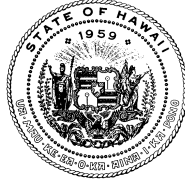


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In reply, please refer to:
File: RB-018-2024

Date: March 25, 2024

To: Interested Parties

Through: Grace Simmons, Program Manager *Gracelda Simmons*
Hazard Evaluation and Emergency Response

From: Roger Brewer, PhD *Roger Brewer*
Hazard Evaluation and Emergency Response

Subject: *Interim Soil and Water Environmental Action Levels (EALs) for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs)*

March 2024 Updates:

- Target Hazard Quotient of “1” used to generate soil action levels for direct exposure;
- Calculation of cumulative noncancer hazard (“Hazard Index”) required for both soil and drinking water data (includes groundwater classified as a current or potential source of drinking water);
- Automatic calculation of a Hazard Index based on input sample data included in Total PFAS Risk spreadsheet accompanying this Technical Memorandum;
- Reference Concentration for 6:2 fluorotelomer sulfonate (6:2 FTS) corrected to 0.001 mg/m³ (MIDEGLE 2020);
- Toxicity factors, physiochemical constants and action levels for following compounds added:
 - Perfluoropentane sulfonate and Perfluoropropanoate (identified in groundwater samples);
 - 6:2 fluorotelomer alcohol and 8:2 fluorotelomer alcohol (used to coat food wrappers and compostable food containers); and
 - 6:2 fluorotelomer thioether amido sulfonate (primary PFAS in modern AFFF);
- Guidance and accompanying Excel spreadsheet added for calculation of sample-specific “Total PFAS Risk.”

A summary of previous updates is provided in Attachment 6.

Information presented in in this Hawai‘i Department of Health (HIDOH) update takes precedence over previous versions of the guidance and should be referred to for projects currently underway in the State of Hawai‘i. Additional guidance on “Total PFAS Risk” included in this update incorporates use of “Total Oxidizable Precursors (TOPs)” and “Total Organic Fluorine (TOF)” to identify and assess the risk posed by PFAS-related compounds that are either unreported by standard test methods or otherwise lack toxicity factors. A Fact Sheet (Attachment

4) is provided to summarize the basis of the Total PFAS Risk approach and guide use of the accompanying Excel spreadsheet (Attachment 5). The approach reflects input from a number of PFAS laboratory and risk assessment experts within and outside of the United States.

Environmental Action Levels (EALs) presented in this memorandum represent an addendum to the HDOH Environmental Hazard Evaluation guidance (HDOH 2024). As is the case for the HDOH guidance in general, recommendations in this document are primarily intended to help quickly screen out low-risk sites where PFASs are tested for as part of a larger-scale environmental investigation. This allows limited resources for more in-depth, site-specific assessments of the risk to human health and the environment to be focused on potentially high-risk sites. A more detailed, site-specific risk assessment might be required by HDOH for high-risk sites on a case-by-case basis.

Assessment of the toxicity of PFASs is continually evolving. The U.S. Environmental Protection Agency (USEPA) as well as other government and private entities are currently carrying out targeted research on many of the topics discussed, including the toxicity of less-well-studied, polyfluoroalkyl substances. This Technical Memorandum will be periodically updated to provide new information as it becomes available. The USEPA is in the process of promulgating drinking water Maximum Contaminant Levels (MCLs) for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) and Maximum Contaminant Levels Goals (MCLGs) for perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA) and hexafluoropropylene oxide dimer acid (HFPO DA) (USEPA 2023a,b,c,d,e,f; also applicable to correlative anionic compounds). Final standards are anticipated by the end of 2023. Proposed MCLGs for PFBS, PFNA and HFPO DA closely align with drinking water action levels presented for these compounds in this updated Technical Memorandum (MCLGs were rounded). Final USEPA drinking water standards for PFOA, PFOS and HFPO DA could differ from action levels presented in the memorandum. This memorandum will be updated to incorporate final toxicity factors and MCLs and MCLGs and related information at the time that final drinking water standards are published. Forthcoming Hazardous Waste regulations for PFASs could also require updates to the guidance.

This guidance should be considered interim and will be updated as new information on PFASs and experience in the field is gained. Comments and suggestions are welcome at any time and should be submitted to Roger Brewer at roger.brewer@doh.hawaii.gov.

Attachment 1: Interim PFAS Guidance (pdf)

Attachment 2: Summary PFAS EALs (pdf)

Attachment 3: Detailed PFAS EALs (pdf)

Attachment 4: Total PFAS Risk Fact Sheet (pdf)

Attachment 5: Total PFASs Risk Calculator (Excel)

Attachment 6: Summary of Previous Updates

Attachment 1

Interim PFAS Guidance (HIDOH March 2024)

1.0	Terminology, Chemistry, Manufacture and Use.....	1
2.0	Sources of PFASs in Soil and Groundwater	4
3.0	Physiochemical Constants	6
4.0	Toxicity Factors	8
5.0	Environmental Fate and Transport.....	12
6.0	Environmental Action Levels for Individually Targeted PFASs.....	14
7.0	Assessment of Total PFAS Risk	23
8.0	Sample Collection and Processing.....	26
9.0	Laboratory Test Methods.....	29
10.0	Limitations	30
11.0	References.....	31

Figures

Figure 1. Structure of octane compared to perfluorooctane sulfonic acid and its anion form perfluorooctane sulfonate and perfluorooctanoic acid and its anion form perfluorooctanoate. Anion forms are more common in contaminated soil, sediment and water.

Figure 2. Primary Terminal Endpoint PFAS compounds with available physiochemical constants and toxicity factors.

Figure 3. Structure of 6:2 FtTAoS⁻.

Figure 4. Example biological degradation of 6:2 FtTAoS⁻ into fluorotelomer sulfonates and carboxylates before ultimately degrading to the Terminal Endpoint compounds PFPeA⁻ and PFHxA⁻ (after Marjanoic et al. 2015).

Figure 5. Example biological degradation of 6:2 FTOH⁻ into carboxylates before ultimately degrading to the Terminal Endpoint compounds PFBA⁻, PFPeA⁻ and PFHxA⁻ (after Tseng et al. 2014).

Figure 6. Predicted partitioning of PFASs upon initial release to vadose zone soil based on the chemical's solubility, sorption coefficient and volatility and default soil parameter values used in HIDOH EAL models.

Figure 7. Hypothetical PFASs groundwater plume separation based on sorption coefficients for individual compounds.

Figure 8. Comparison of PFASs mobility versus toxicity.

Figure 9. Groundwater categories used to develop the Tier 1 EAL lookup tables (HIDOH 2024a)

Tables

Table 1. Nomenclature and abbreviations for per- and polyfluoroalkyl substances with physiochemical constants and toxicity factors.

Table 2a. PFAS physiochemical constants and absorption factors used in EAL Models.

Table 2b. References for PFAS physiochemical constants.

Table 3a. PFASs toxicity factors with multiple sources.

Table 3b. Final noncancer toxicity factors used for development of action levels and assessment of risk.

Table 4. ¹Chronic health effects of PFASs (refer to Attachment 3, Table J for additional information).

Table 5. Summary of Drinking Water Ingestion Rates relative to body weight utilized for calculation of drinking water action levels.

Table 6. Default exposure parameter values used to generate toxicity-based action levels for drinking water and direct- exposure action levels for soil (refer to Appendix 1 and Appendix 2 in 2017 HIDOH EAL guidance).

Interim Soil and Water Environmental Action Levels (EALs) for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs)

1.0 Terminology, Chemistry, Manufacture and Use

The compound naming convention for perfluoroalkyl and polyfluoroalkyl substances (PFASs) recommended by Buck et al. (2011) is generally adhered to for the purposes of this memorandum. Both the singular and plural acronyms “PFAS” and “PFASs” are used. A singular term and acronym is appropriate in many cases when the term is used as an adjective, such as “PFAS Environmental Action Level” and “PFAS manufacturing facilities.” The plural form is appropriate when the group of compounds in general is the subject noun, for example “Environmental Action Levels for PFASs” or “Manufacture of PFASs.” Other examples that include use of the singular form as the subject noun will be grammatically correct, for example “The specific, precursor PFAS associated with the presence of 5:3 FTCA in biosolids is unknown.”

PFASs are used in the manufacture of carpets, clothing, fabrics, paper, packaging for food and other materials in order to make them resistant to water as well as grease or stains, among many other uses. PFASs are also used in firefighting products such as aqueous film forming foams (AFFF). Overviews of the chemistry, production and use of these chemicals are accessible on the internet (e.g., Buck et al. 2011; OECD 2013; ATSDR 2018; DEPA 2018; ITRC 2020; USEPA 2020), as are numerous recorded webinars.

PFASs are manufactured by replacing all of the hydrogen atoms bonded to carbon (“perfluoroalkyl”) or some of the hydrogen atoms bonded to carbon (“polyfluoroalkyl”) in a hydrocarbon compound with fluorine (ITRC 2020). Categorization of PFASs in terms of chemistry and group studies indicate that PFASs groupings in terms of molecular structures can become quite complex. While necessary for a detailed understanding of fate and transport as well as toxicity, groupings of PFASs specifically for assessment of risk can be simplified to two categories: 1) Terminal Endpoint Compounds and 2) Precursor Compounds. Primary Terminal Endpoint compounds are noted in Table 1. Physicochemical constants and toxicity factors available for these compounds allows development of risk-based action levels and direct assessment of risk. The table notes both the protonated, acid form of the compound and the dissociated, anion form more common in the environment. The same abbreviation is often used for both the acid form and the anion form in literature. To denote the difference for the purposes of this technical memorandum, a superscript “-” is added to the abbreviation for the anion form.

Physicochemical constants and toxicity factors are lacking for most precursor compounds, as are laboratory methods for directly identifying and quantifying these compounds in environmental samples. As described in this guidance document, this necessitates the use of alternative, indirect laboratory methods to assess the risk posed by precursor PFAS compounds in the environment.

1.1. Terminal Endpoint Compounds

Terminal Endpoint PFASs (“Terminal PFASs”) are characterized by a chain of fully fluorinated (“perfluoro-”) carbon atoms with a simple carboxylic acid or sulfonic acid function group attached

to one end. The anion forms of these compounds most commonly found in the environment and where the hydrogen has been removed are referred to as “carboxylates” and “sulfonates.”

PFASs are in part named based on the number of linked carbon atoms in the structure, following the procedure used to name aliphatic compounds. Examples of acid and anion forms of eight-carbon terminal PFASs with respect to the correlative, eight-carbon aliphatic compound “octane” are depicted in Figure 1. Primary Terminal PFASs used to assess risk are noted in Figure 2. Compounds are further categorized as “long-chain,” “short-chain” and “ultrashort-chain” based on the number of linked carbon atoms. Carboxylates are categorized as “long-chain” if the compound contains seven or more linked carbon atoms. Sulfonates are categorized as long-chain if they contain six or more linked carbon atoms. Compounds in both categories are categorized as “ultrashort” if they contain less than four linked carbon atoms. Short-chain compounds capture the middle fraction of this grouping. Although not exact, this is in part done to group compounds in terms of both toxicity and mobility. As discussed below, longer-chain compounds tend to be more toxic and less mobile than shorter chain compounds. Groundwater plumes tend to be increasingly dominated by more mobile but less toxic short- and ultra-short compounds with increasing distance from the source area of a release and in PFAS-contaminated wastewater in general.

1.2. Precursor Compounds

Precursor compounds are characterized by partially fluorinated (“polyfluoro-”) chain of carbon atoms with typically more complex functional groups added to obtain desired physical properties. These compounds are referred to as “precursors” because they can degrade via natural metabolism or other processes in the environment to Terminal PFASs. The toxicity invoked by the latter are of most concern for assessment of risk.

The compound 6:2 fluorotelomer thioether amido sulfonic acid (6:2 FtTAoS), used as the dominant PFAS in AFFF since 2005, and its sulfonate anion form (6:2 FtTAoS⁻) are examples of precursor compounds (Figure 3; SERDP 2017). The compound was manufactured to replace the earlier use of PFOA in AFFF, due to concerns over the latter’s potential toxicity. Figure 3 depicts the structure of 6:2 FtTAoS⁻. Hydrogen has been replaced with fluorine on only six of the eight carbons in comparison to PFOA, thus the designation “6:2” (refer to Figure 3). A complex function group – thioether amido sulfonic acid, has been added to the head of the molecule.

A natural terminal endpoint breakdown product of 6:2 FtTAoS could thus be predicted to be the six-carbon compound perfluoro hexanoate, following biological (or chemical) removal of the functional group as well as the two carbon atoms that lack stabilizing fluorine atoms. The breakdown of 6:2 FtTAoS has in fact been shown to be more complex (Figure 4; Marjanoic et al. 2015), with a mixture of short-chain, terminal endpoint compounds that include both PFPeA⁻ and PFHxA⁻ generated, as well as intermediate metabolites that include fluorotelomer sulfonates (e.g., 6:2 FTS⁻) and carboxylates (e.g., 5:3 FTCA⁻). These degradation compounds have been identified in contaminated soil and water at AFFF-release sites in Hawai'i, including a study currently underway by HDOH (Brewer 2023a,b).

Fluorotelomer alcohols, used to make paper, clothing, carpeting as well as food containers and wrappers water- and grease-resistant, represent another example of precursor compounds that can degrade to Terminal PFAS in the environment (Carnero et al. 2021). Figure 5 depicts the microbial

degradation of 6:2 FTOH into a complex mixture of metabolites and the terminal endpoint compounds PFBA⁻, PFPeA⁻ and PFHxA⁻ (Tseng et al. 2014)). Intermediate metabolites are again characterized by fluorotelomer carboxylates such as 5:3 FTCA⁻ and related precursor compounds. Similar mixtures of Terminal PFASs and intermediate precursor compounds have been identified in samples of influent and biosolids collected from wastewater treatment plants in Hawai'i (HIDOH 2024; report pending)

The presence of precursor compounds in soil, water and other PFAS-contaminated media complicates quantification and assessment of the risk posed by the combined exposure to both these compounds and Terminal PFAS already existing in the media (e.g., Nikiforov 2021). This necessitates the development of an approach to quantify and assess the collective toxicity of precursor compound mixtures as well as ultrashort PFAS compounds not routinely reported under standard USEPA and equivalent laboratory methods. An approach for calculation of “Total PFAS Risk” based on the combined use of Total Oxidizable Precursors (TOPs) and Total Organic Fluorine (TOF) methods is described in Section 7.

1.3. Laboratory Reporting of PFASs

Laboratory test methods required to characterize PFAS-contaminated media and assess risk are discussed in Sections 7 and 10. PFASs produced or used by industries are normally present in a salt or acid form. When these compounds are released to soil or water, the hydrogen atom dissociates, leaving the anion form. Anion forms of the compounds are assumed to dominate in contaminated soil and water and are the focus of the Environmental Action Levels (EALs) presented in this memorandum. Current laboratory methods cannot distinguish between the different forms. Sample processing steps instead convert any salt or acid form of a compound present into the anion form prior to testing. The concentration of the anion form of the compound is then reported by the laboratory.

USEPA Standard Operating Procedures for testing of PFASs calls for conversion of anion data to equivalent acid-form concentrations for reporting purposes, even though true acid forms of the compound are unlikely to be found in nature (e.g., USEPA 2020, 2021b, 2021c). This is most likely due to original development of the lab methods to test manufactured product. As discussed in Section 3, modeling the acid form of the compound rather than the anion form that is more likely to be present could introduce significant error into an assessment of the fate and transport of the compounds in the environment (see also ITRC 2020). While the effect on the reported concentration is insignificant (generally <<1%), laboratories should be requested to report environmental data in the original anion form, rather than the acid form. The anion form of the compound should always be used in environmental investigation reports.

2.0 Sources of PFASs in Soil and Groundwater

Contamination of soil and groundwater with PFASs has been associated with the use of PFAS containing foam at firefighting training operations, releases of wastewater and sludge from PFAS manufacturing facilities, releases of leachate from unlined, municipal landfills, use of PFAS containing biosolids from wastewater treatment facilities as a soil amendment and use of treated wastewater for irrigation, among other sources (OECD 2013, SERDP 2017, ITRC 2020). Contamination of groundwater in Hawai'i has to date been identified at only a small number of firefighting training operations. Significant impacts are thus far limited to a single, private well used for drinking and irrigation purposes. Contamination in most cases occurs at airports in coastal areas. These impacts do not threaten a drinking water resource but could pose a concern for nearby shorelines and aquatic habitats. In most cases, landfills are similarly not located in areas that could threaten a drinking water supply.

There are no registered PFAS manufacturing facilities in Hawai'i. Effluent from wastewater treatment plants is used for irrigation of golf courses and road medians in some municipalities and potentially small areas of agricultural fields. Biosolids from treatment plants have also reportedly been used as a soil amendment at golf courses and to a lesser degree in fields.

Published studies indicate that PFASs found in soil and groundwater at fire training sites are typically dominated by PFOS⁻, PFHxA⁻, PFOA⁻ and PFHxS⁻ with lesser amounts of PFNA⁻. This is based largely on PFASs reported under Method 537 and in the absence of TOPs processing of the samples (Tsitonaki et al. 2014). As noted in Section 1.2, the primary PFAS used in firefighting foam since 2005 is in fact 6:2 FtTAoS. This compound is not routinely reported by laboratories. Methods to assess risk were also lacking prior to publication of the toxicity factors noted in this Technical Memorandum. The presence of this compound in a sample is only identifiable if the sample has been processed using TOPs. Data for soil samples collected by HDOH and processed using TOPs had identified concentrations of PFASs hundreds of times higher than indicated by samples tested in the absence of TOPs processing ("pre-TOPs"). This confirms observations in other publications (e.g., Ateia et al. 2023). Impacts to fire training sites based on consideration of only pre-TOPs Terminal PFASs is therefore likely to underestimate actual risk.

The relative proportions of these compounds in contaminated media can vary from site to site, depending on the types of firefighting foam used over time and distance from the initial release area. Testing of water supply wells in California identified nine, primary PFASs, including PFHxS⁻, PFOS⁻, PFOA⁻, PFBS⁻, PFHxA⁻, PFHpA⁻, PFNA⁻, PFDA⁻ and ADONA⁻ (CAEPA 2020). Significant concentrations of "ultrashort" PFASs have also been identified in some samples (personal communication; Wendy Lynk, CAEPA). The occurrence and relative proportions of the compounds varies widely between test sites. In most cases, the source of the PFASs is still under investigation.

An informal review of landfill data from California indicated that leachate is dominated by PFBA⁻, PFHxA⁻, PFOA⁻, PFPeA⁻ and PFHpA⁻, with a less common but still potentially significant component of PFBS⁻, PFOS⁻, NEtFOSSA⁻ and PFUnDA⁻ (Keith Roberson, personal communication; based primarily on Method 537 data). More detailed testing of landfill leachate by Lang et al. (2017) suggests, however, that precursor compounds such as the fluorotelomer

compounds 5:3 FTCA, 6:2 FTCA and 7:3 FTCA typically make up 30-40+% of PFAS compounds rather than traditionally tested for sulfonates and carboxylates. These compounds can form from the biodegradation of other fluorotelomer compounds, including fluorotelomer alcohols such as 6:2 FTOH (Buck et al. 2011, OECD 2013, ITRC 2020). Preliminary data for leachate samples collected from landfills in Hawaii are similar (HIDOH report pending final testing of samples).

Concentrations of PFASs in wastewater treatment plant influent and effluent is higher at facilities that accept industrial wastewater or leachate from landfills (e.g., Kathan 2020). Highly sorptive PFASs tend to be dominant in sludge (ITRC 2020) but the overall PFAS makeup can be highly variable between separate facilities (e.g., Kathan 2020). Landfill leachate can also contain a high proportion of PFAS precursors. Detailed studies of PFASs in contaminated soil and groundwater at AFFF-release sites, landfill leachate, wastewater treatment plant influent, effluent and biosolids currently underway by HIDOH confirm that precursor compounds dominate impacted media in many cases and significantly contribute to potential risk to human health and the environment (Brewer 2023a,b). A report on the HIDOH study is pending final collection and testing of samples and is anticipated in by Spring 2024.

3.0 Physiochemical Constants

Table 2a summarizes physiochemical constants for individually targeted, Terminal PFASs. Constants for a short list of precursor compounds for which toxicity factors are available are also noted. The constants are used to predict the fate and transport of the compounds in the environmental and develop Environmental Action Levels. References for constants are summarized in Table 2b. Primary sources include:

1. US Environmental Protection Agency, CompTox Chemistry Dashboard;
2. Oak Ridge National Laboratories, Risk Assessment Information System;
3. Interstate Technology and Regulatory Council, Per- and Polyfluoroalkyl Substances; and
4. European Chemicals Agency.

The majority of the constants were taken from the USEPA CompTox Chemistry Dashboard (USEPA 2017, and updates). Limited, additional constants were available in PFAS-specific guidance published by ATSDR and the European Chemical Agency. The majority of values for the solubility of a compound were predicted from models rather than directly measured. Confidence in the reliability of the values is moderate to low. Although not specifically referenced in the table, Henry's Constants for a number of PFASs are also available from Sander (2015).

Volatility is categorized in terms of both a chemical's Henry's law constant and the molecular weight of the compound. A chemical is considered to be volatile and subject to emission to ambient air if the Henry's constant is greater than $0.00001 \text{ atm m}^3/\text{mole}$ or the vapor pressure is greater than 1 mm of mercury and the molecular weight is less than 200 (HIDOH 2024; USEPA 2019b). A chemical is considered to be "semi-volatile" if the Henry's constant or vapor pressure criteria are exceeded but the molecular weight is greater than 200.

Perfluoropropanoate (PFPrA⁻) is the only PFAS compound currently categorized as "volatile," due to a theoretical vapor pressure greater than 1 mm Hg and a molecular weight under 200 (refer to Table 2). The compound has thus far been only identified in water. The dissolved-phase, anion form of PFPrA⁻ in water is expected to be significantly less volatile than the acid form. PFPrA⁻ is not currently considered to be a contaminant of potential concern for soil or other particulate matter at PFAS-sites in Hawai'i. Preservation of samples of solids using methanol or other methods is therefore not required at this time. Direct testing of soil vapors and/or indoor air will be recommended if potential risks are identified in the future.

The compounds PFBA⁻, PFPeA⁻, PFHxA⁻, and 6:2 FTOH⁻ are classified as semi-volatile due to high vapor pressures and molecular weights greater than 200 (see Table 2). The Henry's constant listed in the CompTox database for PFBA⁻ also exceeds $0.00001 \text{ atm m}^3/\text{mole}$. Samples to be tested for volatile compounds should in practice be placed in methanol in the field immediately after collection (HIDOH TGM Section 4, Appendix I). Samples of soil, biosolids and other particulates to be tested for semi-volatile and should in practice be subsampled prior to air drying in order to prevent potential loss due to volatilization (refer to HIDOH TGM Section 4.2.6.4). Henry's Law constants and vapor pressures noted in Table 2 are largely modeled rather than directly measured, however, decreasing confidence in their accuracy. Vapor pressure can also be

estimated based on the chemicals molecular weight, Henry's constant and solubility (after ECHA 2016, Equation r.16-4):

$$\text{Vapor Pressure (mm Hg)} = \frac{\left(\text{Henry's Constant} \left(\frac{\text{atm m}^3}{\text{mole}} \right) \times \left(\frac{760 \text{ mm Hg}}{\text{atm}} \right) \times \left(\frac{1,000 \text{ L}}{\text{m}^3} \right) \right) \times \left(\text{Solubility} \left(\frac{\text{mg}}{\text{L}} \right) \times \left(\frac{1 \text{ g}}{1,000 \text{ mg}} \right) \right)}{\text{MW} \left(\frac{\text{g}}{\text{mole}} \right)} \quad \text{Eq 1.}$$

Using this approach and the values for the noted parameters listed in Table 2a, the predicted vapor pressures of PFPeA⁻ and PFHxA⁻ would all fall well below 1 mm Hg, implying that the compounds are unlikely to be even semi-volatile. This suggests that loss during air drying and sieving of soil samples would in fact be minimal and that samples can be processed as normal prior to the collection of analytical subsamples for testing.

A similar conclusion was reached for PFBA⁻ and 6:2 FTOH⁻ following discussions with laboratory chemists familiar with testing for PFASs in soil samples. The applicability of the Henry's law constants and vapor pressures in the CompTox Chemical Dashboard is questionable and significant loss of PFBA⁻ during air drying is not anticipated. The same is anticipated to be true for fluorotelomer alcohols.

For the purposes of this guidance, soil, sediment and other particulate samples to be tested for PFBA⁻, PFPeA⁻, PFHxA⁻ and 6:2 FTOH⁻ can therefore be processed in accordance with methods described in the HEER Office TGM for non-volatile chemicals unless otherwise directed. Minor loss of potentially semi-volatile compounds during processing and resulting error in the sample data is expected to be offset by an increase in the representativeness of the subsample collected for analysis. This issue will be re-evaluated in the future as needed as additional research is carried out. Modified sample collection and laboratory methods for volatile and semi-volatile PFASs will be incorporated into future updates of this guidance, as needed.

Physiochemical constants for individual compounds will be updated as new information becomes available and could result in changes to the action levels presented in this technical memorandum. Additional studies of factors that control potential leaching of these compounds from soil and subsequent impacts to groundwater and surface water are also currently underway by HODOH.

4.0 Toxicity Factors

4.1. Human Toxicity

A summary of toxicity factors compiled for individual PFASs is provided in Table 3a. Final toxicity factors selected to generate EALs are noted in Table 3b. The studies reflect a mix of toxicity associated with protonated acid and anion forms of the compounds (see Table 3a). For the purposes of this document, the toxicity of protonated acid and anion forms of the compounds is assumed to be identical and the toxicity factors apply to both.

A summary of available evidence of health effects indicated by toxicological studies of PFASs is provided in Table 4. An abbreviated summary is provided in Table J of Attachment 3. Health concerns associated with long-term, chronic exposure to PFASs focus on potential systemic (noncancer) effects to liver function, immune system alterations, developmental effects and metabolic and endocrine dysfunction (e.g., USEPA 2022a,b,c; Zeilmaker 2018; ATSDR 2018; Kirk et al. 2018). Refer to the references provided with Table 2b and Table 3b for additional overviews of toxicological studies.

There is significant debate and uncertainty regarding the long-term human health effects of exposure to these and other PFASs. Human epidemiology studies as well as in vitro and animal toxicology studies have often produced conflicting results, contributing to the uncertainty. Toxicity factors used to develop EALs and health effects associated with individual compounds will be updated as new information becomes available. This could result in a future increase or decrease of the action levels presented in this document.

Primary sources referred to for selection of toxicity factors presented in Table 3a include:

1. ATSDR, 2021, Toxicological Profile for Perfluoroalkyls: Agency for Toxic Substances and Disease Registry, May 2021.
2. MIDOE, 2020, Screening Level Evaluation 6:2 Fluorotelomer Sulfonic Acid: Michigan Department of Environment, Great Lakes and Energy, Interoffice Communication from Michael Depa, Toxics Unit, Air Quality Division, September 24, 2020. (toxicity factors for 6:2 FTS-).
3. MIDOE, 2021, Response to Public Comments for 6:2 Fluorotelomer Sulfonic Acid: Michigan Department of Environment, Great Lakes and Energy, Air Quality Division, January 24, 2021
4. MNDOH, 2018, Toxicological Summary for Perfluorobutanoate: Minnesota Department of Health, August 2018.
5. TXCEQ, 2016, Toxicity Factor Derivation for Perfluoro Compounds (PFCs) Under the Texas Risk Reduction Program: Texas Commission on Environmental Quality, January 4, 2016.
6. USEPA, 2018, Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3), Also

Known as “GenX Chemicals” (Public Comment Draft): U.S. Environmental Protection Agency, EPA-823-P-18-001, November 2018.

7. USEPA, 2021, Human Health Toxicity Values for Perfluorobutane Sulfonic Acid (CASRN 375-73-5) and Related Compound Potassium Perfluorobutane Sulfonate (CASRN 29420-49-3): US Environmental Protection Agency, Office of Research and Development, EPA/600/R-20/345F, April 2021.
8. USEPA, 2021, Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3) Also Known as “GenX Chemicals”: US Environmental Protection Agency, Office of Research and Development, EPA Document Number: 822R-21-010, October 2021.
9. USEPA, 2023, Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts: US Environmental Protection Agency, Office of Research and Development, EPA/635/R-23/027Fa, April 2023.
10. WIDHS, 2020, Summary and Scientific Support Documents for Cycle 11 Recommended Groundwater Standards: Wisconsin Department of Health Services, P-02807, November 2020.
11. Zeilmaker, M.J., Fragki, S., Verbruggen, E.M.J. and B.G.H. Bokkers, 2018, Mixture Exposure to PFAS, A Relative Potency Factor Approach: National Institute for Public Health and the Environment, Bilthoven, The Netherlands.

Reference dose (RfD) toxicity factors for oral ingestion were available or could be generated for 23 PFASs. When available, toxicity factors published by the USEPA normally take priority. Draft RfDs for PFOA and PFOS presented in USEPA documents for proposed drinking water Maximum Contaminant Levels (MCLs) are currently under review and will be incorporated into HDOH guidance as appropriate when finalized. The draft RfDs are included in Table 3a for reference purposes only. Toxicity factors for additional PFAS compounds were selected based on the date of the guidance and overall depth of the data reviews. Relative Potency Factors (RFPs) for PFASs published by The Netherlands in 2018 and based on the reference potency of PFOA (acid form) were used to select RfDs for PFPeS⁻, PFHpS⁻, PFDS⁻, PFPeA⁻, PFHpA⁻, PFDA⁻, PFUnDA⁻, PFDoDA⁻, PFTTrDA⁻ and PFTeDA⁻.

Texas was the only entity identified with a published RfD for PFOSA (acid form; TXCEQ 2016) and was used for calculation of PFOSA⁻ action levels. The Texas guidance also includes inhalation Reference Concentration (RfC) for acid forms of PFBS, PFHxS, PFOS, PFBA, PFNA, PFDA and PFDoDA. The RfC values were derived using route-to-route extrapolation from oral RfD values. Based on the review by the toxicologists involved, effects in laboratory studies for these compounds did not appear to be route-specific. The RfC values only come into play in calculation of soil action levels, due to an assumed inhalation exposure to these compounds via airborne dust. With the exception of PFBS, consideration of the RfC in calculation of direct-exposure action levels for soil did not significantly affect action levels based on incidental ingestion only.

Research published by the USEPA suggests a potential cancer risk for adults associated with long-term exposure to perfluorooctanoic acid and proposed a cancer slope factor of 0.07 (mg/kg-day)⁻¹

(ATSDR 2021). The California EPA has published studies of potential cancer concerns for both perfluorooctanoic acid and perfluorooctane sulfonate (CAEPA 2019a). Cancer slope factors proposed by the agency are currently under review. An alternative and much more stringent cancer slope factor for PFOA of $2.93E+04$ (mg/kg-day)⁻¹ is proposed in the supporting technical document for development of an MCL for this compound (USEPA 2023a). A cancer slope factor is proposed for PFOS of $3.95E+01$ (mg/kg-day)⁻¹ in a related MCL document (USEPA 2023b). Both documents are under public review as of the date of this HIDOH guidance. Finalized cancer slope factors will be incorporated into HIDOH guidance as appropriate, anticipated by the end of 2023.

Current noncancer-based action levels for PFOA⁻ based on a Reference Dose published by ATSDR (2021) are lower than cancer-based action levels and therefore take precedence. Noncancer hazards are intended to be protective of young, developing children. The action level presented for PFOA fall within the range of action levels based on an excess cancer risk of 10^{-4} to 10^{-6} and is assumed to be adequately protective of both noncancer risks (hazards) to children as well cancer risk to adults. Action levels presented for PFOS⁻ are similarly based on noncancer health concerns. If adopted, a proposed cancer slope factor for PFOS presented in the draft, USEPA MCL document could result in a cancer-based action level for PFOS that is lower than the level based on noncancer concerns and would therefore take precedence (USEPA 2023a).

Perfluoropentane sulfonate (PFPeS⁻) has been identified in groundwater samples collected in Hawai'i. Published toxicity factors for this compound have not been identified. Zeilmaker et al. (2018) note that based on carbon chain length, the RfP for PFPeS⁻ is anticipated to be more toxic than PFBS⁻ (RfD = 0.0003 mg/kg-day) and less toxic than PFHxS⁻ (RfD = 0.00005 mg/kg-day). The Danish Ministry of Environment (DMOE 2015) review of the toxicity of short-chain PFASs more narrowly notes that PFPeS⁻ is anticipated to demonstrate a slight increase toxicity both respect to PFBS⁻ and PFPeA⁻. (RfD = 0.0004 mg/kg-day). For the purposes of this guidance, an RfD of 0.00016 mg/kg-day, representing the halfway point between PFBS and PFHxS, was assigned to PFPeS⁻ in order to ensure that the potential risk posed by this compound is considered when identified at a site.

Gibb and O'Leary (2023) carried out a review of toxicity studies for 6:2 FtTAoS, 6:2 FTOH and 8:2 FTOH under contract with HIDOH. Toxicity factors generated by the review are noted in Table 3a.

