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Objective for Canadian Drinking Water Quality

Per- and Polyfluoroalkyl Substances

Objective for Public Consultation

Consultation Period ends April 12, 2023

Purpose of consultation

This technical document has been developed with the intent to provide regulatory authorities and decision-makers with an objective for per- and polyfluoroalkyl substances in Canadian drinking water supplies.

This document is available for a 60-day public consultation period. The purpose of this consultation is to solicit comments on the proposed objective, on the approach used to develop it and on the potential impacts of implementing it.

Please send comments (with rationale, where required) to Health Canada via email to water-eau@hc-sc.gc.ca. If email is not feasible, comments may be sent by postal mail to this address:

Water and Air Quality Bureau, Health Canada
269 Laurier Avenue West, A.L. 4903D
Ottawa, ON K1A 0K9

All comments must be received before April 12, 2023. Comments received as part of this consultation will be shared with members of the Federal-Provincial-Territorial Committee on Drinking Water (CDW), along with the name and affiliation of their author. Authors who do not want their name and affiliation shared with CDW members should provide a statement to this effect along with their comments.

Note that this objective document will be revised following the evaluation of comments received. This document should be considered as a draft for comment only.

Information on objectives for drinking water

The main responsibility of the Federal-Provincial-Territorial Committee on Drinking Water is to work in collaboration with Health Canada to develop and update the *Guidelines for Canadian Drinking Water Quality*.

The development of a guideline follows a multi-year, comprehensive scientific process and takes many years to finalize. In rare instances, new information on a contaminant raises concerns that need to be addressed more quickly than the guideline development process allows. In such cases, Health Canada, in collaboration with the provincial and territorial governments, may establish a drinking water objective to reduce exposure while a guideline is revised or developed. This is the case with per- and polyfluoroalkyl substances (PFAS).

Drinking water objectives set out a goal for a maximum level of a contaminant in drinking water, taking into account available treatment technology and analytical methods. They are based on a review of scientific research and consider international regulatory information available at the time of their development. Drinking water objectives are externally peer reviewed to ensure scientific integrity.

Contents

Proposed objective value

To reduce exposure from drinking water, an objective of 30 ng/L is proposed for the sum of total per- and polyfluoroalkyl substances (PFAS) detected in drinking water. Total PFAS should be calculated using the full list of substances in either the United States Environmental Protection Agency (U.S. EPA) Method 533 or U.S. EPA Method 537.1, or both (see Appendix A). A jurisdiction could also validate and apply an alternate analytical method that quantifies a minimum of 18 PFAS. For the purposes of this proposed objective, a result of non-detect is considered to have a value of zero. It is recommended that treatment plants strive to maintain PFAS concentrations in drinking water as low as reasonably achievable (ALARA).

Background

In 2018 and 2019, Health Canada established drinking water guidelines for perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), and screening values for 9 other PFAS including perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA), perfluorohexanoate (PFHxA), perfluoroheptanoate (PFHpA), perfluorononanoate (PFNA), perfluorobutane sulfonate (PFBS), perfluorohexanesulfonate (PFHxS), 6:2 fluorotelomer sulfonate (6:2 FTS) and 8:2 fluorotelomer sulfonate (8:2 FTS). These values applied to water intended for human consumption. Note that full names for any other PFAS mentioned in this document are in Appendix A or B.

On April 24, 2021, the Government of Canada notified Canadians of its intent to move forward with activities that address PFAS as a class. In accordance with this strategy and considering new scientific evidence in the field of hazard and exposure assessment as well as in treatment and analytical technologies, a review of the current PFAS drinking water guidelines and screening values is under way.

To reduce potential exposure to PFAS through drinking water while the reassessment of the guidelines and screening values is being completed, an objective based on the sum of specific detected PFAS is proposed for Canadian drinking water. This objective, when finalized, will replace the 2 previous drinking water guidelines and 9 screening values derived for individual PFAS. This technical document was prepared in collaboration with the Federal-Provincial-Territorial Committee on Drinking Water (CDW).

Exposure considerations

PFAS are a family of thousands of substances that contain linked fluorine and carbon atoms. This chemical link results in a very stable molecule that is essentially unreactive and persists in the environment. Because of their unique properties, PFAS have a wide range of uses including as surfactants, lubricants and repellents (for dirt, water and grease). PFAS can also be found in products as diverse as firefighting foams, textiles (for example, carpets, furniture and clothing), cosmetics and food packaging materials. In Canada, some of the legacy PFAS (that is, PFOA, PFOS and long-chain PFCAs, their salts and their precursors) have been prohibited from manufacture, use and import, with a limited number of exemptions. PFAS primarily enter Canada in products or as constituents of manufactured items. Some PFAS may be used in industrial processes, which may lead to releases from industrial facilities into the environment. Releases can also occur from landfills and wastewater treatment plants, and due to the reuse of biosolids from wastewater treatment plants (Guerra et al., 2014; Hamid et al., 2018). Many studies have demonstrated that PFAS are transported long distances through the atmosphere, in water bodies and within groundwater. In addition to drinking water, research indicates that Canadians can be exposed to PFAS through food (Tittlemier et al., 2007), dust (De Silva et al., 2012; Eriksson and Kärrman, 2015; Karaskova et al., 2016; Kubwabo et al., 2005; Shoeib et al., 2011) and indoor air (Beesoon et al., 2012; Shoeib et al., 2011).

