Canadian Water Quality Guidelines for the Protection of Aquatic Life

PERFLUOROOCTANOIC ACID (PFOA) 2026

Perfluorooctanoic acid (PFOA) is an anthropogenic substance with a chain length of eight carbons, seven of which are perfluorinated. It has a long perfluorocarbon tail that is both hydrophobic and oleophobic, and a charged head that is hydrophilic. It belongs to the class of perfluorocarboxylic acids (PFCAs), which is under the broader class of per- and polyfluoroalkyl substances (PFAS). PFOA is an extremely stable and bioaccumulative substance found in many environmental media, including Canadian fresh and marine waters. In 2012, it was determined that PFOA met the criteria for a toxic substance under the *Canadian Environmental Protection Act* (Environment Canada and Health Canada [EC and HC] 2012).

The following Canadian water quality guidelines (CWQGs) for PFOA (Table 1) considered toxicity data for the acid (CAS Registry Number [RN] 335-67-1), its conjugate base (perfluorooctanoate or PFO) (CAS RN 45285-51-6), branched PFOA (CAS RN 90480-55-0) and PFOA's principal salt forms (various CAS RNs). The PFOA guidelines do not apply to precursors of PFOA, however, guideline users should be aware that precursors can degrade into PFOA and may result in the accumulation of PFOA in the environment. In this document, the term "PFOA" may refer to branched or linear forms of the acid, its conjugate base or its principal salt forms. In cases where it is important to distinguish between species and where specific knowledge is available, it is clearly indicated that which is meant: the acid PFOA (neutral form), the conjugate base PFO (anionic form) or the salt form.

Table 1. CWQGs for the protection of aquatic life for PFOA

	Short-term benchmark (µg/L)	Long-term CWQG (µg/L)
Freshwater	57,000	93
Marine	NRG[a]	NRG[a]

Notes:
NRG = no recommended guideline.
Guideline values are rounded to two significant figures.
Guideline values apply to the ionic form of PFOA.
[a] Insufficient data were available to meet Canadian Council of Ministers of the Environment (CCME) minimum data requirements for derivation of a short-term benchmark or long-term guideline for protection of marine life (CCME 2007).

Sources and Uses

PFOA and its salts have been used in industrial processes and as a component of aqueous firefighting foams. In addition, PFOA has been used in the production of fluoropolymers, where it may remain as a potential contaminant of concern when the fluoropolymer is used to manufacture commercial and consumer products such as cables and hoses, non-stick coatings on cookware, water-resistant or non-stick coatings for textiles and carpets, and personal care products.

Although not known to have been manufactured in Canada, PFOA can enter Canada through the importation of manufactured items. It can also be formed from the breakdown of precursor compounds (Agency for Toxic Substances and Disease Registry [ATSDR] 2021). Releases to the environment can occur directly from the industrial and consumer use of PFOA-containing products, including from the application of firefighting foams, from wastewater effluents and landfill leachates, or from the long-range transport of PFOA or its precursors. Aqueous film-forming foams (AFFF) containing PFAS such as PFOA are commonly used at airports and military bases to fight fires caused by flammable liquids and fuels, where it may cause the contamination of soil and water. The composition of AFFF can vary by product, and the formulations and types of PFAS contained in the foams has changed over time, with some formulations containing PFOA precursors that can degrade to PFOA (Interstate Technology Regulatory Council [ITRC] 2022). PFOA contamination can migrate offsite via groundwater, surface water and leachate to other water sources.

Environmental Fate and Behaviour

PFOA is a surfactant and tends to associate with surfaces and interfaces (Costanza *et al.* 2019). The octanol-water partition coefficient (K_{OW}) for surface-active perfluorinated substances is not considered a reliable indicator of partitioning behavior (National Industrial Chemicals Notification and Assessment Scheme [NICNAS] 2015). When dissolved in water, the free acid readily dissociates to its conjugate base (PFO) (i.e., anionic form). PFOA is expected to have a low acid dissociation constant (pKa), such that over 99% will occur as PFO under most environmental conditions (Goss 2008), suggesting environmental partitioning will be dominated by its anionic form (i.e., PFO) (EC and HC 2012). It has high water solubility and low volatility in the ionized form, and as a result is expected to partition primarily to the aquatic environment; partitioning to sediments may occur but is not expected to be a major sink (EC and HC 2012). Organic carbon content, pH, ionic strength and salinity have all been shown to influence partitioning of PFOA between water and sediment (Ahrens *et al*. 2009; 2011; Ferrey *et al.* 2012; SNC-Lavalin Environment 2012; Wang *et al.* 2012; Xiao *et al.* 2021). PFOA is expected to be mobile in soil and can leach into groundwater (ATSDR 2021), where it could then migrate to other water sources. In the environment, PFOA is considered to be stable owing to the strong carbon-fluorine bond that is resistant to breakdown via hydrolysis, photolysis or biodegradation. PFOA may undergo long-range transport via ocean currents or via atmospheric oxidative transformations and subsequent wet and dry deposition of airborne precursors (Muir *et al.* 2019). PFOA has been detected in remote areas such as the Canadian Arctic (Benskin *et al.* 2012; D'Agostino and Mabury 2017; Lescord *et al.* 2015; Muir *et al*. 2015; Muir *et al.* 2019).