4.2. Ecotoxicity and Food Chain Uptake

HEER Office action levels include consideration of discharges of contaminated groundwater to a surface water body and potential impacts to aquatic flora and fauna (HIDOH 2024a). As a default, contaminants in groundwater should not exceed chronic, aquatic toxicity action levels at the point that the groundwater discharges into a body of surface water. The dilution of contaminated groundwater upon mixing with surface water is not considered. This is intended to be protective of benthic habitats where dilution of groundwater with surface water prior to discharge could be minimal. A less conservative requirement to meet acute, aquatic toxicity action levels prior to discharge is generally acceptable for highly developed harbors and similar areas where the aquatic habitat has otherwise already been significantly disrupted. Natural seepage of groundwater into

stormwater sewers or intentional discharge into storm sewers during construction activities must also be considered.

Toxicity to terrestrial flora and fauna is not addressed in the HEER Office EALs and must be evaluated on a case-by-case basis, as appropriate for the site. Uptake into edible produce is anticipated to take precedence to actual toxicity to the plant in most cases. Additional guidance on this issue will be provided in the future as it becomes available and is applicable to Hawai'i.

The uptake and bioaccumulation of PFASs into benthic organisms and other aquatic flora and fauna and propagation up the food chain could require investigation at sites where PFAS-impacted sediment or surface water is identified. Reliable methods to assess these concerns are still in development. The need to evaluate uptake into edible produce and aquatic organisms should be discussed with the HEER Office on a case-by-case basis.

5.0 Environmental Fate and Transport

An in-dept review of the fate and transport of PFASs in the environment is beyond the scope of this Technical Memorandum. Refer to Guelfo et al. (2019) and ITRC (2020), among other sources for additional information. A summary but still incomplete overview of basic fate and transport considerations is provided below.

The mobility of PFASs in the environment is governed by each chemical's solubility, volatility and tendency to sorb to organic carbon and clay. These processes are still not well understood for PFASs. The breakdown and transformation of PFASs in the environment can similarly be very complex (see ITRC 2020). Basic information on the degradation and fate and transport of precursor compounds is provided in Section 1.2. Research on this topic is ongoing and will be incorporated into HEER Office guidance in the future as available and pertinent to projects in Hawai'i.

The potential for a compound to leach from soil and contaminate underlying groundwater is traditionally evaluated in terms of the chemical's solubility and "sorption coefficient (Koc)," (McCall et al. 1981; refer also to HDOH 2024a). The solubility of PFASs can be dependent on site-specific conditions that promote degradation and transformation into other compounds. This complicates accurate modeling of leaching potential. The sorption coefficient, expressed in units of cm^3/g , reflects the ratio of the mass of the chemical that will sorb to organic carbon to the mass of the chemical that will dissolve in water under ambient, equilibrium conditions. Chemicals with a Koc value of less than approximately $50 \text{ cm}^3/\text{g}$ are considered to be highly mobile (see HDOH 2024). Chemicals with a Koc value greater than $500 \text{ cm}^3/\text{g}$ are considered to have low mobility. Chemicals with Koc values greater than $5,000 \text{ cm}^3/\text{g}$ are considered to be essentially immobile, or not significantly leachable from soil.

Incorporation of the default solubility, Henry's Constant and sorption coefficient into a simple contaminant partitioning model (USEPA 1996) and default, soil parameters used in the USEPA RSL and HDOH EAL models allows prediction of the initial fate of a PFAS when released to soil (Figure 6). This simple exercise predicts that PFASs with a relatively low sorption coefficient and a high solubility like PFHxA⁻ will more easily dissolve into infiltrating water and pose a greater leaching threat than chemicals with relatively high sorption coefficients, such as PFOS⁻.

Such models are likely to overpredict the mobility of aged releases of PFASs in vadose-zone soil. Published sorption coefficients are based on the energy required to physically sorb the chemical to organic carbon. Like sticking a Velcro-covered ping pong ball to an opposing sheet of Velcro, however, much more energy is often required to *desorb* the chemical from the carbon. Soil action levels for leaching concerns based on Koc *sorption* values can therefore significantly overestimate the potential mobility of the PFASs and potential, adverse impacts to groundwater. Electrostatic binding of polar, PFAS compounds to charged particles in the soil over time or diffusion of compounds into clay particles can further inhibit leachability. As discussed below, laboratory testing of leachability and determination of soil-specific "desorption" coefficients will be necessary when action levels are exceeded (HDOH 2024).

A similar separation of PFASs in groundwater plumes migrating away from a source area is also predicted, with lower mobility compounds such as PFOS⁻ remaining concentrated in the source

area and compounds such as PFPrA⁻, PFHxA⁻, PFPeA⁻ and PFBS⁻ characterizing the forward, leading edge of the plume (Figure 7). This in part likely explains the identification of the latter compounds in groundwater in absence of significant PFOS⁻ and PFOA⁻ and highlights the need for risk-based, drinking water action levels for more than just these two compounds.

Figure 8 compares the hypothetical mobility of individual PFASs in terms of the sorption coefficient to the compound's toxicity. This could be useful to predict highly toxic and recalcitrant compounds that could remain trapped in soil or taken up in the food chain and pose similar risk to PCBs. Less mobile PFASs are anticipated to accumulate in soil and biosolids. More mobile compounds could drive risk for uptake into food crops or livestock feed or impacts to groundwater. As noted in Figure 8, the least sorptive compounds that pose the greatest leaching risk to groundwater, such as PFBS⁻ and PFHxA⁻, are fortunately also of relatively lower toxicity.

6.0 Environmental Action Levels for Individually Targeted PFASs

Interim soil and water action levels for PFASs are provided in Tables A and B in Attachment 2. Detailed tables for derivation of the EALs are provided in Attachment 3. These tables represent an addendum to the 2017 EHE guidance document and are presented in the same format (HIDOH 2024a). A separate, Excel-based “EAL Surfer” of electronic lookup tables specific to PFASs is available for download from the HEER Office EHE guidance webpage (refer to weblink in below reference). The action levels represent an addendum to the 2017 EHE guidance and will be incorporated into that guidance in the future. The list of PFAS-related compounds with action levels will be expanded as toxicity factors and physiochemical constants for additional compounds become available.

6.1. Potential Environmental Concerns

Methods used to derive EALs for specific, environmental concerns are discussed in Volume 1 and Volume 2, Appendix 1 of the HEER Office EHE guidance (HIDOH 2024a). Action levels were generated for the following environmental concerns:

Environmental Concern	Action Level Generated?	Notes
Soil		
Direct Exposure	X	All PFASs with available toxicity factors
Vapor Intrusion	-	(not applicable; listed PFASs not volatile)
¹ Leaching to Groundwater	X	All PFASs with available toxicity factors
² Gross Contamination	-	Odor thresholds not identified
Groundwater		
Drinking Water Ingestion	X	All PFASs with available toxicity factors
³ Vapor Intrusion	-	Currently PFPrA ⁻ only
Aquatic Toxicity	X	Limited; drinking water action levels applied for initial screening if aquatic toxicity action levels not available
² Gross Contamination	-	Taste and odor thresholds not identified
Ambient Air and Subslab Vapor		
³ Vapor Intrusion	-	Currently PFPrA ⁻ only

1. Confidence in leaching model used is low; corresponding soil levels predicted to be excessively conservative. Use of laboratory leaching methods (e.g., SPLP and/or Method 1314 soil column) recommended if action levels exceeded (see text).

2. “Gross Contamination” includes short-term risks associated with temporary but high emissions of vapors from disturbed soil or groundwater, sheens in runoff, explosion and fire hazards, etc. (HIDOH 2024a). Action levels currently not available for PFAS compounds and anticipated to be significantly higher than action levels based on direct exposure risks.

3. Vapor intrusion risk posted by volatile and semi-volatile PFASs under review. Soil vapor samples recommended for site-specific assessment if a potentially high-risk concern is identified, with a focus on subslab Large Volume

Purge (LVP) sampling methods (refer to HDOH Technical Guidance Manual, Section 7 (HDOH 2023)). Model-based soil and groundwater action levels considered to be unreliable due to complexity of PFAS fate and transport.

Additional information on each of the targeted concerns is provided in the following sections. Default, USEPA exposure assumptions regarding daily soil ingestion and water consumption as well as the number of days per year and years of exposure were used to calculate the action levels.

Organization of the EAL lookup tables is discussed in Volume 1, Section 2.4 of the EHE guidance. The “Tier 1” action levels for soil listed in Tables A and B are intended to allow unrestricted current and future use of a property. This includes use of the property for residences, schools, medical facilities, day-care centers, and other sensitive purposes with no restrictions regarding regular contact with the soil. Alternative and potentially less stringent soil action levels for sites that will be restricted to commercial/industrial land use only can be considered on a case-by-case basis, as discussed in Section 3 of the EHE guidance.

Groundwater utility is determined based on the location of the site with respect to the Underground Injection Control (UIC) Line and the state Aquifer Identification and Classification technical reports prepared by the University of Hawai'i (Figure 9). Groundwater situated mauka (inland) of the UIC line is classified in most cases as a current or potential source of drinking water. Soil and groundwater action levels applicable to drinking water impact scenarios apply to these areas (Scenarios A-1 and A-2 in Figure 9). Exceptions are discussed in Section 2.4.3 of the EHE guidance.

First-encountered groundwater in areas situated makai (oceanward) of the UIC line is, by regulation, not considered to be a potential source of drinking water. Environmental Action Levels for nondrinking water scenarios apply to both soil and groundwater situated in these areas (Scenarios B-1 and B-2 in Figure 9). Groundwater action levels focus on the protection of aquatic habitats associated with natural or intentional discharges of groundwater to surface water. Action levels based on aquatic toxicity are in most cases less stringent than action levels based on drinking water toxicity. As discussed below, aquatic toxicity action levels are only currently available for only 11 of the 19 PFAS compounds discussed. Drinking water action levels are applied as a substitute in the interim. Groundwater action levels presented in Table A (drinking water resource) and Table B (non-drinking water resource) are therefore identical.

Groundwater action levels should be compared to dissolved-phase chemical concentrations unless instructed by the overseeing regulatory agency. This may require filtering of turbid samples prior to analysis (refer to Section 6 of the HEER Office *Technical Guidance Manual*).

6.1.1. Drinking Water Ingestion

Cancer Risk

Cancer-based drinking water action levels are not currently included in the HDOH PFAS guidance. Draft Cancer Slope Factors are presented for both PFOA and PFOS in the proposed, USEPA MCL documents for these compounds that are currently out for public review (USEPA 2023a,b). Quantitative levels are not presented, however, with the proposed MCL simply be stated to be “zero.” A Cancer Slope Factor is presented for PFOA but not for PFOS in USEPA Drinking Water Advisory Levels for these compounds (USEPA 2022a,b; see also USEPA 2022c). Based on the Cancer Slope Factor available for PFOA at that time, a conclusion was

made that noncancer hazard outweighed cancer risk and that an advisory based strictly on protection of the former would be protective of the latter. This assumption is under reconsideration for both PFOA and PFOS in respective, proposed drinking water MCL documents. Cancer-based action levels for PFOA and PFOS will be incorporated into the HDOH PFAS guidance following finalization of the USEPA MCL documents.

Noncancer Hazard

The method used to derive noncancer-based, MCLGs in the USEPA documents posted for public review was adopted for calculation of noncancer-based drinking water action levels for PFASs in general (USEPA 2023c,f):

$$\text{Health Advisory } (\mu\text{g/L}) = \text{THQ} \times \left(\frac{\text{RfD (mg/kg day)}}{\text{DWIR-BW (L/kg day)}} \right) \times \frac{1000\mu\text{g}}{\text{mg}} \times \text{RSC} \quad \text{Eq 2}$$

where:

THQ = Target Hazard Quotient

RfD: Chemical-specific, chronic, oral Reference Dose;

DWIR-BW: Drinking water ingestion rate per kilogram of body weight of targeted sensitive population of concern; and

RSC: Relative Source Concentration (default 0.2).

The same approach was used to derive earlier USEPA Drinking Water Advisory Levels (USEPA 2022a,c). A Target Hazard Quotient of “1” is inferred but not specifically stated in the USEPA reference equations.

This is similar to the approach used to derive ingestion-based, Tapwater Regional Screening Levels (RSLs) for PFASs published by the USEPA Superfund office (USEPA 2022c):

$$\text{RSL}_{\text{ing}} (\mu\text{g/L}) = \frac{\text{THQ} \times \text{AT}_{\text{res-c}} \times \text{BW}_{\text{res-c}} \times \frac{1000\mu\text{g}}{\text{mg}}}{\text{EF}_{\text{res-c}} \times \text{ED}_{\text{res-c}} \times \frac{1}{\text{RfD}} \times \text{IRW}_{\text{res-c}}} \quad \text{Eq 4}$$

where:

RSL_{ing}: Tapwater Regional Screening Level based on ingestion-only pathway;

THQ: Target Hazard Quotient (default = 1.0);

AT: Averaging Time (default = 365 days/year x 6 years);

BW_{res-c}: Resident Child Body Weight (default = 15 kg);

EF: Resident Child Exposure Frequency (default = 350 days/year);

ED: Resident Child Exposure Duration (default = 6 years);

RfD: Chronic, Oral Reference Dose (chemical specific);

IRW: Resident Child Ingestion Rate Water (default = 0.78 L/day).

The default parameter values noted are taken directly from the USEPA RSL document. Inserting these values and deriving a DWIR-BW rate by division of the default drinking water ingestion rate for young children by the default body weight allows the equation to be simplified to:

$$\text{PRG } (\mu\text{g/L}) = \text{THQ} \times 0.96 \times \left(\frac{\text{RfD (mg/kg day)}}{\text{DWIR-BW (L/kg day)}} \right) \times \frac{1000\mu\text{g}}{\text{mg}} \quad \text{Eq 5}$$

The difference between USEPA RSLs for PFASs and proposed USEPA MCLGs for the same compounds is primarily due to an assumed reduced exposure frequency of 350 days per year in

the RSL model, use of an alternative DWIR-BW rate and more importantly the lack of consideration of a Relative Source Contribution.

The primary route of exposure to PFASs is considered to be ingestion of food and contaminated drinking water (NIEHS 2023). Additional uptake through the skin during bathing or through contact with contaminated soil is possible but considered to be insignificant in comparison to ingestion (e.g., <10% of total exposure; refer to USEPA 2004). Dermal exposure is considered in the model used to calculate soil action levels. Methods to assess dermal uptake from tapwater while bathing are more complex, however, and are not yet fully developed. This pathway will be added to future updates of the action level as this information becomes available. Significant changes in tapwater action levels based only on the ingestion route only are not anticipated.

Default Target Hazard Quotient

The target Hazard Quotient of “1” incorporated into the USEPA MCLG and Drinking Water Advisory model is retained for use in HDOH action levels for PFASs in drinking water. This replaces a default Hazard Quotient of 0.5 included in previous versions of this guidance. Calculation of cumulative noncancer “Hazard Index” is required for assessment of all drinking water resources impacted by more than one PFAS and when an MCL standard for the compound has not been promulgated at either the State or Federal level (USEPA 2023c,f). Refer to Section 7.0 for guidance on calculation of a Hazard Index on a site-specific basis. Automatic calculation of a Hazard Index based on input sample data included in Total PFAS Risk spreadsheet accompanying this Technical Memorandum.

Default Drinking Water Ingestion Rates

A summary of DWIR-BW rates utilized for calculation of drinking water action levels is provided in Table 5. DWIR-BW rates based on targeted exposure populations and incorporated into proposed MCLGs for PFHxS, PFNA, PFBS and HFPO DA were retained for use in this guidance (USEPA 2023c; refer to footnotes to Table 5). DWI-BW rates applied to calculation of USEPA Drinking Water Advisories for PFOA and PFOS were also retained (USEPA 2022a,c). A DWIR-BW rate based on the default, average drinking water ingestion rate and body weight of 0 to 6 year-old children used for calculation of USEPA Tapwater RSLs was applied to all other PFASs (USEPA 2022c; refer to footnotes to Table 5). The discrepancy between the default drinking water ingestion rate for young children referenced in the 2022 PFOA and PFOS Drinking Water Advisories that were utilized in the USEPA Tapwater RSLs is recognized and will be addressed pending finalization of USEPA MCLGs as appropriate.

Default Relative Source Contribution

The 2022 USEPA Health Advisories only take into account exposure to the chemical via drinking water. Exposure to the same chemical in food, indoor dust, contaminated soil and even personal care products could also occur. Compounded exposure to a chemical is addressed through application of a “Relative Source Contribution (RSC)” for exposure to a particular media (see USEPA 2022a,b). The extent of exposure to PFASs in media other than drinking water is still under review. Refer to RSC discussions in earlier USEPA Drinking Water Advisories for PFOA and PFOS for additional information (USEPA 2016a,b). As a precautionary measure, USEPA Health Advisories for PFOA and PFOS as well as proposed MCLGs for other PFASs allocate an RSC of 20% for exposure to PFASs in drinking water (USEPA 2023c). For example, the RfD for PFBA⁻ is 0.0038 mg per kilogram of body weight per day (mg/kg-day) or 3.8 µg/kg-day (see Table 5). Of this maximum daily exposure, 20% or 0.76 µg/kg-day is allotted to exposure to PFBA⁻ in drinking water.

6.1.2. Aquatic Toxicity

Chronic aquatic toxicity action levels are used under HDOH guidance to screen groundwater within 150 meters of a surface water body or groundwater that could enter a storm drain and quickly impact an aquatic habitat (see Figure 9; HDOH 2024). Acute, aquatic toxicity action levels are applied to groundwater situated >150m from a surface water body that does not pose a near-term risk to an aquatic habitat.

Chronic and acute toxicity levels compiled and reviewed by the Washington Department of Ecology served as the primary reference for use in this technical memorandum (refer to Table D-4e of Attachment 3; WADOE 2020). Aquatic toxicity screening levels published by Divine et al (2020) were referred to when levels were not included in the WADOE document. Additional publications with aquatic and/or terrestrial ecological toxicity screening levels for PFASs include Grippo et al. (2021) and Conder et al (2020)

Action levels were available for 11 of the 20 targeted PFASs. The action levels are intended to represent concentrations of the noted compound that did not result in an adverse effect on the health and propagation of fish, invertebrates and other aquatic life. Aquatic toxicity levels are presented for the anion form of sulfur-based PFASs in the WADOE document and the acid form for nonsulfur-based compounds. The reason for the latter is unclear, since the carboxylate form of the compound should be present in water, rather than the carboxylic acids form. Aquatic toxicity levels presented for the acid forms are assumed to be applicable to the anion forms for the purposes of this technical memorandum.

Chronic aquatic toxicity action levels for compounds are applied to acute toxicity if data for the latter were not presented in the Washington document. Studies for freshwater were applied to the marine environment when action levels for the latter were not available, and vice versa. Note that WADOE opted to apply No Observed Effects Concentration data for acute studies to select chronic action levels when supported by other studies for the latter (e.g., PFBS⁻ marine, PFDA⁻ freshwater).

The Washington document is currently under final review for development of formal, surface water standards in that state. The aquatic toxicity action levels selected will be updated as additional information becomes available. The action levels do not take into account bioaccumulation and uptake in the food chain, including potential risk to humans and wildlife that use aquatic organisms as a source of food. Other references include the Australia Cooperative Research Centre (ACRC 2018), Giesy et al. (2010) and the European Chemical Agency (ECHA 2018).

Acute aquatic toxicity action levels for PFOS⁻ and PFOA⁻ in Table 4e of Attachment 3 are based on guidance published by the Australia Cooperative Research Centre (ACRC 2018). Guidelines presented for 80% species protection are intended to protect 80% of exposed organisms from a 10% decrease in a chronic, sub-lethal endpoint. These values were selected as surrogates for “acute” aquatic toxicity. As was the case for the WADOE guidance, the Australia document presents aquatic toxicity levels for perfluorooctane sulfonate, the anion form of the compound, but then somewhat confusingly presents levels for the non-sulfur containing equivalent in terms of perfluorooctanoic acid. Aquatic toxicity levels presented for the latter are again assumed to be applicable to the perfluorooctanoate anion form of the compound.

Acute aquatic toxicity action levels for PFHxA⁻ were derived from a summary of studies published by the European Chemical Agency (ECHA 2018). The document notes that the

compound will be present in the anion form when dissolved in water. The acute action level of 48,000 µg/L for freshwater (also applied to marine habitats) is based on 50% of an LC50 concentration derived for daphnia. This reflects recommendations for development of aquatic toxicity action levels in the USEPA Great Lakes water quality initiative guidance (USEPA 1995; refer to Section 5.3.2 in Volume 2 of the EHE guidance).

Aquatic toxicity action levels could not be identified for the remaining PFASs (see Table D-4b and Table D-4c in Attachment 3). HEER Office guidance calls for the use of toxicity-based, drinking water action levels when aquatic toxicity action levels are not available (HIDOH 2024a). This is intended to ensure that contaminants in groundwater that could pose a threat to surface water habitats are not inadvertently overlooked due to the absence of published action levels. As a result, the final action level for groundwater that is not a source of drinking water (Table B) is identical to the action level for groundwater that is a source of drinking water (Table A).

Drinking water action levels will be replaced with aquatic toxicity action levels as the latter become available in the future. Use of the drinking water action levels as surrogates for aquatic toxicity and decisions regarding the need for remedial actions for PFAS contaminated groundwater is likely to be excessively conservative, based on a comparison of action levels for compounds where both are available. Drinking water action levels for PFOS⁻, PFOA⁻, PFBS⁻, PFHxS⁻ and PFHxA⁻ are significantly lower than chronic, aquatic toxicity action levels for these chemicals. Additional evaluation, including a review of published research and/or laboratory tests of aquatic toxicity, should be carried out when groundwater with PFASs in excess of the interim action levels is identified and could potentially discharge into an aquatic habitat. This should include the use of laboratory bioassay tests in addition to reviews of published literature.

Confidence in the aquatic toxicity action levels presented varies from low to medium (refer to WADOE 2020). **Whole effluent toxicity testing in accordance with Washington State guidance or similar approaches are recommended for site-specific assessment of aquatic toxicity (WADOE 1993).** Test methods and use of resulting data for decision making should be discussed with the HEER Office project manager on a site-by-site basis.

Action levels selected for screening of potential PFAS aquatic toxicity concerns in groundwater were not carried forward for screening of surface water. Surface water action levels are anticipated to be driven in part by bioaccumulation and food chain risks. Action levels for bioaccumulation risk are currently only available for PFOA⁻ and PFOS⁻ (e.g., 99% species protection levels presented in ACRC 2018). Additional action levels and guidance on PFAS contamination of surface water will be included in future updates of the HEER Office guidance as available. Until such time, the detection of PFASs in surface water should be discussed with the HIDOH Clean Water Branch and HEER Office on a case-by-case basis.

6.1.3. Soil Direct Exposure

For use in this document, the term "soil" refers to any unconsolidated, particulate matter found in the subsurface, including actual soil, saprolite, sediment, biosolids, fill material, etc. (HIDOH 2024a). Soil data should be reported on dry-weight basis (refer to Volume 2, Appendix 1, Section 7.3 of the EHE guidance).

HEER Office action levels for direct exposure to contaminants in soil are based on models presented in the USEPA Regional Screening Level (RSL) guidance (USEPA 2019b). Equations,

default exposure assumptions and target risks utilized in the models are presented in Appendix 1 and Appendix 2 of the HEER Office EHE guidance (HIDOH 2024a). Default exposure assumptions and target risks used to develop direct exposure action levels for the targeted PFASs are summarized in Table 6. Modifications include consideration of a Relative Source Contribution of 20% and a target, noncancer Hazard Quotient of “1,” similar to the approach used to develop risk-based action levels for drinking water.

Use of a target Hazard Quotient of 1 to generate soil and drinking water action levels for direct exposure requires calculation of cumulative noncancer hazard (“Hazard Index”) for all sites where PFAS contamination is identified. Methods to calculate a Hazard Index are described in Section 7. Automatic calculation of a Hazard Index based on input sample data included in Total PFAS Risk spreadsheet accompanying this Technical Memorandum.

6.1.4. Soil Leaching

An algorithm based on a combined use of the computer applications SESOIL (vadose-zone migration of contaminants) and AT123D (mixing of leachate with groundwater) was used to generate action levels for potential leaching of PFASs from soil and impacts on groundwater (discussed in Appendix 1 of the EHE guidance; HIDOH 2024a):

$$C_{\text{soil}} = \text{DAF} \times C_{\text{gw}} \times 0.001 \text{ mg}/\mu\text{g} \quad \text{Eq 7}$$

$$\text{DAF} = (6207 \times H) + (0.166 \times K_{\text{oc}}) \quad \text{Eq 8}$$

where: DAF = SESOIL-based dilution/attenuation factor;
 H = Henry's Law Constant (atm-m³/mol);
 K_{oc} = Organic carbon partition coefficient (cm³/g);
 C_{soil} = Leaching based soil concentration (mg/kg);
 C_{gw} = Target groundwater action level (μg/L).

The term DAF is defined for the purposes of the model as the concentration of the contaminant in soil (in mg/kg) divided by the concentration of the contaminant in groundwater (in mg/L).

The algorithm reflects modeling of an assumed annual rainfall of 1,100 mm (approximately 43 inches). A total of 720 mm (28 inches) of the total rainfall is assumed to infiltrate the ground surface and reach groundwater. This is considered to be adequately conservative for the majority of developed areas in Hawai'i. The model incorporates a three-meter-thick vadose zone characterized by one meter of impacted soil sandwiched between two, one-meter-thick layers of clean soil. The lower layer immediately overlies groundwater. All vadose-zone soil is conservatively assumed to be very permeable sand that freely allows the migration of leachate to groundwater. The organic carbon content of the soil is assumed to be 0.1%.

Leaching based soil action levels are lower than action levels based on direct-exposure concerns for most of the PFASs listed in cases where underlying groundwater is a source of drinking water (refer to Attachment 3, Table A-1, A-2). This was therefore selected as the final soil action level for those chemicals (Summary Table A). Leaching based action levels are lower than direct

exposure action levels for only a few of the PFASs in cases where underlying groundwater is not a source of drinking water and the latter was in turn selected as the final, soil action level (Summary Table B; refer to Attachment 3, B-1 and B-2). This reflects the significantly higher groundwater action levels for non-drinking water that are based instead on toxicity to aquatic organisms (refer to above discussion).

Synthetic Precipitation Leaching Procedure (SPLP) laboratory tests should be carried out on soil samples that exceed these action levels. Refer to the HEER Office guidance document *Use of Laboratory Batch Tests to Evaluate Potential Leaching of Contaminants From Soil* (HIDOH 2024) for additional information on the use of SPLP data to assess leaching risk. Soil column leaching tests such as LEAF Method 1314 might also prove very useful in assessing leaching tests (USEPA 2019c). Modified Method 1314 protocols more suitable to the collection of Multi Increment soil samples and investigation questions specific to leaching of PFASs from soil are currently under development. Contact Roger Brewer of the HEER Office for further information.

Aged compounds in soil can be significantly more sorptive than predicted by published, sorption coefficients for the compounds (HIDOH 2024). In-house reviews of SPLP batch sample data for soil samples collected in Hawaii suggest that the model *over predicts* the mobility and leaching risk posed by contaminants present in soil in general at very low concentrations. This could be due in part to sorption of PFASs to clays or diffusion into clay lattices, which is not considered in the model. Combined with target groundwater action levels in the parts-per-trillion, resulting leaching based action levels for several PFASs are likely to be lower than laboratory detection limits.

In order to partially address this issue, leaching based action levels for chemicals with Koc values greater than 5,000 cm³/g, are based on the theoretical soil saturation level ("sat") rather than the SESOIL-ATM123 leaching models, if higher. Examples include PFDS⁻ (see Table E-1 in Attachment 3). Soil saturation levels were calculated using the saturation equation presented in USEPA Regional Screening Levels guidance (USEPA 2019; see Appendix 2 of HIDOH EHE guidance).

The SESOIL model scenario assumes that the depth to groundwater from the base of the impacted layer of soil is only one meter. This might seem overly conservative. The thickness of the clean layer of soil between the base of the impacted layer and the top of groundwater does not, however, significantly affect the concentration of the contaminant in leachate as it migrates through the vadose zone unless the contaminant is highly volatile or highly biodegradable. Neither is true for the targeted PFASs. Temporary sorption to organic carbon in the soil will retard the rate that the contaminants migrate through vadose but in theory will not significantly reduce the concentration of the contaminants within the leachate itself.

Site-specific modeling of leaching impacts using SESOIL or similar models is therefore unlikely to generate significantly different soil action levels, even for cases where the depth to groundwater is very deep. The time it takes for the contaminants to reach groundwater will simply increase. In practice, however, diffusion of PFASs into clays in the soil and essential immobilization could significantly reduce contaminant concentrations in leachate by the point that the leachate reaches the water table. This factor, which is not taken into consideration in the models, should be assessed on a site-specific basis as necessary.

6.1.5. Vapor Intrusion

Vapors emitted from soil or groundwater contaminated with volatile compounds can pose a potential vapor intrusion risk to existing or future overlying buildings (HIDOH 2024).

Perfluoropropanoate (PFPrA⁻) is currently the only PFAS compound categorized as “volatile” (refer to Table 2). The compound has thus far been only identified in water and in areas that do not pose a vapor intrusion risk to nearby buildings. Potential vapor intrusion concerns have also been raised for fluorotelomer alcohols, in particular where these compounds are manufactured or in association with vapors released from landfills (e.g., Roth 2019). No manufacturing facilities are located in Hawai'i. Potential offsite vapor intrusion risks associated with municipal landfills is not anticipated due to the typical separation distance of these facilities from offsite residential or commercial areas.

Assessment of potential vapor intrusion concerns associated with PFASs is not required at this time but could be required in the future on a case-by-case basis. Future assessment of vapor intrusion concerns associated with PFASs will likely rely on the direct collection of soil vapor and/or indoor air samples rather than comparison of soil or groundwater data to HIDOH action levels. Methods for the collection and testing of vapor-phase PFASs still under development and not widely available.

6.1.6. Uptake into Food Crops and Livestock Feed

The use of PFAS containing biosolids and/or treated wastewater poses potential concerns for uptake of these compounds into food crops and livestock feed (Ghisi et al. 2019; Blaine et al. 2013, 2014). Laboratory-based studies using spiked water indicate a potential accumulation of long-chain PFASs in root crops and uptake of more mobile, short-chain (and likely ultrashort-chain) PFASs into other portions of a plant (e.g., Higgins 2017). An in-depth review of this issue by HIDOH is anticipated in 2024.

Assessment of risk will likely necessitate case-by-case reviews due to variability in anticipated controlling factors such as soil characteristics (organic carbon and clay content, pH, soil microbiome, etc.), plant type; use of roots, stems or fruit; industrial versus domestic source of biosolids amendments and treated irrigation water; use of fertilizers, etc. Action levels developed for soil and treated wastewater to prevent adverse accumulation of PFASs in targeted crops and feed will similarly likely be site-specific, although some general trends might become apparent. Assessment will also require development of risk-based action levels for individual and/or combined groupings of crops and feed.

7.0 Assessment of Total PFAS Risk

A Fact Sheet that summarizes the approach for assessment of Total PFAS Risk is provided in Attachment 4. A three-step approach is presented: 1) Comparison of data for Terminal PFASs originally present in a sample to risk-based action levels (“Pre-TOPs PFASs”), 2) Comparison of additional Terminal PFASs generated by oxidation of the sample and assumed related to precursor compounds in the sample to the same action levels (“Post-TOPs Precursor PFASs”) and 3) Estimation of the concentration of additional PFASs present based on Total Organic Fluorine (TOF) data and comparison to a default action level (“Excess Fluorine PFASs”). A Total PFAS Risk spreadsheet that accompanies this Technical Memorandum allows rapid calculation of the cumulative risk posed by each group of compounds.

Terminal PFASs initially present in a sample can be identified and quantified using standard laboratory methods (see Section 10). Retesting of samples using Total Oxidizable Precursors (TOPs) will identify additional “precursor” PFAS compounds not reported by standard laboratory methods or compounds that lack toxicity factors (Houtz and Sedlak 2012, Ateia 2023, Pelch 2023). Assessment of risk could in practice be carried out based solely on post-TOPs data, since terminal endpoint compounds originally present in the sample would in theory be unaffected still be present. Inclusion of pre-TOPs data is important to understand the overall makeup of the original PFAS mixture, however, as well as necessary for comparison to USEPA and HIDOH drinking water Maximum Contaminant Levels (MCLs) anticipated to be promulgated in the near future.

The risk assessment approach presented in this guidance document focuses the development of toxicity factors and action levels for assessment of potential noncancer health hazards and the protection of young children (i.e., ingestion and dermal absorption Reference Doses and inhalation Reference Concentrations). This is assumed to take precedence over potential cancer-related risks posed to older adults. This assumption will be reviewed as additional information on the carcinogenicity of PFAS compounds evolves.

7.1. Step 1: Pre-TOPs PFASs

Calculate and sum noncancer Hazard Quotients for each Terminal PFASs reported in pre-TOPs data. A Hazard Quotient is calculated as the ratio of the reported concentration of the compound divided by the corresponding, risk-based action level listed in Attachment 3 to this document. Soil data are compared to Direct Exposure action levels presented in Table I-1 (Unrestricted/Residential), Table I-2 (Commercial/Industrial) and/or Table I-3 (Construction-Trench Workers), depending on current or anticipated future use of the site. Data for groundwater or surface water that is a current or potential source of drinking water are compared to toxicity-based drinking water action levels presented in Table D-3a. Both the soil and water action levels are based on an HQ of “1.” The sum of the Hazard Quotients is referred to as the “Hazard Index” (USEPA 2023c,e; refer also to HIDOH 2024, Volume 2, Section 1.4).