In Canada, major sources of PFAS contamination of the aquatic environment are associated with both point and non-point sources. Non-point sources of PFAS may include surface runoff from urban areas and wet/dry atmospheric deposition (Lalonde and Garron, 2022). The most common point sources of PFAS contamination are associated with the use of aqueous film-forming foams (AFFFs) to extinguish fuel fires or during firefighting training (for example, at airports and military bases) (D'Agostino and Mabury, 2017; Liu et al., 2021). These AFFFs contain proprietary mixtures of PFAS and other chemicals. A number of PFAS are detected in groundwater at former fire-training areas. However, PFAS are also reported in ground and surface water at other types of sites (for example, emergency response locations, AFFF lagoons, hangar-related storage tanks, firefighting equipment maintenance areas and pipelines or infrastructure impacted by AFFFs) (Awad et al., 2011; Anderson et al., 2016; Milley et al., 2018). PFAS can migrate long distances through soil and water beyond the point at which they entered the environment.

There are limited data regarding PFAS in Canadian freshwater sources and drinking water. The number and suite of PFAS present in any given drinking water source will vary depending on the source of contamination, environmental conditions as well as new and historical patterns of use.

In a study focused on examining the presence of PFAS in freshwater, 29 sites across Canada were sampled from 2013 to 2020 for 13 different PFAS to determine concentrations and trends. Sampling sites and frequencies varied during the study. Detection limits ranged from 0.4 to 1.6 ng/L. Of the 13 PFAS detected in 566 freshwater samples, the study found PFBA, PFPeA, PFHxA, PFHpA, PFOA and PFOS to have higher detection frequencies than the other PFAS. Within this group of PFAS, concentrations of PFBA and PFPeA increased significantly over the 2013 to 2020 period whereas concentrations of PFHpA, PFOA and PFOS decreased. The highest concentrations were noted to be 138 ng/L for PFBS (although this PFAS had fewer detections than the six PFAS identified above) and PFHxA at 137 ng/L. The authors note that this study found a higher frequency of detections of the replacement PFAS, such as PFBA, PFPeA, PFHxA, PFHpA and PFBS, than that seen in older Canadian studies (Lalonde and Garron, 2022).

In Saskatchewan, the Water Security Agency collected drinking water samples (n = 7) from 7 water treatment plants in 2018–2019 to determine levels of PFOA and PFOS in treated drinking water. Neither PFOA nor PFOS were detected (method detection limit [MDL]: 2 ng/L) in the drinking water of 6 out of 7 communities. PFOA was detected in the single sample from one drinking water treatment plant at a concentration of 3 ng/L (Saskatchewan Water Security Agency, 2022).

Between 2012 and 2016, the Ontario Ministry of the Environment, Conservation and Parks measured the occurrence and concentrations of 14 PFAS (PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFBS, PFHxS, PFOS, PFDS and PFOSA) in 25 drinking water systems in Ontario (water intakes and treated drinking water). MDLs ranged from 0.5 to 1 ng/L, and results less than the MDL were substituted with a value of half the MDL (Kleywegt et al., 2020). PFUnA, PFDoA PFDS and PFOSA were not detected in any drinking water samples. The most frequently detected compounds in Ontario drinking water were PFOA (73%; median 1.1 ng/L, maximum 6.6 ng/L), PFBA (67%; median 2.4 ng/L, maximum 10 ng/L), PFHxA (54%; median 1.3 ng/L, maximum 13 ng/L), PFPeA (51%; median 1.0 ng/L, maximum 15 ng/L) and PFOS (50%; median 0.63 ng/L, maximum 5.9 ng/L).

Between 2016 and 2021, Quebec's Ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC) sampled 41 drinking water treatment systems, testing for 18 PFAS (PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFBS, PFHxS, PFHpS, PFOS, PFDS, FHUEA, FOUEA, 4:2 FTS, 6:2 FTS, 8:2 FTS). Both surface and groundwater systems were included, with groundwater systems added in 2018 (MELCC, 2022). The sampling sites were selected based on previous PFAS detections and/or concerns in those locations, or due to their proximity to known potential point sources of PFAS. Detection limits ranged from 0.5 to 5 ng/L for raw water samples and from 0.3 to 5 ng/L for treated water samples. Among the 18 PFAS analyzed, 6 (PFPeA, PFHxA, PFHpA, PFOA, PFNA and PFOS) were detected in 10% or more of the samples taken. The 2016 data showed a reduction in the maximum concentrations of PFOA and PFOS (6 ng/L and 3 ng/L, respectively) when compared with the maximum surface water concentrations from the same sites sampled in 2007–2008 (66 ng/L for PFOA and 8.8 ng/L for PFOS). In the St. Lawrence River and other rivers, 5 substances (PFHxA, PFHpA, PFOA, PFNA and PFOS) were detected in at least 30% of the samples. PFOA and PFHxA were detected at the highest frequency (72% and 59%, respectively); both had a maximum concentration of 6 ng/L and a median concentration of 2 ng/L. In Lake Memphremagog, PFOA (median 1 ng/L, maximum 2 ng/L) and PFHxA (median 1.5 ng/L, maximum 3 ng/L) were detected in raw water; both were also found in treated drinking water at a maximum of 1 ng/L and median of 1 ng/L each. In groundwater sources, PFPeA (median 4 ng/L, maximum 48 ng/L) and PFHxA (median 3 ng/L, maximum 30 ng/L) were found in 14% and 17% of samples respectively, while PFOA (median 2 ng/L, maximum 4 ng/L) and PFOS (median 2 ng/L, maximum 3 ng/L) were found in 6% and 4% of samples (MELCC, 2022).

