Canadian Soil and Groundwater Quality Guidelines for the Protection of Environmental and Human Health

PERFLUOROOCTANE SULFONATE (PFOS)

2021

Perfluorooctane sulfonate (PFOS) ($C_8HF_{17}SO_3$) is an extremely stable anthropogenic compound present in significant quantities in many environmental media. PFOS is present in numerous products such as firefighting foams, insecticides, coatings used for textiles and paper, and cleaning products. PFOS can be released directly into the environment as a result of its production, use (in consumer, commercial and industrial products) and disposal, or it may result indirectly from the biodegradation, photo oxidation, photolysis and hydrolysis of precursor per- and polyfluoroalkyl substances (PFAS).

PFOS contains a perfluorinated carbon chain with eight carbons connected to a sulfonate group at one end. It is classified as a perfluorinated alkyl acid. PFOS can exist as an acid, as various salts (e.g., potassium, ammonium, lithium, diethanolamine) and polymers (Organisation for Economic Co-Operation and Development [OECD] 2002), or, most commonly, as an anion (Barber *et al*. 2007). PFOS does not occur naturally; it is released into the environment from anthropogenic sources (Butt *et al*. 2010). Measured concentrations of PFOS in soil, sediment, air, surface water, drinking water, precipitation, biota, snow, food and human fluids/tissues in Canada and internationally are presented in Appendix A of CCME (2021).

PFOS has been manufactured globally for more than 50 years but never in Canada. The 3M Company manufactured PFOS and its perfluorooctane sulfonyl fluoride–based precursors in the United States until 2001, and a voluntary phase-out was completed in 2002 (Agency for Toxic Substances and Disease [ATSDR] 2015). From 1997 until 2000, approximately 600 tonnes of perfluorinated alkyl compounds were imported into Canada, primarily from the United States. PFOS and its precursors constituted approximately 43% of that amount, and PFOS alone was less than 2% (reviewed in Environment Canada [EC] [2006*a*, 2006*b*]). The manufacture, use, and importation of PFOS and PFOS-related compounds in Canada is regulated under the *Prohibition of Certain Toxic Substances Regulations, 2012* (Government of Canada 2012).

Canadian Soil Quality Guidelines (CSoQGs) are numerical concentrations or narrative statements that specify levels of toxic substances or other parameters in soil that are recommended to maintain, improve or protect environmental quality or human health. They are developed using the procedures described in CCME (2006) to ensure scientifically defensible values that are consistent throughout Canada. Canadian Groundwater Quality Guidelines (CGWQGs) are derived according to procedures described in CCME (2015).

The CSoQGs and the CGWQGs presented in this factsheet are intended as generic guidance. Site-specific conditions should be considered when applying these values (see CCME [1996] for specific guidance on developing site-specific soil or groundwater quality objectives) or consult local jurisdictions for applicable implementation procedures. CCME (2006) provides further implementation guidance pertaining to the generic guidelines. Soil quality guidelines (SoQGs) are calculated to approximate "no- to low effect" level (or threshold level) based only on the toxicological information and other scientific data (fate, behaviour, etc.) available for the substance of interest. The guidelines do not consider socio-economic, or technological factors. Site managers should consider these non-scientific factors at the site-specific level as part of the risk management process.

Table 1 shows SoQGs for PFOS for the protection of environmental and human health. Table 2 shows groundwater quality guidelines (GWQGs) for PFOS for the protection of environmental and human health. This factsheet provides an overview of the decision points and information used to calculate the soil quality and groundwater quality guidelines. A scientific criteria document describes the data and derivation of the environmental and human health guidelines (CCME 2021).