PFOA was found to bioaccumulate and biomagnify in terrestrial and marine mammals via protein binding rather than lipid partitioning (EC and HC 2012). It was found to have a low to moderate potential to accumulate in aquatic species (EC and HC 2012). PFOA is considered to be persistent (EC and HC 2012).

Environmental Concentrations

Concentrations of PFOA in ambient surface water in Canada are generally low. However, greater amounts of anthropogenic activity may contribute to elevated concentrations, and levels are higher in areas with known point-sources of pollution. Freshwater sites (including reference, urban and

mixed development sites as well as sites associated with municipal wastewater treatment plants) sampled across Canada between 2013 and 2020 had maximum and mean concentrations of PFOA of 24.4 and 1.52 ng/L, respectively (Lalonde and Garron 2022). Surface water sites downstream from or close to areas that have used AFFF can have greatly elevated levels of PFOA (Bhavsar *et al.* 2016; de Solla *et al.* 2012; Muir *et al.* 2019; Stock *et al.* 2007). Concentrations of PFOA at contaminated sites in Canada have reached up to 11,300 ng/L (11.3 µg/L) (Moody *et al.* 2002). Available data may or may not represent the most contaminated sites as data are limited. In addition, as the composition of AFFF can and has varied with time, it is uncertain if available data on AFFF contaminated surface water represent use of AFFF formulations containing higher PFOA concentrations or its precursors.

Effects on Aquatic Life

The mechanism of toxic action of PFAS and PFOA in aquatic organisms is an ongoing field of research. Adverse impacts of perfluoroalkyl acids on aquatic organisms include disruptions to metabolism, reproduction, immune system and endocrine system, in addition to neurotoxicity and developmental toxicity. Effects are initiated by the activation of various nuclear receptors or other factors, which in turn result in transcriptional changes, followed by metabolic- and tissue-level changes (Lee *et al.* 2020). Studies with invertebrates have demonstrated signs of oxidative stress as well as effects on antioxidant defense systems (Ankley *et al.* 2020). PFOA exposure has also been associated with neurotoxic effects in invertebrate species (Ankley *et al.* 2020). In fish, studies have shown PFAS to cause oxidative stress, as well as apoptosis. Although the mechanism through which PFAS elicits the oxidative stress is currently not well understood, some potential triggers include increased β-oxidation of fatty acids as well as mitochondrial toxicity (Ankley *et al.* 2020). PFAS exposure in fish has also been associated with endocrine disruption, which can impact reproduction and sexual development (Ankley *et al.* 2020). PFOA has been shown to be estrogenic (Benninghoff *et al.* 2011) and to activate nuclear receptors involved in lipid metabolism in fish (Ankley *et al.* 2020).

Water Quality Guideline Derivation

Both the short-term benchmark and long-term CWQG for PFOA for freshwater followed the derivation procedures as described in *A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life* (CCME 2007). Endpoints for PFOA salts were standardized to the ionic form of PFOA prior to inclusion in guideline derivation to allow the comparison of toxicity on the same chemical basis (see CCME 2026 for details).

Short-term Benchmark Concentration

CCME derives short-term benchmark concentrations using severe effects data (such as lethality) for defined short-term exposure periods. These benchmarks are estimators of severe effects to the aquatic ecosystem and are intended to give guidance on the impacts of severe but transient situations, such as spill events and inappropriate use or disposal. Short-term benchmark concentrations protect only a specified fraction of individuals and are not intended to provide complete protection against all negative effects for all forms of aquatic life over an indefinite exposure period (CCME 2007).