In Nova Scotia, as of 2019, municipalities have been required to test the raw and treated drinking water for the presence of PFOA and PFOS. Neither PFOA nor PFOS have been detected (MDL: 20 ng/L) in the 9 systems tested to date (NSECC, 2022).

Similar median concentrations of PFBA, PFPeA, PFHxA, PFOA and PFOS were reported in samples of drinking water sourced from 19 sites around Lake Ontario and the St. Lawrence River (n = 8) and other lakes and small rivers in Canada (n = 11). Maximum concentrations of PFAS ranged from 0.1 ng/L (PFDA) to 4.1 ng/L (PFOS) in the Great Lakes–St. Lawrence samples, and 0.1 ng/L (PFUnA) to 4.9 ng/L (PFOA) for the rest of the Canadian tap water samples. PFHxA was detected in all Canadian tap water samples from this study. Other PFAS that were frequently detected included PFBA (95%), and PFHxS and PFOS (both 89%), while PFPeA, PFHpA, PFOA, PFNA, PFDA and PFBS were detected in at least 84% of the samples. Compounds detected less frequently in Canadian waters included FOSA (53%), 6:2 FTSA (37%) and 5:3 FTCA (11%), as well as PFUnA, PFDoA and 7:3 FTCA, which were each detected in less than 10% of samples. A qualitative screening approach indicated that FBSA, FHxSA, PFECHS and PFPeS were occasionally present in tap water (concentrations ranged from below the limit of detection to 1.2 ng/L), whereas PFEtS, PFPrS and PFPeS were below the limit of detection for all Canadian samples. The limits of detection for tap water ranged from 0.01 to 0.08 ng/L (Kaboré et al., 2018).

The U.S. EPA completed drinking water monitoring of 6 PFAS (PFHpA, PFOA, PFNA, PFBS, PFHxS and PFOS) between 2013 and 2015 under the Third Unregulated Contaminant Monitoring Rule (UCMR3). The results showed that 1.6% of the 36 977 samples and 4% of the

4 920 public water systems reported at least one detectable PFAS compound (Guelfo and Adamson, 2018). The minimum reporting levels (MRLs) ranged from 10 to 90 ng/L for the monitored PFAS compounds and were generally higher than the limit of quantitation of most published studies (Hu et al., 2016). PFOA (MRL 20 ng/L) and PFOS (MRL 40 ng/L) were detected most frequently across all system sizes and source types at 1.03% and 0.79%, respectively. The highest maximum concentrations of PFOS (7 000 ng/L), PFHxS (1 600 ng/L), PFHpA (410 ng/L), PFOA (349 ng/L) and PFNA (56 ng/L) were detected in large systems with a groundwater source. PFBS (MRL 90 ng/L) was detected only in large systems, and the highest maximum concentration of 370 ng/L was observed in a large system supplied by a surface water source (Crone et al., 2019). An analysis of the UCMR3 data found that approximately 50% of samples with PFAS detections contained 2 or more PFAS and 72% of detections occurred in groundwater (Guelfo and Adamson, 2018). Certain activities were significant predictors of PFAS detection frequencies and concentrations in public water supplies (that is, the number of industrial sites that manufacture or use PFAS compounds, the number of military fire training areas and the number of wastewater treatment plants) (Hu et al., 2016).

Health considerations

While many substances and groups within the PFAS class are data poor and exhibit different properties, well-studied PFAS are persistent in the environment and have been detected in humans, wildlife and environmental media worldwide (Wang et al., 2017). Some PFAS biomagnify in food webs and have the potential to adversely affect both wildlife and human health. In humans, some well-studied PFAS, such as the perfluorocarboxylic and sulfonic acids, have been shown to be readily absorbed in the body and bind to proteins in the blood which serve as the primary transport mechanism (Kudo, 2015; Forsthuber et al., 2020). Once distributed throughout the body, these substances accumulate in the blood and well-perfused tissues such as the liver and kidneys (Kudo, 2015). Some of these substances can cross the placental barrier, resulting in potential in utero exposure to the developing fetus (Mamsen et al., 2019; Wang et al., 2019; Li et al., 2020) and can also be transferred to infants and children via human milk (VanNoy et al., 2018). Available data show that certain PFAS are eliminated very slowly from the body, likely due to their strong protein binding affinity and internal reabsorption processes (Yang et al., 2010; EFSA, 2020). As such, some PFAS (for example, PFOA, PFNA, PFHxS and PFOS) can accumulate and persist in the body for years (ATSDR, 2021). Other shorter chain PFAS (such as PFBA and PFHxA) are eliminated more quickly with estimated half-lives ranging from several days to several weeks (Chang et al., 2008; Russell et al., 2015).