Table 1. Soil Quality Guidelines for PFOS (mg/kg dry weight [dw])

	Land Use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Final Guideline	**0.01**	**0.01**	**0.01**	**0.01**
$SoQG_{HH}$	0.01	0.01	0.01	0.01
Limiting pathway for $SoQG_{HH}$	Protection of potable groundwater	Protection of potable groundwater	Protection of potable groundwater[a]	Protection of potable groundwater[a]
$SoQG_{E}$	0.01	0.01	0.2 (coarse)[b] 0.1 (fine)[c]	0.2 (coarse)[b] 0.1 (fine)[c]
Limiting pathway for $SoQG_{E}$	Livestock and wildlife soil and food ingestion[d]	Livestock and wildlife soil and food ingestion[d]	Groundwater (aquatic life)[e]	Groundwater (aquatic life)[e]

Notes: $SoQG_E$ = soil quality guideline for environmental health; $SoQG_{HH}$ = soil quality guideline for human health.

[a] For pH between 5 and 7. Based on a median K_{oc} of 1445 L/kg; PFOS K_{oc} is highly variably (229 to 6,310 L/kg; Franz Environmental Inc. 2014), therefore the level of protection afforded by this $SoQG_{PW}$ may not be appropriate for all sites. Where groundwater is used as a potable water source, groundwater concentrations should be compared directly to the $GWQG_{PW}$ value. Where groundwater is used for other purposes (e.g., irrigation of produce), this should be evaluated on a site-specific basis.

[b] Coarse-grained soil is soil in which more than 50% of particles (by mass) are larger than 75 µm mean diameter (D_{50} > 75 µm).

[c] Fine-grained soil is soil in which more than 50% of particles (by mass) are smaller than 75 µm mean diameter (D_{50} < 75 µm).

[d] Numerous toxicological studies on soil organisms were critically evaluated (i.e., plants, invertebrates, mammals and birds) for the various land use/exposure pathways. Secondary consumers (organisms which consume both plants and soil invertebrates) were the most sensitive and therefore the soil quality guideline for environmental health is based on these receptors.

[e] The surface water guideline used to calculate the protection of aquatic life soil guideline is taken directly from and is identical to the Federal Environmental Quality Guidelines (FEQG) (ECCC 2018). The FEQG is based on toxicity data for a wide range of aquatic species (fish, aquatic invertebrates, amphibians and aquatic plants). See ECCC (2018) for derivation details.

Table 2. Groundwater quality guidelines for PFOS (mg/L) considering ecological and human receptors

	Soil type[a]	
	Coarse	**Fine**
Final groundwater quality guideline ($GWQG_F$)[b]	**0.0006**	**0.0006**
Groundwater guideline for the protection of human health ($GWQG_{PW}$)[c]	0.0006	0.0006
Groundwater guideline for the protection of ecological receptors ($GWQG_E$)[d]	0.007	0.007
Groundwater contact ($GWQG_{GC}$) by soil-dependent organisms	1	1
Protection of freshwater life ($GWQG_{FL}$)[e]	0.007	0.007
Protection of marine life ($GWQG_{ML}$)	NC	NC
Protection of livestock watering ($GWQG_{LW}$)	0.3	0.3
Protection of irrigation water ($GWQG_{IR}$)	NC	NC
Management considerations ($GWQG_M$) – 50% solubility	200	200

NC = not calculated

[a] Coarse-grained soil contains more than 50%, by mass, particles larger than 75 µm mean diameter (D_{50}>75 µm). Fine-grained soil contains more than 50%, by mass, particles smaller than 75 µm mean diameter (D_{50}<75 µm).

[b] The final groundwater quality guideline ($GWQG_F$) is the lowest of the pathway-specific guidelines for ecological and human receptors and considers other management factors such as substance solubility, analytical detection limits and background concentrations.

[c] $GWQG_{PW}$ are adopted directly from the Guidelines for Canadian Drinking Water Quality, developed by Health Canada (CCME 2015). Therefore, the $GWQG_{PW}$ is equivalent to the Maximum Acceptable Concentration (MAC) of 0.0006 mg/L developed by Health Canada (HC 2018*a*).

[d] The groundwater quality guideline for the protection of ecological receptors ($GWQG_E$) is the lowest of the pathway-specific guidelines for ecological receptors.