7.2. Step 2: Post-TOPs Precursor PFASs

Initial testing of the sample for PFASs is followed by processing and retesting of the sample using Total Oxidizable Precursors (TOPs) method (e.g., Houtz and Sedlak 2012). The sample is

heated with an oxidizing agent under alkaline conditions. Terminal PFASs originally in the sample are assumed to have been preserved largely unchanged in the post-TOPs data. Much like pruning branches from a tree to exposure the underlying trunk, functional groups are stripped from any “precursor” PFAS compounds present, exposing the underlying, Terminal PFASs that forms the backbone of the compounds. This indirectly mimics end products generated by natural metabolism of the compounds (refer to Tseng et al. 2014; Marjanoic et al. 2015).

Reported concentrations of Pre-TOPs Terminal Endpoint PFASs are subtracted from the Post-TOPs data in order to determine the concentrations of Terminal Endpoint PFASs associated with precursor compounds. Separate Hazard Quotients and a cumulative Hazard Index are then calculated for this group of compounds in the same manner as described for Pre-TOPs PFASs noted above.

7.3. Step 3: Excess Fluorine PFAS

The final step involves the use of “Total Organic Fluorine (TOF)” data to determine the presence of additional, PFAS-related compounds not captured by the post-TOPs data. The concentration of TOF in the sample is first predicted based on the chemical formulas and concentrations of reported, Post-TOPs PFASs:

$$\begin{aligned}
 & \text{Predicted TOF} \\
 &= (\text{Conc.}_{\text{PFAS}\#1} \times \frac{(AM_{\text{Fluorine}} \times \#\text{Fluorine Atoms})}{MW_{\text{PFAS}\#1}} \\
 &+ (\text{Conc.}_{\text{PFAS}\#2} \times \frac{(AM_{\text{Fluorine}} \times \#\text{Fluorine Atoms})}{MW_{\text{PFAS}\#2}} \\
 &+ (\text{Conc.}_{\text{PFAS}\#3} \times \frac{(AM_{\text{Fluorine}} \times \#\text{Fluorine Atoms})}{MW_{\text{PFAS}\#3}} + \text{etc.}
 \end{aligned}$$

where “AM_{fluorine}” is the atomic mass of fluorine (18.998) and “MW_{PFAS}” is the molecular weight (mass) of the specific PFAS compound. The molecular weight of individually targeted PFAS compounds is included in Table 2.

The sum of the predicted concentration of fluorine attributable to the post-TOPs PFASs is compared to actual TOF data for the sample. The latter is reported by the laboratory as Absorbable Organic Fluorine (AOF) for liquids and Extractable Organic Fluorine (EOF) for solids. Subtraction of the predicted TOF from the reported TOF yields the concentration of “Excess Fluorine.”

The excess fluorine is assumed in this guidance to be attributable to other, PFAS-related compounds in the sample. Nontargeted Analysis (NTA) testing of water samples collected by HDOH as part of an ongoing field study of PFAS at WWTPs and AFFF-release sites as well as unpublished drinking water data collected by California (personal communication, Wendy Lynk 2023) indicates that the majority of fluorine is attributable to ultrashort PFAS compounds such as PFPrA- and perfluoropropane sulfonate (PFPrS-; HDOH report anticipated in early 2024). The origin of these compounds is uncertain but presumably attributable to an original presence in the product released and/or related to natural degradation of longer-chain compounds (Björnsdotter et al. 2019, Zheng et al. 2023).

Ultrashort PFASs are assumed to be less toxic than short- and in particular long-chain PFASs (ITRC 2020). Toxicity factors for PFPrA⁻ have been published by the USEPA (refer to Table 3b). For the purposes of this Technical Memorandum, the weighted toxicity of Excess Fluorine-related compounds in a sample is assumed to approximately equal to the toxicity of PFPrA⁻. The need to re-evaluate this assumption based on sample-specific NTA data can be determined on a case-by-case basis, either at the option of the Responsible Party or as requested by HDOH.

The concentration of compounds associated with the excess fluorine is estimated by assuming an average, molecular weight for the mixture as a whole:

$$\text{Conc. EFRC} = \frac{\text{Average MW EFRC}}{AM_{\text{Fluorine}}}$$

Where “EFRC” is the estimated concentration of Excess Fluorine-Related Compounds in the sample and Average MW EFRC is the average molecular weight of the compounds. For the purposes of this Technical Memorandum, the average molecular weight of compounds associated with identified Excess Fluorine is assumed to be equal to that of PFPrA⁻. While inexact, this allows approximation of both the concentration and weighted toxicity of additional PFAS compounds in a sample not captured in either the pre-TOPs or post-TOPs data, as well as the potential health risks posed by these compounds. These assumptions can be evaluated on a site-specific basis as needed based on more detailed sample data or reference to related information.

7.4. Step 4. Calculation of Total PFAS Risk

Total PFAS Risk is calculated by summing the Hazard Indices calculated for Pre-TOPs PFAS and Post-TOPs Precursor PFASs as described above and the Hazard Quotient calculated for Excess Fluorine PFASs. The final Hazard Index is rounded to a single, significant digit for decision making (USEPA 1989, HDOH 2024). An exceedance of a Hazard Index of “1” indicates a need for additional action to assess exposure and health risk.

These calculations are automatically carried out in the accompanying Total PFAS Risk Excel spreadsheet based on input site data (Attachment 5, separate Excel file). Use of the spreadsheet for reports submitted to HDOH for review is strongly recommended. Cancer risk is assessed based on individually targeted compounds, such as PFOA⁻. Protection of young children against noncancer-related health hazards as described in this guidance is currently assumed to also be protective of future cancer risks to older children and adults. This assumption will be reviewed as additional information on the health effects posed by PFASs is obtained.

8.0 Sample Collection and Processing

8.1. General

Investigations of PFASs-contaminated soil and groundwater should adhere to sampling protocols presented in the HEER Office *Technical Guidance Manual* (TGM; HDOH 2023). This includes the collection of Multi Increment samples for testing of soil, sediment and biosolids (TGM Sections 3-5). Discrete soil or other particulate matter sample data are not acceptable for final decision making (refer to TGM Section 3). The collection of Multi Increment-type samples should also be considered for testing of surface water (TGM Section 6). This might include, for example, the continuous collection of a sample during purges of large, risk-based volumes of water from a single well, referred to as “Large Volume Purge (LVP)” sampling methods, rather than the collection of traditional, small-volume, “discrete” waters samples.

Guidance documents published by the USEPA and other states caution against the use of specific equipment and materials that could result in inadvertent contamination of samples with PFASs (e.g., USEPA 2019, CAEPA 2019b,c, 2020a,b; MADEP 2019; MIDEQ 2019). Note that statements made in early regulatory guidance regarding the potential presence of PFAS in sampling equipment, sample bags, sunscreen and other field material have in some cases proven to be incorrect. Research has not, for example, indicated significant cross contamination of environmental samples with equipment and material typically used to collect samples (Denly et al. 2019; Kaminski 2019; Rodowa et al. 2020). This includes the lack of PFASs in the manufacturing of low-density polyethylene bags (LPDE) recommended in the HEER TGM for the collection of soil, sediment and other particulate media. [The lack of PFASs in their food storage bags was confirmed by representatives of SC Johnson, the maker of Ziplock[®] storage bags (Cataldo 2020) as well as the makers of Hydrosleeve[®] samplers (Ciomek 2020) and Snap Samplers (QED 2019), used for the collection of groundwater samples. The lack of PFASs in Banana Boat sunscreen was similarly confirmed by representatives of that company.]

Contact the makers of specific sampling equipment and other field supplies to determine the potential use or inadvertent presence of PFAS containing compounds of interest in these materials. It is not the intent of the HEER Office to require the use of or avoidance of tools, containers, personal protective equipment and other products that might come into contact with samples, particularly as formulations may change over time. Field and laboratory workers should be aware of and take into consideration a products formulation that could lead to inadvertent contamination of samples with PFASs. Material that is specifically identified as waterproof, water resistant or stain-resistant and might come into contact with a sample should be avoided or tested for the potential presence of PFASs. The use of material that contains fluoropolymers is acceptable provided that the material does not introduce targeted PFASs or related precursor compounds into the samples.

Inadvertent contamination of properly collected soil samples is highly unlikely if proper Multi Increment sampling methods are used and simple precautions are taken to avoid cross contamination. Equipment blanks for soil samples are therefore not necessary or recommended. The use of equipment blanks is highly recommended, however, for the collection of water samples.

8.2. Collection and Processing of Liquid Samples

“Ultra-clean” collection methods are especially warranted for the collection of water samples in order to minimize inadvertent, secondary contamination of samples due to the potential presence of PFASs in clothing, cosmetics and other material taken into the field. Refer to the guidance documents noted above and related information for specific details. The collection of equipment blanks is recommended to assess and document potential cross contamination of samples.

Action levels for drinking water and aquatic toxicity are based on the dissolved-phase concentrations of PFAS compounds. Turbid samples should be filtered prior to testing in order to more accurately assess these concerns. Filtering should be carried out at the laboratory. Data for unfiltered samples might be required if the objective of the study is to assess total, mass loading associated, for example, with discharge of wastewater to a surface water body. These issues should be evaluated and tied to recommended sample collection and processing methods as part of the systematic planning process and discussed in the sampling and analysis plan (refer to Section 3 of the HEER TGM).

8.3. Collection and Processing of Particulate Media Samples

Decision Unit and Multi Increment Sample (DU-MIS) investigation methods must be used for the collection of soil, sediment, biosolids and other particulate matter (refer to Section 4 of the TGM). This includes preparation of a minimum 1-2kg sample composed of at least 50 increments collected in a systematic, random manner within the targeted DU area. Discrete sample data are not acceptable for decision making purposes, including the presence or absence of targeted compounds of concern.

The use of new, heavy-duty, low-density or high-density polyethylene (HDPE, LDPE) freezer bags (e.g., Ziplock® bags) to collect Multi Increment soil, sediment and other particulate samples as recommended in Section 4 of the HEER Office TGM is recommended for the collection of samples to be tested for PFASs. PFASs are not used in the production of these bags, contrary to statements in some early sampling guidance (Cataldo 2022). Significant, cross contamination of large, Multi Increment samples from equipment or containers that inadvertently contain trace levels of PFASs is furthermore unlikely given the mass of the sample prepared. Sampling equipment should be cleaned in accordance with guidance in Section 5.9 of the TGM. As noted in that section, the collection of equipment rinsate samples is not necessary.

As a default, **the <2 mm diameter particle size fraction should be targeted for testing of particulate matter such as soil, sediment and biosolids** and for comparison to the HEER EALs (refer to Section 4.2.6 of the HEER TGM, HIDOH 2023). The analytical subsample (aliquot) should be collected following MI sample processing methods discussed in Section 4.2.6.2 of the HEER TGM. The targeted PFAS anions are not anticipated to be significantly volatile (refer to following section). Standard laboratory protocols for processing of Multi Increment soil samples should therefore be followed, including air drying, sieving to < 2mm particle size and the use of Multi Increment-type methods for collection of subsamples for analysis (refer to Section 4.2.6 of the HEER Office TGM; HIDOH 2023).

Extraction and testing of a minimum, ten-gram analytical subsample is required in order to ensure that the subsample is representative of the sample. A default, 10-gram subsample mass for the <2mm particle-size fraction is recommended in the HEER Office TGM. Discussions with laboratories indicate that this might be cost- and labor-prohibitive at this time. Testing of a

5-gram subsample is acceptable provided that replicate (triplicate) subsamples are collected and tested from 20% of the samples submitted for a given project (minimum two samples if more than one sample to be tested for PFASs). Laboratories might need to modify standard test methods to achieve a five-gram subsample mass or conduct multiple small subsample extractions and combine them for analysis. This might also increase the standard analytical fee. Some labs, for example, only test 0.5 grams of soil as a default analytical subsample mass for PFASs. The potential error in estimation of a mean contaminant concentration for the sample as a whole is, however, unacceptable. Alternative methods should be discussed with the HEER Office and justified in the sampling and analysis plan.

Particulate samples to be tested for potentially volatile PFAS, including some fluorotelomer alcohols, should be collected in accordance with guidance presented in Section 4 of the HEER Office Technical Guidance Manual (HIDOH 2023). Guidance specific to the collection of soil samples to be tested for volatile PFASs has not been identified. The use of methanol to preserve a sample should be discussed with the laboratory prior to collection in the field, since this could increase method reporting limits. Alternative sample preservation approaches are discussed in the TGM. Discrete samples are not allowed under HIDOH guidance (HIDOH 2023). Consider the collection and testing of soil vapor samples for PFASs as an alternative and a more direct way to assess potential vapor intrusion risk.

9.0 Laboratory Test Methods

Methods for testing of PFASs in water and other media are still evolving (USEPA 2019d, 2021a). The most common methods currently in use include U.S. Environmental Protection Agency (USEPA) Methods 533 (USEPA 2019a) and Method 537.1 (USEPA 2020) for drinking water, Method 8327 for groundwater, surface water and wastewater (USEPA 2021b) and Method 1633 for testing of biological material (e.g., fish tissue), biosolids, soils and sediments (USEPA 2021c). The joint Department of Defense and Department of Energy *Quality Systems Manual* includes a test method for a combined and extended list of PFASs, referred to as DoD QSM 5.3 in Table 7 (DOD-DOE 2019; refer to Table B-15 and Table C-44 in manual). Commercial laboratories have developed similar, propriety methods to improve identification and quantification of PFAS-related compounds.

Ensure that the laboratory selected for testing of samples is able to process samples using Total Oxidizable Precursors (TOPs) methods. Current methods utilized by laboratories are proprietary but in general follow the approaches described in published literature (e.g., Houtz and Sedlak 2012). The USEPA is working with commercial laboratories to develop a Standard Operating Procedure (SOP) procedure.

Select a method most appropriate for the release scenario of interest. Testing for PFASs reportable under both Method 537.1 and Method 533 or separately under DoD QSM 5.3 or an equivalent laboratory method is recommended in order to obtain data for all PFASs for which toxicity factors are available. Method 1633 tests for a much broader scope of PFAS compounds and can be useful for initial investigation and identification of key contaminants of concern. Less extensive and less costly methods can normally be adequate for followup testing.

Current USEPA laboratory methods for PFASs might require modification for testing of soil, turbid water or other types of media. Discuss collection and processing requirements with the laboratory prior to submittal of samples for analysis.

10.0 Limitations

An understanding of the fate and transport and toxicity of PFASs is continually evolving. Physiochemical constants and toxicity factors used to generate action levels in this guidance will be updated as new information is obtained. Guidance on more reliable, laboratory-based leaching methods as an alternative to the use of default soil action levels is anticipated by the end of 2024.

TOPs methods discussed in this guidance are also continually evolving and being standardized. Guidance on preferred methods published by the USEPA and other entities will be incorporated into this document as they become available. Use of TOPs data to assess risk assumes the full oxidation of precursor compounds to terminal endpoint compounds in the human body. Some researchers have suggested that partial oxidation is more likely and that this assumption could be overly conservative. Other researchers have suggested that partially oxidized metabolites could in fact be more toxic than the parent compounds. New information will be incorporated into the guidance document as it becomes available. A more in-depth review of these issues can be evaluated in a site-specific risk assessment, if needed.

The guidance currently does not address potential risk posed the uptake of PFASs into food crops. This is a potential concern for agricultural fields where biosolids have been applied as soil amendment or treated wastewater used for irrigation. Biosolids and wastewater from industries that manufacture or heavily use PFASs are currently assumed to pose the primary risk. Concentrations of PFASs in biosolids and wastewater associated with domestic wastewater treatment plants tend to be significantly lower and the PFASs present of lower toxicity. Research on these issues is ongoing. Field studies of PFASs in domestic biosolids and wastewater in Hawai'i is currently underway by HDOH. An initial report on testing and assessment of samples is anticipated by the summer of 2024.

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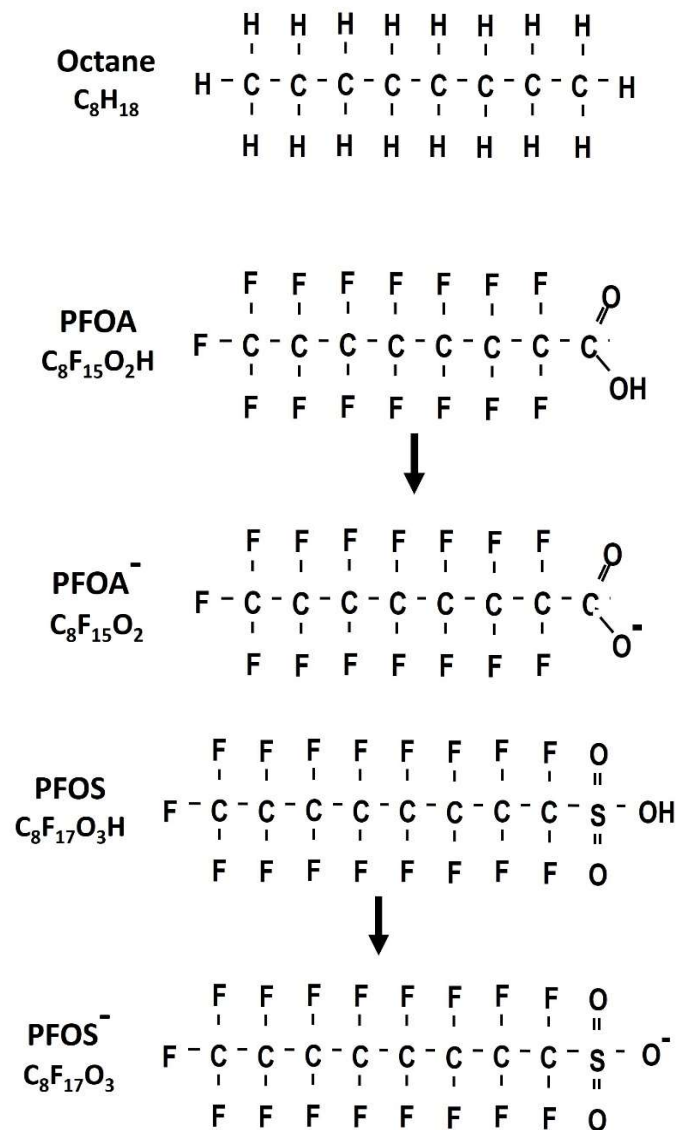


Figure 1. Structure of octane compared to perfluorooctane sulfonic acid and its anion form perfluorooctane sulfonate and perfluorooctanoic acid and its anion form perfluorooctanoate. Anion forms are more common in contaminated soil, sediment and water.

	Terminal Endpoint Compound	Abbreviation	# Carbons
Sulfonates	Perfluoro butane sulfonate	PFBS ⁻	4
	Perfluoro pentane sulfonate	PFPeS ⁻	5
	Perfluoro hexane sulfonate	PFHxS ⁻	6
	Perfluoro heptane sulfonate	PFHpS ⁻	7
	Perfluoro octane sulfonate	PFOS ⁻	8
	Perfluoro decane sulfonate	PFDS ⁻	10
Carboxylates	Perfluoro propanoate	PFPrA ⁻	3
	Perfluoro butanoate	PFBA ⁻	4
	Perfluoro pentanoate	PFPeA ⁻	5
	Perfluoro hexanoate	PFHxA ⁻	6
	Perfluoro heptanoate	PFHpA ⁻	7
	Perfluoro octanoate	PFOA ⁻	8
	Perfluoro nonanoate	PFNA ⁻	9
	Perfluoro decanoate	PFDA ⁻	10
	Perfluoro undecanoate	PFUnDA ⁻	11
	Perfluoro dodecanoate	PFDoDA ⁻	12
Perfluoro tridecanoate	PFTTrDA ⁻	13	
Perfluoro tetradecanoate	PFTeDA ⁻	14	

Figure 2. Primary Terminal Endpoint PFAS compounds with available physiochemical constants and toxicity factors; used to assess risk posed by PFAS-contaminated media.

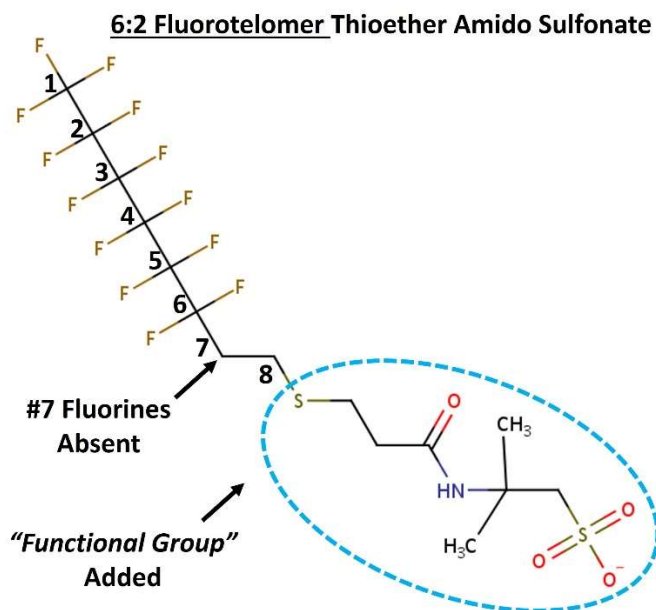


Figure 3. Structure of 6:2 FtTAoS⁻ (compare to structure of PFOA depicted in Figure 1).

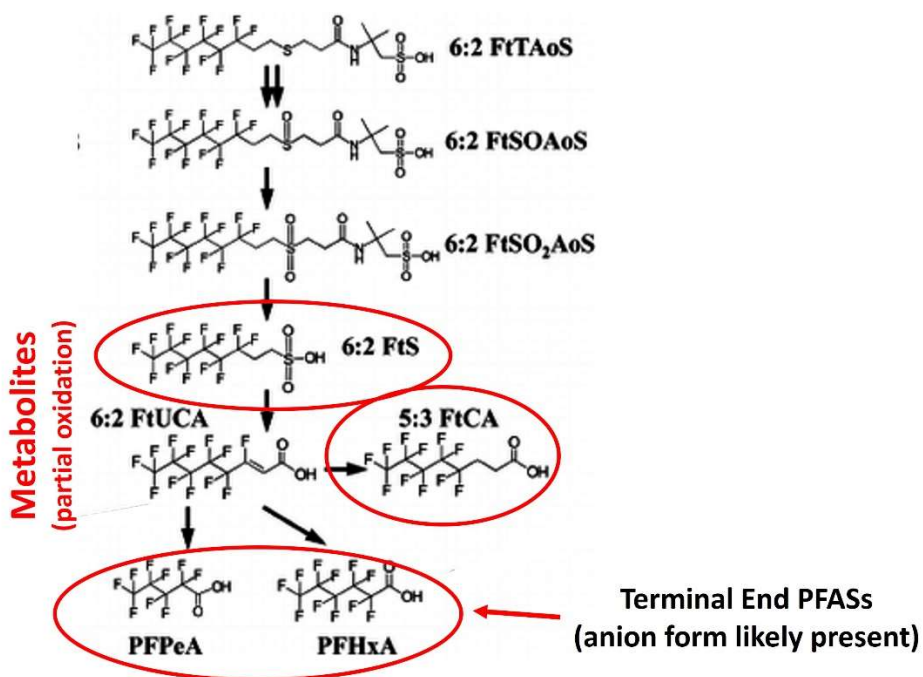


Figure 4. Example biological degradation of 6:2 FtTAoS⁻ into fluoretelomer sulfonates and carboxylates before ultimately degrading to the Terminal Endpoint compounds PFPeA⁻ and PFHxA⁻ (after Marjanoic et al. 2015). Structures should be in anion forms rather than acid forms, as depicted (hydrogen removed from hydroxyl group).

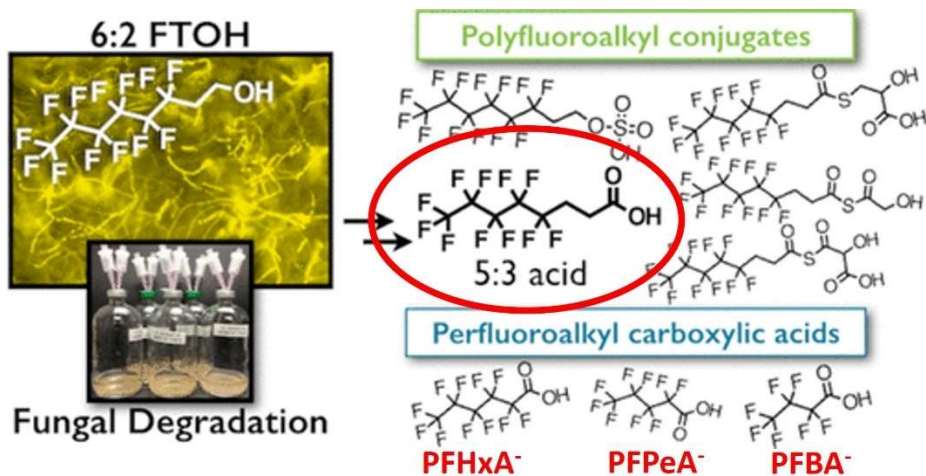


Figure 5. Example biological degradation of 6:2 FTOH⁻ into carboxylates before ultimately degrading to the short-chain Terminal Endpoint compounds PFHxA⁻, PFPeA⁻ and PFBA⁻ (after Tseng et al. 2014). Structures should be in anion forms rather than acid forms, as depicted (hydrogen removed from hydroxyl group).

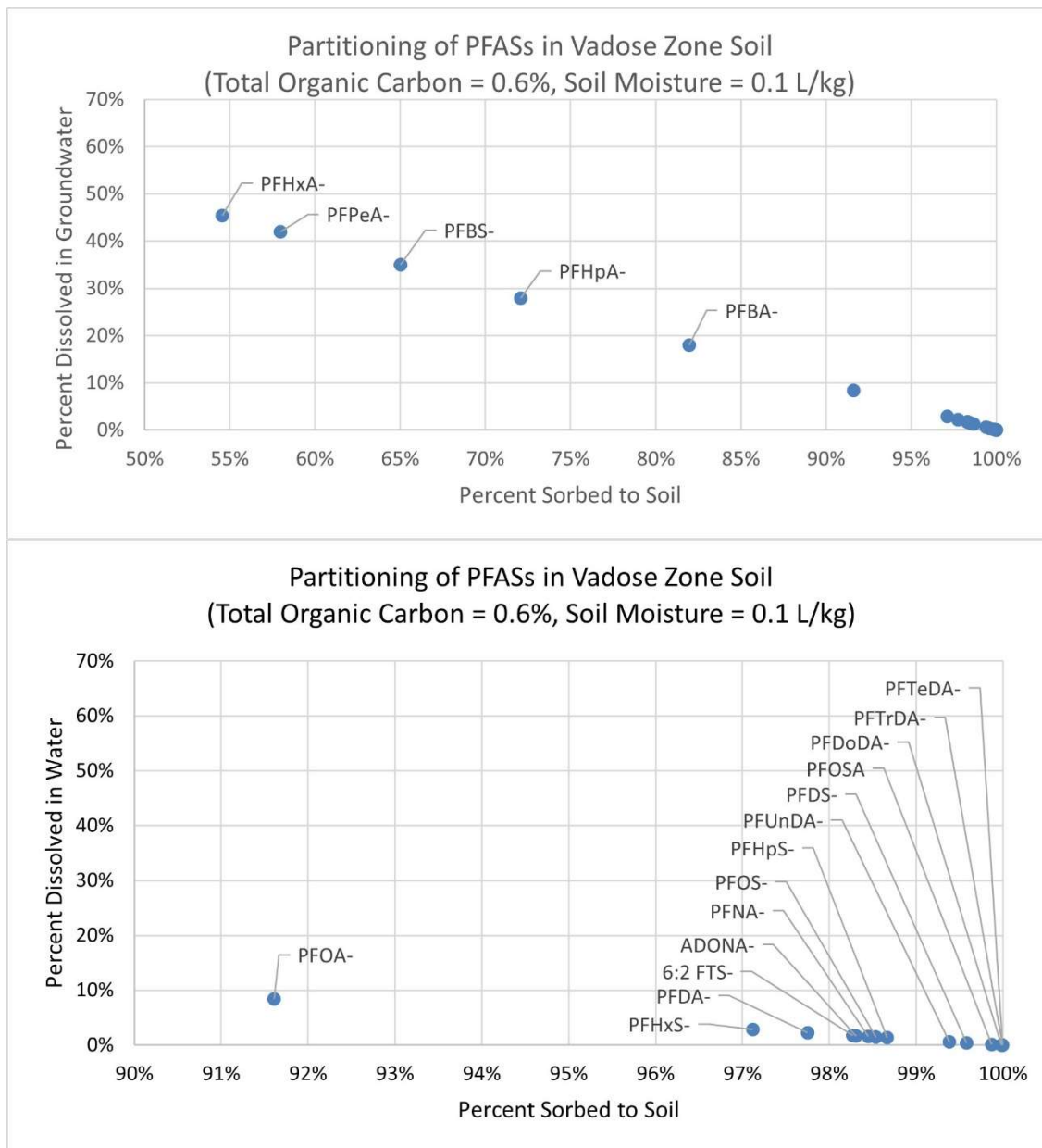


Figure 6. Predicted partitioning of PFASs upon initial release to vadose zone soil based on the chemical’s solubility, sorption coefficient and volatility and default soil parameter values used in HIDOH EAL models.

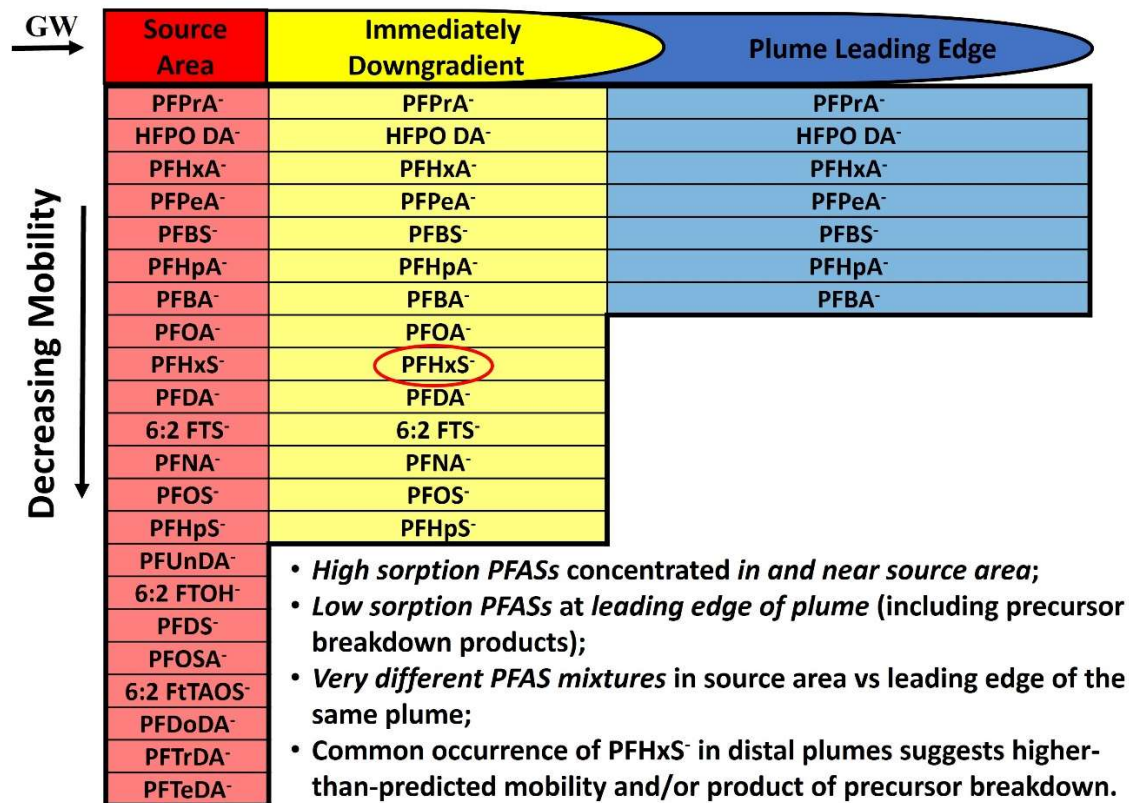


Figure 7. Hypothetical PFASs groundwater plume separation based on sorption coefficients for individual compounds.