Toxicological (in vitro and in vivo) and epidemiological information is available for only a limited number of PFAS. The most comprehensively studied PFAS are PFOS and PFOA. Limited information exists for several other PFAS (for example ether PFAS and fluorotelomer-based substances), while no data are available on the vast majority of PFAS (Pelch et al., 2021). Based on the available information, it is evident that exposure to certain PFAS has the potential to affect multiple systems and organs (ATSDR, 2021). Further, many PFAS have been shown to affect the same organs and systems. The main targets affected in humans include the liver, immune system, endocrine system (thyroid), fertility, development and metabolism (cholesterol, body weight) (Sanexen, 2021). In addition, testicular and kidney cancers have been specifically linked to exposures to PFOA (IARC, 2017) and the California EPA has added PFOS to its list of chemicals known to cause cancer (OEHHA, 2021). Many of the effects seen in humans are supported by experimental studies in animal models. New information on well-studied PFAS shows effects at lower levels than previous studies (for example, HFPO-DA and its ammonium salt [U.S. EPA, 2021a]) and key endpoints of concern that were not previously considered as critical effects (Sanexen, 2021). Currently, only a small number of PFAS are monitored in human biomonitoring surveys. These PFAS have been found in the blood (plasma or serum) of the general population in Canada and internationally. Canadians are exposed to multiple PFAS simultaneously as can be seen from biomonitoring data (Health Canada, 2021a). The hazards of exposure to PFAS mixtures are largely unknown, although antagonistic, synergistic and additive effects have all been observed in a limited number of in vitro and in vivo studies (Ojo et al., 2021). Studies also indicate that, in areas where drinking water is an important exposure source for PFAS, the treatment of drinking water to reduce PFAS levels can reduce serum PFAS levels and possibly adverse health outcomes (Herrick et al., 2017; Waterfield et al., 2020).

Analytical considerations

This proposed objective for PFAS in drinking water refers to two validated, standardized U.S. EPA methods that are available for the quantitation of a combined total of 29 compounds: EPA Methods 533 and 537.1 (respectively, U.S. EPA 2019, 2020). These analytical methods are specific, sensitive and practical for application in commercial laboratories. The MRLs established under the 5th cycle of the UCMR (UCMR 5) (U.S. EPA, 2021b) for the analysis of PFAS using these methods range from 2 to 20 ng/L and are listed in Appendix A. A jurisdiction could also validate and apply an alternate analytical method that quantifies a minimum of 18 PFAS.

EPA Method 533 is an isotope-dilution/anion exchange/solid-phase extraction (SPE) liquid chromatography/tandem mass spectrometry (LC-MS/MS) method for the determination of select PFAS in drinking water. It requires the use of MS/MS in multiple-reaction-monitoring (MRM) mode to enhance selectivity and specificity for compounds of interest. EPA Method 533 measures 25 specific PFAS (none greater than C12 chain length), including perfluorinated acids, sulfonates, fluorotelomer sulfonates and poly/perfluorinated ether carboxylic acids.

EPA Method 537.1 is an isotope-dilution/hydrophobic SPE LC-MS/MS method for the determination of select PFAS in drinking water. This method measures 18 specific PFAS, including perfluorocarboxylic acids up to 14 carbons in length. It differs from Method 533 in that the concentration technique used relies on hydrophobic interactions, and as such is not suitable for the more hydrophilic shorter carbon chain PFAS, such as PFBA and PFPeA.

EPA Method 533 complements EPA Method 537.1, with 14 PFAS in common and no inherent differences in MRLs. However, Method 533 can measure 11 additional PFAS compared with Method 537.1, including more hydrophilic chemicals such as PFBA. By combining both methods, a total of 29 unique PFAS can be effectively measured in drinking water. Many laboratories can reliably report at 2 ng/L for most PFAS and 5 ng/L for the rest (see Appendix A). Because they rely on different sample concentration techniques, the 2 methods require separate sample preparation procedures and cannot be combined into a single analysis. In Canada, laboratories are generally accredited for EPA Method 537.1 (CALA, 2022). However, it is recognized that EPA Method 533 would provide better coverage of the PFAS observed in Canadian data noted in the exposure considerations section.

Given the overlap between the 2 EPA methods and to avoid duplication, the authorities responsible for drinking water may specify one method be used. Utilities should take into consideration the potential sources of PFAS and select a method that will provide analyses that include PFAS that may be present in the drinking water. Guidance on site characterization is available elsewhere (U.S. EPA, 2022a; ITRC, 2020, 2022a).

Total PFAS should include all PFAS listed in a method and detected in a sample. Any value above the MDL should be included in the summation for total PFAS, recognizing that a value of zero is assigned for any value below the detection limit. Where possible, utilities should strive to analyze as many PFAS as possible to gain a better understanding of the PFAS present in the drinking water to inform the selection of treatment that will reduce exposure to the greatest extent possible. Any detected PFAS, from all analyses undertaken, should be summed, and this sum should still not exceed the proposed objective value of 30 ng/L. When more than one method is used for the analysis, it is not necessary to do a duplicate analysis where there is overlap between methods. However, if duplicate analysis occurs, the highest of the duplicate individual PFAS results should be taken for the summation.