[e] $GWQG_{FL}$ is the concentration in *groundwater* that is expected to protect against potential impacts on freshwater life from PFOS originating in soil that may enter groundwater and subsequently discharge to a surface water body. This pathway may be applicable under any land use category where a surface water body sustaining aquatic life is present (i.e., within 10 km of the site). Where the distance to the nearest surface water body is greater than 10 km, application of the pathway should be evaluated on a case-by-case basis by considering the site-specific conditions.

Environmental Fate and Behaviour

PFOS has both hydrophobic and hydrophilic properties, and thus it acts as a surfactant (Ahrens 2011; Jia et al. 2010) and tends to accumulate at interfaces between media (Interstate Technology Regulatory Council [ITRC] 2018). PFOS vapour pressure and solubility (and Henry's law constant) indicate that it is more likely to partition to water than air (Giesy and Kannan 2002; Weremiuk et al. 2006) and is essentially non-volatile. Furthermore it will remain in solution until it is adsorbed onto particulate matter or until it is taken up by organisms (EC 2006*a*). PFOS adsorbs to sediments, soil, and sludge (3M 2003; Beach et al. 2006; Hekster et al. 2002). A hydrolysis half-life of 41 years for PFOS in water was calculated at environmentally relevant pH (reviewed by ATSDR 2015 and EC 2006*a*).

PFOS can be found in soil at great distances from any known source; however, direct discharges (such as aqueous film-forming foam (AFFF) and the application of biosolids or leaching from landfills) are the principal sources of PFOS-contaminated soil. Once released to the environment, PFOS is mobile and can move through soil and contaminated groundwater (ITRC 2018). A mass balance study by Filipovic *et al*. (2015) indicates that a significant portion of perfluorinated alkyl acids (PFAAs) from atmospheric deposition is stored in soil, where it can be a source of groundwater contamination. Strynar *et al*. (2012) estimated that approximately 6% of total PFOS production is distributed globally in surface soils (estimate based on a median PFOS surface soil concentration of 0.472 ng/g).

The long-distance transport of PFOS is assumed to be occurring via weather and ocean currents (Armitage *et al.* 2006; Ellis *et al.* 2004; Martin *et al*. 2004), which may explain its occurrence at locations far removed from point sources. Both wet and dry deposition occur, as does leaching to groundwater from soils (Strynar *et al*. 2012).

ITRC (2018) provides additional information on the fate and transport of PFAS in relation to their principal source, including AFFF use.

Rather than partitioning into lipid tissue, PFOS has been shown to bind to protein in organisms (Kerstner-Wood *et al*. 2003). EC (2006*a*, 2006*b*) concluded that the weight of evidence indicates that PFOS is bioaccumulative. PFOS has also been shown to biomagnify in a vegetation-caribou food chain (Muller *et al*. 2011). As a result of its bioaccumulating/biomagnifying behaviour, soil quality guidelines for environmental health consider not only the toxicity of PFOS to plants and invertebrates in direct contact with soil, but also the toxicity of PFOS in organisms at three levels of the terrestrial food chain.

Behaviour and Effects in Biota

Terrestrial Plants and Invertebrates

Toxicity values as a result of direct soil exposure to PFOS are available for eight plant species: alfalfa [*Medicago sativa*], ryegrass [*Lolium perenne*], soybean [*Glycine max*], lettuce [*Lactuca sativa*], flax [*Linum usitatissimum*], tomato [*Lycopersicon esculentum*], onion [*Allium cepa*] and pak choi [*Brassica chinensis*] (Brignole *et al*. 2003; Zhao *et al*. 2011). Effects observed include reduced seedling emergence, plant height, weight and survival, at PFOS values ranging from 3.9 to 393 mg/kg soil.

The literature provides data on the invertebrate earthworm (*Eisenia fetida*) (Joung *et al.* 2010; Stubberud 2006). Environment Canada performed definitive tests with springtail (*Folsomia candida*) and oribatid mite (*Oppia nitens*), which resulted in measured effects in the range of 12 to 256 mg/kg for number of juvenile/cocoons and survival (EC 2015). The available information shows that plants and invertebrates have overlapping sensitivity to PFOS, with plants appearing to be slightly more sensitive than invertebrates.