CCME minimum data requirements were met for the Type A (Species Sensitivity Distribution [SSD]) approach for short-term freshwater exposure, and data for 32 species were included in the SSD (Figure 1; Table 2) following criteria outlined by CCME (2007). Where multiple comparable endpoints were available for the same species, effect, life stage, exposure duration and chemical identity, a geometric mean was calculated. A model averaged SSD and associated statistics were generated using ssdtools and R software (Dalgarno 2018; Thorley and Schwarz 2018). The short-term benchmark concentration is the hazard concentration for the fifth percentile (HC_5) from the short-term SSD and is 57,000 µg/L PFOA (rounded to two significant figures).

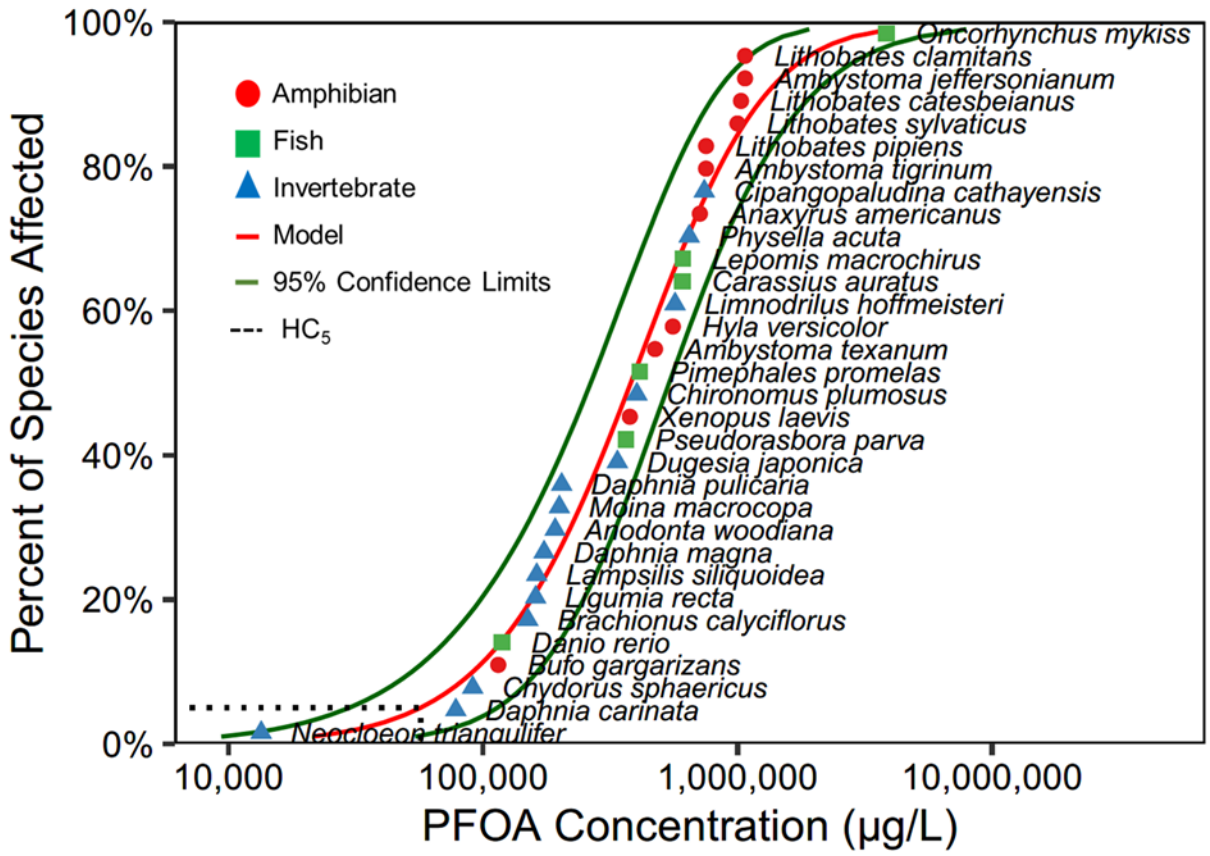

Figure 1. Short-term model-averaged SSD for PFOA in freshwater
Note: The HC_5 is 57,000 µg/L PFOA.