S*creening methods*

PFAS precursors can degrade to perfluoroalkyl acids (PFAAs) under the right environmental conditions. The Total Oxidizable Precursors (TOP) assay oxidizes PFAS precursors into their corresponding PFAAs, which can then be measured using the EPA methods or other methodologies. It is a useful screening tool that can help provide a better understanding of the amount of PFAS in a sample including unknown precursor species that might otherwise be missed (that is, total PFAS load). Because the TOP assay does not identify individual precursors, data typically are reported as the net change in PFAA concentrations before and after oxidation (Rodowa et al., 2020). The TOP assay may under-quantify short-chain PFAA precursors that are telomer-based (ITRC, 2022b).

Another common surrogate analysis for PFAS is the Total Organic Fluorine (TOF) analysis, which can be used for drinking water. While the TOF analysis can be useful, it is indiscriminate and may capture fluorine from non-PFAS compounds. To date, there has been no demonstrated method that avoids having to employ sample preparation steps and that loses a portion of the TOF. The U.S. EPA (2022b) has released a draft Adsorbable Organic Fluorine (AOF) method (EPA Draft Method 1621) for wastewaters that uses carbon adsorption to prepare the sample for the fluoride wash and the final combustion ion chromatography process. However, the application to drinking water is limited because the minimum detection limit is well above concentrations typically seen in drinking water sources.

The TOP assay and TOF analysis can more comprehensively assess the concentration of PFAS beyond the 29 listed in the above methods. However, they are qualitative techniques and not yet standardized, nor have they undergone multi-laboratory validation. Despite their limitations, these assays can provide a better understanding of which PFAS are or may be present in water and their impact on the treatment system's operations. These additional PFAS may break through more rapidly, necessitating more frequent media change-out or regeneration. Data from these assays could be used to augment the data from quantitative methods (ITRC, 2022b).

Treatment considerations

Municipal water treatment

Typically, treatment efficacy studies are carried out with a limited suite of PFAS at concentrations much higher than those observed in raw and treated drinking waters (Crone et al., 2019). Removal efficacies may differ greatly for PFAS with different physicochemical properties (for example, carbon chain length) when evaluated at concentrations relevant to drinking water. A vulnerability assessment should be undertaken to identify hazards, including potential sources of contamination and susceptibility of the source water to PFAS contamination (Health Canada, 2021b). Thorough characterization of the source water is necessary to evaluate the presence, identity and concentration of any PFAS; this information is required to establish operational conditions and to estimate how long treatment media will last before breakthrough occurs. The most effective treatment technologies (> 90% removal efficiencies for certain PFAS) are granular activated carbon (GAC), membrane filtration (reverse osmosis [RO] and nanofiltration [NF]) and anion exchange (AIX) (Appleman et al., 2013, 2014; Dickenson and Higgins, 2016; Sanexen, 2022). Generally, the key issues to consider when selecting treatment technologies for PFAS removal are the presence of competing anions and PFAS species, organic matter and the frequency of regeneration or replacement required for the sorptive medium used (Appleman et al., 2013). The effectiveness of drinking water treatment for PFAS removal will depend on several factors, including source water characteristics, concentration and type of PFAS, treatment goals and proper operation of the system at all times.

Common drinking water treatment technologies (for example, coagulation, flocculation and oxidation) are not effective for PFAS removal. While there are treatment technologies that can effectively remove certain PFAS, no single treatment can remove a wide range of PFAS under all conditions. Each treatment technology has advantages and disadvantages. Achieving the proposed objective may require a treatment train that includes more than one technology, or a technology used multiple times in series to treat the suite of PFAS present in the raw water. To ensure continued and effective removal, each facility should establish operational conditions and parameters based on the selected treatment technology(ies) and the characteristics of the raw water, including PFAS type, concentration and treatment goals.

Disposal or manipulation of sorptive media, concentrates or residuals is also a consideration when selecting a treatment technology for PFAS removal. Treatment and/or disposal of the spent GAC filtration media and backwash water; the ion exchange resins and regeneration concentrates; and the membrane concentrates and wash water, which contain elevated PFAS concentrations, are major issues to consider in the selection and operation of PFAS treatment technology. For example, spent filtration (such as GAC) and ion-exchange media will require specialized disposal (for example, high-temperature regeneration/destruction) to avoid release of PFAS back into the environment. Similarly, membrane technologies will require treatment and disposal of the concentrate, wash water or residual stream (U.S. EPA, 2022c). The availability of disposal options for treatment residuals (including media) may also limit the selection of a treatment technology. The selection may also be limited due to disposal requirements of the relevant authority.

A limited number of bench-scale studies have evaluated the removal of perfluorocarboxylates and perfluorosulfonates by powdered activated carbon (PAC). Based on those study results, median removal efficiency for individual PFAS by PAC was 64.5%

(Sanexen, 2022). Due to inefficiencies, PAC needs to be combined with other treatment technologies to achieve a removal rate of 90% or more. Also, how the settled sludge containing the PFAS-laden PAC will be disposed of needs to be considered.