Vertebrates, Birds and Other Wildlife

Toxicity data in non-human vertebrates (cynomolgus monkeys [*Macaca fascicularis*], rabbits [*Oryctolagus cuniculus*], mice and rats) and avian species (northern bobwhite quail [*Colinus virginianus*], Japanese quail [*Coturnix japonica*] and mallard [*Anas platyrhynchos*]) were reviewed. Effects observed include increased liver weights, as well as hepatocellular adenomas, peroxisome proliferation, and a reduction in testicular size and altered spermatogenesis (EC 2006*a*, 2006*b*; Gallagher *et al*. 2003; Luebker *et al*. 2005; York 1999). Since no toxicity data were available for wildlife, the lowest adverse effect dose for primary consumer (ED_{1C}) was based on the lowest observed adverse effect level (LOAEL) in a two-year chronic toxicity diet study in rats (Covance Laboratories Inc. 2002). This study reported hepatocellular degeneration at concentration of PFOS in diet of 2,000 µg PFOS/kg food. Given weekly food intake over the 104-week test period, this corresponds to a lowest observed effect dose (LOED) of 108.6 µg PFOS/kg bw/day. This value was used to calculate the daily threshold effects dose for mammalian species in soil and food ingestion guideline calculation. For avian species, the ED_{1C} LOAEL dose rate was determined in northern bobwhites, at 772 µg/kg bw/day. This resulted in reduced chick survival 14 days post exposure (Newsted *et al.* 2007). Toxicity data for laboratory mammalian and avian species were used to derive soil quality guidelines to protect primary-, secondary- and tertiary-level wildlife species (e.g., shrew, mouse, robin, wolf, and fox), which can be exposed to PFOS through the food chain.

Health Effects in Humans and Experimental Animals

PFOS is readily absorbed from the gastrointestinal tract and to a lesser extent the lungs and the skin. PFOS is distributed through the entire organism, including the central nervous system. It is found in breast milk and is also able to cross the placenta and enter the fetus.

Many toxic effects observed in humans and experimental animals have been associated with PFOS exposure, including altered immune response, hepatic effects, altered lipid and glucose homeostasis, endocrine (e.g., thyroid) and neuroendocrine disruption, neurotoxicity, reproductive and developmental effects, and tumours (e.g., ATSDR 2015; EFSA 2008; HC 2006). The half-life of PFOS is much longer in humans (average of approximately 4–5 years) than in other animals (e.g., 2–70 days in rodents, 110–132 days in monkeys). This suggests a much greater body burden in humans for an equivalent (external) dose of exposure.

PFOS has not been reviewed for carcinogenicity by the International Agency for Research on Cancer, the U.S. EPA Integrated Risk Information System or the U.S. National Toxicology Program. PFOS has been identified as non-genotoxic in many assays. Health Canada derived a tolerable daily intake (TDI) of 6×10^{-5} mg/kg bw/day, which is protective of all PFOS endpoints (cancer and non-cancer) (HC 2018*a*).

PFOS and perfluorooctanoic acid (PFOA), another PFAS, have similar toxic effects in humans. When found together at a contaminated site, additivity of risk should be considered.

Guideline Derivation

Canadian soil and groundwater quality guidelines are derived for different land uses following the process outlined in CCME (2006, 2015). The supporting scientific criteria document (CCME 2021) provides details on the toxicological data and calculation methods used for derivation of the soil quality guidelines for PFOS. Table 1 shows the final soil quality guidelines, Table 2 presents the groundwater quality guidelines, and Table 3 shows the detailed soil guideline values with the check mechanisms.