Table 2. Endpoints used to determine the short-term freshwater benchmark concentration for PFOA

SSD rank	Species	Endpoint	Concentration (µg/L PFOA)[a]
1	*Neocloeon triangulifer* (mayfly)	96-h LC_{50}	13,451
2	*Daphnia carinata* (water flea)	48-h EC_{50}	78,200
3	*Chydorus sphaericus* (cladoceran)	48-h EC_{50}	91,100
4	*Bufo gargarizans* (Asiatic toad)	96-h LC_{50}	114,740
5	*Danio rerio* (zebrafish)	96-h LC_{50}	118,820
6	*Brachionus calyciflorus* (rotifer)	24-h LC_{50}	150,000
7	*Ligumia recta* (black sandshell)	24-h EC_{50}	161,000
8	*Lampsilis siliquoidea* (fatmucket)	48-h EC_{50}	162,600
9	*Daphnia magna* (water flea)	48-h LC_{50}	173,762[b]
10	*Anodonta woodiana* (Chinese pond mussel)	48-h LC_{50}	192,083
11	*Moina macrocopa* (cladoceran)	48-h EC_{50}	199,510
12	*Daphnia pulicaria* (water flea)	48-h EC_{50}	203,722
13	*Dugesia japonica* (dugesiid)	96-h LC_{50}	337,200[b,c]
14	*Pseudorasbora parva* (topmouth gudgeon)	96-h LC_{50}	365,020
15	*Xenopus laevis* (South African clawed frog)	96-h LC_{50}	377,466
16	*Chironomus plumosus* (midge)	96-h LC_{50}	402,240
17	*Pimephales promelas* (fathead minnow)	96-h LC_{50}	413,200
18	*Ambystoma texanum* (small-mouthed salamander)	96-h LC_{50}	474,000
19	*Hyla versicolor* (gray treefrog)	96-h LC_{50}	557,000
20	*Limnodrilus hoffmeisteri* (Huo Fu tubifex)	96-h LC_{50}	568,200
21	*Carassius auratus* (crucian carp)	96-h LC_{50}	606,610
22	*Lepomis macrochirus* (bluegill sunfish)	96-h LC_{50}	608,955[c]
23	*Physella acuta* (formerly *Physa acuta*) (acute bladder snail)	96-h LC_{50}	645,454[c]
24	*Anaxyrus americanus* (American toad)	96-h LC_{50}	711,000
25	*Cipangopaludina cathayensis* (mud snail)	96-h LC_{50}	740,070
26	*Ambystoma tigrinum* (Eastern tiger salamander)	96-h LC_{50}	752,000
27	*Lithobates pipiens* (Northern leopard frog)	96-h LC_{50}	752,000
28	*Lithobates sylvaticus* (wood frog)	96-h LC_{50}	999,000
29	*Lithobates catesbeianus* (American bullfrog)	96-h LC_{50}	1,031,620[b]
30	*Ambystoma jeffersonianum* (Jefferson salamander)	96-h LC_{50}	1,070,000
31	*Lithobates clamitans* (green frog)	96-h LC_{50}	1,070,000
32	*Oncorhynchus mykiss* (rainbow trout)	96-h LC_{50}	3,842,946[c]

Notes:
EC_{50} = effect concentration, meaning the concentration affecting 50% of the test organisms; LC_{50} = lethal concentration for 50% of the test organisms; h = hour.
[a] Effect concentrations are for the ionic form of PFOA.
[b] Based on geometric mean of multiple comparable values.
[c] The original study was conducted with PFOA ammonium salt (ammonium perfluorooctanoate [APFO]). Endpoint was standardized to µg/L PFOA for inclusion in SSD (see CCME 2026 for details).

Long-term Canadian Water Quality Guideline

Long-term exposure guidelines identify waterborne concentrations intended to protect all forms of aquatic life for indefinite exposure periods. These guidelines are preferentially derived using no-effects data for long-term effects. CCME minimum data requirements were met for the Type A (i.e., SSD) approach for long-term freshwater exposure, and data for 22 species were included in the SSD (Figure 2; Table 3) following criteria outlined by CCME (2007). Where multiple comparable endpoints were available for the same species, effect, life stage, exposure duration and chemical identity, a geometric mean was calculated. A model averaged SSD and associated statistics were generated using ssdtools and R software (Dalgarno 2018; Thorley and Schwarz 2018). The long-term freshwater CWQG is the HC_5 value from the long-term SSD and is 93 µg/L PFOA (rounded to two significant figures).