GAC technology has the most field-relevant data at full- and pilot-scale (Sanexen, 2022), and has proven to effectively remove PFAS from drinking water at relatively low concentrations (Appleman et al., 2014). Additionally, GAC can maintain its performance across a broad range of water chemistries. However, GAC has demonstrated greater affinity for PFAS with chain lengths greater than 6 carbons compared with shorter chain PFAS (Gagliano et al., 2020). In addition, perfluorinated sulfonates are adsorbed more easily by GAC than their carboxylic acid counterparts due to their higher hydrophobicity (Du et al., 2014). As a result, increased frequency of GAC regeneration or replacement will be required when treating certain PFAS (Rodowa et al., 2020). Operational parameters such as GAC type (for example, bituminous coal), bed size and hydraulic loading rate also influence filter run time (Belkouteb et al., 2020). Anion-exchange resin properties, such as porosity, functional group and polymer matrix, influence PFAS treatment efficacy (Gagliano et al., 2020). Given many PFAS exist as anions at drinking water pH, strong base AIX resins are capable of removing these PFAS species (Crone et al., 2019). The AIX process also preferentially removes longer chain PFAS and perfluorosulfonates (Appleman et al., 2014). However, adjustments to AIX resin characteristics (for example, hydrophobicity of functional group) can increase the sorption capacity for less hydrophobic PFAS (Chularueangaksorn et al., 2014; Zaggia et al., 2016). Although AIX resins have the advantage of greater adsorption capacity than GAC, they are typically limited to a single use for drinking water applications (Crone et al., 2019; Ross et al., 2018). However, AIX resin regeneration has been achieved in some studies (Crone et al., 2019), albeit utilizing complex or unconventional procedures.

Membrane technologies such as RO and NF are both highly effective for removal of many PFAS. RO effectively removes PFAS of all chain lengths as a function of size exclusion and charge rejection; NF relies principally on electrostatic repulsion and hydrophobicity, particularly for removal of shorter chain PFAS (Dickenson & Higgins, 2016; Zeng et al., 2017). The degree of RO and NF rejection may vary among PFAS and may be substantially lower for charge-neutral PFAS such as FOSA (Steinle-Darling and Reinhard, 2008; Steinle-Darling et al., 2010; Sanexen, 2022). Both membrane technologies are subject to fouling and scaling problems, which limit their wide-scale application.

Treatment achievability

Studies assessing pilot- and full-scale PFAS treatment achievability have demonstrated that GAC, AIX and RO can each effectively reduce concentrations of shorter chain PFCA and PFSA to below detection limits of < 1 to 2 ng/L for individual PFAS. However, to achieve these concentrations, the treatment systems need to be configured and operated properly. Achieving such low concentrations may also lead to challenging operating conditions, such as very long empty bed contact times or frequent media regeneration or replacement and may not be practically or economically feasible for some water treatment facilities (Sanexen, 2022).

Residential-scale (private well) water treatment technologies

In cases where an individual household obtains their drinking water from a private well, a drinking water treatment device may reduce the concentration of a limited number of PFAS in drinking water. Treatment devices can be certified to NSF Standard 53 (GAC) and NSF

Standard 58 (RO) (NSF International, 2021a, b) for the reduction of PFOS and PFOA from drinking water to a total concentration of 70 ng/L. NSF International has developed revised criteria to reduce total PFAS in drinking water for the following 7 PFAS: PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS and PFOS. The revised criteria are expected to be published in NSF Standard 53 and NSF Standard 58 in early 2023. The use of treatment devices certified to the revised criteria will help homeowners further reduce their exposure to PFAS. Homeowners should consult with local authorities to determine available options for the disposal of treatment media and/or residuals that may contain elevated PFAS concentrations.

Rationale

Given the potential for exposure to multiple PFAS at the same time, the potential for negative health impacts, the uncertainty and the limited data on many PFAS, a precautionary group-based approach to PFAS is warranted. The lower the levels of PFAS, the lower the risk to public health. As such, the proposed objective for PFAS in drinking water is based on the total PFAS detected in drinking water. Total PFAS should be calculated using the full list of substances in EPA Method 533 or EPA Method 537.1 (or both) (see Appendix A) or using a method validated by another jurisdiction that measures a minimum of 18 PFAS, such that the sum of their concentrations does not exceed 30 ng/L. For the purposes of this proposed objective, a result of non-detect is considered to have a value of zero. For the reasons noted above, it is also recommended that treatment plants strive to maintain PFAS concentrations in drinking water as low as reasonably achievable (or ALARA).

The proposed objective value of 30 ng/L was determined by considering:

- published treatment data with a focus on the median removal efficacy of the reported PFAS for a variety of water qualities at both pilot- and full-scale treatment operations (Sanexen, 2022);
- the concentration of PFAS consistently achieved at pilot- and full-scale for each of GAC, AIX and RO treatment technologies with influent concentrations similar to those found in Canadian waters;
- reporting levels for PFAS for which a validated and recognized analytical method is available (U.S. EPA, 2019, 2020);
- Canadian monitoring data (MELCC, 2022; Kleywegt et al., 2020; Lalonde and Garron, 2022; Kaboré et al., 2018; Saskatchewan Water Security Agency, 2022); and
- the lowest concentrations that are technically achievable for a larger number of quantifiable PFAS to reduce potential exposure to PFAS in drinking water.

The proposed objective offers the Canadian drinking water sector an efficient approach for risk management by providing only one target value for the total concentration of this group of chemicals, thereby reducing exposure to PFAS, and potential health risk.