Soil Quality Guidelines: Environment

The final environmental soil quality guideline for PFOS, for each land use, is the lowest of the guideline values from the applicable exposure pathways and check mechanisms (see Table 1). Soil quality guidelines for PFOS were derived considering organisms (plants and invertebrates) in direct contact with soil. As PFOS is a biomagnifying substance, the protection of primary, secondary and tertiary consumers exposed to PFOS via soil and food ingestion was also considered. The soil quality guideline for soil and food ingestion pathway is the lowest guideline (i.e., highest exposure) that considered scenarios for primary, secondary and tertiary consumers. Common shrew had the highest exposure and the lowest guideline due to its low body weight (0.0041 kg), a high food intake rate (0.34 kg wet food/kg bw/day) relative to its body weight, and a diet dominated by insects and invertebrates (95%), which have been shown to bioaccumulate PFOS (BCF soil to invertebrates 10.9) to the greatest extent. Shrew is a relevant indicator species given its widespread occurrence in Canada. Due to the lack of toxicity data for shrew, the most sensitive mammalian toxicity endpoint (rat) was scaled to shrew to account for body weight, food ingestion rate, soil ingestion rate, concentration of PFOS in prey, and bioaccumulation from soil to prey. Detailed equations are found in CCME (2006) and input values are provided in Appendix L of CCME (2021).

As contamination that migrates through soil to groundwater may affect the water quality in surface waterbodies, dugouts, or water wells used for livestock watering or crop irrigation, soil guidelines for these pathways were also calculated. Due to lack of data, the nutrient and energy cycling check was not derived. Since soils from commercial and industrial sites can migrate off-site to more sensitive land uses via wind erosion, PFOS SoQGs for the off-site migration check for commercial and industrial land were also calculated. Nearby surface water bodies may be affected by contaminated soil; therefore, the soil quality guideline to protect surface freshwater life ($SoQG_{FL}$) was also calculated (for equations see CCME (2006); for input values see Appendix L of CCME [2021]). While it is recognized that a large number of perfluorinated compounds can co-exist at a site, environmental guidelines are only provided for PFOS at this time. Guidelines for other perfluorinated compounds are outside the scope of this document.

Groundwater Quality Guidelines: Environment

The final environmental groundwater quality guideline ($GWQG_F$) for PFOS is a concentration in groundwater that considers: i) the protection of soil-dependent organisms (e.g., plants) ($GWQG_{GC}$), ii) the protection of surface freshwater aquatic life ($GWQG_{FL}$), iii) livestock watering ($GWQG_{LW}$), and iv) the solubility of PFOS. Equations for the fate and transport model used to calculate the GWQG guidelines are described in CCME (2015). The SoQG hydrologic and hydrogeological assumptions are presented in Appendix L of CCME (2021).

Soil Quality Guidelines: Human Health

PFOS is considered to be non-genotoxic and believed to have a critical effect threshold. For this type of contaminant, a Tolerable Daily Intake (TDI) is required to derive human-health soil-quality guidelines. The TDI calculated by Health Canada (60 ng/kg bw/day) (HC 2018*a*; CCME 2021), based on hepatocellular hypertrophy in rats (Butenhoff *et al*. 2012) was used to derive the soil quality guidelines.

Estimated daily intakes (EDIs) for Canadians have been calculated based on the PFOS concentrations found in environmental media (for which there was no evidence of contamination) and on the EDI from food. The total average EDIs for PFOS were estimated at 1.7 ng/kg bw/day for non-breastfed infants, 3.8 ng/kg bw/day for toddlers, 2.8 ng/kg bw/day for children and 2.3 ng/kg bw/day for adults.

Since PFOS is rapidly absorbed through the gastrointestinal tract, by default a relative absorption factor of 100% was retained for ingestion as well as for inhalation. Due to lack of PFOS dermal absorption data, a 10% absorption factor was applied, based on available data for PFOA (perfluorinated compound presenting similar physicochemical properties to PFOS).

In developing the soil quality guidelines, toddlers are considered the most sensitive receptor in agricultural, residential and commercial sites, as this age category (seven months to four years) has the largest ratio of soil exposure to body weight. In industrial sites, adults were assumed to be the most sensitive receptors. Since soils from commercial and industrial sites can migrate off site to more sensitive land uses, PFOS concentration SoQGs for the off-site migration check for commercial and industrial land were calculated. For PFOS, sorption is the only chemical-specific attenuation mechanism in soil and groundwater, since PFOS does not volatilize or biodegrade (EC 2013; OECD 2002). Other attenuation mechanisms are purely based on hydrogeological and hydrological conditions. On this basis, K_{oc} is a key parameter to derive an SoQG for potable water ($SoQG_{PW}$) for PFOS.