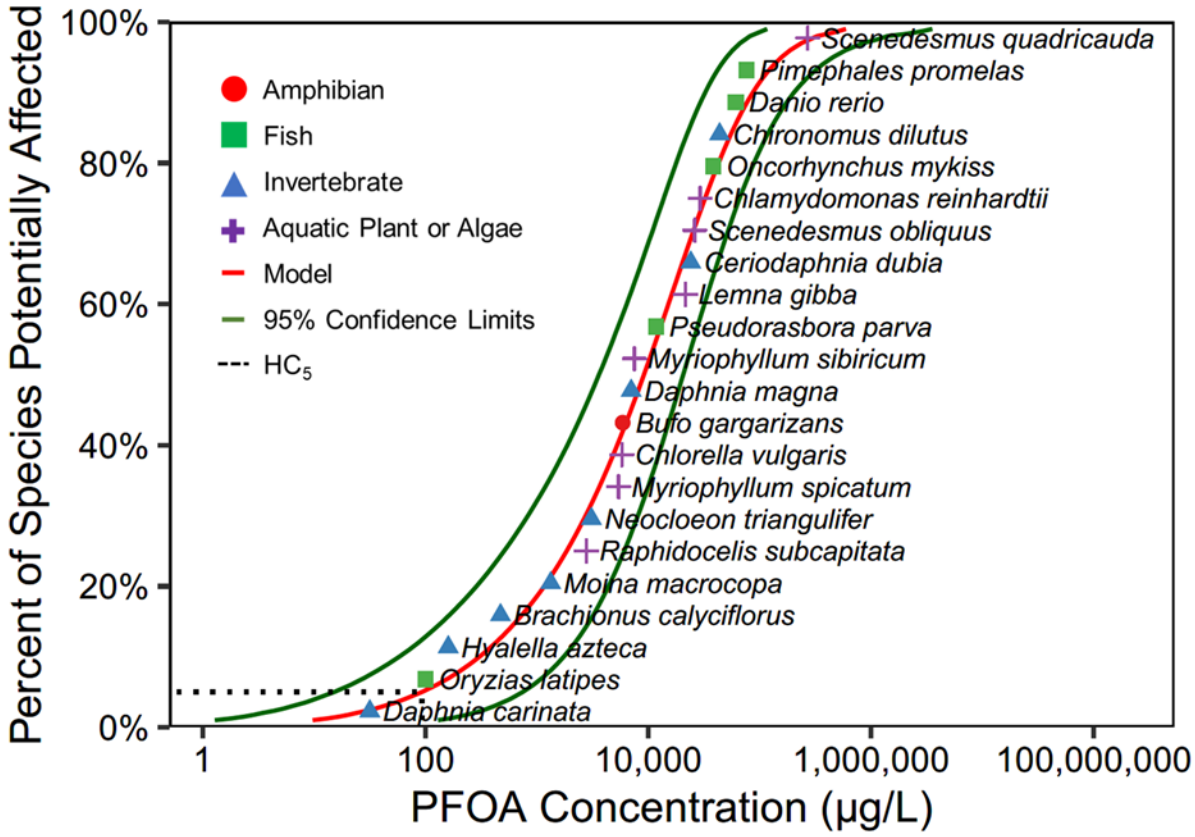

Figure 2. Long-term model-averaged SSD for PFOA in freshwater
Note: The HC_5 is 93 µg/L PFOA.

Table 3. Endpoints used to determine the long-term freshwater PFOA CWQG

SSD rank	Species	Endpoint	Concentration (µg/L PFOA)[a]
1	*Daphnia carinata* (water flea)	21-d MATC (reproduction, offspring)	31.6
2	*Oryzias latipes* (Japanese ricefish (medaka))	28-d post-hatch LOEC (survival in F1)[b]	100
3	*Hyalella azteca* (amphipod)	42-d EC_{10} (growth)	160
4	*Brachionus calyciflorus* (rotifer)	Life-cycle EC_{10} (intrinsic rate of natural increase)	471
5	*Moina macrocopa* (cladoceran)	7-d EC_{10} (reproduction, number of young per adult)	1,330
6	*Raphidocelis subcapitata* (green algae)	10-d EC_{10} (growth, cell count)	2,785[c]
7	*Neocloeon triangulifer* (mayfly)	14-d NOEC (survival/growth/emergence)	≥3,085[d]
8	*Myriophyllum spicatum* (Eurasian water-milfoil)	21-d EC_{10} (plant length)	5,413[e]
9	*Chlorella vulgaris* (green algae)	96-h IC_{10} (growth inhibition)	5,797
10	*Bufo gargarizans* (Asiatic toad)	30-d EC_{10} (longevity)	5,890
11	*Daphnia magna* (water flea)	21-d EC_{10} (total number of spawning events)	7,020
12	*Myriophyllum sibiricum* (northern water-milfoil)	21-d EC_{10} (dry mass)	7,502[e]
13	*Pseudorasbora parva* (topmouth gudgeon)	30-d EC_{10} (longevity)	11,780
14	*Lemna gibba* (duckweed)	7-d IC_{10} (growth inhibition)	21,532
15	*Ceriodaphnia dubia* (water flea)	7-d EC_{10} (reproduction)	24,062[f]
16	*Scenedesmus obliquus* (green algae)	96-h IC_{10} (growth inhibition)	26,100

