.epa.gov/system/files/documents/2023-03/MAIN_Proposed%20MCLG%20for%20PFOA%20in%20Drinking%20Water_3.9.23_For%20Proposal.pdf

73. Environmental Protection Agency (EPA). Public comment draft toxicity assessment and proposed maximum contaminant level goal for perfluorooctane sulfonic acid (PFOS) in drinking water [Internet]. Washington, DC: EPA; 2023 [cited 2023 Mar 16]. Available from: https://www.epa.gov/system/files/documents/2023-03/MAIN_Proposed%20MCLG%20for%20PFOS%20in%20Drinking%20Water_3.9.23_For%20Proposal_0.pdf

74. Environmental Protection Agency (EPA). Public review draft: maximum contaminant level goal (MCLG) summary document for a mixture of four per- and polyfluoroalkyl substances (PFAS): HFPO-DA and its ammonium salt (also known as GenX chemicals), PFBS, PFNA, and PFHxS [Internet]. Washington, DC: EPA; 2023 [cited 2023 Mar 16]. Available from: https://www.epa.gov/system/files/documents/2023-03/PFAS%20HI%20MCLG%20Public%20Review%20Draft%2009%20March%202023.pdf

75. Interstate Technology Regulatory Council (ITRC). Fact sheets: PFAS water and soil regulatory and guidance values table excel file [Internet]. Washington, DC: ITRC; 2022 [cited 2023 Mar 22]. Available from: https://pfas-1.itrcweb.org/wp-content/uploads/2022/09/ITRCPFASWaterandSoilValuesTables_AUG2022-Final.xlsx

76. Environmental Protection Agency (EPA). Reducing PFAS in drinking water with treatment technologies [Internet]. Washington, DC: EPA; 2018 [cited 2023 Mar 22]. Available from: https://www.epa.gov/sciencematters/reducing-pfas-drinking-water-treatment-technologies

77. NSF. PFOA/PFOS reduction claims requirements added to NSF standards for drinking water treatment devices [Internet]. Guelph, ON: NSF; 2019 [cited 2023 Mar 22]. Available from: https://www.nsf.org/news/pfoa-pfos-reduction-claims-requirements-added-to-nsf-standards

78. Canadian Council of Ministers of the Environment (CCME). Scientific criteria document for the development of the Canadian soil and groundwater quality guidelines for the protection of environmental and human health [Internet]. 2021. Available from: https://ccme.ca/en/res/pfossoilandgroundwaterqualityguidelinesscden.pdf

79. Canadian Council of Ministers of the Environment (CCME). Guidelines: Canadian Environmental Quality Guidelines (CEQGs) provide science-based goals for the quality of aquatic and terrestrial ecosystems. Gatineau, QC: Canadian Council of Ministers of the Environment; 2021. Available from: https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines

80. Environmental Protection Agency (EPA). Meaningful and achievable steps you can take to reduce your risk [Internet]. Washington, DC: EPA; 2022 [cited 2022 Sep 12]. Available from: https://www.epa.gov/pfas/meaningful-and-achievable-steps-you-can-take-reduce-your-risk

81. Ontario. Ministry of the Environment, Conservation and Parks. Map: guide to eating Ontario fish [Internet]. Toronto, ON: King's Printer for Ontario; 2022 [cited 2023 Mar 22]. Available from: https://www.ontario.ca/page/eating-ontario-fish

82. Agency for Toxic Substances and Disease Registry (ATSDR). PFAS exposure assessment community update – online information session [Internet]. Boston, MA: ATSDR; 2021 [cited 2022 Sep 13]. Available from: https://www.atsdr.cdc.gov/pfas/activities/assessments/online-session.html

83. European Environment Agency. Emerging chemical risks in Europe — 'PFAS' [Internet]. Copenhagen; European Environment Agency; 2019 [cited 2022 Sep 14]. Available from: https://www.eea.europa.eu/publications/emerging-chemical-risks-in-europe

84. Whitehead HD, Venier M, Wu Y, Eastman E, Urbanik S, Diamond ML, et al. Fluorinated compounds in north american cosmetics. Environ Sci Technol Lett. 2021;8(7):538-44. Available from: https://doi.org/10.1021/acs.estlett.1c00240

85. Environment and Climate Change Canada. Canadian Environmental Protection Act, 1999: Federal Environmental Quality Guidelines, Perfluorooctane Sulfonate (PFOS) [Internet]. Ottawa, ON: Government of Canada; 2018 [cited 2023 Mar 22]. Available from: https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/federal-environmental-quality-guidelines-perfluorooctane-sulfonate.html