Other jurisdictions, such as the European Commission, Sweden, Denmark and some US states, have established a similar single guideline value addressing a combination of PFAS in drinking water. For example, the council of the European Union has adopted a directive that includes limits of 100 ng/L for the sum of 20 PFAS and 500 ng/L for the sum of all PFAS in drinking water (EU, 2020). In its draft background document for PFOA and PFOS in drinking water, the World Health Organization has proposed individual provisional guideline values of

100 ng/L for each of PFOA and PFOS and a combined provisional guideline value of 500 ng/L for total PFAS (WHO, 2022).

A traditional health-based approach was not adopted to derive the proposed objective in part due to the rapidly evolving science. Further, the science is complex, there is currently no consensus regarding the most sensitive health effects, and approaches to hazard and risk assessment are varied. Consequently, health-based values derived by various jurisdictions differ from each other, and many are more stringent than the previous Canadian guidelines and screening values for PFAS in drinking water. As more toxicity data are published, an increasing number of health effects are being associated with exposure to PFAS and toxicological reference values (TRVs) for these substances are being set at lower levels. Furthermore, Canadians are exposed to multiple PFAS simultaneously and the potential hazard associated with exposure to these mixtures is unknown. Consequently, a substance-by-substance assessment of the TRVs available for each PFAS is not a sustainable approach for managing PFAS in drinking water. Despite the approach not being health-based, the toxicity data are generally supportive of the proposed objective. A review of some of the current data for the most data-rich PFAS indicates that when these TRVs are combined with standard reference values (such as for body weight and drinking water intake), the resulting health-based values for individual PFAS in drinking water are often in the low ng/L range.

Many of the PFAS addressed under the proposed objective include the most studied PFAS (that is, perfluorocarboxylic and sulfonic acids) and PFAS that are currently considered to be among the most toxicologically potent (for example, PFOA, PFNA, PFDA, PFHxS and PFOS) (Bil et al., 2021; Sanexen, 2021). This group also includes the most commonly detected PFAS in drinking water (for example, PFHxA, PFOA and PFOS). While there are limited monitoring data for PFAS in Canadian drinking water (Kleywegt et al., 2020; Kaboré et al., 2018; MELCC, 2022; NSECC, 2022; Saskatchewan Water Security Agency, 2022), data from other jurisdictions show that many of these substances are found in water and other environmental media and indicate the potential for transfer or leaching into drinking water (Reade and Pelch, 2020).

The proposed objective includes the PFAS targeted by the available validated analytical methods, or a method validated by a jurisdiction, to ensure a reduction of exposure to PFAS that can be quantified, while still allowing some flexibility in which method to use. However, the presence of any individual PFAS in a given drinking water sample can be highly variable. Such variability indicates that relying on a small group of selected PFAS for the proposed objective may not reduce exposure to the same extent as establishing a total for the sum of a broader group of PFAS that can reliably be analyzed in drinking water. Where possible, utilities should strive to analyze as many PFAS as possible using validated methods to better understand the PFAS in the drinking water and better inform treatment selection.

In adopting a group-based objective, several principal considerations were taken into account. The PFAS studied to date have been shown to be extremely persistent, mobile and difficult, if not impossible, to remove from the environment once released. These properties make exposure to PFAS inevitable and potentially continuous. The adverse effects associated with every individual PFAS are currently unknown. However, for well-studied PFAS (such as PFOA and PFOS), more adverse effects are coming to light identified at ever lower levels. For less well-studied PFAS, as more research is conducted, additional adverse effects are identified. Therefore, based on what is known about well-studied PFAS and the potential for other PFAS to behave similarly, there are potential human health concerns for the group of PFAS. Consequently, a precautionary group-based approach is warranted.

Acknowledging all the above considerations, this proposed objective is deemed the most appropriate approach to reduce Canadians' potential exposure to multiple PFAS through drinking water while the formal guidelines are being revised. The full revision of the guidelines for PFAS in drinking water will include a comprehensive review of new toxicological evidence (for example, TRVs) and risk assessments such as the U.S. EPA's 2022 health advisories for 4 PFAS (U.S. EPA, 2022 d, e, f, g). The revision will also include a comprehensive review of new information on analytical and treatment methods for PFAS as well as new findings for the management of treatment residuals.

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Appendix A – List of PFAS and minimum reporting levels and detection limits for analysis by U.S. EPA Methods 533 and 537.1