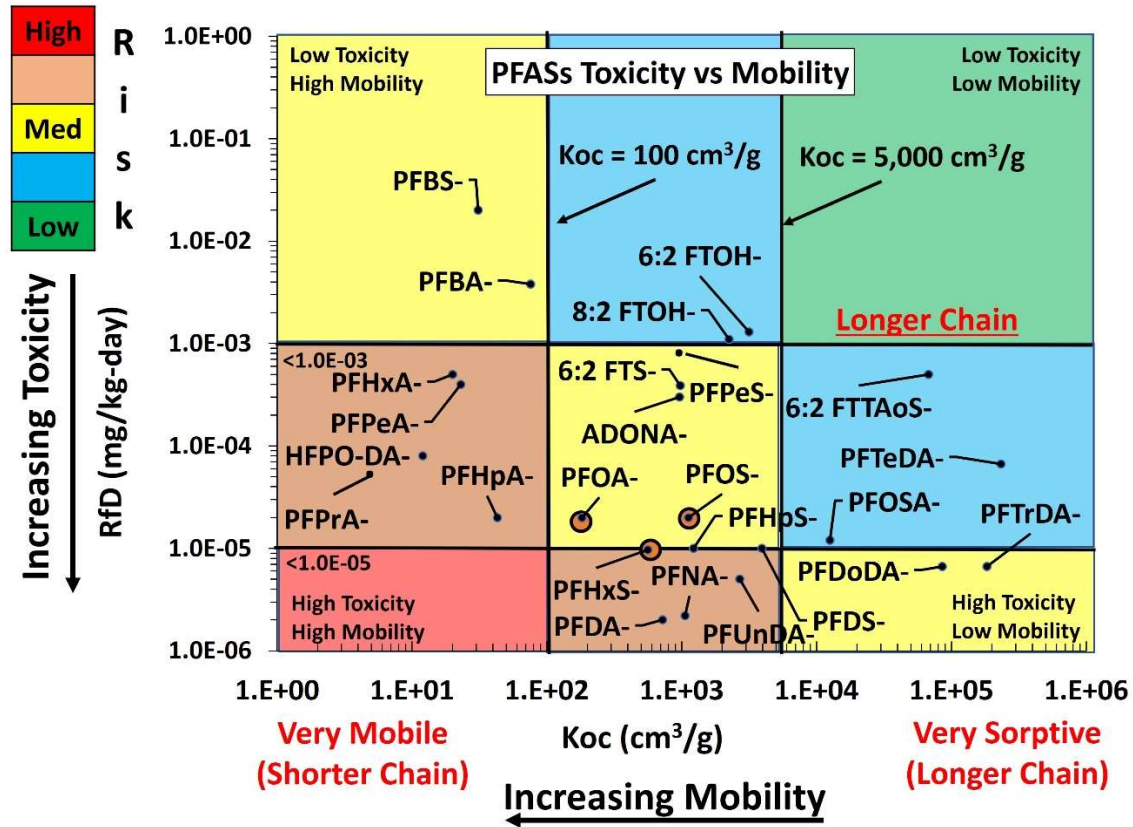


Figure 8. Comparison of PFASs mobility versus toxicity.

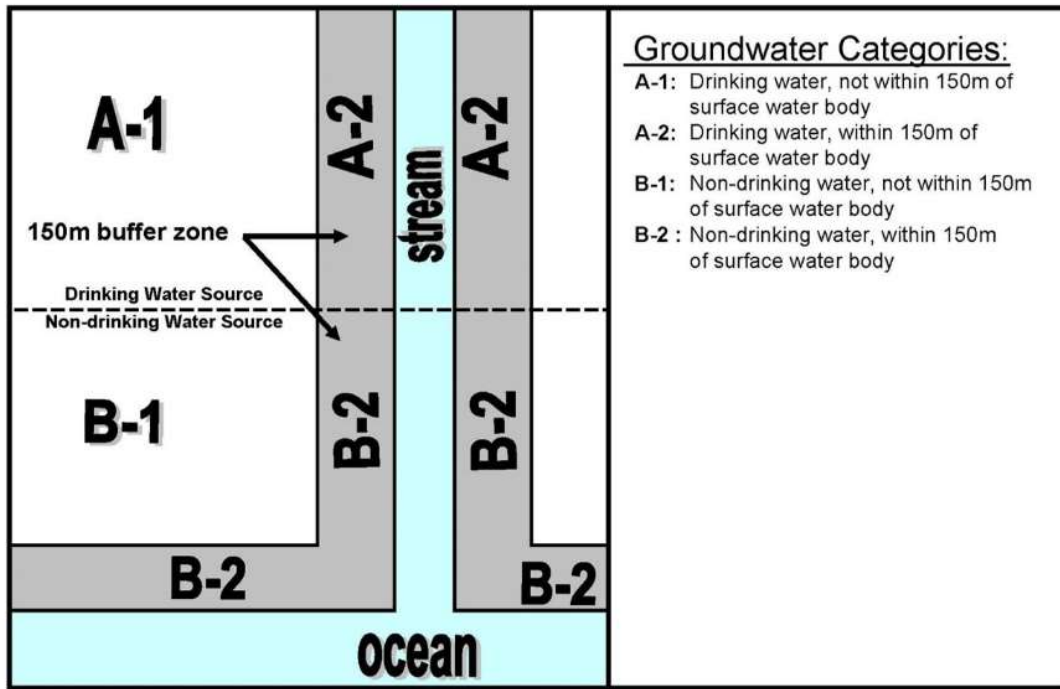


Figure 9. Groundwater categories used to develop the Tier 1 EAL lookup tables (HIDOH 2024a).

Table 1. Nomenclature and abbreviations for per- and polyfluoroalkyl substances with physiochemical constants and toxicity factors.

Group	Protonated Acid Form	CAS Number	Abbreviation
Perfluoroalkyl Sulfonic Acids and Sulfonates	Perfluorobutane sulfonic acid	375-73-5	PFBS
	Perfluoropentane sulfonic acid	1035556	PFPeS
	Perfluorohexane sulfonic acid	355-46-4	PFHxS
	Perfluoroheptane sulfonic acid	375-92-8	PFHpS
	Perfluorooctane sulfonic acid	1763-23-1	PFOS
	Perfluorodecane sulfonic acid	335-77-3	PFDS
Perfluoroalkyl Carbonic Acids and Carboxylates	Perfluoro propanoic acid	422-64-0	PFPrA
	Perfluoro butanoic acid	375-22-4	PFBA
	Perfluoro pentanoic acid	2706-90-3	PFPeA
	Perfluoro hexanoic acid	307-24-4	PFHxA
	Perfluoro heptanoic acid	375-85-9	PFHpA
	Perfluoro octanoic acid	335-67-1	PFOA
	Perfluoro nonanoic acid	375-95-1	PFNA
	Perfluoro decanoic acid	335-76-2	PFDA
	Perfluoro undecanoic acid	2058-94-8	PFUnDA
	Perfluoro dodecanoic acid	307-55-1	PFDoDA
	Perfluoro tridecanoic acid	72629-94-8	PFTTrDA
	Perfluoro tetradecanoic acid	376-06-7	PFTeDA
Other	Perfluroctane sulfonamide	754-91-6	PFOSA
	Hexafluoropropylene oxide dimer acid	13252-13-6	HFPO-DA
	6:2 Fluorotelemer Sulfonic Acid	27619-97-2	6:2 FTS
	4,8-Dioxa-3H-perfluorononanoic acid	919005-14-4	DONA
	6:2 Fluorotelomer alcohol	647-42-7	6:2 FTOH
	8:2 Fluorotelomer alcohol	678-39-7	8:2 FTOH
	6:2 Fluorotelomer Thioether Amido Sulfonic Acid	62880-95-9	6:2 FtTAoS

Anion Form Found in the Environment	CAS Number	Abbreviation
Perfluorobutane sulfonate	45187-15-3	PFBS ⁻
Perfluoropentane sulfonate	175905-36-9	PFPeS ⁻
Perfluorohexane sulfonate	108427-53-8	PFHxS ⁻
Perfluoroheptane sulfonate	146689-46-5	PFHpS ⁻
Perfluorooctane sulfonate	45298-90-6	PFOS ⁻
Perfluorodecane sulfonate	126105-34-8	PFDS ⁻
Perfluoro propanoate	44864-55-3	PFPrA ⁻
Perfluoro butanoate	45048-62-2	PFBA ⁻
Perfluoro pentanoate	45167-47-3	PFPeA ⁻
Perfluoro hexanoate	92612-52-7	PFHxA ⁻
Perfluoro heptanoate	120885-29-2	PFHpA ⁻
Perfluoro octanoate	45285-51-6	PFOA ⁻
Perfluoro nonanoate	72007-68-2	PFNA ⁻
Perfluoro decanoate	73829-36-4	PFDA ⁻
Perfluoro undecanoate	196859-54-8	PFUnDA ⁻
Perfluoro dodecanoate	171978-95-3	PFDoDA ⁻
Perfluoro tridecanoate	862374-87-6	PFTTrDA ⁻
Perfluoro tetradecanoate	365971-87-5	PFTeDA ⁻
Perfluorooctane sulfonate	45298-90-6	PFOS ⁻
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate	122499-17-6	HFPO-DA ⁻
6:2 Fluorotelemer sulfonate	27619-97-2	6:2 FTS ⁻
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate	958445-44-8	ADONA ⁻
6:2 Fluorotelomer alcohol	647-42-7	6:2 FTOH ⁻
8:2 Fluorotelomer alcohol	678-39-7	8:2 FTOH ⁻
6:2 Fluorotelomer Thioether Amido Sulfonate	88992-47-6	6:2 FtTAoS ⁻

Table 1 (cont.). Acid vs anion nomenclature for Per- and Polyfluoroalkyl substances with available physiochemical constants and toxicity factors.

Notes:

1. Superscript “-” after abbreviation of anion form of compound to distinguish with protonated acid form.
2. CAS # for ADONA noted (example anion salt of DONA).

Table 2a. PFAS physiochemical constants and absorption factors used in EAL Models.

¹PFAS	¹CAS #	²Physical State		Molecular Weight	Organic Carbon Partition coefficient,	Diffusivity in Air	Diffusivity in Water	Pure Component Solubility in Water	⁴Vapor Pressure	Henry's Law Constant	Henry's Law Constant	GI Tract Absorption Factor	Skin Absorption Factor
					K _{oc}	D _a	D _w	S	VP	H	H'	GIABS	ABS
				MW	(cm³/g)	(cm²/s)	(cm²/s)	(mg/L)	(mm Hg)	(atm·m³/mol)	(unitless)	(unitless)	(unitless)
PFBS ⁻	45187-15-3	NV	S	299	3.10E+01	2.70E-02	7.17E-06	2.17E+03	1.15E-08	2.95E-10	1.21E-08	1.00E+00	1.00E-01
PFPeS ⁻	175905-36-9	NV	S	349	1.05E+03			1.31E+05	2.82E-07	2.14E-10	8.75E-09	1.00E+00	1.00E-01
PFHxS ⁻	108427-53-8	NV	S	399	5.62E+02	3.50E-02	4.09E-06	1.70E+05	8.13E-09	1.94E-10	7.93E-09	1.00E+00	1.00E-01
PFHpS ⁻	146689-46-5	NV	S	449	1.23E+03			3.53E+05	3.31E-07	1.79E-10	7.32E-09	1.00E+00	1.00E-01
PFOS ⁻	45298-90-6	NV	S	499	1.12E+03	2.07E-02	5.26E-06	5.64E+05	2.45E-06	1.80E-11	7.36E-10	1.00E+00	1.00E-01
PFDS ⁻	126105-34-8	NV	S	599	3.94E+03			1.08E+06	8.13E-06	3.31E-10	1.35E-08	1.00E+00	1.00E-01
PFPrA ⁻	44864-55-3	V	L	164	5.89E+00			2.44E+04	2.30E+01	3.63E-06	1.48E-04	1.00E+00	1.00E-01
PFBA ⁻	45048-62-2	SV	L	213	7.60E+01			1.46E+05	2.18E+01	5.01E-05	2.05E-03	1.00E+00	1.00E-01
PFPeA ⁻	45167-47-3	NV	L	263	2.30E+01			2.43E+05	7.27E+00	2.97E-10	1.21E-08	1.00E+00	1.00E-01
PFHxA ⁻	92612-52-7	NV	L	313	2.00E+01			3.44E+05	2.00E+00	2.35E-10	9.61E-09	1.00E+00	1.00E-01
PFHpA ⁻	120885-29-2	NV	S	363	4.30E+01			5.30E+05	3.03E-01	2.09E-10	8.54E-09	1.00E+00	1.00E-01
PFOA ⁻	45285-51-6	NV	S	413	1.82E+02			6.24E+05	1.92E-01	1.92E-10	7.85E-09	1.00E+00	1.00E-01
PFNA ⁻	72007-68-2	NV	S	463	1.06E+03			7.78E+05	8.98E-02	1.18E-09	4.82E-08	1.00E+00	1.00E-01
PFDA ⁻	73829-36-4	NV	S	513	7.24E+02			9.54E+05	2.39E-02	1.50E-10	6.13E-09	1.00E+00	1.00E-01
PFUnDA ⁻	196859-54-8	NV	S	563	2.69E+03			1.16E+06	1.27E-02	3.34E-10	1.37E-08	1.00E+00	1.00E-01
PFDoDA ⁻	171978-95-3	NV	S	613	8.54E+04			1.40E+06	4.72E-03	3.40E-10	1.39E-08	1.00E+00	1.00E-01
PFTrDA ⁻	862374-87-6	NV	S	663	1.84E+05			1.69E+06	2.13E-03	3.48E-10	1.42E-08	1.00E+00	1.00E-01
PFTeDA ⁻	365971-87-5	NV	S	713	2.33E+05			2.03E+06	1.20E-03	3.55E-10	1.45E-08	1.00E+00	1.00E-01
PFOSA	754-91-6	NV	S	499	1.26E+04	3.02E-02	3.53E-06	6.64E-01	2.48E-01	1.26E-09	5.15E-08	1.00E+00	1.00E-01
HFPO-DA ⁻	122499-17-6	NV	S	329	1.20E+01			1.00E+06	2.40E-01	4.06E-06	1.66E-04	1.00E+00	1.00E-01
6:2 FTS ⁻	425670-75-3	NV	S	427	9.47E+02			5.72E+05	8.24E-07	1.83E-10	7.48E-09	1.00E+00	1.00E-01
ADONA ⁻	958445-44-8	NV	S	395	9.67E+02			2.17E+05	1.32E-02	1.80E-10	7.36E-09	1.00E+00	1.00E-01
6:2 FTOH ⁻	647-42-7	SV	L	364	3.16E+03			1.76E+01	1.70E+00	2.60E-10	1.06E-08	1.00E+00	1.00E-01
8:2 FTOH ⁻	678-39-7	NV	S	464	2.24E+03			1.98E-01	2.09E-01	2.09E-10	8.54E-09	1.00E+00	1.00E-01
6:2 FtTAoS ⁻	88992-47-6	NV	S	586	6.76E+04			1.92E+02	2.57E-09	8.91E-10	3.64E-08	1.00E+00	1.00E-01

Table 2a (cont.). PFAS physiochemical constants and absorption factors used in EAL Models.

Notes:

- 1. Abbreviations** refer to anion form of compound, assumed to be dominant in environmental samples (noted by "-" sign after abbreviation; refer to Table 1a in November 2020 Technical Memorandum).
- 2. Physical state of chemical at ambient conditions** (V - volatile, NV - nonvolatile, SV-semivolatile, S - solid, L - liquid, G - gas). *Chemical considered to be "volatile" if Henry's number ($\text{atm m}^3/\text{mole}$) >0.00001 and molecular weight <200 , and "semi-volatile" if molecular weight >200 .
- 3. Volatility** determined based on Molecular Weight and Henry's Constant (see Table 3a).
- 4. Dimensionless Henry's Law constant** calculated based on Sander (2015) assuming a temperature of 25°C .
- 5. Confidence in modeled vapor pressures** is low; not considered in determination of a compound as volatile or semivolatile.
- 6. HFPO DA:** Skin Absorption omitted in USEPA Regional Screening Levels guidance (USEPA 2022c).

Table 2b. References for PFAS physiochemical constants.

'PFAS	'CAS #	'Physical State		Molecular Weight MW	Organic Carbon Partition Coefficient	Diffusivity in Air	Diffusivity in Water	Pure Component Solubility in Water	Henry's Law Constant	² Henry's Law Constant	GI Tract Absorption Factor	Skin Absorption Factor
					K _{oc} (cm ³ /g)	D _a (cm ² /s)	D _w (cm ² /s)	S (mg/L)	H (atm·m ³ /mol)	H' (unitless)	GIABS (unitless)	ABS (unitless)
PFBS ⁻	45187-15-3	*	1	1	3	2	2	1	1	1 (calc)	2	2
PFPeS ⁻	175905-36-9	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFHxS ⁻	108427-53-8	*	1	1	3	2	2	1	1	1 (calc)	2	2
PFHpS ⁻	146689-46-5	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFOS ⁻	45298-90-6	*	1	1	3	2	2	1	1	1 (calc)	2	2
PFDS ⁻	126105-34-8	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFPrA ⁻	44864-55-3	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFBA ⁻	45048-62-2	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFPeA ⁻	45167-47-3	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFHxA ⁻	92612-52-7	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFHpA ⁻	120885-29-2	*	1	1	3	-	-	1	1	1 (calc)	2	2
PFOA ⁻	45285-51-6	*	1	1	3	-	-	1	1	1 (calc)	2	2
PFNA ⁻	72007-68-2	*	1	1	3	-	-	1	1	1 (calc)	2	2
PFDA ⁻	73829-36-4	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFUnDA ⁻	196859-54-8	*	1	1	3	-	-	1	1	1 (calc)	after 2	after 2
PFDoDA ⁻	171978-95-3	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFTTrDA ⁻	862374-87-6	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFTeDA ⁻	365971-87-5	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
PFOSA	754-91-6	*	1	1	3	2	2	1	1	1 (calc)	after 2	after 2
HFPO-DA ⁻	122499-17-6	*	4	4	4	-	-	4	4	4 (calc)	after 2	after 2
6:2 FTS ⁻	425670-75-3	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
ADONA ⁻	958445-44-8	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
6:2 FTOH ⁻	647-42-7	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
8:2 FTOH ⁻	678-39-7	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2
6:2 FtAoS ⁻	88992-47-6	*	1	1	1	-	-	1	1	1 (calc)	after 2	after 2

Table 2b (cont.). References for PFAS physiochemical constants.

References

1. USEPA, 2017, The CompTox Chemistry Dashboard: US Environmental Protection Agency. Journal of Cheminformatics, Vol. 9, Article No: 61 (2017). Accessed 5/11/20. <https://comptox.epa.gov/dashboard> (values selected in order of preference: Experimental Median Value, Predicted Median Value, Experimental Average Value, Predicted Average Value)
2. ORNL, 2020, Risk Assessment Information System: Oak Ridge National Laboratories, Office of Environmental Management, accessed 5/5/20. <https://rais.ornl.gov/>
3. ITRC, 2020, Per- and Polyfluoroalkyl Substances: Interstate Technology and Regulatory Council, April 2020.
4. ECHA, 2019, Support Document for HFPO-DA and It's Salts/Ally Halides as Substances of Very High Concern: European Chemicals Agency, Adopted on 26 June 2019.
5. PubChem.

Table 3a. PFASs toxicity factors with multiple sources.

'PFAS	'CAS	USEPA RfDo		ATSDR (2021) Minimum Risk Level		Michigan SAW (2019) DEGLE (2020) Chronic RfDo		³ Zeilmaker et al. (2018) Equivalent Chronic RfDo			Texas CEQ (2016) Chronic RfDo		Minnesota DEQ (2017-2019) Chronic RfD	
		RfD (mg/kg-d)	² Primary Study Form	RfD (mg/kg-d)	² Primary Study Form	RfD (mg/kg-d)	² Primary Study Form	RPF	RfD (mg/kg-d)	² Primary Study Form	RfD (mg/kg-d)	² Primary Study Form	RfD	² Primary Study Form
PFBS ⁻	45187-15-3	3.00E-04	H+ Acid			3.00E-04	Anion	0.001	2.00E-02	Anion	1.40E-03	Anion	1.30E-03	Anion
PFPeS ⁻	175905-36-9							0.6	3.30E-05	H+ Acid				
PFHxS ⁻	108427-53-8			2,00E-05	H+ Acid	9.70E-06	Anion	0.6	3.30E-05	Anion	3.80E-06	Anion	9.70E-06	Anion
PFHpS ⁻	146689-46-5							2	1.00E-05	H+ Acid				
PFOS ⁻	45298-90-6	7.90E-09		2,00E-06	H+ Acid	2.89E-06	Anion	2	1.00E-05	Anion	2.30E-05	Anion	3.10E-06	Anion
PFDS ⁻	126105-34-8							2	1.00E-05	H+ Acid	1.20E-05	Anion		
PFPrA ⁻	44864-55-3	5.00E-04	H+ Acid											
PFBA ⁻	45048-62-2							0.05	4.00E-04	Anion	2.90E-03	H+ Acid	3.80E-03	Anion
PFPeA ⁻	45167-47-3							0.05	4.00E-04	H+ Acid	3.80E-06	H+ Acid		
PFHxA ⁻	92612-52-7	5.0E-04	H+ Acid			8.30E+00	H+ Acid	0.01	2.00E-03	Anion	3.80E-06	H+ Acid		
PFHpA ⁻	120885-29-2							1	2.00E-05	H+ Acid	2.30E-05	H+ Acid		
PFOA ⁻	45285-51-6	1.50E-09		3,00E-06	H+ Acid	3.90E-06	H+ Acid	1	2.00E-05	H+ Acid	1.20E-05	H+ Acid	1.80E-05	Anion
PFNA ⁻	72007-68-2			3,00E-06	H+ Acid	2.20E-06	H+ Acid	10	2.00E-06	H+ Acid	1.20E-05	H+ Acid		
PFDA ⁻	73829-36-4							10	2.00E-06	H+ Acid	1.50E-05	H+ Acid		
PFUnDA ⁻	196859-54-8							4	5.00E-06	H+ Acid	1.20E-05	H+ Acid		
PFDoDA ⁻	171978-95-3							3	6.70E-06	H+ Acid	1.20E-05	H+ Acid		
PFTTrDA ⁻	862374-87-6							3	6.70E-06	H+ Acid	1.20E-05	H+ Acid		
PFTeDA ⁻	365971-87-5							0.3	6.70E-05	H+ Acid	1.20E-05	H+ Acid		
PFOSA	754-91-6										1.20E-05	H+ Acid		
HFPO DA ⁻	13252-13-6	3.00E-06	H+ Acid	7.70E-05	H+ Acid									
6:2 FTS ⁻	425670-75-3			3.90E-04	H+ Acid									
ADONA-	958445-44-8													
6:2 FTOH-	647-42-7													
8:2 FTOH-	678-39-7													
6:2 FtTAoS-	88992-47-6													

Table 3a (cont.). Selection of PFASs toxicity factors.

Notes:

1. CAS number reflects anion form. Negative sign added to abbreviation to avoid confusion with H⁺ acid form.
2. Anion versus protonated (H⁺) acid form of compound that served as primary basis for the stated RfD noted, based on information provided in the noted references.
3. Reference Doses calculated based on the Zeilmaker et al. 2018 Relative Potency Factor multiplied by the RfD selected for PFOA.
5. NJDEP has published an RfD for PFNA of 7.4E-07 (see 2015 PFNA document).

References:

- ATSDR, 2021, Toxicological Profile for Perfluoroalkyls: Agency for Toxic Substances and Disease Registry, May 2021.
- MISAW, 2019, Health Based Drinking Water Values for PFAS in Michigan: Michigan Science Advisory, Workgroup Lansing, Michigan, June 27, 2019. (all listed toxicity factors except 6:2 FTS⁻).
- MIDOE, 2020, Screening Level Evaluation 6:2 Fluorotelomer Sulfonic Acid: Michigan Department of Environment, Great Lakes and Energy, Interoffice Communication from Michael Depa, Toxics Unit, Air Quality Division, September 24, 2020. (toxicity factors for 6:2 FTS⁻).
- MIDOE, 2021, Response to Public Comments for 6:2 Fluorotelomer Sulfonic Acid: Michigan Department of Environment, Great Lakes and Energy, Air Quality Division, January 24, 2021.
- MNDOH, 2017, Toxicological Summary for: Perfluorobutane sulfonate: Minnesota Department of Health, December 2017.
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- USEPA, 2021b, Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3) Also Known as “GenX Chemicals”: US Environmental Protection Agency, Office of Research and Development, EPA Document Number: 822R-21-010, October 2021.
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- USEPA, 2022a, *Drinking Water Health Advisory: Perfluorooctanoic Acid (PFOA) CASRN 335-67-1*: U.S. Environmental Protection Agency, Office of Water, EPA/822/R-22/003. June 2022.
- USEPA, 2022b, *Interim Drinking Water Health Advisory: Perfluorooctane Sulfonic Acid (PFOS) CASRN 1763-23-1*: U.S. Environmental Protection Agency, Office of Water, EPA/822/R-22/004. June 2022.
- Zeilmaker, M.J., Fragki, S., Verbruggen, E.M.J. and B.G.H. Bokkers, 2018, Mixture Exposure to PFAS, A Relative Potency Factor Approach: National Institute for Public Health and the Environment, Bilthoven, The Netherlands.

Table 3b. Final noncancer toxicity factors used for development of action levels and assessment of risk.

PFAS	¹ CAS	² Selected Reference Dose (RfD) mg/kg-day	Reference	² Selected Reference Concentration (RfC) mg/m ³	Reference
PFBS-	45187-15-3	3.00E-04	USEPA 2021a	4.90E-03	TXCEQ (2015)
³ PFPeS-	175905-36-9	1.60E-04	after DMOE (2015)		
PFHxS-	108427-53-8	2.00E-05	ATSDR (2021)	1.30E-05	TXCEQ (2015)
PFHpS-	146689-46-5	1.00E-05	Zeilmaker et al. (2018)		
⁴ PFOS-	45298-90-6	2.00E-06	ATSDR (2021)	8.10E-05	TXCEQ (2015)
PFDS-	126105-34-8	1.00E-05	Zeilmaker et al. (2018)		
PFPrA-	44864-55-3	5.00E-04	USEPA (2023)	1.75E-03	(extrapolated from RfD)
PFBA-	45048-62-2	3.80E-03	MNDOH (2018)	1.00E-02	TXCEQ (2015)
PFPeA-	45167-47-3	4.00E-04	Zeilmaker et al. (2018)	1.40E-03	(extrapolated from RfD)
PFHxA-	92612-52-7	5.00E-04	USEPA (2022a)	1.75E-03	(extrapolated from RfD)
PFHpA-	120885-29-2	2.00E-05	Zeilmaker et al. (2018)		
⁴ PFOA-	45285-51-6	3.00E-06	ATSDR (2021)	4.10E-06	
PFNA-	72007-68-2	3.00E-06	ATSDR (2021)	2.80E-05	TXCEQ (2015)
PFDA-	73829-36-4	2.00E-06	Zeilmaker et al. (2018)	5.30E-05	TXCEQ (2015)
PFUnDA-	196859-54-8	5.00E-06	Zeilmaker et al. (2018)		
PFDoDA-	171978-95-3	6.70E-06	Zeilmaker et al. (2018)	4.20E-05	TXCEQ (2015)
PFTrDA-	862374-87-6	6.70E-06	Zeilmaker et al. (2018)		
PFTeDA-	365971-87-5	6.70E-05	Zeilmaker et al. (2018)		
PFOSA	754-91-6	1.20E-05	Texas CEQ (2016)		
HFPO DA-	13252-13-6	3.00E-06	USEPA 2021b		
6:2 FTS-	425670-75-3	3.90E-04	MIDOE (2020, 2021)	1.00E-03	MIDOE (2020, 2021)
DONA-	958445-44-8	3.00E-04	WIDHS (2020)		
6:2 FTOH-	647-42-7	1.30E-03	Gibb and O'Leary (2023)	4.55E-03	Gibb and O'Leary (2023)
8:2 FTOH-	678-39-7	1.10E-03	Gibb and O'Leary (2023)	3.85E-03	Gibb and O'Leary (2023)
6:2 FtTAoS-	88992-47-6	5.00E-04	Gibb and O'Leary (2023)		

Table 3b (cont.). Final noncancer toxicity factors used for development of action levels and assessment of risk.

Notes:

1. CAS numbers reflects anion form when available. Negative sign added to abbreviation to avoid confusion with H⁺ acid form. Laboratory data should be presented in unadjusted, anion form of targeted compounds for comparison to action levels and assessment of risk and fate and transport.
2. See text for order of preference of references noted for toxicity factors.
3. After DMOE (2015): "Toxicity data on PFPeS have not been available. Considering the conclusions on chain length and presence of functional groups of PFAS, it can be expected that PFPeS shows slightly increased toxicity compared to PFBS (0.0003 mg/kg-d), as well as increased toxicity compared to PFPeA (0.0004 mg/kg-d)." Selected interim RfD 0.00016 mg/kg-day = Halfway between PFBS- and PFHxS⁻.
4. ATSDR (2021) RfDs for PFOS and PFOA referenced pending finalization of toxicity factors selected by USEPA for promulgation of drinking water Maximum Contaminant Level for these compounds.

References

- ATSDR, 2021, *Toxicological Profile for Perfluoroalkyls*: Agency for Toxic Substances and Disease Registry, May 2021.
- DMOE, 2015, *Short-chain Polyfluoroalkyl Substances (PFAS)*: Danish Ministry of Environment, Environmental project No. 1707.
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- USEPA, 2018, Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3), Also Known as "GenX Chemicals" (Public Comment Draft): U.S. Environmental Protection Agency, EPA-823-P-18-001, November 2018.
- USEPA, 2021a, Human Health Toxicity Values for Perfluorobutane Sulfonic Acid (CASRN 375-73-5) and Related Compound Potassium Perfluorobutane Sulfonate (CASRN 29420-49-3): US Environmental Protection Agency, Office of Research and Development, EPA/600/R-20/345F, April 2021.
- USEPA, 2021b, Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3) Also Known as "GenX Chemicals": US Environmental Protection Agency, Office of Research and Development, EPA Document Number: 822R-21-010, October 2021.

USEPA, 2023a, Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts: US Environmental Protection Agency, Office of Research and Development, EPA/635/R-23/027Fa, April 2023.

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Zeilmaker, M.J., Fragki, S., Verbruggen, E.M.J. and B.G.H. Bokkers, 2018, Mixture Exposure to PFAS, A Relative Potency Factor Approach: National Institute for Public Health and the Environment, Bilthoven, The Netherlands.

Table 4. ¹Chronic health effects of PFASs (refer to Attachment 3, Table J for additional information).

CHEMICAL PARAMETER	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
Perfluorobutane sulfonate (PFBS-)					15 ^A	15 ^A			15 ^A				
Perfluoropentane sulfonate (PFPeS-)													
Perfluorohexane sulfonate (PFHxS-)			1 ^H ,4 ^A		1 ^A ,9 ^H	4 ^A		1 ^H ,2 ^H ,9 ^H		11 ^A	10 ^H		5 ^H
Perfluoroheptane sulfonate (PFHpS-)													
Perfluorooctane sulfonate (PFOS-)	13 ^A ,17	1 ^H ,2 ^H	1 ^H 1 ^A ,5 ^H	1 ^H	1 ^H 1 ^A ,9 ^H	1 ^H		1 ^H 1 ^A ,2 ^H ,9 ^H ,13 ^A	2 ^H ,5 ^H	11 ^A	1 ^H ,10 ^H		5 ^H
Perfluorodecane sulfonate (PFDS-)													
Perfluoro propanoate (PFPrA-)		24 ^A	24 ^A				24 ^A		24 ^A				
Perfluoro butanoate (PFBA-)			3 ^A		1 ^A ,3 ^A	3 ^A	3 ^A						
Perfluoro pentanoate (PFPeA-)													
Perfluoro hexanoate (PFHxA-)			1 ^A , 21 ^A	1 ^H	1 ^A , 21 ^A	1 ^A	1 ^A , 21 ^A		1 ^A				
Perfluoro heptanoate (PFHpA-)			1 ^A										
Perfluoro octanoate (PFOA-)	6 ^H ,7 ^H ,13 ^A ,16,18	1 ^H ,2 ^H ,6 ^H ,7 ^H	1 ^H 1 ^A ,5 ^H ,6 ^H	1 ^H ,5 ^H ,6 ^H ,7 ^H	1 ^H 1 ^A ,5 ^H ,6 ^H	1 ^H ,5 ^H ,7 ^H	8 ^A	1 ^H 1 ^A ,2 ^H ,5 ^H ,6 ^H ,7 ^H ,9 ^H ,13 ^A	2 ^H ,5 ^H ,6 ^H	11 ^A ,5 ^H	1 ^H 1 ^A ,8 ^A ,10 ^H	1 ^H	5 ^H
Perfluoro nonanoate (PFNA-)		1 ^H ,10 ^H			1 ^A								5 ^H
Perfluoro decanoate (PFDA-)		1 ^H			1 ^A			1 ^H ,2 ^H					
Perfluoro undecanoate (PFUnDA-)					1 ^A								
Perfluoro dodecanoate (PFDoDA-)													
Perfluoro tridecanoate (PFTrDA-)													
Perfluoro tetradecanoate (PFTeDA-)													
Perfluorooctane sulfonamide (PFOSA)													
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	14 ^A		14 ^A		14 ^A		14 ^A	14 ^A					
6:2 Fluorotelomer sulfonate (6:2 FTS-)			19 ^A , 20 ^A	19 ^A					20 ^A				20 ^A
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)		12 ^A			12 ^A		12 ^A						
6:2 Fluorotelomer alcohol (6:2 FTOH-)			23 ^A		23 ^A	23 ^A							23 ^A
8:2 Fluorotelomer alcohol (8:2 FTOH-)			23 ^A		23 ^A				23 ^A				
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)					23 ^A			23 ^A					

Table 4 (cont.). ¹Chronic health effects of PFASs (refer to Attachment 3, Table J for additional information).**Notes**

1. For general reference only. "A" = Animal study; "H" = Human epidemiological study. Primary health risk long-May not be adequately comprehensive for some chemicals. Specific form of compound used in studies can vary. Some effects may be clinically insignificant. Presence of effect in animal studies may not translate to effect in humans. Refer to original reference documents for more information.
2. Cancer slope factor (CSF) currently only available for PFOA (draft CSF included in USEPA proposed MCL for PFOS; USEPA 2023b).
3. Compilation of chronic health effects incomplete; assumed similar to PFOA and PFOS (see Zeilmaker et al. 2018).