86. Gewurtz SB, Bradley LE, Backus S, Dove A, McGoldrick D, Hung H, et al. Perfluoroalkyl acids in Great Lakes precipitation and surface water (2006–2018) indicate response to phase-outs, regulatory action, and variability in fate and transport processes. Environ Sci Technol. 2019 Aug 6;53(15):8543-52. Available from: https://doi.org/10.1021/acs.est.9b01337

Appendix A: PFAS Levels in the Environment

Table A: PFOS levels measured in Canadian water, fish, sediment, and air as reported in various studies.[26,27,38,85,86]

Environmental Sample Type	Sample Description	Measured PFOS Concentrations
Surface Water	Samples collected from 29 sampling sites across Canada between 2013-2020	Median concentration of 2.3 ng/L Maximum concentration of 27.6 ng/L
	Samples collected from the Great Lakes Nearshore Index and Reference Stations between 2005 and 2019	Median concentrations of 2.30 ng/L (2005-2007) and 2.15 ng/L (2018-2019) Mean (95% CI) concentrations of 3.74 ng/L (2005-2007) and 2.03 ng/L (2018-2019) Maximum concentrations of 15 ng/L (2005-2007) and 10 ng/L (2018-2019)
	Samples collected from the Great Lakes basin between 2006 and 2018 (includes precipitation and surface water)	Median concentration of 0.93 and 2.1 ng/L in precipitation and surface water, respectively Maximum concentration of 7.4 and 14 ng/L in precipitation and surface water, respectively
	Samples collected from 8 drainage sites across Canada between 2016-2017	Concentration range of 2 – 26.1 ng/L
	Samples collected from 11 drainage regions across Canada between 2007-2010	Maximum concentration of 10 ng/L
Fish	Lake Ontario lake trout tissue collected between 2013-2014	Concentration range of 40-60 µg/kg
	Lake Ontario lake trout and walleye collected in 2006 and 2010	Geometric mean of 62 µg/kg
	Lake Erie lake trout and walleye collected in 2006 and 2010	Geometric mean of 90 µg/kg
Sediment	Samples collected from 18 sites across Canada in 2008	Maximum concentration of 0.010 µg/g dry-weight from Lake Ontario

Environmental Sample Type	Sample Description	Measured PFOS Concentrations
Air	High-volume air samples collected from three locations in 2009	Geometric mean: Toronto, ON: 1.5 pg/m^3 Lake Superior: 0.43 pg/m^3 Alert, NU: 0.2 pg/m^3
	Passive air samples collected from eight locations in 2009	Single sample results: Northern Ontario: 18 pg/m^3 Toronto, ON: 8 pg/m^3 Saskatchewan: 5 pg/m^3 Whistler, BC: 4 pg/m^3 Alert, NU: 2 pg/m^3 (Not detected at other sites)
Groundwater	Samples collected from sites with known PFAS contamination (firefighting training areas at airports)	Concentration range: London, ON: 5,000 – 130,000 ng/L Hamilton, ON: <20 – 560,000 ng/L

Note: Groundwater data has been converted from µg/L to ng/L for comparison purposes

Appendix B: Drinking water guideline values for PFAS in Ontario and Canada

Table B - MECP interim drinking water guidelines and Health Canada maximum acceptable concentrations and screening values for various PFAS. All concentrations are expressed in nanograms per litre (ng/L).

PFAS Chemical	MECP Interim Guideline[64]	Health Canada Guidelines[39]
Perfluorobutanoate (PFBA)	-	30000^{SV}
Perfluoropentanoate (PFPeA)	-	200^{SV}
Perfluorohexanoate (PFHxA)	-	200^{SV}
Perfluoroheptanoate (PFHpA)	-	200^{SV}
Perfluorobutane sulfonate (PFBS)	-	15000^{SV}
Perfluorooctanoic acid (PFOA)	-	200^{MAC}
Perfluorononanoate (PFNA)[1]	-	20^{SV}
Perfluorodecanoic acid (PFDA)	-	-
Perfluoroundecanoic acid (PFUnA)	-	-
Perfluorododecanoic acid (PFDoA)	-	-
Perfluorohexanesulfonate (PFHxS)	-	600^{SV}
Perfluorooctane sulfonate (PFOS)	-	600^{MAC}
Perfluorodecanesulfonic acid (PFDS)	-	-
Perfluorodecanesulfonic acid (PFOSA)	-	-
6:2 fluorotelomer sulfonate (6:2 FTS)	-	200^{SV}
8:2 fluorotelomer sulfonate (8:2 TS)	-	200^{SV}
Sum of eleven PFAS chemicals	70	-

Notes:
The MECP's interim drinking water guideline for PFAS is based on the sum of 11 PFAS chemicals.
Values denoted with MAC are maximum allowable concentrations.
Values denoted with SV are screening values.
"-" guideline value is not available for this substance.

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