Franz Environmental Inc. (2014) identified a mean K_{oc} for PFOS, for pH between 5 and 7, of 1445 L/kg, which was used to derive $SoQG_{PW}$'s of 0.013 mg/kg and 0.009 mg/kg for coarse and fine soils, respectively. Owing to the high variability in K_{oc} (Franz Environmental Inc. 2014), the level of protection afforded by this $SoQG_{PW}$ may not be appropriate for all sites. To protect human health, the allowable concentration in potable water is the Groundwater Quality Guideline for the protection of potable water ($GWQG_{PW}$ = 0.0006 mg/L) (0.6 µg/L). $GWQG_{PW}$ are adopted directly from the Guidelines for Canadian Drinking Water Quality, developed by Health Canada (CCME 2015). Therefore, the $GWQG_{PW}$ is equivalent to the Maximum Acceptable Concentration (MAC) of 0.0006 mg/L (0.6 µg/L) developed by Health Canada (HC 2018*a*). CCME (2015) recommends that this value be used to directly screen samples from groundwater that may be used as a drinking water source (see additivity guidance below). Where groundwater is used for other purposes (e.g., irrigation of produce), this should be evaluated on a site-specific basis.

Exposure through local produce, meat and dairy is possible. There is limited available transfer-factor information for fish, shellfish and mammals due to variability and uncertainty inherent in the data, which is attributable to several different factors. Based on a literature review, the available information does not support the derivation of generic transfer factors for animal-based foods for use in the derivation of SoQGs to protect human health (Intrinsik 2018). This review also found very limited data for plant-based food, but food concentration data suggest that fruits, vegetables and cereals contribute less to human exposure than protein-rich foods (Intrinsik 2018). Should consumption of produce, meat and milk be relevant at a site, site-specific conditions and parameters would need to be considered to develop a site-specific guideline, as outlined in CCME (2006). It is suggested that any transfer factors selected be site-specific and specific to the tissues relevant to consumption (e.g., root, shoot, leaves, fruit, organ meat, muscle, skin, etc.). Consideration should also be made for potential differences between exposure concentrations, plant species, and adjustments for soil organic carbon and other soil properties, such as pH and redox potential. Where groundwater is used for other purposes (e.g., irrigation of produce), these uses should be evaluated on a site-specific basis. The check mechanism for consumption of produce, meat and milk was not calculated, due to lack of information.

PFOS is one substance of a suite of PFAS. The health effects of PFOS and PFOA are similar and well documented. Based on science current to 2016, PFOS and PFOA impact the liver in similar ways, therefore, additivity of PFOS and PFOA needs to be considered at contaminated sites (HC 2019*a*, 2019*b*). Thus, when PFOS and PFOA are found together in soil or groundwater, to protect human health, CCME recommends that both chemicals be considered together. This is done by adding the ratio of the measured concentration for PFOS to its relevant guideline ($SoQG_{HH}$ or $GWQG_{PW}$) with the ratio of the measured concentration for PFOA to its relevant guideline[1]. If the result is less than or equal to one (≤1.0), then the soil or groundwater is considered acceptable for its expected use. Current science does not justify the use of this approach for other PFAS.

Recommended additivity approach:

$$\frac{[PFOS]}{SoQG_{HH-PFOS}\ or\ GWQG_{PW-PFOS}} + \frac{[PFOA]}{SoQG_{HH-PFOA}\ or\ GWQG_{PW-PFOA}} \leq 1$$

where:

- [PFOS] and [PFOA] are the measured soil or groundwater concentrations
- $SoQG_{HH-PFOS}$ and $SoQG_{HH-PFOA}$ are the soil quality guidelines for the protection of human health, for PFOS and PFOA, respectively, and
- $GWQG_{PW-PFOS}$ and $GWQG_{PW-PFOA}$ are the groundwater quality guidelines for PFOS and PFOA for the protection of human health, respectively.