References

- 1^H**: Human Epi Studies correlation in ATSDR 2018 Toxicological Profile for Perfluoroalkyls, Draft for Public Comment (<https://www.atsdr.cdc.gov/toxprofiles/tp200-c2.pdf>)
- 1^A**: Animal Studies correlation in ATSDR 2018 Toxicological Profile for Perfluoroalkyls, Draft for Public Comment (<https://www.atsdr.cdc.gov/toxprofiles/tp200-c2.pdf>)
- 2^H**: Kirk M et al 2018 The PFAS Health Study: Systematic Literature Review
- 3^A**: MDH 2018 Toxicological Summary for PFBA (<https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfba2summ.pdf>), animal studies only
- 4^A**: MDH 2019 Toxicological Summary for PFHxS (<https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfhxs.pdf>). Animal studies only
- 5^H**: Expert Health Panel for Per- and Poly- Fluoroalkyl Substances (PFAS) 2018 Australian Report to the Minister (<https://www1.health.gov.au/internet/main/publishing.nsf/Content/C9734ED6BE238EC0CA2581BD00052C03/%24File/expert-panel-report.pdf>)
- 6^H**: Rijs et al RIVM Dutch National Institute for Public Health and the Environment 2017 PFOA exposure and Health: A review of scientific literature. (<https://www.rivm.nl/bibliotheek/rapporten/2017-0086.pdf>)
- 7^H**: C8 Science Panel 2012 Probable Link Reports (http://www.c8sciencepanel.org/prob_link.html)
- 8^{H,A}**: Sunderland et al 2018 A review of pathways of human exposure to PFAS and present understanding of health effects
- 9^H**: Liew Z et al 2018 Developmental exposures to PFAS: an update of associated health outcomes
- 10^H**: Lin CY et al 2009 Association among serum PFAS chemicals, glucose homeostasis risk, and metabolic syndrome
- 11^A**: Johansson et al 2008 Neonatal Exposures to PFOS and PFOA causes neurobehavioral defects in adult mice
- 12^A**: Gordon SC 2011 Toxicological evaluation of ADONA
- 13^A**: National Toxicology Program 2019 Technical Report on the toxicology and carcinogenic studies of PFOA administered in feed to Sprague-Dawley Rats
- 14^A**: USEPA 2018 Draft human toxicity values for HFPO (GenX) (https://www.epa.gov/sites/production/files/2018-11/documents/genx_public_comment_draft_toxicity_assessment_nov2018-508.pdf)
- 15^A**: USEPA 2018 Draft human toxicity values for PFBS (https://www.epa.gov/sites/production/files/2018-11/documents/pfbs_public_comment_draft_toxicity_assessment_nov2018-508.pdf)
- 16^{AH}**: USEPA 2016 Drinking water health advisory for PFOA (https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final_508.pdf)
- 17^{AH}**: USEPA 2016 Drinking water health advisory for PFOS (https://www.epa.gov/sites/production/files/2016-05/documents/pfos_health_advisory_final_508.pdf)
- 18**: IARC 2016 Monograph 110: PFOA (<https://monographs.iarc.fr/wp-content/uploads/2018/06/mono110-01.pdf>)
- 19^A**: Michigan Dept of Environment, Great Lakes and Energy Interoffice Communication on 6:2 FTSA, September 2020
- 20^A**: NASF, 6:2 FluorotelomerSulfonate (6:2 FTS), Toxicology at a Glance: National Association for Surface Finishing, March 2019
- 21^A**: USEPA Toxicological Review of Perfluorohexanoic Acid and Related Salts April 2023
- 22A**. Gibb and Oleary, 2023, Risk Evaluation of Select PFAS, Report to the Hawaii State Department of Health: Prepared by Gibb & O'Leary Epidemiology Consulting July 26, 2023.
- 23A**. USEPA, 2023g, Human Health Toxicity Value for Perfluoropropanoic Acid. EPA/600/R-22/042F, July 2023.

Table 5. Summary of Drinking Water Ingestion Rates relative to body weight utilized for calculation of drinking water action levels.

PFAS	CAS	DWIR-BW (L/kg bw-day)	Targeted Exposure Population	^{1,2,3} Reference
PFBS ⁻	45187-15-3	0.0354	Women of child-bearing age	USEPA 2023c
PFHxS ⁻	108427-53-8	0.0340	General adults	USEPA 2023c
PFHpS ⁻	146689-46-5	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFOS ⁻	45298-90-6	0.0701	Young children (0-<5yrs)	USEPA 2022b
PFDS ⁻	126105-34-8	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFBA ⁻	45048-62-2	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFPeA ⁻	45167-47-3	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFHxA ⁻	92612-52-7	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFHpA ⁻	120885-29-2	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFOA ⁻	45285-51-6	0.0701	Young children (0-<5yrs)	USEPA 2022a
PFNA ⁻	72007-68-2	0.0469	Lactating women	USEPA 2023c
PFDA ⁻	73829-36-4	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFUnDA ⁻	196859-54-8	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFDoDA ⁻	171978-95-3	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFTTrDA ⁻	862374-87-6	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFTeDA ⁻	365971-87-5	0.0520	Young children (0-6 yrs)	USEPA 2022c
PFOSA	754-91-6	0.0520	Young children (0-6 yrs)	USEPA 2022c
HFPO DA ⁻	13252-13-6	0.0469	Lactating women	USEPA 2023c
6:2 FTS ⁻	425670-75-3	0.0520	Young children (0-6 yrs)	USEPA 2022c
ADONA ⁻	958445-44-8	0.0520	Young children (0-6 yrs)	USEPA 2022c

Notes

1. PFOA⁻ and PFOS⁻: DWI-BW of 0.0701 L/kg-day used in 2022 USEPA PFOA and PFOS Drinking Water Advisories, based on exposure of 0 to <5 yr old children. DWIR-BW rates not stated in proposed MCL documents for PFOA and PFOS (USEPA 2023b,c).

2. PFBS⁻, PFHxS⁻, PFNA⁻, HFPO DA⁻: DWIR-BW values as presented in proposed USEPA MCLGs for noted chemicals (USEPA 2023c).

3. All Other PFASs: DWIR-BW value calculated based on default, average drinking water ingestion rate and body weight of 0-6 year old children utilized in USEPA Regional Screening Levels for tapwater. DWIR-BW = (0.78 L/day)/15 kg = 0.0520 L/kg-day.

Table 6. Default exposure parameter values used to generate toxicity-based action levels for drinking water and direct- exposure action levels for soil (refer to Appendix 1 and Appendix 2 in 2017 HDOH EAL guidance).

Symbol	Definition (units)	Default	References
CSFo	Cancer slope factor oral (mg/kg-d) ⁻¹	--	Chemical specific – Table 4
CSFi	Cancer slope factor inhaled (mg/kg-d) ⁻¹	--	Chemical specific – Table 4
RfDo	Reference dose oral (mg/kg-d)	--	Chemical specific – Table 4
RfDi	Reference dose inhaled (mg/kg-d)	--	Chemical specific – Table 4
¹ TRr/o	Target cancer risk - residential, occupational/ industrial exposure scenario	10 ⁻⁵	(refer to memorandum text).
¹ TRctw	Target cancer risk - construction/trench worker exposure scenario	10 ⁻⁵	(refer to memorandum text)
² THQs	Target hazard quotient (soil)	1.0	(refer to memorandum text)
² THQdw	Target hazard quotient (drinking water)	1.0	(refer to memorandum text)
RSCdw	Relative Source Contribution (drinking water)	0.2	(refer to memorandum text)
BWa	Body weight, adult (kg) (soil exposure)	55	HIDOH
BWc	Body weight, child (kg)	15	USEPA 2022c
ATc	Average time – carcinogens (days)	25,550	USEPA 2022c
ATn	Average time – noncarcinogens (days)	EDx365	USEPA 2022c
SAar	Exposed surface area, adult res. (cm ² /day)	6,032	USEPA 2022c
SAaw	Exposed surface area, adult occ. (cm ² /day)	2,373	USEPA 2022c
SAc	Exposed surface area, child (cm ² /day)	3,527	USEPA 2022c
SAac/tw	Exposed surface area, construction/trench worker (cm ² /day)	5,800	USEPA 2011b
AFar	Adherence factor, adult res. (mg/cm ²)	0.07	USEPA 2022c
AFaw	Adherence factor, occupational (mg/cm ²)	0.12	USEPA 2022c
AFctw	Adherence factor, construction/trench worker (mg/cm ²)	0.30	USEPA 2022c
AFc	Adherence factor, child (mg/cm ²)	0.20	USEPA 2022c
ABS	Skin absorption (unitless): chemical specific	--	USEPA 2022c
IRAA	Inhalation rate – adult (m ³ /day)	20	USEPA 2022c
IRAc	Inhalation rate – child (m ³ /day)	10	USEPA 2022c
IRActw	Inhalation rate – construction/trench worker (m ³ /day)	20	USEPA 2011b
IRWa	Drinking water ingestion – adult (L/day)	-	Chemical specific (see Table 5)
IRWc	Drinking water ingestion – child (L/day)	-	Chemical specific (see Table 5)
IRSa	Soil ingestion – adult (mg/day)	100	USEPA 2022c
IRSc	Soil ingestion – child (mg/day)	200	USEPA 2022c
IRSo	Soil ingestion – occupational (mg/day)	100	USEPA 2022c
IRSctw	Soil ingestion–construction/trench worker (mg/day)	330	USEPA 2002
EF _{DW}	Exposure frequency (Drinking Water; d/y)	365	USEPA 2022c,b
EF _{soil}	Exposure frequency (Soil, Residential; d/y)	350	USEPA 2022c
EFo	Exposure frequency (Soil, Occupational; d/y)	250	USEPA 2022c
EFctw	Exposure frequency – construction/trench worker (d/y)	20	Massachusetts DEP (1994)
EDr	Exposure duration – residential (years)	26	USEPA 2022c
EDc	Exposure duration – child (years)	6	USEPA 2022c
EDo	Exposure duration – occupational (years)	25	USEPA 2022c
EDctw	Exposure duration – construction/trench worker (years)	7	modified from Massachusetts DEP (1994)

Attachment 2

Summary PFAS EALs (HIDOH March 2024)

**TABLE A. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS Current or Potential Source of Drinking Water**

CHEMICAL PARAMETER	>150m to Surface Water Body		<150m to Surface Water Body	
	¹ Soil (mg/kg)	² Groundwater (ug/L)	¹ Soil (mg/kg)	² Groundwater (ug/L)
Perfluorobutane sulfonate (PFBS-)	8.7E-03	1.7E+00	8.7E-03	1.7E+00
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	6.2E-01	1.1E-01	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	7.2E-03	7.7E-02	7.2E-03	7.7E-02
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	3.8E-02	7.9E-03	3.8E-02
Perfluorooctane sulfonate (PFOS-)	1.4E-03	7.7E-03	1.4E-03	7.7E-03
Perfluorodecane sulfonate (PFDS-)	2.5E-02	3.8E-02	2.5E-02	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	5.1E-01	5.1E-04	5.1E-01
Perfluoro butanoate (PFBA-)	1.9E-01	1.5E+01	1.9E-01	1.5E+01
Perfluoro pentanoate (PFPeA-)	5.9E-03	1.5E+00	5.9E-03	1.5E+00
Perfluoro hexanoate (PFHxA-)	6.4E-03	1.9E+00	6.4E-03	1.9E+00
Perfluoro heptanoate (PFHpA-)	5.5E-04	7.7E-02	5.5E-04	7.7E-02
Perfluoro octanoate (PFOA-)	3.5E-04	1.2E-02	3.5E-04	1.2E-02
Perfluoro nonanoate (PFNA-)	2.0E-03	1.2E-02	2.0E-03	1.2E-02
Perfluoro decanoate (PFDA-)	9.2E-04	7.7E-03	9.2E-04	7.7E-03
Perfluoro undecanoate (PFUnDA-)	8.6E-03	1.9E-02	8.6E-03	1.9E-02
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	2.6E-02	8.5E-02	2.6E-02
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	2.6E-02	8.5E-02	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	2.6E-01	8.5E-01	2.6E-01
Perfluroroctane sulfonamide (PFOSA)	1.5E-01	4.6E-02	1.5E-01	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.3E-05	1.2E-02	2.3E-05	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.4E-01	1.5E+00	2.4E-01	1.5E+00
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.9E-01	1.2E+00	1.9E-01	1.2E+00
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	5.0E+00	2.6E+00	5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	4.2E+00	1.6E+00	4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	1.9E+00	6.3E+00	1.9E+00

Notes:

1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.

2. Assumes potential impacts to drinking water source and discharge of groundwater into a freshwater, marine or estuary surface water system. Compare to *dissolved-phase* concentration.

Source of Soil Action Levels: Refer to Appendix 1, Tables A-1 and A-2.

Source of Groundwater Action Levels: Appendix 1, Table D-1a (<150m to Surface Water Body) and Table D-1b (>150m to Surface Water Body).

Soil data should be reported on dry-weight basis (see Appendix 1, Section 6.2).

Soil Action Levels intended to address direct-exposure, groundwater protection (leaching) and gross contamination hazards. The need for a site-specific, ecological risk assessment should be evaluated if sensitive, terrestrial or aquatic habitats are within or nearby areas of contaminated soil.

Groundwater Action Levels intended to address impacts to drinking water resources, discharge to surface water and aquatic toxicity, and gross contamination hazards. Availability of aquatic toxicity action levels for PFAS compounds limited. Drinking water action level used for screening in interim (refer to Table D-4b and Table D-4c).

Groundwater action levels should be compared to dissolved-phase chemical concentrations unless otherwise instructed by HDOH.

Groundwater ALs >150m to Surface Water Body: Groundwater screened with respect to acute aquatic toxicity action levels (See Table D-1b).

Groundwater ALs <=150m to Surface Water Body: Groundwater screened with respect to chronic aquatic toxicity action levels (see Table D-1a).

**TABLE B. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS NOT Current or Potential Source of Drinking Water**

CHEMICAL PARAMETER	>150m to Surface Water Body		<150m to Surface Water Body	
	¹ Soil (mg/kg)	² Groundwater (ug/L)	¹ Soil (mg/kg)	² Groundwater (ug/L)
Perfluorobutane sulfonate (PFBS-)	3.8E+00	5.0E+04	3.8E+00	5.0E+04
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	6.2E-01	1.1E-01	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	2.5E-01	1.0E+01	2.5E-01	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	3.8E-02	7.9E-03	3.8E-02
Perfluorooctane sulfonate (PFOS-)	2.5E-02	3.1E+01	2.5E-02	1.1E+00
Perfluorodecane sulfonate (PFDS-)	2.5E-02	3.8E-02	2.5E-02	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	5.1E-01	5.1E-04	5.1E-01
Perfluoro butanoate (PFBA-)	4.8E+01	4.2E+03	1.1E+01	8.3E+02
Perfluoro pentanoate (PFPeA-)	5.9E-03	1.5E+00	5.9E-03	1.5E+00
Perfluoro hexanoate (PFHxA-)	6.3E+00	4.8E+04	6.3E+00	6.3E+03
Perfluoro heptanoate (PFHpA-)	5.5E-04	7.7E-02	5.5E-04	7.7E-02
Perfluoro octanoate (PFOA-)	3.8E-02	1.2E+02	3.8E-02	8.3E+00
Perfluoro nonanoate (PFNA-)	3.8E-02	1.0E+01	3.8E-02	8.0E+00
Perfluoro decanoate (PFDA-)	2.5E-02	1.0E+01	2.5E-02	1.0E+01
Perfluoro undecanoate (PFUnDA-)	6.3E-02	4.4E+02	6.3E-02	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	6.4E+02	8.5E-02	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	2.6E-02	8.5E-02	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	2.6E-01	8.5E-01	2.6E-01
Perfluroroctane sulfonamide (PFOSA)	1.5E-01	4.6E-02	1.5E-01	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.3E-05	1.2E-02	2.3E-05	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E+00	1.1E+04	4.9E+00	2.6E+02
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	3.8E+00	1.0E+04	3.8E+00	1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	5.0E+00	2.6E+00	5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	4.2E+00	1.6E+00	4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	1.9E+00	6.3E+00	1.9E+00

1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
2. Assumes potential discharge of groundwater into a freshwater, marine or estuary surface water system. Compare to *dissolved-phase* concentration.

Source of Soil Action Levels: Refer to Appendix 1, Tables B-1 and B-2.

Source of Groundwater Action Levels: Appendix 1, Table D-1c (≤150m to Surface Water Body) and Table D-1d (>150m to Surface Water Body). Soil data should be reported on dry-weight basis (see Appendix 1, Section 6.2).

Soil Action Levels intended to address direct-exposure, groundwater protection (leaching) and gross contamination hazards. The need for a site-specific, ecological risk assessment should be evaluated if sensitive, terrestrial or aquatic habitats are within or nearby areas of contaminated soil. Groundwater Action Levels intended to address discharge to surface water and aquatic toxicity and gross contamination hazards. Availability of aquatic toxicity action levels for PFAS compounds limited. Drinking water action level used for screening in interim (refer to Table D-4b and Table D-4c).

Groundwater action levels should be compared to dissolved-phase chemical concentrations unless otherwise instructed by HDOH.

Groundwater ALs >150m to Surface Water Body: Groundwater screened with respect to acute aquatic toxicity action levels (See Table D-1d).

Groundwater ALs ≤150m to Surface Water Body: Groundwater screened with respect to chronic aquatic toxicity action levels (see Table D-1c).

Groundwater action levels for PFBS- base on "Gross Contamination" upper limit of 50,000 µg/L (Appendix 1, Table G-2). Identical groundwater action levels for >150m and <150m indicate gross contamination cutoff or the lack of one or both chronic and acute action levels (refer to Appendix 1, Table D-3a).

**TABLE C. ENVIRONMENTAL ACTION LEVELS (EALs)
Indoor Air and Soil Vapor
(¹Vapor Intrusion Hazards)**

CHEMICAL PARAMETER	Physical State		INDOOR AIR ACTION LEVELS		SHALLOW SOIL VAPOR ACTION LEVELS	
			Residential (ug/m ³)	Commercial/Industrial (ug/m ³)	Residential (ug/m ³)	Commercial/Industrial (ug/m ³)
Perfluorobutane sulfonate (PFBS-)	NV	S	-	-	-	-
Perfluoropentane sulfonate (PFPeS-)	NV	S	-	-	-	-
Perfluorohexane sulfonate (PFHxS-)	NV	S	-	-	-	-
Perfluoroheptane sulfonate (PFHpS-)	NV	S	-	-	-	-
Perfluorooctane sulfonate (PFOS-)	NV	S	-	-	-	-
Perfluorodecane sulfonate (PFDS-)	NV	S	-	-	-	-
Perfluoro propanoate (PFPrA-)	V	L	1.8E+00	7.7E+00	3.7E+03	3.1E+04
Perfluoro butanoate (PFBA-)	SV	L	1.0E+01	4.4E+01	-	-
Perfluoro pentanoate (PFPeA-)	SV	L	1.5E+00	6.1E+00	-	-
Perfluoro hexanoate (PFHxA-)	SV	L	1.8E+00	7.7E+00	-	-
Perfluoro heptanoate (PFHpA-)	NV	S	-	-	-	-
Perfluoro octanoate (PFOA-)	NV	S	-	-	-	-
Perfluoro nonanoate (PFNA-)	NV	S	-	-	-	-
Perfluoro decanoate (PFDA-)	NV	S	-	-	-	-
Perfluoro undecanoate (PFUnDA-)	NV	S	-	-	-	-
Perfluoro dodecanoate (PFDoDA-)	NV	S	-	-	-	-
Perfluoro tridecanoate (PFTrDA-)	NV	S	-	-	-	-
Perfluoro tetradecanoate (PFTeDA-)	NV	S	-	-	-	-
Perfluorooctane sulfonamide (PFOSA)	NV	S	-	-	-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV	S	-	-	-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	-	-	-	-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV	S	-	-	-	-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV	L	4.7E+00	2.0E+01	-	-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV	S	-	-	-	-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV	S	-	-	-	-

Notes:

1. Targeted PFASs not significantly volatile. Vapor intrusion risks from contaminated soil and groundwater assumed to be insignificant.

TABLE D. ENVIRONMENTAL ACTION LEVELS (EALs)
¹Surface Water Bodies

CHEMICAL PARAMETER	¹ SURFACE WATER ACTION LEVELS		
	² Freshwater (ug/L)	³ Marine (ug/L)	⁴ Estuarine (ug/L)
Perfluorobutane sulfonate (PFBS-)	-	-	-
Perfluoropentane sulfonate (PFPeS-)	-	-	-
Perfluorohexane sulfonate (PFHxS-)	-	-	-
Perfluoroheptane sulfonate (PFHpS-)	-	-	-
Perfluorooctane sulfonate (PFOS-)	-	-	-
Perfluorodecane sulfonate (PFDS-)	-	-	-
Perfluoro propanoate (PFPrA-)	-	-	-
Perfluoro butanoate (PFBA-)	-	-	-
Perfluoro pentanoate (PFPeA-)	-	-	-
Perfluoro hexanoate (PFHxA-)	-	-	-
Perfluoro heptanoate (PFHpA-)	-	-	-
Perfluoro octanoate (PFOA-)	-	-	-
Perfluoro nonanoate (PFNA-)	-	-	-
Perfluoro decanoate (PFDA-)	-	-	-
Perfluoro undecanoate (PFUnDA-)	-	-	-
Perfluoro dodecanoate (PFDoDA-)	-	-	-
Perfluoro tridecanoate (PFTrDA-)	-	-	-
Perfluoro tetradecanoate (PFTeDA-)	-	-	-
Perfluorooctane sulfonamide (PFOSA)	-	-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	-	-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	-	-	-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	-	-	-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	-	-	-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	-	-	-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	-	-	-
Notes: 1. Pending due to limited information on chronic and acute toxicity of PFASs to aquatic organisms and bioaccumulation and uptake in the food chain. Refer to Tables D-4e (chronic and acute aquatic toxicity) and D-4f (bioaccumulation) for available action levels. Surface water action levels for PFASs pending development of action levels 2. Source of Freshwater EALs: Refer to Appendix 1, Table D-2a for basis. Includes consideration of drinking water action levels. 3. Source of Marine EALs: Refer to Appendix 1, Table D-2b for basis. 4. Source of Estuarine EALs: Refer to Appendix 1, Table D-2c for basis. Surface water action levels lowest of drinking water goal (freshwater only), chronic aquatic habitat goal, goal to address bioaccumulation in aquatic organisms and subsequent consumption by humans, and general nuisance goal (odors, etc.). Refer to Chapter 2 of text and Appendix 1 for details. Estuarine action levels lowest of freshwater and marine action levels.			

**TABLE E. 1 SOIL VAPOR SCREENING LEVELS
FOR EVALUATION OF VADOSE-ZONE LEACHATE
(Potential impacts to highly vulnerable drinking water aquifers)**

CHEMICAL PARAMETER	Target Groundwater Screening Level (µg/L)	Soil Vapor Screening Level (µg/m³)
Perfluorobutane sulfonate (PFBS-)	-	-
Perfluoropentane sulfonate (PFPeS-)	-	-
Perfluorohexane sulfonate (PFHxS-)	-	-
Perfluoroheptane sulfonate (PFHpS-)	-	-
Perfluorooctane sulfonate (PFOS-)	-	-
Perfluorodecane sulfonate (PFDS-)	-	-
Perfluoro propanoate (PFPrA-)	5.1E-01	1.5E+00
Perfluoro butanoate (PFBA-)	-	-
Perfluoro pentanoate (PFPeA-)	-	-
Perfluoro hexanoate (PFHxA-)	-	-
Perfluoro heptanoate (PFHpA-)	-	-
Perfluoro octanoate (PFOA-)	-	-
Perfluoro nonanoate (PFNA-)	-	-
Perfluoro decanoate (PFDA-)	-	-
Perfluoro undecanoate (PFUnDA-)	-	-
Perfluoro dodecanoate (PFDoDA-)	-	-
Perfluoro tridecanoate (PFTrDA-)	-	-
Perfluoro tetradecanoate (PFTeDA-)	-	-
Perfluorooctane sulfonamide (PFOSA)	-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	-	-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	-	-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	-	-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	-	-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	-	-
Notes:		
1. Not applicable. Targeted PFASs not significantly volatile.		

Attachment 3

Detailed PFAS EALs

(HIDOH March 2024. Supplement to Volume 1,
Appendix 1 of HIDOH EHE Guidance)

TABLE A-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CHEMICAL PARAMETER	(mg/kg)							
	Final EAL	Basis	¹ Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	¹ Human Health		Leaching & Groundwater Protection
						Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	8.7E-03	Groundwater Protection	1.0E+03			3.8E+00	(not volatile)	8.7E-03
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	Groundwater Protection	1.0E+03			2.0E+00	(not volatile)	1.1E-01
Perfluorohexane sulfonate (PFHxS-)	7.2E-03	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	7.2E-03
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	7.9E-03
Perfluorooctane sulfonate (PFOS-)	1.4E-03	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	1.4E-03
Perfluorodecane sulfonate (PFDS-)	2.5E-02	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	2.5E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	Groundwater Protection	1.0E+03			5.0E+00	NA	5.1E-04
Perfluoro butanoate (PFBA-)	1.9E-01	Groundwater Protection	1.0E+03			4.8E+01	(not volatile)	1.9E-01
Perfluoro pentanoate (PFPeA-)	5.9E-03	Groundwater Protection	1.0E+03			5.1E+00	(not volatile)	5.9E-03
Perfluoro hexanoate (PFHxA-)	6.4E-03	Groundwater Protection	1.0E+03			6.3E+00	(not volatile)	6.4E-03
Perfluoro heptanoate (PFHpA-)	5.5E-04	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	5.5E-04
Perfluoro octanoate (PFOA-)	3.5E-04	Groundwater Protection	1.0E+03			3.8E-02	(not volatile)	3.5E-04
Perfluoro nonanoate (PFNA-)	2.0E-03	Groundwater Protection	1.0E+03			3.8E-02	(not volatile)	2.0E-03
Perfluoro decanoate (PFDA-)	9.2E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	9.2E-04
Perfluoro undecanoate (PFUnDA-)	8.6E-03	Groundwater Protection	1.0E+03			6.3E-02	(not volatile)	8.6E-03
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	Direct Exposure	1.0E+03			8.5E-01	(not volatile)	1.0E+06
Perfluorooctane sulfonamide (PFOSA)	1.5E-01	Direct Exposure	1.0E+03			1.5E-01	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.3E-05	Groundwater Protection	1.0E+03			4.7E-02	(not volatile)	2.3E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.4E-01	Groundwater Protection	1.0E+03			4.9E+00	(not volatile)	2.4E-01
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.9E-01	Groundwater Protection	1.0E+03			3.8E+00	(not volatile)	1.9E-01
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	Groundwater Protection	1.0E+03			1.6E+01	(not volatile)	2.6E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	Groundwater Protection	1.0E+03			1.4E+01	(not volatile)	1.6E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	7.8E+04

Notes:
1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
NA= Toxicity factors not available.
Final Environmental Action Level is lowest of gross contamination, ecotoxicity, direct-exposure, vapor intrusion and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Chapter 7).

TABLE A-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CHEMICAL PARAMETER	(mg/kg)							
	Final EAL	Basis	¹ Gross Contamination (Odors, etc.)	Terrestrial Ecotoxicity	Background	¹ Human Health		Leaching & Groundwater Protection
			Table F-2	Table L	Table K	Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	8.7E-03	Groundwater Protection	1.0E+03			3.8E+00	(not volatile)	8.7E-03
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	Groundwater Protection	1.0E+03			2.0E+00	(not volatile)	1.1E-01
Perfluorohexane sulfonate (PFHxS-)	7.2E-03	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	7.2E-03
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	7.9E-03
Perfluorooctane sulfonate (PFOS-)	1.4E-03	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	1.4E-03
Perfluorodecane sulfonate (PFDS-)	2.5E-02	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	2.5E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	Groundwater Protection	1.0E+03			5.0E+00	NA	5.1E-04
Perfluoro butanoate (PFBA-)	1.9E-01	Groundwater Protection	1.0E+03			4.8E+01	(not volatile)	1.9E-01
Perfluoro pentanoate (PFPeA-)	5.9E-03	Groundwater Protection	1.0E+03			5.1E+00	(not volatile)	5.9E-03
Perfluoro hexanoate (PFHxA-)	6.4E-03	Groundwater Protection	1.0E+03			6.3E+00	(not volatile)	6.4E-03
Perfluoro heptanoate (PFHpA-)	5.5E-04	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	5.5E-04
Perfluoro octanoate (PFOA-)	3.5E-04	Groundwater Protection	1.0E+03			3.8E-02	(not volatile)	3.5E-04
Perfluoro nonanoate (PFNA-)	2.0E-03	Groundwater Protection	1.0E+03			3.8E-02	(not volatile)	2.0E-03
Perfluoro decanoate (PFDA-)	9.2E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	9.2E-04
Perfluoro undecanoate (PFUnDA-)	8.6E-03	Groundwater Protection	1.0E+03			6.3E-02	(not volatile)	8.6E-03
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	Direct Exposure	1.0E+03			8.5E-01	(not volatile)	1.0E+06
Perfluroroctane sulfonamide (PFOSA)	1.5E-01	Direct Exposure	1.0E+03			1.5E-01	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoroproxy) propanoate (HFPO DA-)	2.3E-05	Groundwater Protection	1.0E+03			4.7E-02	(not volatile)	2.3E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.4E-01	Groundwater Protection	1.0E+03			4.9E+00	(not volatile)	2.4E-01
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.9E-01	Groundwater Protection	1.0E+03			3.8E+00	(not volatile)	1.9E-01
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	Groundwater Protection	1.0E+03			1.6E+01	(not volatile)	2.6E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	Groundwater Protection	1.0E+03			1.4E+01	(not volatile)	1.6E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	7.8E+04

Notes:
1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
NA= Toxicity factors not available.
Final Environmental Action Level is lowest of gross contamination, ecotoxicity, direct-exposure, vapor intrusion and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Chapter 7).

TABLE B-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CHEMICAL PARAMETER	(mg/kg)							
	Final EAL	Basis	¹ Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	¹ Human Health		Leaching & Groundwater Protection
						Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	NON-Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.8E+00	Direct Exposure	1.0E+03			3.8E+00	(not volatile)	2.6E+02
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	Groundwater Protection	1.0E+03			2.0E+00	(not volatile)	1.1E-01
Perfluorohexane sulfonate (PFHxS-)	2.5E-01	Direct Exposure	1.0E+03			2.5E-01	(not volatile)	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	7.9E-03
Perfluorooctane sulfonate (PFOS-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	5.8E+00
Perfluorodecane sulfonate (PFDS-)	2.5E-02	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	2.5E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	Groundwater Protection	1.0E+03			5.0E+00	NA	5.1E-04
Perfluoro butanoate (PFBA-)	4.8E+01	Direct Exposure	1.0E+03			4.8E+01	(not volatile)	5.4E+01
Perfluoro pentanoate (PFPeA-)	5.9E-03	Groundwater Protection	1.0E+03			5.1E+00	(not volatile)	5.9E-03
Perfluoro hexanoate (PFHxA-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	1.6E+02
Perfluoro heptanoate (PFHpA-)	5.5E-04	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	5.5E-04
Perfluoro octanoate (PFOA-)	3.8E-02	Direct Exposure	1.0E+03			3.8E-02	(not volatile)	3.6E+00
Perfluoro nonanoate (PFNA-)	3.8E-02	Direct Exposure	1.0E+03			3.8E-02	(not volatile)	1.8E+00
Perfluoro decanoate (PFDA-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	1.2E+00
Perfluoro undecanoate (PFUnDA-)	6.3E-02	Direct Exposure	1.0E+03			6.3E-02	(not volatile)	2.0E+02
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	Direct Exposure	1.0E+03			8.5E-01	(not volatile)	1.0E+06
Perfluorooctane sulfonamide (PFOSA)	1.5E-01	Direct Exposure	1.0E+03			1.5E-01	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.3E-05	Groundwater Protection	1.0E+03			4.7E-02	(not volatile)	2.3E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E+00	Direct Exposure	1.0E+03			4.9E+00	(not volatile)	1.7E+03
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	3.8E+00	Direct Exposure	1.0E+03			3.8E+00	(not volatile)	1.6E+03
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	Groundwater Protection	1.0E+03			1.6E+01	(not volatile)	2.6E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	Groundwater Protection	1.0E+03			1.4E+01	(not volatile)	1.6E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	7.8E+04

Notes:
1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
NA= Toxicity factors not available.
Final Environmental Action Level is lowest of gross contamination, ecotoxicity, direct-exposure, vapor intrusion and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Chapter 7).