Abbreviation	PFAS (carbon chain length)	CASRN	In U.S. EPA Method 533 (Y/N)	In U.S. EPA Method 537.1 (Y/N)	533 MRL[a] (DL)[b] ng/L	537.1 DL[b] ng/L
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (C9)	763051-92-9	Y	Y	5 (1.5)	1.5
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (C8)	756426-58-1	Y	Y	2 (1.4)	1.8
ADONA	4,8-Dioxa-3H-perfluorononanoic acid (C7)	919005-14-4	Y	Y	3 (0.88)	0.55
HFPO-DA[c]	Hexafluoropropylene oxide dimer acid (C6)	13252-13-6	Y	Y	5 (1.9)	1.9
PFBS	Perfluorobutanesulfonic acid (C4)	375-73-5	Y	Y	3	1.8
PFDA	Perfluorodecanoic acid (C10)	335-76-2	Y	Y	3 (1.6)	1.6
PFDoA	Perfluorododecanoic acid (C12)	307-55-1	Y	Y	3 (1.2)	1.2
PFHpA	Perfluoroheptanoic acid (C7)	375-85-9	Y	Y	3 (0.71)	n/a
PFHxS	Perfluorohexanesulfonic acid (C6)	355-46-4	Y	Y	3 (1.4)	1.4
PFHxA	Perfluorohexanoic acid (C6)	307-24-4	Y	Y	3 (1.7)	1.0
PFNA	Perfluorononanoic acid (C9)	375-95-1	Y	Y	4 (0.70)	0.70
PFOS	Perfluorooctanesulfonic acid (C8)	1763-23-1	Y	Y	4 (1.1)	1.1
PFOA	Perfluorooctanoic acid (C8)	335-67-1	Y	Y	4 (0.53)	0.53
PFUnA	*Perfluoroundecanoic acid (C11)	2058-94-8	Y	Y	2 (1.6)	1.6

Abbreviation	PFAS (carbon chain length)	CASRN	In U.S. EPA Method 533 (Y/N)	In U.S. EPA Method 537.1 (Y/N)	533 MRL[a] (DL)[b] ng/L	537.1 DL[b] ng/L
NFDHA	Nonafluoro-3,6-dioxaheptanoic acid (C7)	151772-58-6	Y	N	20 (16)*	n/a
PFBA	Perfluorobutanoic acid (C4)	375-22-4	Y	N	5 (13)*	n/a
8:2FTS	1H,1H, 2H, 2H-Perfluorodecane sulfonic acid (C8)	39108-34-4	Y	N	5 (9.1)*	n/a
PFEESA	Perfluoro(2-ethoxyethane)sulfonic acid (C4)	113507-82-7	Y	N	3 (2.6)*	n/a
PFHpS	Perfluoroheptanesulfonic acid (C7)	375-92-8	Y	N	3 (5.1)*	n/a
4:2FTS	1H,1H, 2H, 2H-Perfluorohexane sulfonic acid (C4)	757124-72-4	Y	N	3 (4.7)*	n/a
PFMPA	Perfluoro-3-methoxypropanoic acid (C4)	377-73-1	Y	N	4 (3.8)*	n/a
PFMBA	Perfluoro-4-methoxybutanoic acid (C5)	863090-89-5	Y	N	3 (3.7)*	n/a
6:2FTS	1H,1H, 2H, 2H-Perfluorooctane sulfonic acid (C6)	27619-97-2	Y	N	5 (14)*	n/a
PFPeA	Perfluoropentanoic acid (C5)	2706-90-3	Y	N	3 (3.9)*	n/a
PFPeS	Perfluoropentanesulfonic acid (C5)	2706-91-4	Y	N	4 (6.3)*	n/a
PFTA	Perfluorotetradecanoic acid (C14)	376-06-7	N	Y	8 (1.1)	1.1
PFTrDA	Perfluorotridecanoic acid (C13)	72629-94-8	N	Y	7 (0.72)	0.72

Abbreviation	PFAS (carbon chain length)	CASRN	In U.S. EPA Method 533 (Y/N)	In U.S. EPA Method 537.1 (Y/N)	533 MRL[a] (DL)[b] ng/L	537.1 DL[b] ng/L
NEtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid (C8)	2991-50-6	N	Y	5 (2.8)	2.8
NMeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid (C8)	2355-31-9	N	Y	6 (2.4)	2.4

[a] MRL = Minimum reporting level (U.S. EPA, 2021b) [b] DL = Detection limits (U.S. EPA, 2020) [c] HFPO-DA and the ammonium salt of HFPO-DA are components of the GenX processing aid technology, and both are measured as the anion of HFPO-DA by this method.

* LCMRL = Lowest concentration minimum reporting level (U.S. EPA, 2019)

Adapted from U.S. EPA (2021b)

Appendix B – List of abbreviations

(Note that this list includes only PFAS that are not listed and spelled out in Appendix A)

AOF	adsorbable organic fluorine
AFFF	aqueous film-forming foams
AIX	anion exchange
ALARA	as low as reasonably achievable
FOSA or PFOSA	perfluorooctane sulfonamide
FHUEA	2H-perfluoro-2-octenoic acid
FOUEA	2H-perfluoro-2-decenoic acid
FTCA	fluorotelomer carboxylic acid
FTSA	fluorotelomer sulfonic acid
GAC	granular activated carbon
LC-MS/MS	liquid chromatography/tandem mass spectrometry
MDL	method detection limit
MRM	multiple-reaction-monitoring
NF	nanofiltration
PAC	powdered activated carbon
PFAAs	perfluoroalkyl acids
PFAS	per- and polyfluoroalkyl substances
PFDS	perfluorodecane sulfonic acid
PFECHS	perfluoroethylcyclohexane sulfonic acid
PFEtS	perfluoroethane sulfonic acid
PFOSA or FOSA	perfluorooctane sulfonamide
PFPrS	perfluoropropane sulfonic acid
RO	reverse osmosis
SPE	solid-phase extraction
TOF	total organic fluorine
TOP	total oxidizable precursors
TRV	toxicological reference value
UCMR	Unregulated Contaminants Monitoring Rule
U.S. EPA	United States Environmental Protection Agency