[1] At the time of publication, $SoQG_{HH}$ and $GWQG_{PW}$ have not been produced for PFOA. Consult the local jurisdiction to determine whether other reference values can be used in the additivity equation, for example the MAC for PFOA (HC 2018*b*) or soil screening value for PFOA (HC 2019*a*, 2019*b*).

Table 3. Soil quality guidelines and check values for PFOS (mg/kg dw)

	Land use			
	Agricultural	**Residential/ Parkland**	**Commercial**	**Industrial**
Guideline	0.01	0.01	0.01	0.01
Human health guidelines/check values				
$SoQG_{HH}$[c]	0.01	0.01	0.01	0.01
Direct contact guideline $SoQG_{DH}$[d]	2	2	3	40
Inhalation of indoor air guideline $SoQG_{IAQ}$[e]	NC	NC	NC	NC
Soil quality guideline for the protection of potable groundwater $SoQG_{PW}$[f,]	0.01	0.01	0.01	0.01
Produce, meat and milk check $SoQG_{FI}$	NC	NC	—	—
Off-site migration check $SoQG_{OM\text{-}HH}$	—	—	0.1	0.1
Environmental health guidelines/check values				
$SoQG_{E}$[h]	0.01	0.01	0.2 (coarse[a]) 0.1 (fine[b])	0.2 (coarse[a]) 0.1 (fine[b])
Soil contact guideline $SoQG_{SC}$	10	10	60	60
Soil and food ingestion guideline $SoQG_{I}$	0.01	0.01	—	—
Nutrient and energy cycling check $SoQG_{NEC}$	NC	NC	NC	NC
Off-site migration check $SoQG_{OM\text{-}E}$	—	—	1	1
Soil quality guideline for the protection of groundwater: livestock watering and irrigation $SoQG_{LW}$ and $SoQG_{IR}$	7 (coarse) 5 (fine)	—	—	
Soil quality guideline for the protection of groundwater: freshwater life $SoQG_{FL}$[i]	0.2 (coarse[a]) 0.1 (fine[b])	0.2 (coarse[a]) 0.1 (fine[b])	0.2 (coarse[a]) 0.1 (fine[b])	0.2 (coarse[a]) 0.1 (fine[b])

NC = not calculated; ND = not determined; $SoQG_E$ = SoQG for environmental health; $SoQG_{HH}$ = SoQG for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Coarse-grained soil contains more than 50% by mass particles larger than 75 µm mean diameter (D_{50} >75 µm).

[b] Fine-grained soil contains more than 50% by mass particles smaller than 75 µm mean diameter (D_{50} <75 µm).

[c] The $SoQG_{HH}$ is the lowest of the human health guidelines and check values.

[d] The direct human health–based SoQG is based on direct exposure to soil via ingestion, dermal contact and particulate inhalation.

[e] The inhalation of indoor air guideline applies to volatile organic compounds. PFOS is essentially non-volatile.

[f] For pH between 5 and 7. Based on a K_{oc} of 1445 L/kg; PFOS K_{oc} is highly variably (229 to 6,310 L/kg; Franz Environmental Inc. 2014), therefore the level of protection afforded by this $SoQG_{PW}$ may not be appropriate for all sites. Where groundwater is used as a potable water source, groundwater concentrations should be compared directly to the $GWQG_{PW}$ value. Where groundwater is used for other purposes (e.g., irrigation of produce), this should be evaluated on a site-specific basis.

[g] The $SoQG_E$ is the lowest of the environmental health guidelines and check values.

[h] $SoQG_{FL}$ is the concentration in *soil* that is expected to protect against potential impacts on aquatic systems from PFOS originating in soil that may enter the groundwater and subsequently discharge to a surface water body. This pathway may be applicable under any land use category where a surface water body sustaining aquatic life is present (e.g., within 10 km of the site). Note that individual jurisdictions may establish a specific distance requirement for inclusion of this pathway. If surface water bodies are located closer to the remediated soils than 10 metres, then this generic guideline may not be appropriate and a site-specific evaluation may be necessary on a case-by-base basis since the saturated zone transport model is not considered to be appropriate for use at distances less than 10 metres.

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