TABLE B-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CHEMICAL PARAMETER	(mg/kg)							
	Final EAL	Basis	¹ Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	¹ Human Health		Leaching & Groundwater Protection
						Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	NON-Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.8E+00	Direct Exposure	1.0E+03			3.8E+00	(not volatile)	2.6E+02
Perfluoropentane sulfonate (PFPeS-)	1.1E-01	Groundwater Protection	1.0E+03			2.0E+00	(not volatile)	1.1E-01
Perfluorohexane sulfonate (PFHxS-)	2.5E-01	Direct Exposure	1.0E+03			2.5E-01	(not volatile)	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	7.9E-03	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	7.9E-03
Perfluorooctane sulfonate (PFOS-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	2.0E-01
Perfluorodecane sulfonate (PFDS-)	2.5E-02	Groundwater Protection	1.0E+03			1.3E-01	(not volatile)	2.5E-02
Perfluoro propanoate (PFPrA-)	5.1E-04	Groundwater Protection	1.0E+03			5.0E+00	NA	5.1E-04
Perfluoro butanoate (PFBA-)	1.1E+01	Groundwater Protection	1.0E+03			4.8E+01	(not volatile)	1.1E+01
Perfluoro pentanoate (PFPeA-)	5.9E-03	Groundwater Protection	1.0E+03			5.1E+00	(not volatile)	5.9E-03
Perfluoro hexanoate (PFHxA-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	2.1E+01
Perfluoro heptanoate (PFHpA-)	5.5E-04	Groundwater Protection	1.0E+03			2.5E-01	(not volatile)	5.5E-04
Perfluoro octanoate (PFOA-)	3.8E-02	Direct Exposure	1.0E+03			3.8E-02	(not volatile)	2.5E-01
Perfluoro nonanoate (PFNA-)	3.8E-02	Direct Exposure	1.0E+03			3.8E-02	(not volatile)	1.4E+00
Perfluoro decanoate (PFDA-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	1.2E+00
Perfluoro undecanoate (PFUnDA-)	6.3E-02	Direct Exposure	1.0E+03			6.3E-02	(not volatile)	4.5E+00
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	Direct Exposure	1.0E+03			8.5E-02	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	Direct Exposure	1.0E+03			8.5E-01	(not volatile)	1.0E+06
Perfluorooctane sulfonamide (PFOSA)	1.5E-01	Direct Exposure	1.0E+03			1.5E-01	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.3E-05	Groundwater Protection	1.0E+03			4.7E-02	(not volatile)	2.3E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E+00	Direct Exposure	1.0E+03			4.9E+00	(not volatile)	4.1E+01
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	3.8E+00	Direct Exposure	1.0E+03			3.8E+00	(not volatile)	1.6E+03
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.6E+00	Groundwater Protection	1.0E+03			1.6E+01	(not volatile)	2.6E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.6E+00	Groundwater Protection	1.0E+03			1.4E+01	(not volatile)	1.6E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	Direct Exposure	1.0E+03			6.3E+00	(not volatile)	7.8E+04

Notes:
1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
NA= Toxicity factors not available.
Final Environmental Action Level is lowest of gross contamination, ecotoxicity, direct-exposure, vapor intrusion and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Chapter 7).

**TABLE C-1a. GROUNDWATER ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION HAZARDS
(volatile chemicals only)**

CHEMICAL PARAMETER	Physical State		^{1,3} Unrestricted Land Use	Commercial/Industrial Land Use Only
			(ug/L)	(ug/L)
Perfluorobutane sulfonate (PFBS-)	NV	S	(not volatile)	(not volatile)
Perfluoropentane sulfonate (PFPeS-)	NV	S	(not volatile)	(not volatile)
Perfluorohexane sulfonate (PFHxS-)	NV	S	(not volatile)	(not volatile)
Perfluoroheptane sulfonate (PFHpS-)	NV	S	(not volatile)	(not volatile)
Perfluorooctane sulfonate (PFOS-)	NV	S	(not volatile)	(not volatile)
Perfluorodecane sulfonate (PFDS-)	NV	S	(not volatile)	(not volatile)
Perfluoro propanoate (PFPrA-)	V	L	NA	NA
Perfluoro butanoate (PFBA-)	SV	L	(not volatile)	(not volatile)
Perfluoro pentanoate (PFPeA-)	SV	L	(not volatile)	(not volatile)
Perfluoro hexanoate (PFHxA-)	SV	L	(not volatile)	(not volatile)
Perfluoro heptanoate (PFHpA-)	NV	S	(not volatile)	(not volatile)
Perfluoro octanoate (PFOA-)	NV	S	(not volatile)	(not volatile)
Perfluoro nonanoate (PFNA-)	NV	S	(not volatile)	(not volatile)
Perfluoro decanoate (PFDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro undecanoate (PFUnDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro dodecanoate (PFDoDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro tridecanoate (PFTrDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro tetradecanoate (PFTeDA-)	NV	S	(not volatile)	(not volatile)
Perfluorooctane sulfonamide (PFOSA)	NV	S	(not volatile)	(not volatile)
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	(not volatile)	(not volatile)
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV	L	(not volatile)	(not volatile)
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV	S	(not volatile)	(not volatile)

Notes:

1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.
2. Soil model: One meter dry sandy soil (92% sand, 5% silt, 3% clay) over one meter moist clayey loam (33% sand, 34% silt, 33% clay). Used to reflect general field calibration of groundwater data to soil gas data.
3. For inclusion in Tier 1 action levels, all groundwater assumed to potentially migrate under a residential area. Action levels for protection of indoor air under a residential exposure scenario carried forward for use at both residential and commercial/industrial sites (see Table D series).

Action levels calculated using spreadsheet provided with User's Guide for the USEPA vapor intrusion guidance (USEPA 2004)

Assumed vadose-zone thickness/depth to groundwater three meters. See Appendix 1 text for model details.

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S -solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Target cancer risk = 1E-06, Target Hazard Quotient = 1.0 except as noted.

"#": Nonchlorinated VOCs (except MTBE) adjusted upwards by factor of ten to account for assumed biodegradation in vadose-zone prior to emission at surface.

**TABLE C-1b. SOIL ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION HAZARDS
(volatile chemicals only)
(Use with Soil Gas Action Levels for sites with significant VOC releases)**

CHEMICAL PARAMETER	Physical State		¹ Unrestricted Land Use	Commercial/Industrial Land Use Only
			(mg/kg)	(mg/kg)
Perfluorobutane sulfonate (PFBS-)	NV	S	(not volatile)	(not volatile)
Perfluoropentane sulfonate (PFPeS-)	NV	S	(not volatile)	(not volatile)
Perfluorohexane sulfonate (PFHxS-)	NV	S	(not volatile)	(not volatile)
Perfluoroheptane sulfonate (PFHpS-)	NV	S	(not volatile)	(not volatile)
Perfluorooctane sulfonate (PFOS-)	NV	S	(not volatile)	(not volatile)
Perfluorodecane sulfonate (PFDS-)	NV	S	(not volatile)	(not volatile)
Perfluoro propanoate (PFPrA-)	V	L	NA	NA
Perfluoro butanoate (PFBA-)	SV	L	(not volatile)	(not volatile)
Perfluoro pentanoate (PFPeA-)	SV	L	(not volatile)	(not volatile)
Perfluoro hexanoate (PFHxA-)	SV	L	(not volatile)	(not volatile)
Perfluoro heptanoate (PFHpA-)	NV	S	(not volatile)	(not volatile)
Perfluoro octanoate (PFOA-)	NV	S	(not volatile)	(not volatile)
Perfluoro nonanoate (PFNA-)	NV	S	(not volatile)	(not volatile)
Perfluoro decanoate (PFDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro undecanoate (PFUnDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro dodecanoate (PFDoDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro tridecanoate (PFTrDA-)	NV	S	(not volatile)	(not volatile)
Perfluoro tetradecanoate (PFTeDA-)	NV	S	(not volatile)	(not volatile)
Perfluorooctane sulfonamide (PFOSA)	NV	S	(not volatile)	(not volatile)
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	(not volatile)	(not volatile)
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV	L	(not volatile)	(not volatile)
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV	S	(not volatile)	(not volatile)

Notes:

1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.

Action levels calculated using spreadsheet provided with User's Guide for the USEPA vapor intrusion guidance (USEPA 2004)
Soil model: Two meters dry sandy soil (92% sand, 5% silt, 3% clay) directly underlying building foundation.
Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S -solid, L - liquid, G - gas).
Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.
Target cancer risk = 1E-06, Target Hazard Quotient = 1.0 except as noted.

"#": Nonchlorinated VOCs (except MTBE) adjusted upwards by factor of ten to account for assumed biodegradation in vadose-zone prior to emission at surface.

**TABLE C-2. ¹SHALLOW SOIL VAPOR ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION HAZARDS
(volatile chemicals only)**

CHEMICAL PARAMETER	Physical State	² Unrestricted Land Use			Commercial/Industrial Land Use Only		
		Lowest Residential	Carcinogenic Effects	Noncarcinogenic Effects	Lowest	Carcinogenic	Noncarcinogenic
		(ug/m ³)	(ug/m ³)	(ug/m ³)	C/I (ug/m ³)	Effects (ug/m ³)	Effects (ug/m ³)
Perfluorobutane sulfonate (PFBS-)	NV S	(not volatile)			(not volatile)		
Perfluoropentane sulfonate (PFPeS-)	NV S	(not volatile)			(not volatile)		
Perfluorohexane sulfonate (PFHxS-)	NV S	(not volatile)			(not volatile)		
Perfluoroheptane sulfonate (PFHpS-)	NV S	(not volatile)			(not volatile)		
Perfluorooctane sulfonate (PFOS-)	NV S	(not volatile)			(not volatile)		
Perfluorodecane sulfonate (PFDS-)	NV S	(not volatile)			(not volatile)		
Perfluoro propanoate (PFPrA-)	V L	3.7E+03		3.7E+03	3.1E+04		3.1E+04
Perfluoro butanoate (PFBA-)	SV L	(not volatile)			(not volatile)		
Perfluoro pentanoate (PFPeA-)	SV L	(not volatile)			(not volatile)		
Perfluoro hexanoate (PFHxA-)	SV L	(not volatile)			(not volatile)		
Perfluoro heptanoate (PFHpA-)	NV S	(not volatile)			(not volatile)		
Perfluoro octanoate (PFOA-)	NV S	(not volatile)			(not volatile)		
Perfluoro nonanoate (PFNA-)	NV S	(not volatile)			(not volatile)		
Perfluoro decanoate (PFDA-)	NV S	(not volatile)			(not volatile)		
Perfluoro undecanoate (PFUnDA-)	NV S	(not volatile)			(not volatile)		
Perfluoro dodecanoate (PFDoDA-)	NV S	(not volatile)			(not volatile)		
Perfluoro tridecanoate (PFTrDA-)	NV S	(not volatile)			(not volatile)		
Perfluoro tetradecanoate (PFTeDA-)	NV S	(not volatile)			(not volatile)		
Perfluorooctane sulfonamide (PFOSA)	NV S	(not volatile)			(not volatile)		
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV S	(not volatile)			(not volatile)		
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV S	(not volatile)			(not volatile)		
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV S	(not volatile)			(not volatile)		
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV L	(not volatile)			(not volatile)		
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV S	(not volatile)			(not volatile)		
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV S	(not volatile)			(not volatile)		

Notes:

1. Shallow soil gas defined as soil gas sample data collected within 1.5 meters (five feet) from a building foundation or the ground surface. Assumes very permeable (e.g., sandy) fill material immediately beneath building slab or could be present below future buildings following redevelopment. Evaluation of deeper soil gas data (e.g., >1.5m bgs) should be carried out on a site-specific basis.

2. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.

Soil gas action levels intended to be protective of indoor air quality, calculated for volatile chemicals only.
Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).
Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Target cancer risk = 1E-06, Target Hazard Quotient = 1.0 for all chemicals except as noted.

Residential soil gas:indoor air attenuation factor = 0.0005 (1/2000). Commercial/industrial soil gas:indoor air attenuation factor = 0.00025 (1/4000). See Section 3.3.

Soil gas action levels for TPHgasolines based on action levels for TPHmiddle distillates due to potential for mixture of fuel types at release sites.

Soil gas action levels do not address mass-balance issues. May be overly conservative for sites with low permeability soils immediately beneath a building slab or limited soil impacts and no source of VOCs in groundwater.

Indoor-air sampling and/or passive vapor mitigation measures may be prudent for sites where concentrations of chemicals in soil gas approach but do not exceed action levels. Consider other sources of VOCs in all indoor air studies.

**TABLE C-3. INDOOR AIR ACTION LEVELS
(volatile and semi-volatile chemicals)**

CHEMICAL PARAMETER	Physical State		Health-Based Action Levels							50% Odor Recognition Threshold (Table F-2) (ug/m ³)	
			Unit Risk Factor URF (ug/m ³) ⁻¹	Reference Concentration RfC (ug/m ³)	Unrestricted Land Use			Commercial/Industrial Use Only			
					Lowest Residential (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	Lowest C/I (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)		Indoor Air (noncarcinogens) (ug/m ³)
Perfluorobutane sulfonate (PFBS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoropentane sulfonate (PFPeS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluorohexane sulfonate (PFHxS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoroheptane sulfonate (PFHpS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluorooctane sulfonate (PFOS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluorodecane sulfonate (PFDS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro propanoate (PFPrA-)	V	L	NA	1.8E+00	1.8E+00		1.8E+00	7.7E+00		7.7E+00	
Perfluoro butanoate (PFBA-)	SV	L	NA	1.0E+01	1.0E+01		1.0E+01	4.4E+01		4.4E+01	
Perfluoro pentanoate (PFPeA-)	SV	L	NA	1.4E+00	1.5E+00		1.5E+00	6.1E+00		6.1E+00	
Perfluoro hexanoate (PFHxA-)	SV	L	NA	1.8E+00	1.8E+00		1.8E+00	7.7E+00		7.7E+00	
Perfluoro heptanoate (PFHpA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro octanoate (PFOA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro nonanoate (PFNA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro decanoate (PFDA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro undecanoate (PFUnDA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro dodecanoate (PFDoDA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro tridecanoate (PFTrDA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perfluoro tetradecanoate (PFTeDA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Perflurooctane sulfonamide (PFOSA)	NV	S	NA	NA	(not volatile)			(not volatile)			
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	NA	NA	(not volatile)			(not volatile)			
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV	S	NA	NA	(not volatile)			(not volatile)			
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV	L	NA	4.6E+00	4.7E+00		4.7E+00	2.0E+01		2.0E+01	
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV	S	NA	NA	(not volatile)			(not volatile)			
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV	S	NA	NA	(not volatile)			(not volatile)			

Notes:

1. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.

NA=Not available.

Target cancer risk = 10⁻⁶, Target Hazard Quotient = 1.0 for all chemicals except as noted

Target Hazard Quotient = 1.0 for TPH (see Appendix 1 and Appendix 9 Fall 2011 EAL update memo).

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Action levels calculated using spreadsheet provided with User's Guide for the USEPA vapor intrusion guidance (USEPA 2004, refer to Appendix 2 for equations and default input parameter values).

Indoor air action levels listed only for volatile chemicals included in database of referenced model spreadsheet (plus MTBE).

Indoor air action levels listed only for volatile chemicals included in database of referenced model spreadsheet.

TABLE D-1a. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS located within 150 meters of release site)
 µg/L

CONTAMINANT	1 Final Groundwater Action Level	Basis	Gross Contamination (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Into Buildings	Aquatic Habitat Impacts (chronic)
			Table G-1	Table D-3a	Table C-1a	Table D-4a
Perfluorobutane sulfonate (PFBS-)	1.7E+00	Drinking Water Toxicity	5.0E+04	1.7E+00	(not volatile)	1.3E+05
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	Drinking Water Toxicity	5.0E+04	6.2E-01	(not volatile)	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	7.7E-02	Drinking Water Toxicity	5.0E+04	7.7E-02	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	Drinking Water Toxicity	5.0E+04	3.8E-02	(not volatile)	3.8E-02
Perfluorooctane sulfonate (PFOS-)	7.7E-03	Drinking Water Toxicity	5.0E+04	7.7E-03	(not volatile)	1.1E+00
Perfluorodecane sulfonate (PFDS-)	3.8E-02	Drinking Water Toxicity	5.0E+04	3.8E-02	(not volatile)	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	Drinking Water Toxicity	5.0E+04	5.1E-01	NA	5.1E-01
Perfluoro butanoate (PFBA-)	1.5E+01	Drinking Water Toxicity	5.0E+04	1.5E+01	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	1.5E+00	Drinking Water Toxicity	5.0E+04	1.5E+00	(not volatile)	1.5E+00
Perfluoro hexanoate (PFHxA-)	1.9E+00	Drinking Water Toxicity	5.0E+04	1.9E+00	(not volatile)	6.3E+03
Perfluoro heptanoate (PFHpA-)	7.7E-02	Drinking Water Toxicity	5.0E+04	7.7E-02	(not volatile)	7.7E-02
Perfluoro octanoate (PFOA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	8.3E+00
Perfluoro nonanoate (PFNA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	8.0E+00
Perfluoro decanoate (PFDA-)	7.7E-03	Drinking Water Toxicity	5.0E+04	7.7E-03	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	1.9E-02	Drinking Water Toxicity	5.0E+04	1.9E-02	(not volatile)	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	2.6E-02	Drinking Water Toxicity	5.0E+04	2.6E-02	(not volatile)	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	Drinking Water Toxicity	5.0E+04	2.6E-02	(not volatile)	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	Drinking Water Toxicity	5.0E+04	2.6E-01	(not volatile)	2.6E-01
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	Drinking Water Toxicity	3.3E+02	4.6E-02	(not volatile)	4.6E-02
2,3,5-trifluoro-2-(heptadecylpropoxy) propanoate (HTFOA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.5E+00	Drinking Water Toxicity	5.0E+04	1.5E+00		2.6E+02
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.2E+00	Drinking Water Toxicity	5.0E+04	1.2E+00		1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	Drinking Water Toxicity	8.8E+03	5.0E+00		5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	Drinking Water Toxicity	9.9E+01	4.2E+00		4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	Drinking Water Toxicity	5.0E+04	1.9E+00		1.9E+00

Notes:
1. Lowest of action levels for gross contamination, drinking water toxicity, vapor intrusion and aquatic habitat impacts. Used to develop soil leaching action levels for protection of groundwater quality.

NA = Not available.
 Gross Contamination: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation.
 Drinking Water Toxicity: Based on primary maximum concentration levels (MCLs), or equivalent. Considered protective of human health.
 Vapor Intrusion: Addresses potential emission of volatile chemicals from groundwater into buildings and subsequent impact on indoor air. Assumes moderately permeable, sandy soil or fill material immediately beneath building slab and unrestricted ("residential") land use (refer to Chapter 5).
 Aquatic Habitat Impacts: Addresses potential discharge of groundwater to estuarine aquatic habitat and subsequent impact on aquatic life; dilution of groundwater upon discharge to surface water not considered, in order to take into account potential impacts to benthic organisms (see Chapter 5).
 Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-1b. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Gross Contamination (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Into Buildings	Aquatic Habitat Impacts (acute)
			Table G-1	Table D-3a	Table C-1a	Table D-4a
Perfluorobutane sulfonate (PFBS-)	1.7E+00	Drinking Water Toxicity	5.0E+04	1.7E+00	(not volatile)	1.3E+05
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	Drinking Water Toxicity	5.0E+04	6.2E-01	(not volatile)	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	7.7E-02	Drinking Water Toxicity	5.0E+04	7.7E-02	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	Drinking Water Toxicity	5.0E+04	3.8E-02	(not volatile)	3.8E-02
Perfluorooctane sulfonate (PFOS-)	7.7E-03	Drinking Water Toxicity	5.0E+04	7.7E-03	(not volatile)	3.1E+01
Perfluorodecane sulfonate (PFDS-)	3.8E-02	Drinking Water Toxicity	5.0E+04	3.8E-02	(not volatile)	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	Drinking Water Toxicity	5.0E+04	5.1E-01	NA	5.1E-01
Perfluoro butanoate (PFBA-)	1.5E+01	Drinking Water Toxicity	5.0E+04	1.5E+01	(not volatile)	4.2E+03
Perfluoro pentanoate (PFPeA-)	1.5E+00	Drinking Water Toxicity	5.0E+04	1.5E+00	(not volatile)	1.5E+00
Perfluoro hexanoate (PFHxA-)	1.9E+00	Drinking Water Toxicity	5.0E+04	1.9E+00	(not volatile)	4.8E+04
Perfluoro heptanoate (PFHpA-)	7.7E-02	Drinking Water Toxicity	5.0E+04	7.7E-02	(not volatile)	7.7E-02
Perfluoro octanoate (PFOA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	1.2E+02
Perfluoro nonanoate (PFNA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	1.0E+01
Perfluoro decanoate (PFDA-)	7.7E-03	Drinking Water Toxicity	5.0E+04	7.7E-03	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	1.9E-02	Drinking Water Toxicity	5.0E+04	1.9E-02	(not volatile)	4.4E+02
Perfluoro dodecanoate (PFDoDA-)	2.6E-02	Drinking Water Toxicity	5.0E+04	2.6E-02	(not volatile)	6.4E+02
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	Drinking Water Toxicity	5.0E+04	2.6E-02	(not volatile)	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	Drinking Water Toxicity	5.0E+04	2.6E-01	(not volatile)	2.6E-01
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	Drinking Water Toxicity	3.3E+02	4.6E-02	(not volatile)	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	Drinking Water Toxicity	5.0E+04	1.2E-02	(not volatile)	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.5E+00	Drinking Water Toxicity	5.0E+04	1.5E+00		1.1E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.2E+00	Drinking Water Toxicity	5.0E+04	1.2E+00		1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	Drinking Water Toxicity	8.8E+03	5.0E+00		5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	Drinking Water Toxicity	9.9E+01	4.2E+00		4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	Drinking Water Toxicity	5.0E+04	1.9E+00		1.9E+00

Notes:
1. Lowest of action levels for gross contamination, drinking water toxicity, vapor intrusion and aquatic habitat impacts. Used to develop soil leaching action levels for protection of groundwater quality.

NA = Not available.
Gross Contamination: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation.
Drinking Water Toxicity: Based on primary maximum concentration levels (MCLs), or equivalent. Considered protective of human health.
Vapor Intrusion: Addresses potential emission of volatile chemicals from groundwater into buildings and subsequent impact on indoor air. Assumes moderately permeable, sandy soil or fill material immediately beneath building slab and unrestricted ("residential") land use (refer to Chapter 5).
Aquatic Habitat Impacts: Addresses potential discharge of groundwater to estuarine aquatic habitat and subsequent impact on aquatic life; dilution of groundwater upon discharge to surface water not considered, in order to take into account potential impacts to benthic organisms (see Chapter 5).
Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-1c. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Gross Contamination (Odors, etc.)	Vapor Intrusion Into Buildings	Aquatic Habitat Impacts (chronic)
			Table G-2	Table C-1a	Table D-4a
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Gross Contamination	5.0E+04	(not volatile)	1.3E+05
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.8E-02
Perfluorooctane sulfonate (PFOS-)	1.1E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.1E+00
Perfluorodecane sulfonate (PFDS-)	3.8E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	Aquatic Habitat Goal	5.0E+04	NA	5.1E-01
Perfluoro butanoate (PFBA-)	8.3E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	1.5E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.5E+00
Perfluoro hexanoate (PFHxA-)	6.3E+03	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.3E+03
Perfluoro heptanoate (PFHpA-)	7.7E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	7.7E-02
Perfluoro octanoate (PFOA-)	8.3E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.3E+00
Perfluoro nonanoate (PFNA-)	8.0E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.0E+00
Perfluoro decanoate (PFDA-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.6E-01
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	Aquatic Habitat Goal	3.3E+02	(not volatile)	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.6E+02	Aquatic Habitat Goal	5.0E+04		2.6E+02
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+04	Aquatic Habitat Goal	5.0E+04		1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	Aquatic Habitat Goal	8.8E+03		5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	Aquatic Habitat Goal	9.9E+01		4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTIAoS-)	1.9E+00	Aquatic Habitat Goal	5.0E+04		1.9E+00

Notes:

1. Lowest of action levels for gross contamination, vapor intrusion and aquatic habitat impacts. Used to develop soil leaching action levels for protection of groundwater.

2. Toxicity-based drinking water action level used as surrogate for aquatic toxicity if action level for latter not available (refer to Tables D-4b and D-4c). Re-assess on site-specific basis if discharge of groundwater to an aquatic habitat is suspected

NA = Not available.

Gross Contamination: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation.

Vapor Intrusion: Addresses potential emission of volatile chemicals from groundwater into buildings and subsequent impact on indoor air. Assumes moderately permeable, sandy soil or fill material immediately beneath building slab and unrestricted ("residential") land use (refer to Chapter 5).

Aquatic Habitat Impacts: Addresses potential discharge of groundwater to estuarine aquatic habitat and subsequent impact on aquatic life; dilution of groundwater upon discharge to surface water not considered, in order to take into account potential impacts to benthic organisms (see Chapter 5).

Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-1d. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Gross Contamination (Odors, etc.)	Vapor Intrusion Into Buildings	Aquatic Habitat Impacts (acute)
			Table G-2	Table C-1a	Table D-4a
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Gross Contamination	5.0E+04	(not volatile)	1.3E+05
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.2E-01
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.8E-02
Perfluorooctane sulfonate (PFOS-)	3.1E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.1E+01
Perfluorodecane sulfonate (PFDS-)	3.8E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	Aquatic Habitat Goal	5.0E+04	NA	5.1E-01
Perfluoro butanoate (PFBA-)	4.2E+03	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.2E+03
Perfluoro pentanoate (PFPeA-)	1.5E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.5E+00
Perfluoro hexanoate (PFHxA-)	4.8E+04	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.8E+04
Perfluoro heptanoate (PFHpA-)	7.7E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	7.7E-02
Perfluoro octanoate (PFOA-)	1.2E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.2E+02
Perfluoro nonanoate (PFNA-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoro decanoate (PFDA-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	4.4E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.4E+02
Perfluoro dodecanoate (PFDoDA-)	6.4E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.4E+02
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.6E-01
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	Aquatic Habitat Goal	3.3E+02	(not volatile)	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.1E+04	Aquatic Habitat Goal	5.0E+04		1.1E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+04	Aquatic Habitat Goal	5.0E+04		1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	Aquatic Habitat Goal	8.8E+03		5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	Aquatic Habitat Goal	9.9E+01		4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAcS-)	1.9E+00	Aquatic Habitat Goal	5.0E+04		1.9E+00

Notes:

1. Lowest of action levels for gross contamination, vapor intrusion and aquatic habitat impacts. Used to develop soil leaching action levels for protection of groundwater.

2. Toxicity-based drinking water action level used as surrogate for aquatic toxicity if action level for latter not available (refer to Tables D-4b and D-4c). Re-assess on site-specific basis if discharge of groundwater to an aquatic habitat is suspected

NA = Not available.

Gross Contamination: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation.

Vapor Intrusion: Addresses potential emission of volatile chemicals from groundwater into buildings and subsequent impact on indoor air. Assumes moderately permeable, sandy soil or fill material immediately beneath building slab and unrestricted ("residential") land use (refer to Chapter 5).

Aquatic Habitat Impacts: Addresses potential discharge of groundwater to estuarine aquatic habitat and subsequent impact on aquatic life; dilution of groundwater upon discharge to surface water not considered, in order to take into account potential impacts to benthic organisms (see Chapter 5).

Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-2a. SURFACE WATER ACTION LEVELS
Fresh Water Habitats
(ug/l)

CHEMICAL PARAMETER	¹ Final Surface Water Action Level	Basis	Gross Contamination (Taste & Odors, etc.)	Drinking Water (Toxicity)	Fresh Water Aquatic Habitat Goal (Chronic Toxicity)	Bioaccumulation and Human Consumption
			Table G-3	Table D-3a	Table D-4a	Table D-4f
Perfluorobutane sulfonate (PFBS-)						
Perfluoropentane sulfonate (PFPeS-)						
Perfluorohexane sulfonate (PFHxS-)						
Perfluoroheptane sulfonate (PFHpS-)						
Perfluorooctane sulfonate (PFOS-)						
Perfluorodecane sulfonate (PFDS-)						
Perfluoro propanoate (PFPrA-)						
Perfluoro butanoate (PFBA-)						
Perfluoro pentanoate (PFPeA-)						
Perfluoro hexanoate (PFHxA-)						
Perfluoro heptanoate (PFHpA-)						
Perfluoro octanoate (PFOA-)						
Perfluoro nonanoate (PFNA-)						
Perfluoro decanoate (PFDA-)						
Perfluoro undecanoate (PFUnDA-)						
Perfluoro dodecanoate (PFDoDA-)						
Perfluoro tridecanoate (PFTrDA-)						
Perfluoro tetradecanoate (PFTeDA-)						
Perfluroctane sulfonamide (PFOSA)						
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)						
6:2 Fluorotelomer sulfonate (6:2 FTS-)						
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)						
6:2 Fluorotelomer alcohol (6:2 FTOH-)						
8:2 Fluorotelomer alcohol (8:2 FTOH-)						
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)						

Notes:

1. Lowest of gross contamination, drinking water toxicity, aquatic habitat and bioaccumulation action levels. Surface water action levels for PFASs on hold pending development of bioaccumulation action levels.

NA = Not available.

Gross Contamination: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit nuisances and general resource degradation.

Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-2b. SURFACE WATER ACTION LEVELS
Marine Habitats
(ug/l)

CHEMICAL PARAMETER	¹ Final Surface Water Action Level	Basis	Gross Contamination (Odors, etc.)	Marine Aquatic Habitat Goal (Chronic Toxicity)	Bioaccumulation and Human Consumption
			Table G-4	Table D-4a	Table D-4F
Perfluorobutane sulfonate (PFBS-)					
Perfluoropentane sulfonate (PFPeS-)					
Perfluorohexane sulfonate (PFHxS-)					
Perfluoroheptane sulfonate (PFHpS-)					
Perfluorooctane sulfonate (PFOS-)					
Perfluorodecane sulfonate (PFDS-)					
Perfluoro propanoate (PFPrA-)					
Perfluoro butanoate (PFBA-)					
Perfluoro pentanoate (PFPeA-)					
Perfluoro hexanoate (PFHxA-)					
Perfluoro heptanoate (PFHpA-)					
Perfluoro octanoate (PFOA-)					
Perfluoro nonanoate (PFNA-)					
Perfluoro decanoate (PFDA-)					
Perfluoro undecanoate (PFUnDA-)					
Perfluoro dodecanoate (PFDoDA-)					
Perfluoro tridecanoate (PFTrDA-)					
Perfluoro tetradecanoate (PFTeDA-)					
Perfluorooctane sulfonamide (PFOSA)					
2,2,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPPODA-)					
6:2 Fluorotelomer sulfonate (6:2 FTS-)					
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)					
6:2 Fluorotelomer alcohol (6:2 FTOH-)					
8:2 Fluorotelomer alcohol (8:2 FTOH-)					
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)					
Notes:					
1. Lowest of gross contamination, aquatic habitat and bioaccumulation action levels. Surface water action levels for PFASs on hold pending development of bioaccumulation action levels.					
NA = Not available.					
Ceiling Level: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit nuisances and general resource degradation.					
Method reporting limits and background concentrations replace final screening level as appropriate.					

TABLE D-2c. SURFACE WATER ACTION LEVELS
***Estuary Habitats**
(ug/l)

	¹ Final Surface Water Action Level	Basis	Gross Contamination (Odors, etc.) Table G-4	Estuary Aquatic Habitat Goal (Chronic Toxicity) Table D-4a	Bioaccumulation and Human Consumption Table D-4f
CHEMICAL PARAMETER					
Perfluoro undecanoate (PFUnDA-)					
Perfluoro dodecanoate (PFDoDA-)					
Perfluoro tridecanoate (PFTrDA-)					
Perfluoro tetradecanoate (PFTeDA-)					
Perflurooctane sulfonamide (PFOSA)					
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)					
6:2 Fluorotelomer sulfonate (6:2 FTS-)					
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)					
6:2 Fluorotelomer alcohol (6:2 FTOH-)					
8:2 Fluorotelomer alcohol (8:2 FTOH-)					
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)					

Notes:
***Estuary Habitats: Mixed freshwater/marine water habitats.**

1. Lowest of gross contamination, aquatic habitat and bioaccumulation action levels. Surface water action levels for PFASs on hold pending development of bioaccumulation action levels.

NA = Not available.
Ceiling Level: Odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit nuisances and general resource degradation.

Method reporting limits and background concentrations replace final screening level as appropriate.

TABLE D-3a. FINAL DRINKING WATER ACTION LEVELS FOR HUMAN TOXICITY.
(ug/L)

CHEMICAL PARAMETER	Final Action Level	Basis	HDOH Primary MCL	Other Criteria	Reference	Risk-Based Action Level (Table D-3b)	Basis
Perfluorobutane sulfonate (PFBS-)	1.7E+00	noncarcinogenic effects				1.7E+00	noncarcinogenic effects
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	noncarcinogenic effects				6.2E-01	noncarcinogenic effects
Perfluorohexane sulfonate (PFHxS-)	7.7E-02	noncarcinogenic effects				7.7E-02	noncarcinogenic effects
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	noncarcinogenic effects				3.8E-02	noncarcinogenic effects
Perfluorooctane sulfonate (PFOS-)	7.7E-03	noncarcinogenic effects				7.7E-03	noncarcinogenic effects
Perfluorodecane sulfonate (PFDS-)	3.8E-02	noncarcinogenic effects				3.8E-02	noncarcinogenic effects
Perfluoro propanoate (PFPrA-)	5.1E-01	noncarcinogenic effects				5.1E-01	noncarcinogenic effects
Perfluoro butanoate (PFBA-)	1.5E+01	noncarcinogenic effects				1.5E+01	noncarcinogenic effects
Perfluoro pentanoate (PFPeA-)	1.5E+00	noncarcinogenic effects				1.5E+00	noncarcinogenic effects
Perfluoro hexanoate (PFHxA-)	1.9E+00	noncarcinogenic effects				1.9E+00	noncarcinogenic effects
Perfluoro heptanoate (PFHpA-)	7.7E-02	noncarcinogenic effects				7.7E-02	noncarcinogenic effects
Perfluoro octanoate (PFOA-)	1.2E-02	noncarcinogenic effects				1.2E-02	noncarcinogenic effects
Perfluoro nonanoate (PFNA-)	1.2E-02	noncarcinogenic effects				1.2E-02	noncarcinogenic effects
Perfluoro decanoate (PFDA-)	7.7E-03	noncarcinogenic effects				7.7E-03	noncarcinogenic effects
Perfluoro undecanoate (PFUnDA-)	1.9E-02	noncarcinogenic effects				1.9E-02	noncarcinogenic effects
Perfluoro dodecanoate (PFDoDA-)	2.6E-02	noncarcinogenic effects				2.6E-02	noncarcinogenic effects
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	noncarcinogenic effects				2.6E-02	noncarcinogenic effects
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	noncarcinogenic effects				2.6E-01	noncarcinogenic effects
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	noncarcinogenic effects				4.6E-02	noncarcinogenic effects
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	noncarcinogenic effects				1.2E-02	noncarcinogenic effects
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.5E+00	noncarcinogenic effects				1.5E+00	noncarcinogenic effects
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.2E+00	noncarcinogenic effects				1.2E+00	noncarcinogenic effects
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	noncarcinogenic effects				5.0E+00	noncarcinogenic effects
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	noncarcinogenic effects				4.2E+00	noncarcinogenic effects
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	noncarcinogenic effects				1.9E+00	noncarcinogenic effects

References:
Final health-based action level for drinking water: Promulgated state or federal MCLs not available. Action levels based on USEPA RSL model for tapwater, including a Relative Source Concentration of 20%, a target, noncancer Hazard Quotient of 1.0 and a target Excess Cancer Risk of 10⁻⁶ (see Table D-3b). Refer to accompanying Technical Memorandum for additional details.