SSD rank	Species	Endpoint	Concentration (µg/L PFOA)[a]
17	*Chlamydomonas reinhardtii* (green algae)	96-h IC_{10} (growth inhibition)	29,200
18	*Oncorhynchus mykiss* (rainbow trout)	85-d NOEC (mortality, growth)	≥38,420[c,g]
19	*Chironomus dilutus* (midge)	7-d EC_{10} (growth)	43,649
20	*Danio rerio* (zebrafish)	7-d LC_{10} (mortality)	61,128
21	*Pimephales promelas* (fathead minnow)	21-d NOEC (growth)	>76,000[h]
22	*Scenedesmus quadricauda* (green algae)	96-h EC_{50} (growth inhibition)	269,630

Notes:
EC_x = effect concentration, meaning the concentration affecting x% of the test organisms; IC_{10} = inhibitory concentration, meaning the concentration causing 10% inhibition; d = day; h= hour; LOEC = lowest observed effect concentration; NOEC = no observed effect concentration; MATC = maximum acceptable toxicant concentration (geometric mean of the NOEC and LOEC).
[a] Effect concentrations are for the ionic form of PFOA.
[b] Transgenerational study; F0 (parental generation) exposed to 100 µg/L for 14 days, F1 (progeny generation) exposed to 100 µg/L and mortality assessed at 28 days post hatch.
[c] The original study was conducted with APFO. Endpoint was standardized to µg/L PFOA for inclusion in SSD (see CCME 2026 for details).
[d] Value plotted as 3,085 µg/L in species sensitivity distribution.
[e] The original study was conducted with PFOA sodium salt. Endpoint was standardized to µg/L PFOA for inclusion in SSD (see CCME 2026 for details).
[f] Based on geometric mean of multiple comparable values.
[g] Value plotted as 38,420 µg/L in SSD.
[h] Value plotted as 76,000 µg/L in SSD.

A protectiveness assessment was completed for the long-term CWQG (CCME 2026), which found that it achieved the intended level of protection as per the protocol (CCME 2007).

Marine Water Quality Guideline

There were insufficient data to meet CCME minimum data requirements for derivation of a short-term benchmark or long-term guideline for the protection of marine life. It is not appropriate to apply the freshwater PFOA guidelines in a marine environment as there may be a difference in toxicity between freshwater and marine organisms. The limited available marine toxicity data suggest that marine invertebrate species may be more sensitive to PFOA than freshwater organisms (CCME 2026; Hayman *et al*. 2021).

Implementation and Other Considerations

Aquatic life may be chronically exposed to a substance as a result of gradual release from soils or sediments and gradual entry through groundwater or runoff, emissions from industrial processes and long-range transport. There is potential for PFOA present at contaminated sites to migrate through groundwater, surface water and leachate to off-site water sources away from contaminated sites.

The effect of PFOA on aquatic organisms may vary among sites due to species composition and/or physicochemical characteristics (CCME 2007). Therefore, this document may be used as a basis for the derivation of site-specific guidelines and objectives when needed (CCME 2003). Additionally, although these guidelines do not apply to intact (i.e., not degraded) precursors of PFOA, consideration should be given to the potential for precursors to degrade into PFOA and cause accumulation in the environment. A list of potential precursors can be found in EC and HC (2012). Furthermore, the presence of other toxicants could interact additively or synergistically with PFOA. For example, other PFAS are often present with PFOA, especially with applications

of AFFF. Lastly, the guidelines do not address exposure through food or bioaccumulation to higher trophic levels. As such, aquatic life that is exposed to PFOA primarily through food may not be adequately protected by the CWQG and these guidelines for PFOA may not prevent the accumulation of PFOA in aquatic life. Users should be aware of these considerations when implementing these guidelines at their site.

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