Notes:
Used for development of groundwater and soil screening levels.
NA=Not available.

**TABLE D-3b. RISK-BASED ACTION LEVELS FOR TAPWATER
(ug/l)**

CHEMICAL PARAMETER	Lowest Tapwater Goal (ug/L)	Basis	Carcinogenic Effects	Mutagenic Effects	Noncancer Effects
Perfluorobutane sulfonate (PFBS-)	1.7E+00	noncarcinogenic effects			1.7E+00
Perfluoropentane sulfonate (PFPeS-)	6.2E-01	noncarcinogenic effects			6.2E-01
Perfluorohexane sulfonate (PFHxS-)	7.7E-02	noncarcinogenic effects			7.7E-02
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	noncarcinogenic effects			3.8E-02
Perfluorooctane sulfonate (PFOS-)	7.7E-03	noncarcinogenic effects			7.7E-03
Perfluorodecane sulfonate (PFDS-)	3.8E-02	noncarcinogenic effects			3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	noncarcinogenic effects			5.1E-01
Perfluoro butanoate (PFBA-)	1.5E+01	noncarcinogenic effects			1.5E+01
Perfluoro pentanoate (PFPeA-)	1.5E+00	noncarcinogenic effects			1.5E+00
Perfluoro hexanoate (PFHxA-)	1.9E+00	noncarcinogenic effects			1.9E+00
Perfluoro heptanoate (PFHpA-)	7.7E-02	noncarcinogenic effects			7.7E-02
Perfluoro octanoate (PFOA-)	1.2E-02	noncarcinogenic effects			1.2E-02
Perfluoro nonanoate (PFNA-)	1.2E-02	noncarcinogenic effects			1.2E-02
Perfluoro decanoate (PFDA-)	7.7E-03	noncarcinogenic effects			7.7E-03
Perfluoro undecanoate (PFUnDA-)	1.9E-02	noncarcinogenic effects			1.9E-02
Perfluoro dodecanoate (PFDoDA-)	2.6E-02	noncarcinogenic effects			2.6E-02
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	noncarcinogenic effects			2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	noncarcinogenic effects			2.6E-01
Perfluroroctane sulfonamide (PFOSA)	4.6E-02	noncarcinogenic effects			4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	noncarcinogenic effects			1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.5E+00	noncarcinogenic effects			1.5E+00
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.2E+00	noncarcinogenic effects			1.2E+00
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	noncarcinogenic effects			5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	noncarcinogenic effects			4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTI AoS-)	1.9E+00	noncarcinogenic effects			1.9E+00

References:

See Technical Memorandum for equations and assumptions used to calculate action levels.

Notes:

Final health-based action level for drinking water: Promulgated state or federal MCLs not available. Action levels based on USEPA RSL model for tapwater, including a Relative Source Concentration of 20%, a target, noncancer Hazard Quotient of 1.0 and a target Excess Cancer Risk of 10-5. Refer to accompanying Technical Memorandum for additional details.

NA=Not available.

TABLE D-4a. SUMMARY OF AQUATIC HABITAT GOALS

CHEMICAL PARAMETER	Estuarine		Freshwater		Marine	
	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)
Perfluorobutane sulfonate (PFBS-)	1.3E+05	1.3E+05	5.0E+05	8.9E+05	1.3E+05	1.3E+05
Perfluoropentane sulfonate (PFPeS-)	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	3.8E-02	3.8E-02	3.8E-02	3.8E-02	3.8E-02
Perfluorooctane sulfonate (PFOS-)	1.1E+00	3.1E+01	2.3E+00	3.1E+01	1.1E+00	1.3E+02
Perfluorodecane sulfonate (PFDS-)	3.8E-02	3.8E-02	3.8E-02	3.8E-02	3.8E-02	3.8E-02
Perfluoro propanoate (PFPrA-)	5.1E-01	5.1E-01	5.1E-01	5.1E-01	5.1E-01	5.1E-01
Perfluoro butanoate (PFBA-)	8.3E+02	4.2E+03	8.3E+02	4.2E+03	4.2E+03	4.2E+03
Perfluoro pentanoate (PFPeA-)	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00
Perfluoro hexanoate (PFHxA-)	6.3E+03	4.8E+04	6.3E+03	4.8E+04	4.8E+04	4.8E+04
Perfluoro heptanoate (PFHpA-)	7.7E-02	7.7E-02	7.7E-02	7.7E-02	7.7E-02	7.7E-02
Perfluoro octanoate (PFOA-)	8.3E+00	1.2E+02	8.3E+00	1.8E+03	1.2E+02	1.2E+02
Perfluoro nonanoate (PFNA-)	8.0E+00	1.0E+01	8.0E+00	1.1E+03	1.0E+01	1.0E+01
Perfluoro decanoate (PFDA-)	1.0E+01	1.0E+01	1.0E+01	1.0E+01	3.9E+01	3.9E+01
Perfluoro undecanoate (PFUnDA-)	1.0E+01	4.4E+02	1.0E+01	4.4E+02	4.4E+02	4.4E+02
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	6.4E+02	2.0E+01	6.4E+02	6.4E+02	6.4E+02
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02	2.6E-02
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	2.6E-01	2.6E-01	2.6E-01	2.6E-01	2.6E-01
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	4.6E-02	4.6E-02	4.6E-02	4.6E-02	4.6E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.6E+02	1.1E+04	2.6E+03	1.1E+05	2.6E+02	1.1E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+04	1.0E+04	1.0E+05	1.0E+05	1.0E+04	1.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	4.2E+00	6.7E+00	6.0E+01	4.2E+00	4.2E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00

Notes:
Reference: Appendix 1, Table D-4b (chronic) and D-4c (acute). NA=Not available.
Aquatic goals for estuarine environments based on lowest of lowest of freshwater and marine goals. Drinking water action level referenced if aquatic toxicity action levels not available (refer to Table 4b and Table 4c).

TABLE D-4b. SUMMARY OF SELECTED CHRONIC AQUATIC HABITAT GOALS

CHEMICAL PARAMETER	¹ Aquatic Habitat Goals					
	¹ Estuarine Aquatic Habitat Goal (ug/L)	Basis	Lowest Freshwater Aquatic Habitat Goal (ug/L)	Basis	Lowest Marine Aquatic Habitat Goal (ug/L)	Basis
Perfluorobutane sulfonate (PFBS-)	1.3E+05	=acute LCO	5.0E+05	NOEC Daphnia Magna	1.3E+05	=acute LCO
Perfluoropentane sulfonate (PFPeS-)	2.5E+00	=Drinking Water Toxicity	2.5E+00	=Drinking Water Toxicity	2.5E+00	=Drinking Water Toxicity
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	=freshwater chronic	1.0E+01	infection risk	1.0E+01	=freshwater chronic
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity
Perfluorooctane sulfonate (PFOS-)	1.1E+00	PNOEC	2.3E+00	NOEC	1.1E+00	PNOEC
Perfluorodecane sulfonate (PFDS-)	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity
Perfluoro propanoate (PFPrA-)	5.1E-01	=Drinking Water Toxicity	5.1E-01	=Drinking Water Toxicity	5.1E-01	=Drinking Water Toxicity
Perfluoro butanoate (PFBA-)	8.3E+02	NOEC	8.3E+02	NOEC	4.2E+03	=freshwater chronic
Perfluoro pentanoate (PFPeA-)	1.5E+00	=Drinking Water Toxicity	1.5E+00	=Drinking Water Toxicity	1.5E+00	=Drinking Water Toxicity
Perfluoro hexanoate (PFHxA-)	6.3E+03	120 hr post fertilization	6.3E+03	120 hr post fertilization	4.8E+04	=freshwater chronic
Perfluoro heptanoate (PFHpA-)	7.7E-02	=Drinking Water Toxicity	7.7E-02	=Drinking Water Toxicity	7.7E-02	=Drinking Water Toxicity
Perfluoro octanoate (PFOA-)	8.3E+00	developmental defects	8.3E+00	developmental defects	1.2E+02	NOEC
Perfluoro nonanoate (PFNA-)	8.0E+00	NOEC Daphnia Magna	8.0E+00	NOEC Daphnia Magna	1.0E+01	NOEC
Perfluoro decanoate (PFDA-)	1.0E+01	=acute NOEC	1.0E+01	=acute NOEC	3.9E+01	50% EC50
Perfluoro undecanoate (PFUnDA-)	1.0E+01	NOEC	1.0E+01	NOEC	4.4E+02	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	NOEC	2.0E+01	NOEC	6.4E+02	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	=Drinking Water Toxicity	2.6E-02	=Drinking Water Toxicity	2.6E-02	=Drinking Water Toxicity
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	=Drinking Water Toxicity	2.6E-01	=Drinking Water Toxicity	2.6E-01	=Drinking Water Toxicity
Perfluorooctane sulfonamide (PFOSA)	4.6E-02	=Drinking Water Toxicity	4.6E-02	=Drinking Water Toxicity	4.6E-02	=Drinking Water Toxicity
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	=Drinking Water Toxicity	1.2E-02	=Drinking Water Toxicity	1.2E-02	=Drinking Water Toxicity
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.6E+02	after ECHA 2022 (FW chronic + 10)	2.6E+03	ECHA 2022 (units corrected to mg/L)	2.6E+02	after ECHA 2022 (FW chronic + 10)
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+04	after ECHA 2022 (FW chronic + 10)	1.0E+05	ECHA 2020 (NOEC)	1.0E+04	after ECHA 2022 (FW chronic + 10)
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	=Drinking Water Toxicity	5.0E+00	=Drinking Water Toxicity	5.0E+00	=Drinking Water Toxicity
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	=Drinking Water Toxicity	6.7E+00	SERDP 2020	4.2E+00	=Drinking Water Toxicity
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	=Drinking Water Toxicity	1.9E+00	=Drinking Water Toxicity	1.9E+00	=Drinking Water Toxicity

Notes:

1. Refer to Table D-4d and D-4e for summary of aquatic habitat goal sources. Used for selection of groundwater action levels.
2. Estuarine Goal = Lowest of Freshwater vs Saltwater chronic goals.

3. Drinking water goal substituted as aquatic habitat goal if latter was not available (see text). Additional evaluation of aquatic toxicity should be carried out if the action level is exceeded, including review of published research and/or laboratory bioassay tests.

TABLE D-4c. SUMMARY OF SELECTED ACUTE AQUATIC HABITAT GOALS

CONTAMINANT	¹ Aquatic Habitat Goals					
	¹ Estuarine Acute Aquatic Habitat Goal (ug/L)	Basis	Freshwater Acute Aquatic Habitat Goal (ug/L)	Basis	Saltwater Acute Aquatic Habitat Goal (ug/L)	Basis
Perfluorobutane sulfonate (PFBS-)	1.3E+05	Acute LC0	8.9E+05	Giesey et al 2010	1.3E+05	Acute LC0
Perfluoropentane sulfonate (PFPeS-)	2.5E+00	=Drinking Water Toxicity	2.5E+00	=Drinking Water Toxicity	2.5E+00	=Drinking Water Toxicity
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic
Perfluoroheptane sulfonate (PFHpS-)	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity
Perfluorooctane sulfonate (PFOS-)	3.1E+01	ACRA 2018 (80% species protection)	3.1E+01	ACRA 2018 (80% species protection)	1.3E+02	ACRA 2018 (80% species protection)
Perfluorodecane sulfonate (PFDS-)	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity	3.8E-02	=Drinking Water Toxicity
Perfluoro propanoate (PFPrA-)	5.1E-01	=Drinking Water Toxicity	5.1E-01	=Drinking Water Toxicity	5.1E-01	=Drinking Water Toxicity
Perfluoro butanoate (PFBA-)	4.2E+03	=freshwater chronic	4.2E+03	SERDP 2020	4.2E+03	=freshwater chronic
Perfluoro pentanoate (PFPeA-)	1.5E+00	=Drinking Water Toxicity	1.5E+00	=Drinking Water Toxicity	1.5E+00	=Drinking Water Toxicity
Perfluoro hexanoate (PFHxA-)	4.8E+04	=freshwater chronic	4.8E+04	50% LC50 (ECHA 2018)	4.8E+04	=freshwater chronic
Perfluoro heptanoate (PFHpA-)	7.7E-02	=Drinking Water Toxicity	7.7E-02	=Drinking Water Toxicity	7.7E-02	=Drinking Water Toxicity
Perfluoro octanoate (PFOA-)	1.2E+02	=marine chronic	1.8E+03	ACRA 2018 (80% species protection)	1.2E+02	=marine chronic
Perfluoro nonanoate (PFNA-)	1.0E+01	=marine chronic	1.1E+03	SERDP 2020	1.0E+01	=marine chronic
Perfluoro decanoate (PFDA-)	1.0E+01	acute NOEC	1.0E+01	acute NOEC	3.9E+01	=marine chronic
Perfluoro undecanoate (PFUnDA-)	4.4E+02	=freshwater chronic	4.4E+02	SERDP 2020	4.4E+02	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)	6.4E+02	=freshwater chronic	6.4E+02	SERDP 2020	6.4E+02	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)	2.6E-02	=Drinking Water Toxicity	2.6E-02	=Drinking Water Toxicity	2.6E-02	=Drinking Water Toxicity
Perfluoro tetradecanoate (PFTeDA-)	2.6E-01	=Drinking Water Toxicity	2.6E-01	=Drinking Water Toxicity	2.6E-01	=Drinking Water Toxicity
Perfluroroctane sulfonamide (PFOSA)	4.6E-02	=Drinking Water Toxicity	4.6E-02	=Drinking Water Toxicity	4.6E-02	=Drinking Water Toxicity
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.2E-02	=Drinking Water Toxicity	1.2E-02	=Drinking Water Toxicity	1.2E-02	=Drinking Water Toxicity
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.1E+04	=freshwater acute + 10	1.1E+05	ECHA 2022 (units corrected to mg/L)	1.1E+04	=freshwater acute + 10
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+04	=freshwater acute + 10	1.0E+05	= freshwater chronic	1.0E+04	=freshwater acute + 10
6:2 Fluorotelomer alcohol (6:2 FTOH-)	5.0E+00	=Drinking Water Toxicity	5.0E+00	=Drinking Water Toxicity	5.0E+00	=Drinking Water Toxicity
8:2 Fluorotelomer alcohol (8:2 FTOH-)	4.2E+00	=Drinking Water Toxicity	6.0E+01	SERDP 2020	4.2E+00	=Drinking Water Toxicity
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.9E+00	=Drinking Water Toxicity	1.9E+00	=Drinking Water Toxicity	1.9E+00	=Drinking Water Toxicity

Notes:
1. Refer to Table D-4d and D-4e for summary of aquatic habitat goal sources. Used for selection of groundwater action levels.
2. Estuarine Goal = Lowest of Freshwater vs Saltwater chronic goals.
3. Drinking water goal substituted as aquatic habitat goal if latter was not available (see text). Additional evaluation of aquatic toxicity should be carried out if the action level is exceeded, including review of published research and/or laboratory bioassay tests.

**TABLE D-4d. SUMMARY OF HAWAI'I CHRONIC AND ACUTE
SURFACE WATER (AQUATIC HABITAT) STANDARDS**

CONTAMINANT	Freshwater (ug/L)		Saltwater (ug/L)	
	Chronic	Acute	Chronic	Acute
Perfluorobutane sulfonate (PFBS-)				
Perfluoropentane sulfonate (PFPeS-)				
Perfluorohexane sulfonate (PFHxS-)				
Perfluoroheptane sulfonate (PFHpS-)				
Perfluorooctane sulfonate (PFOS-)				
Perfluorodecane sulfonate (PFDS-)				
Perfluoro propanoate (PFPrA-)				
Perfluoro butanoate (PFBA-)				
Perfluoro pentanoate (PFPeA-)				
Perfluoro hexanoate (PFHxA-)				
Perfluoro heptanoate (PFHpA-)				
Perfluoro octanoate (PFOA-)				
Perfluoro nonanoate (PFNA-)				
Perfluoro decanoate (PFDA-)				
Perfluoro undecanoate (PFUnDA-)				
Perfluoro dodecanoate (PFDoDA-)				
Perfluoro tridecanoate (PFTrDA-)				
Perfluoro tetradecanoate (PFTeDA-)				
Perfluorooctane sulfonamide (PFOSA)				
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)				
6:2 Fluorotelomer sulfonate (6:2 FTS-)				
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)				
6:2 Fluorotelomer alcohol (6:2 FTOH-)				
8:2 Fluorotelomer alcohol (8:2 FTOH-)				
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)				
Primary Reference:				
1. Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria, October 2012.				

**TABLE D-4e. SUMMARY OF USEPA AND OTHER PUBLISHED AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	Freshwater						Marine					
	USEPA Reg IV Chronic	USEPA Reg IV Acute	Other Chronic	¹ Basis	Acute	¹ Basis	USEPA Reg IV Chronic	USEPA Reg IV Acute	Other Chronic	¹ Basis	Acute	¹ Basis
Perfluorobutane sulfonate (PFBS-)			5.0E+05	NOEC Daphnia Magna	8.9E+05	Giesey et al 2010			1.3E+05	=acute LC0	1.3E+05	Acute LC0
Perfluoropentane sulfonate (PFPeS-)												
Perfluorohexane sulfonate (PFHxS-)			1.0E+01	infection risk	1.0E+01	=freshwater chronic			1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic
Perfluoroheptane sulfonate (PFHpS-)												
Perfluorooctane sulfonate (PFOS-)			2.3E+00	NOEC	3.1E+01	ACRA 2018 (80% species protection)			1.1E+00	PNOEC	1.3E+02	ACRA 2018 (80% species protection)
Perfluorodecane sulfonate (PFDS-)												
Perfluoro propanoate (PFPrA-)												
Perfluoro butanoate (PFBA-)			8.3E+02	NOEC	4.2E+03	SERDP 2020			4.2E+03	=freshwater chronic	4.2E+03	=freshwater chronic
Perfluoro pentanoate (PFPeA-)												
Perfluoro hexanoate (PFHxA-)			6.3E+03	120 hr post fertilization	4.8E+04	50% LC50 (ECHA 2018)			4.8E+04	=freshwater chronic	4.8E+04	=freshwater chronic
Perfluoro heptanoate (PFHpA-)												
Perfluoro octanoate (PFOA-)			8.3E+00	developmental defects	1.8E+03	ACRA 2018 (80% species protection)			1.2E+02	NOEC	1.2E+02	=marine chronic
Perfluoro nonanoate (PFNA-)			8.0E+00	NOEC Daphnia Magna	1.1E+03	SERDP 2020			1.0E+01	NOEC	1.0E+01	=marine chronic
Perfluoro decanoate (PFDA-)			1.0E+01	=acute NOEC	1.0E+01	acute NOEC			3.9E+01	50% EC50	3.9E+01	=marine chronic
Perfluoro undecanoate (PFUnDA-)			1.0E+01	NOEC	4.4E+02	SERDP 2020			4.4E+02	=freshwater chronic	4.4E+02	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)			2.0E+01	NOEC	6.4E+02	SERDP 2020			6.4E+02	=freshwater chronic	6.4E+02	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)												
Perfluoro tetradecanoate (PFTeDA-)												
Perfluorooctane sulfonamide (PFOSA) 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPPOA)												
6:2 Fluorotelomer sulfonate (6:2 FTS-)			2.6E+03	ECHA 2022 (units corrected to mg/L)	1.1E+05	ECHA 2022 (units corrected to mg/L)			2.6E+02	after ECHA 2022 (FW chronic + 10)	1.1E+04	=freshwater acute + 10
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)			1.0E+05	ECHA 2020 (NOEC)	1.0E+05	= freshwater chronic			1.0E+04	after ECHA 2022 (FW chronic + 10)	1.0E+04	=freshwater acute + 10
6:2 Fluorotelomer alcohol (6:2 FTOH-)												
8:2 Fluorotelomer alcohol (8:2 FTOH-)			6.7E+00	SERDP 2020	6.0E+01	SERDP 2020						
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)												

Notes:
1. Aquatic toxicity action level based on WADOE (2020) unless otherwise noted.

References
WADOE, 2020, PFAS Ecological Receptors - Concentrations Protective of Surface Water and Upland Soil (Draft); Washington Department of Ecology, September 2020.

ACRC, 2018, Practitioner guide to risk-based assessment, remediation and management of PFAS site contamination: Australia Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, Technical Report no. 43, Newcastle, Australia.

Giesy, J.P., Nalle, J.E., Khim, J.S., Jones, P.D. and J.L. Newsted, 2010, Aquatic Toxicology of Perfluorinated Chemicals: D.M. Whitacre (ed.), Reviews of Environmental Contamination and Toxicology, 202, DOI 10.1007/978-1-4419-1157-5_1.

ECHA, 2018, Proposal for identification of Undecafluorohexanoic Acid and it's Ammonium Salt as Substances of Very High Concern: European Chemical Agency, August 2018.

ECHA, 2020, Substance Evaluation Conclusion Document, Ammonium 2,2,3-trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluoromethoxypropoxy) propanoate: European Chemical Agency, EC No 480-310-4, Decembe2 22, 2020.

ECHA, 2022, Brief Profile: 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulphonic acid: European Chemicals Agency (last updated Dec 13, 2022).

Notes:
Used for development of groundwater and soil action levels.
See text for prioritization and selection of surface water quality action levels.

AWQC: Aquatic Water Quality Criteria
NOEC: No Observed Effects Level
PNOEC: Predicted No Observed Effects Level
EC50: 50% Effects Concentration
LC0: 0% Lethal Concentration
LC50: 50% Lethal Concentration

**TABLE D-4f. SURFACE WATER QUALITY STANDARDS FOR BIOACCUMULATION
AND HUMAN CONSUMPTION OF AQUATIC ORGANISMS
(ug/L)**

CONTAMINANT	Freshwater		Marine		Freshwater			Marine		
	Selected Criteria	Basis	Selected Criteria	Basis	¹ ACRC 2018	² Other	Other Ref	¹ ACRC 2018	² Other	Other Ref
Perfluorobutane sulfonate (PFBS-)										
Perfluoropentane sulfonate (PFPeS-)										
Perfluorohexane sulfonate (PFHxS-)										
Perfluoroheptane sulfonate (PFHpS-)	2.3E-04	Australia CRC 2018	2.9E-01	Australia CRC 2018	2.3E-04			2.9E-01		
Perfluorooctane sulfonate (PFOS-)										
Perfluorodecane sulfonate (PFDS-)										
Perfluoro propanoate (PFPrA-)										
Perfluoro butanoate (PFBA-)										
Perfluoro pentanoate (PFPeA-)										
Perfluoro hexanoate (PFHxA-)	1.9E+01	Australia CRC 2018	3.0E+00	Australia CRC 2018	1.9E+01			3.0E+00		
Perfluoro heptanoate (PFHpA-)										
Perfluoro octanoate (PFOA-)										
Perfluoro nonanoate (PFNA-)										
Perfluoro decanoate (PFDA-)										
Perfluoro undecanoate (PFUnDA-)										
Perfluoro dodecanoate (PFDoDA-)										
Perfluoro tridecanoate (PFTrDA-)										
Perfluoro tetradecanoate (PFTeDA-)										
Perfluorooctane sulfonamide (PFOSA)										
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)										
6:2 Fluorotelomer sulfonate (6:2 FTS-)										
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)										
6:2 Fluorotelomer alcohol (6:2 FTOH-)										
8:2 Fluorotelomer alcohol (8:2 FTOH-)										
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)										

References:
1. ACRC, 2018, Practitioner guide to risk-based assessment, remediation and management of PFAS site contamination: Australia Cooperative Research Centre or Contamination Assessment and Remediation of the Environment, Technical Report no. 43. Newcastle, Australia.
2. See reference.

Notes:
Hawai'i Surface Water Quality Standards for fish consumption considered if available.
Addresses potential accumulation of chemical in aquatic organisms and subsequent consumption by humans.

**TABLE D-5. AGRICULTURAL
WATER QUALITY GOALS
(ug/l)**

CHEMICAL PARAMETER	Agricultural Water Quality Goals
Perfluorobutane sulfonate (PFBS-)	
Perfluoropentane sulfonate (PFPeS-)	
Perfluorohexane sulfonate (PFHxS-)	
Perfluoroheptane sulfonate (PFHpS-)	
Perfluorooctane sulfonate (PFOS-)	
Perfluorodecane sulfonate (PFDS-)	
Perfluoro propanoate (PFPrA-)	
Perfluoro butanoate (PFBA-)	
Perfluoro pentanoate (PFPeA-)	
Perfluoro hexanoate (PFHxA-)	
Perfluoro heptanoate (PFHpA-)	
Perfluoro octanoate (PFOA-)	
Perfluoro nonanoate (PFNA-)	
Perfluoro decanoate (PFDA-)	
Perfluoro undecanoate (PFUnDA-)	
Perfluoro dodecanoate (PFDoDA-)	
Perfluoro tridecanoate (PFTrDA-)	
Perfluoro tetradecanoate (PFTeDA-)	
Perflurooctane sulfonamide (PFOSA)	
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	
6:2 Fluorotelomer sulfonate (6:2 FTS-)	
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	
6:2 Fluorotelomer alcohol (6:2 FTOH-)	
8:2 Fluorotelomer alcohol (8:2 FTOH-)	
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	
References:	
Notes: Addresses use of water (including groundwater) for agricultural/irrigation purposes.	

TABLE E-1. SOIL ACTION LEVELS FOR LEACHING CONCERNS

Chemical	Organic Carbon Coefficient (Koc)	Henry's Law Constant (H)	Dilution/Attenuation Factor (DAF)	Saturation Limit	Target Groundwater Concentrations				Soil Leaching Action Levels			
					Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
					Target Groundwater Concentration (Surface Water Within 150m; Table D-1a)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)
(cm ³ /g)	(atm-m ³ /mol)	(mg/kg)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)		
Perfluorobutane sulfonate (PFBS-)	3.10E+01	2.95E-10	5.15E+00	6.2E+02	1.7E+00	1.7E+00	5.0E+04	5.0E+04	8.7E-03	8.7E-03	2.6E+02	2.6E+02
Perfluoropentane sulfonate (PFPeS-)	1.05E+03	2.14E-10	1.74E+02	8.4E+05	6.2E-01	6.2E-01	6.2E-01	6.2E-01	1.1E-01	1.1E-01	1.1E-01	1.1E-01
Perfluorohexane sulfonate (PFHxS-)	5.62E+02	1.94E-10	9.33E+01	5.9E+05	7.7E-02	7.7E-02	1.0E+01	1.0E+01	7.2E-03	7.2E-03	9.3E-01	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	1.23E+03	1.79E-10	2.04E+02	1.0E+06	3.8E-02	3.8E-02	3.8E-02	3.8E-02	7.9E-03	7.9E-03	7.9E-03	7.9E-03
Perfluorooctane sulfonate (PFOS-)	1.12E+03	1.80E-11	1.86E+02	1.0E+06	7.7E-03	7.7E-03	1.1E+00	3.1E+01	1.4E-03	1.4E-03	2.0E-01	5.8E+00
Perfluorodecane sulfonate (PFDS-)	3.94E+03	3.31E-10	6.53E+02	1.0E+06	3.8E-02	3.8E-02	3.8E-02	3.8E-02	2.5E-02	2.5E-02	2.5E-02	2.5E-02
Perfluoro propanoate (PFPrA-)	5.89E+00	3.63E-06	1.00E+00	3.3E+03	5.1E-01	5.1E-01	5.1E-01	5.1E-01	5.1E-04	5.1E-04	5.1E-04	5.1E-04
Perfluoro butanoate (PFBA-)	7.60E+01	5.01E-05	1.29E+01	8.1E+04	1.5E+01	1.5E+01	8.3E+02	4.2E+03	1.9E-01	1.9E-01	1.1E+01	5.4E+01
Perfluoro pentanoate (PFPeA-)	2.30E+01	2.97E-10	3.82E+00	5.8E+04	1.5E+00	1.5E+00	1.5E+00	1.5E+00	5.9E-03	5.9E-03	5.9E-03	5.9E-03
Perfluoro hexanoate (PFHxA-)	2.00E+01	2.35E-10	3.32E+00	7.6E+04	1.9E+00	1.9E+00	6.3E+03	4.8E+04	6.4E-03	6.4E-03	2.1E+01	1.6E+02
Perfluoro heptanoate (PFHpA-)	4.30E+01	2.09E-10	7.14E+00	1.9E+05	7.7E-02	7.7E-02	7.7E-02	7.7E-02	5.5E-04	5.5E-04	5.5E-04	5.5E-04
Perfluoro octanoate (PFOA-)	1.82E+02	1.92E-10	3.02E+01	7.4E+05	1.2E-02	1.2E-02	8.3E+00	1.2E+02	3.5E-04	3.5E-04	2.5E-01	3.6E+00
Perfluoro nonanoate (PFNA-)	1.06E+03	1.18E-09	1.76E+02	1.0E+06	1.2E-02	1.2E-02	8.0E+00	1.0E+01	2.0E-03	2.0E-03	1.4E+00	1.8E+00
Perfluoro decanoate (PFDA-)	7.24E+02	1.50E-10	1.20E+02	1.0E+06	7.7E-03	7.7E-03	1.0E+01	1.0E+01	9.2E-04	9.2E-04	1.2E+00	1.2E+00
Perfluoro undecanoate (PFUnDA-)	2.69E+03	3.34E-10	4.47E+02	1.0E+06	1.9E-02	1.9E-02	1.0E+01	4.4E+02	8.6E-03	8.6E-03	4.5E+00	2.0E+02
Perfluoro dodecanoate (PFDoDA-)	8.54E+04	3.40E-10	1.42E+04	1.0E+06	2.6E-02	2.6E-02	2.0E+01	6.4E+02	1.0E+06	1.0E+06	1.0E+06	1.0E+06
Perfluoro tridecanoate (PFTriDA-)	1.84E+05	3.48E-10	3.05E+04	1.0E+06	2.6E-02	2.6E-02	2.6E-02	2.6E-02	1.0E+06	1.0E+06	1.0E+06	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	2.33E+05	3.55E-10	3.87E+04	1.0E+06	2.6E-01	2.6E-01	2.6E-01	2.6E-01	1.0E+06	1.0E+06	1.0E+06	1.0E+06
Perfluorooctane sulfonamide (PFOSA)	1.26E+04	1.26E-09	2.09E+03	5.0E+01	4.6E-02	4.6E-02	4.6E-02	4.6E-02	5.0E+01	5.0E+01	5.0E+01	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.20E+01	4.06E-06	2.02E+00	1.7E+05	1.2E-02	1.2E-02	1.2E-02	1.2E-02	2.3E-05	2.3E-05	2.3E-05	2.3E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	9.47E+02	1.83E-10	1.57E+02	1.0E+06	1.5E+00	1.5E+00	2.6E+02	1.1E+04	2.4E-01	2.4E-01	4.1E+01	1.7E+03
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	9.67E+02	1.80E-10	1.61E+02	1.0E+06	1.2E+00	1.2E+00	1.0E+04	1.0E+04	1.9E-01	1.9E-01	1.6E+03	1.6E+03
6:2 Fluorotelomer alcohol (6:2 FTOH-)	3.16E+03	2.60E-10	5.25E+02	3.4E+02	5.0E+00	5.0E+00	5.0E+00	5.0E+00	2.6E+00	2.6E+00	2.6E+00	2.6E+00
8:2 Fluorotelomer alcohol (8:2 FTOH-)	2.24E+03	2.09E-10	3.72E+02	2.7E+00	4.2E+00	4.2E+00	4.2E+00	4.2E+00	1.6E+00	1.6E+00	1.6E+00	1.6E+00
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.76E+04	8.91E-10	1.12E+04	7.8E+04	1.9E+00	1.9E+00	1.9E+00	1.9E+00	7.8E+04	7.8E+04	7.8E+04	7.8E+04

Notes:
 Soil leaching equation from Ontario MOEE guidance (see text).
 Groundwater Category Drinking Water Resource - protective of groundwater that is a source of drinking water AND protective of discharge of groundwater to a surface water and subsequent impact on aquatic life.
 Groundwater Category NON-Drinking Water Resource - protective of discharge of impacted groundwater to surface water and subsequent impact on aquatic life.

Leaching model used considered to be excessively conservative for highly sorptive chemicals. For chemicals with koc values greater than 5,000 cm³/g, theoretical soil saturation level ("sat") used in place of leaching model action level if higher (see text). Soil saturation levels calculated using equation presented in USEPA Regional Screening Levels guidance (see Appendix 2). Laboratory SPLP batch tests and LEAF Method 1314 soil column tests recommended to assess site-specific leaching hazard.

TABLE E-2. ¹SOIL VAPOR ACTION LEVELS FOR EVALUATION OF VADOSE-ZONE LEACHATE AND PROTECTION OF DRINKING WATER AQUIFERS
²volatile hydrocarbons, solvents, explosives and fumigants)

CHEMICAL	Physical State		² Potential Vapor-Phase COPC?	³ Henry's Law Constant (H') (unitless)	⁴ Target Groundwater Screening Level (µg/L) (ug/L)	¹ Soil Vapor Action Level (ug/m3)
Perfluorobutane sulfonate (PFBS-)	NV	S	No	-	-	-
Perfluoropentane sulfonate (PFPeS-)	NV	S	No	-	-	-
Perfluorohexane sulfonate (PFHxS-)	NV	S	No	-	-	-
Perfluoroheptane sulfonate (PFHpS-)	NV	S	No	-	-	-
Perfluorooctane sulfonate (PFOS-)	NV	S	No	-	-	-
Perfluorodecane sulfonate (PFDS-)	NV	S	No	-	-	-
Perfluoro propanoate (PFPrA-)	V	L	Yes	1.48E-04	5.1E-01	1.5E+00
Perfluoro butanoate (PFBA-)	SV	L	No	-	-	-
Perfluoro pentanoate (PFPeA-)	SV	L	No	-	-	-
Perfluoro hexanoate (PFHxA-)	SV	L	No	-	-	-
Perfluoro heptanoate (PFHpA-)	NV	S	No	-	-	-
Perfluoro octanoate (PFOA-)	NV	S	No	-	-	-
Perfluoro nonanoate (PFNA-)	NV	S	No	-	-	-
Perfluoro decanoate (PFDA-)	NV	S	No	-	-	-
Perfluoro undecanoate (PFUnDA-)	NV	S	No	-	-	-
Perfluoro dodecanoate (PFDoDA-)	NV	S	No	-	-	-
Perfluoro tridecanoate (PFTrDA-)	NV	S	No	-	-	-
Perfluoro tetradecanoate (PFTeDA-)	NV	S	No	-	-	-
Perfluorooctane sulfonamide (PFOSA)	NV	S	No	-	-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	NV	S	No	-	-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	No	-	-	-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	NV	S	No	-	-	-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	SV	L	No	-	-	-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	NV	S	No	-	-	-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	NV	S	No	-	-	-

Notes:

- Equivalent concentration of VOC in vadose-zone, soil gas when concentration in pore water/leachate is equal to drinking water screening level times a default dilution-attenuation factor of twenty; see Section 3.5 in Appendix 1 text and Section 4.3.4 in Volume 1). Downward attenuation during migration through the vadose zone (e.g., via volatilization)not considered; most applicable to vapors from leachate in close proximity to the water table.
- Common COPCs include: petroleum, chlorinated solvent or agricultural fumigant volatile chemicals of potential concern or related breakdown products (refer also to Section 9 of the Hawai'i DOH Technical Guidance Manual (HDOH 2016). Petroleum VOCs focus on TPHg, TPHmd, BTEX, MTBE and naphthalene.
- Lowest of drinking water goals based on toxicity and taste and odors (see Table D-1a).

**TABLE F-1. CRITERIA FOR ASSIGNMENT
OF SOIL GROSS CONTAMINATION ACTION LEVELS**

Soil Category	Criteria	Gross Contamination Action Level (mg/kg)
Surface Soils		
Unrestricted Land Use (includes Residential, Schools, Parkland, etc.)	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	100
	0.1 \leq Odor Index < 100 OR no Odor Index and Vapor Pressure < 1 Torr	500
	Odor Index < 0.1 OR non-odorous chemical	1000
Industrial/Commercial Land Use Only	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	500
	0.1 \leq Odor Index < 100 OR no Odor Index and Vapor Pressure < 1 Torr	1000
	Odor Index < 0.1 OR non-odorous chemical	2500
Subsurface Soils		
Unrestricted Land Use (includes Residential, Schools, Parkland, etc.)	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	500
	0.1 \leq Odor Index < 100 OR no Odor Index and Vapor Pressure < 1 Torr	1000
	Odor Index < 0.1 OR non-odorous chemical	2500
Industrial/Commercial Land Use Only	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	1000
	0.1 \leq Odor Index < 100 OR no Odor Index and Vapor Pressure < 1 Torr	2500
	Odor Index < 0.1 OR non-odorous chemical	5000
Modified from Ontario Ministry of Environment and Energy (MOEE 1996) and Massachusetts Department of Environmental Protection (MADEP 1994).		

**TABLE F-2. GROSS CONTAMINATION ACTION LEVELS FOR ¹EXPOSED OR POTENTIALLY EXPOSED SOIL
(mg/kg)**

CONTAMINANT	² Final Unrestricted Land Use Action Level	Final Industrial/ Commercial Land Use Action Level	² Raw Unrestricted Action Level	Raw Industrial/ Commercial Action Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
Perfluorobutane sulfonate (PFBS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoropentane sulfonate (PFPeS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluorohexane sulfonate (PFHxS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoroheptane sulfonate (PFHpS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluorooctane sulfonate (PFOS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluorodecane sulfonate (PFDS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro propanoate (PFPrA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	3.3E+03			-	-
Perfluoro butanoate (PFBA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro pentanoate (PFPeA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro hexanoate (PFHxA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro heptanoate (PFHpA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro octanoate (PFOA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro nonanoate (PFNA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro decanoate (PFDA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro undecanoate (PFUnDA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro dodecanoate (PFDoDA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro tridecanoate (PFTrDA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluoro tetradecanoate (PFTeDA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Perfluorooctane sulfonamide (PFOSA)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-

Notes:

1. Default 0-3m below ground surface for residential settings and 0-1m below ground surface for commercial/industrial settings.
2. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.
3. Referred to as "ceiling levels" in original MADEP guidance (MADEP 1994).

Odor Index = VP/ORT in ppm-v

Odor Recognition Threshold in parts per million - volume (ppm-v = (concentration in mg/m³) x (24/molecular weight)).

Ceiling Level: Based on comparison of vapor pressure and odor index to Table F-1 or saturation limit, if lower.

Saturation limits calculated using equation in USEPA RSL guidance for chemicals that are liquid at ambient temperatures and pressures (refer to Appendix 2).

References for odor threshold data:

Not available for PFAS compounds.

**TABLE F-3. GROSS CONTAMINATION ACTION LEVELS FOR ¹DEEP OR OTHERWISE ISOLATED SOILS
(mg/kg)**

CONTAMINANT	² Final Unrestricted Land Use Action Level	Final Industrial/ Commercial Land Use Action Level	² Raw Unrestricted Action Level	Raw Industrial/ Commercial Action Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
Perfluorobutane sulfonate (PFBS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoropentane sulfonate (PFPeS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluorohexane sulfonate (PFHxS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoroheptane sulfonate (PFHpS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluorooctane sulfonate (PFOS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluorodecane sulfonate (PFDS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro propanoate (PFPrA-)	2.5E+03	3.3E+03	2.5E+03	5.0E+03	3.3E+03				-
Perfluoro butanoate (PFBA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro pentanoate (PFPeA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro hexanoate (PFHxA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro heptanoate (PFHpA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro octanoate (PFOA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro nonanoate (PFNA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro decanoate (PFDA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro undecanoate (PFUnDA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro dodecanoate (PFDoDA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro tridecanoate (PFTrDA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluoro tetradecanoate (PFTeDA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Perfluorooctane sulfonamide (PFOSA)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
8:2 Fluorotelomer alcohol (8:2 FTOH-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-

Notes:

1. Default >3m below ground surface for residential settings and >1m below unpaved ground surface for commercial/industrial settings.
2. Based on unrestricted current or future land use. Considered adequate for residential housing, schools, medical facilities, day-care centers and other sensitive uses.
3. Referred to as "ceiling levels" in original MADEP guidance (MADEP 1994).

Odor Index = VP/ORT in ppm-v

Odor Recognition Threshold in parts per million - volume (ppm-v = (concentration in mg/m³) x (24/molecular weight)).

Ceiling Level: Based on comparison of vapor pressure and odor index to Table F-1 or saturation limit, if lower.

Saturation limits calculated using equation in USEPA RSL guidance for chemicals that are liquid at ambient temperatures and pressures (refer to Appendix 2).

References for odor threshold data:

Not available for PFAS compounds.

TABLE G-1. GROUNDWATER GROSS CONTAMINATION ACTION LEVELS
(groundwater IS a current or potential source of drinking water)
(ug/L)

CHEMICAL PARAMETER	Final Action Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Upper Limit	1.1E+06			5.0E+04
Perfluoropentane sulfonate (PFPeS-)	5.0E+04	Upper Limit	6.6E+07			5.0E+04
Perfluorohexane sulfonate (PFHxS-)	5.0E+04	Upper Limit	8.5E+07			5.0E+04
Perfluoroheptane sulfonate (PFHpS-)	5.0E+04	Upper Limit	1.8E+08			5.0E+04
Perfluorooctane sulfonate (PFOS-)	5.0E+04	Upper Limit	2.8E+08			5.0E+04
Perfluorodecane sulfonate (PFDS-)	5.0E+04	Upper Limit	5.4E+08			5.0E+04
Perfluoro propanoate (PFPrA-)	5.0E+04	Upper Limit	1.2E+07			5.0E+04
Perfluoro butanoate (PFBA-)	5.0E+04	Upper Limit	7.3E+07			5.0E+04
Perfluoro pentanoate (PFPeA-)	5.0E+04	Upper Limit	1.2E+08			5.0E+04
Perfluoro hexanoate (PFHxA-)	5.0E+04	Upper Limit	1.7E+08			5.0E+04
Perfluoro heptanoate (PFHpA-)	5.0E+04	Upper Limit	2.7E+08			5.0E+04
Perfluoro octanoate (PFOA-)	5.0E+04	Upper Limit	3.1E+08			5.0E+04
Perfluoro nonanoate (PFNA-)	5.0E+04	Upper Limit	3.9E+08			5.0E+04
Perfluoro decanoate (PFDA-)	5.0E+04	Upper Limit	4.8E+08			5.0E+04
Perfluoro undecanoate (PFUnDA-)	5.0E+04	Upper Limit	5.8E+08			5.0E+04
Perfluoro dodecanoate (PFDoDA-)	5.0E+04	Upper Limit	7.0E+08			5.0E+04
Perfluoro tridecanoate (PFTrDA-)	5.0E+04	Upper Limit	8.5E+08			5.0E+04
Perfluoro tetradecanoate (PFTeDA-)	5.0E+04	Upper Limit	1.0E+09			5.0E+04
Perfluorooctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	5.0E+04	Upper Limit	5.0E+08			5.0E+04
6:2 Fluorotelomer sulfonate (6:2 FTS-)	5.0E+04	Upper Limit	2.9E+08			5.0E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	5.0E+04	Upper Limit	1.1E+08			5.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	8.8E+03	Solubility	8.8E+03			5.0E+04
8:2 Fluorotelomer alcohol (8:2 FTOH-)	9.9E+01	Solubility	9.9E+01			5.0E+04
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	5.0E+04	Upper Limit	9.6E+04			5.0E+04

References:

Taste and odor thresholds not currently available for PFAS compounds.
Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).

Notes:

Ceiling Level: lowest of 1/2 solubility, taste and odor threshold and 50000 ug/L maximum level

**TABLE G-2. GROUNDWATER GROSS CONTAMINATION ACTION LEVELS
(groundwater IS NOT a current or potential source of drinking water)
(ug/L)**

CHEMICAL PARAMETER	Final Action Level	Basis	Solubility (1/2)	Nuisance Odor Threshold	Basis	Upper Limit
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Upper Limit	1.1E+06			5.0E+04
Perfluoropentane sulfonate (PFPeS-)	5.0E+04	Upper Limit	6.6E+07			5.0E+04
Perfluorohexane sulfonate (PFHxS-)	5.0E+04	Upper Limit	8.5E+07			5.0E+04
Perfluoroheptane sulfonate (PFHpS-)	5.0E+04	Upper Limit	1.8E+08			5.0E+04
Perfluorooctane sulfonate (PFOS-)	5.0E+04	Upper Limit	2.8E+08			5.0E+04
Perfluorodecane sulfonate (PFDS-)	5.0E+04	Upper Limit	5.4E+08			5.0E+04
Perfluoro propanoate (PFPrA-)	5.0E+04	Upper Limit	1.2E+07			5.0E+04
Perfluoro butanoate (PFBA-)	5.0E+04	Upper Limit	7.3E+07			5.0E+04
Perfluoro pentanoate (PFPeA-)	5.0E+04	Upper Limit	1.2E+08			5.0E+04
Perfluoro hexanoate (PFHxA-)	5.0E+04	Upper Limit	1.7E+08			5.0E+04
Perfluoro heptanoate (PFHpA-)	5.0E+04	Upper Limit	2.7E+08			5.0E+04
Perfluoro octanoate (PFOA-)	5.0E+04	Upper Limit	3.1E+08			5.0E+04
Perfluoro nonanoate (PFNA-)	5.0E+04	Upper Limit	3.9E+08			5.0E+04
Perfluoro decanoate (PFDA-)	5.0E+04	Upper Limit	4.8E+08			5.0E+04
Perfluoro undecanoate (PFUnDA-)	5.0E+04	Upper Limit	5.8E+08			5.0E+04
Perfluoro dodecanoate (PFDoDA-)	5.0E+04	Upper Limit	7.0E+08			5.0E+04
Perfluoro tridecanoate (PFTrDA-)	5.0E+04	Upper Limit	8.5E+08			5.0E+04
Perfluoro tetradecanoate (PFTeDA-)	5.0E+04	Upper Limit	1.0E+09			5.0E+04
Perfluorooctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	5.0E+04	Upper Limit	5.0E+08			5.0E+04
6:2 Fluorotelomer sulfonate (6:2 FTS-)	5.0E+04	Upper Limit	2.9E+08			5.0E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	5.0E+04	Upper Limit	1.1E+08			5.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	8.8E+03	Solubility	8.8E+03			5.0E+04
8:2 Fluorotelomer alcohol (8:2 FTOH-)	9.9E+01	Solubility	9.9E+01			5.0E+04
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	5.0E+04	Upper Limit	9.6E+04			5.0E+04

References:

Nuisance odor thresholds not currently available for PFAS compounds.
Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).

Notes:

Nuisance Odor Thresholds assume ten-fold attenuation/dilution of chemical in groundwater upon discharge to surface water.
Ceiling Level: lowest of 1/2 solubility, odor/taste threshold and 50000 ug/L maximum level (intended to limit general groundwater resource degradation).

TABLE G-3. SURFACE WATER GROSS CONTAMINATION ACTION LEVELS
(surface water IS a current or potential source of drinking water)
(ug/L)

CHEMICAL PARAMETER	Final Action Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Upper Limit	1.1E+06			5.0E+04
Perfluoropentane sulfonate (PFPeS-)	5.0E+04	Upper Limit	6.6E+07			5.0E+04
Perfluorohexane sulfonate (PFHxS-)	5.0E+04	Upper Limit	8.5E+07			5.0E+04
Perfluoroheptane sulfonate (PFHpS-)	5.0E+04	Upper Limit	1.8E+08			5.0E+04
Perfluorooctane sulfonate (PFOS-)	5.0E+04	Upper Limit	2.8E+08			5.0E+04
Perfluorodecane sulfonate (PFDS-)	5.0E+04	Upper Limit	5.4E+08			5.0E+04
Perfluoro propanoate (PFPrA-)	5.0E+04	Upper Limit	1.2E+07			5.0E+04
Perfluoro butanoate (PFBA-)	5.0E+04	Upper Limit	7.3E+07			5.0E+04
Perfluoro pentanoate (PFPeA-)	5.0E+04	Upper Limit	1.2E+08			5.0E+04
Perfluoro hexanoate (PFHxA-)	5.0E+04	Upper Limit	1.7E+08			5.0E+04
Perfluoro heptanoate (PFHpA-)	5.0E+04	Upper Limit	2.7E+08			5.0E+04
Perfluoro octanoate (PFOA-)	5.0E+04	Upper Limit	3.1E+08			5.0E+04
Perfluoro nonanoate (PFNA-)	5.0E+04	Upper Limit	3.9E+08			5.0E+04
Perfluoro decanoate (PFDA-)	5.0E+04	Upper Limit	4.8E+08			5.0E+04
Perfluoro undecanoate (PFUnDA-)	5.0E+04	Upper Limit	5.8E+08			5.0E+04
Perfluoro dodecanoate (PFDoDA-)	5.0E+04	Upper Limit	7.0E+08			5.0E+04
Perfluoro tridecanoate (PFTrDA-)	5.0E+04	Upper Limit	8.5E+08			5.0E+04
Perfluoro tetradecanoate (PFTeDA-)	5.0E+04	Upper Limit	1.0E+09			5.0E+04
Perfluorooctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	5.0E+04	Upper Limit	5.0E+08			5.0E+04
6:2 Fluorotelomer sulfonate (6:2 FTS-)	5.0E+04	Upper Limit	2.9E+08			5.0E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	5.0E+04	Upper Limit	1.1E+08			5.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	8.8E+03	Solubility	8.8E+03			5.0E+04
8:2 Fluorotelomer alcohol (8:2 FTOH-)	9.9E+01	Solubility	9.9E+01			5.0E+04
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	5.0E+04	Upper Limit	9.6E+04			5.0E+04

References:
Taste and odor thresholds not currently available for PFAS compounds.
Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).

Notes:
Ceiling Level: lowest of 1/2 solubility, taste and odor threshold and 50000 ug/L maximum level

TABLE G-4. SURFACE WATER GROSS CONTAMINATION ACTION LEVELS
(surface water IS NOT a current or potential source of drinking water)
(ug/L)

CHEMICAL PARAMETER	Final Action Level	Basis	Solubility (1/2)	Nuisance Odor Threshold	Basis	Upper Limit
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Upper Limit	1.1E+06			5.0E+04
Perfluoropentane sulfonate (PFPeS-)	5.0E+04	Upper Limit	6.6E+07			5.0E+04
Perfluorohexane sulfonate (PFHxS-)	5.0E+04	Upper Limit	8.5E+07			5.0E+04
Perfluoroheptane sulfonate (PFHpS-)	5.0E+04	Upper Limit	1.8E+08			5.0E+04
Perfluorooctane sulfonate (PFOS-)	5.0E+04	Upper Limit	2.8E+08			5.0E+04
Perfluorodecane sulfonate (PFDS-)	5.0E+04	Upper Limit	5.4E+08			5.0E+04
Perfluoro propanoate (PFPrA-)	5.0E+04	Upper Limit	1.2E+07			5.0E+04
Perfluoro butanoate (PFBA-)	5.0E+04	Upper Limit	7.3E+07			5.0E+04
Perfluoro pentanoate (PFPeA-)	5.0E+04	Upper Limit	1.2E+08			5.0E+04
Perfluoro hexanoate (PFHxA-)	5.0E+04	Upper Limit	1.7E+08			5.0E+04
Perfluoro heptanoate (PFHpA-)	5.0E+04	Upper Limit	2.7E+08			5.0E+04
Perfluoro octanoate (PFOA-)	5.0E+04	Upper Limit	3.1E+08			5.0E+04
Perfluoro nonanoate (PFNA-)	5.0E+04	Upper Limit	3.9E+08			5.0E+04
Perfluoro decanoate (PFDA-)	5.0E+04	Upper Limit	4.8E+08			5.0E+04
Perfluoro undecanoate (PFUnDA-)	5.0E+04	Upper Limit	5.8E+08			5.0E+04
Perfluoro dodecanoate (PFDoDA-)	5.0E+04	Upper Limit	7.0E+08			5.0E+04
Perfluoro tridecanoate (PFTrDA-)	5.0E+04	Upper Limit	8.5E+08			5.0E+04
Perfluoro tetradecanoate (PFTeDA-)	5.0E+04	Upper Limit	1.0E+09			5.0E+04
Perfluorooctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	5.0E+04	Upper Limit	5.0E+08			5.0E+04
6:2 Fluorotelomer sulfonate (6:2 FTS-)	5.0E+04	Upper Limit	2.9E+08			5.0E+04
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	5.0E+04	Upper Limit	1.1E+08			5.0E+04
6:2 Fluorotelomer alcohol (6:2 FTOH-)	8.8E+03	Solubility	8.8E+03			5.0E+04
8:2 Fluorotelomer alcohol (8:2 FTOH-)	9.9E+01	Solubility	9.9E+01			5.0E+04
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	5.0E+04	Upper Limit	9.6E+04			5.0E+04

References:

Nuisance odor thresholds not currently available for PFAS compounds.
 Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).

Notes:

Nuisance Odor Thresholds assume no attenuation/dilution of chemical in surface water.
 Ceiling Level: lowest of 1/2 solubility, odor/taste threshold and 50000 ug/L maximum level (intended to limit general groundwater resource degradation).

TABLE H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS.

CAS #	Chemical	Physical State		Molecular Weight	Modeled Molecular Weight	Organic Carbon Partition coefficient,	Diffusivity in Air	Diffusivity in Water	Pure Component Solubility in Water	Vapor Pressure	Henry's Law Constant	Henry's Law Constant	GI Tract Absorption Factor	Skin Absorption Factor	Cancer Slope Factor (oral)	Cancer Inhalation Unit Risk	Reference Dose (oral)	Reference Concentration (inhalation)
						K _{oc}	D _a	D _w	S	VP	H	H'	GIABS	ABS	CSFo	IUR	RfDo	RfC
				MW	MW	(cm ³ /g)	(cm ² /s)	(cm ² /s)	(mg/L)	(mm Hg)	(atm·m ³ /mol)	(unitless)	(unitless)	(unitless)	(mg/kg-d) ⁻¹	(ug/m ³) ⁻¹	(mg/kg-d)	(mg/m ³)
45187-15-3	Perfluorobutane sulfonate (PFBS)	NV	S	299	299	3.10E+01	2.70E-02	7.17E-06	2.17E+03	1.15E-08	2.95E-10	1.21E-08	1.00E+00	1.00E-01			3.0E-04	4.90E-03
175905-36-9	Perfluoropentane sulfonate (PFPeS)	NV	S	349	349	1.05E+03			1.31E+05	2.82E-07	2.14E-10	8.75E-09	1.00E+00	1.00E-01			1.6E-04	
108427-53-8	Perfluorohexane sulfonate (PFHxS)	NV	S	399	399	5.62E+02	3.50E-02	4.09E-06	1.70E+05	8.13E-09	1.94E-10	7.93E-09	1.00E+00	1.00E-01			2.0E-05	1.30E-05
146689-46-5	Perfluoroheptane sulfonate (PFHpS)	NV	S	449	449	1.23E+03			3.53E+05	3.31E-07	1.79E-10	7.32E-09	1.00E+00	1.00E-01			1.0E-05	
45298-90-6	Perfluorooctane sulfonate (PFOS)	NV	S	499	499	1.12E+03	2.07E-02	5.26E-06	5.64E+05	2.45E-06	1.80E-11	7.36E-10	1.00E+00	1.00E-01			2.0E-06	8.10E-05
126105-34-8	Perfluorodecane sulfonate (PFDS)	NV	S	599	599	3.94E+03			1.08E+06	8.13E-06	3.31E-10	1.35E-08	1.00E+00	1.00E-01			1.0E-05	
44864-55-3	Perfluoro propanoate (PFPrA)	V	L	164	164	5.89E+00	5.07E-02	9.30E-06	2.44E+04	2.30E+01	3.63E-06	1.48E-04	1.00E+00	1.00E-01			5.00E-04	1.75E-03
45048-62-2	Perfluoro butanoate (PFBA)	SV	L	213	213	7.60E+01			1.46E+05	2.18E+01	5.01E-05	2.05E-03	1.00E+00	1.00E-01			3.8E-03	1.00E-02
45167-47-3	Perfluoro pentanoate (PFPeA)	SV	L	263	263	2.30E+01			2.43E+05	7.27E+00	2.97E-10	1.21E-08	1.00E+00	1.00E-01			4.0E-04	1.40E-03
92612-52-7	Perfluoro hexanoate (PFHxA)	SV	L	313	313	2.00E+01			3.44E+05	2.00E+00	2.35E-10	9.61E-09	1.00E+00	1.00E-01			5.0E-04	1.75E-03
120885-29-2	Perfluoro heptanoate (PFHpA)	NV	S	363	363	4.30E+01			5.30E+05	3.03E-01	2.09E-10	8.54E-09	1.00E+00	1.00E-01			2.0E-05	
45285-51-6	Perfluoro octanoate (PFOA)	NV	S	413	413	1.82E+02			6.24E+05	1.92E-01	1.92E-10	7.85E-09	1.00E+00	1.00E-01			3.0E-06	4.10E-06
72007-68-2	Perfluoro nonanoate (PFNA)	NV	S	463	463	1.06E+03			7.78E+05	8.98E-02	1.18E-09	4.82E-08	1.00E+00	1.00E-01			3.0E-06	2.80E-05
73829-36-4	Perfluoro decanoate (PFDA)	NV	S	513	513	7.24E+02			9.54E+05	2.39E-02	1.50E-10	6.13E-09	1.00E+00	1.00E-01			2.0E-06	5.30E-05
196859-54-8	Perfluoro undecanoate (PFUnDA)	NV	S	563	563	2.69E+03			1.16E+06	1.27E-02	3.34E-10	1.37E-08	1.00E+00	1.00E-01			5.0E-06	
171978-95-3	Perfluoro dodecanoate (PFDoDA)	NV	S	613	613	8.54E+04			1.40E+06	4.72E-03	3.40E-10	1.39E-08	1.00E+00	1.00E-01			6.7E-06	4.20E-05
862374-87-6	Perfluoro tridecanoate (PFTrDA)	NV	S	663	663	1.84E+05			1.69E+06	2.13E-03	3.48E-10	1.42E-08	1.00E+00	1.00E-01			6.7E-06	
365971-87-5	Perfluoro tetradecanoate (PFTeDA)	NV	S	713	713	2.33E+05			2.03E+06	1.20E-03	3.55E-10	1.45E-08	1.00E+00	1.00E-01			6.7E-05	
754-91-6	Perfluorooctane sulfonamide (PFOSA)	NV	S	499	499	1.26E+04	3.02E-02	3.53E-06	6.64E-01	2.48E-01	1.26E-09	5.15E-08	1.00E+00	1.00E-01			1.20E-05	
122499-17-6	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA)	NV	S	329	329	1.20E+01			1.00E+06	2.40E-01	4.06E-06	1.66E-04	1.00E+00				3.0E-06	
425670-75-3	6:2 Fluorotelomer sulfonate (6:2 FTS)	NV	S	427	427	9.47E+02			5.72E+05	8.24E-07	1.83E-10	7.48E-09	1.00E+00	1.00E-01			3.9E-04	1.00E-03
958445-44-8	Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA)	NV	S	395	395	9.67E+02			2.17E+05	1.32E-02	1.80E-10	7.36E-09	1.00E+00	1.00E-01			3.0E-04	
647-42-7	6:2 Fluorotelomer alcohol (6:2 FTOH)	SV	L	364	364	3.16E+03			1.76E+01	1.70E+00	2.60E-10	1.06E-08	1.00E+00	1.00E-01			1.3E-03	4.6E-03
678-39-7	8:2 Fluorotelomer alcohol (8:2 FTOH)	NV	S	464	464	2.24E+03			1.98E-01	2.09E-01	2.09E-10	8.54E-09	1.00E+00	1.00E-01			1.1E-03	3.9E-03
88992-47-6	6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS)	NV	S	586	586	6.76E+04			1.92E+02	2.57E-09	8.91E-10	3.64E-08	1.00E+00	1.00E-01			5.0E-04	

General Notes:

- Abbreviations** refer to anion form of compound, assumed to be dominant in environmental samples (noted by "-" sign after abbreviation; refer to Table 1a in November 2020 Technical Memorandum).
- Physical state of chemical** at ambient conditions (V - volatile, NV - nonvolatile, SV-semivolatile, S - solid, L - liquid, G - gas). Chemical considered to be "volatile" if Henry's number (atm m3/mole) >0.00001 and molecular weight <200, and "semi-volatile" if molecular weight >200.
- Confidence in Koc values low** (USEPA CompTox database - modeled).
- Confidence in published, modeled vapor pressures** is low (e.g., USEPA 2017); not considered in determination of a compound as volatile or semivolatile except in case of 6:2 FTOH.
- Dimensionless Henry's Law constant** calculated based on Sander (2015) assuming a temperature of 25°C.

References:
Refer to PFAS Technical Memorandum Table 3b for reference documents used to compile physiochemical constants for individual PFAS.
Refer to PFAS Technical Memorandum Table 4a for reference documents used to compile toxicity factors for individual PFAS.

TABLE I-1. DIRECT-EXPOSURE ACTION LEVELS
¹UNRESTRICTED LAND USE SCENARIO

CHEMICAL	Final Action Level (mg/kg)	Basis	² Carcinogens (mg/kg)	² Mutagens (mg/kg)	³ Noncarcinogens (Final) (mg/kg)	³ Noncarcinogens (HQ = 1.0) (mg/kg)	Saturation (mg/kg)
Perfluorobutane sulfonate (PFBS-)	3.8E+00	noncarcinogenic effects			3.8E+00	3.8E+00	NA
Perfluoropentane sulfonate (PFPeS-)	2.0E+00	noncarcinogenic effects			2.0E+00	2.0E+00	NA
Perfluorohexane sulfonate (PFHxS-)	2.5E-01	noncarcinogenic effects			2.5E-01	2.5E-01	NA
Perfluoroheptane sulfonate (PFHpS-)	1.3E-01	noncarcinogenic effects			1.3E-01	1.3E-01	NA
Perfluorooctane sulfonate (PFOS-)	2.5E-02	noncarcinogenic effects			2.5E-02	2.5E-02	NA
Perfluorodecane sulfonate (PFDS-)	1.3E-01	noncarcinogenic effects			1.3E-01	1.3E-01	NA
Perfluoro propanoate (PFPrA-)	5.0E+00	noncarcinogenic effects			5.0E+00	5.0E+00	3.3E+03
Perfluoro butanoate (PFBA-)	4.8E+01	noncarcinogenic effects			4.8E+01	4.8E+01	NA
Perfluoro pentanoate (PFPeA-)	5.1E+00	noncarcinogenic effects			5.1E+00	5.1E+00	NA
Perfluoro hexanoate (PFHxA-)	6.3E+00	noncarcinogenic effects			6.3E+00	6.3E+00	NA
Perfluoro heptanoate (PFHpA-)	2.5E-01	noncarcinogenic effects			2.5E-01	2.5E-01	NA
Perfluoro octanoate (PFOA-)	3.8E-02	noncarcinogenic effects			3.8E-02	3.8E-02	NA
Perfluoro nonanoate (PFNA-)	3.8E-02	noncarcinogenic effects			3.8E-02	3.8E-02	NA
Perfluoro decanoate (PFDA-)	2.5E-02	noncarcinogenic effects			2.5E-02	2.5E-02	NA
Perfluoro undecanoate (PFUnDA-)	6.3E-02	noncarcinogenic effects			6.3E-02	6.3E-02	NA
Perfluoro dodecanoate (PFDoDA-)	8.5E-02	noncarcinogenic effects			8.5E-02	8.5E-02	NA
Perfluoro tridecanoate (PFTrDA-)	8.5E-02	noncarcinogenic effects			8.5E-02	8.5E-02	NA
Perfluoro tetradecanoate (PFTeDA-)	8.5E-01	noncarcinogenic effects			8.5E-01	8.5E-01	NA
Perfluorooctane sulfonamide (PFOSA)	1.5E-01	noncarcinogenic effects			1.5E-01	1.5E-01	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	4.7E-02	noncarcinogenic effects			4.7E-02	4.7E-02	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E+00	noncarcinogenic effects			4.9E+00	4.9E+00	NA
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	3.8E+00	noncarcinogenic effects			3.8E+00	3.8E+00	NA
6:2 Fluorotelomer alcohol (6:2 FTOH-)	1.6E+01	noncarcinogenic effects			1.6E+01	1.6E+01	NA
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.4E+01	noncarcinogenic effects			1.4E+01	1.4E+01	NA
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	6.3E+00	noncarcinogenic effects			6.3E+00	6.3E+00	NA

Primary source: Refer to accompanying PFAS Technical Memorandum.

Notes:

- Based on assumed residential exposure scenario. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
- Carcinogens: Default target excess cancer risk = 10⁻⁶.
- Noncarcinogens: Final action level based on Relative Source Contribution of 20% and target Hazard Quotient = 1.0.
- NA = Toxicity factors not available.

See text for equations and assumptions used in models.

Final action level is lowest of individual screening levels for carcinogenic effects and noncarcinogenic effects or action level for construction/trench workers if lower (see Table I-3). Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

**TABLE I-2. DIRECT-EXPOSURE ACTION LEVELS
COMMERCIAL/INDUSTRIAL LAND USE SCENARIO**

CHEMICAL	Final Action Level (mg/kg)	Basis	¹ Carcinogens (Risk = 10 ⁻⁶) (mg/kg)	² Noncarcinogens (Final) (mg/kg)	² Noncarcinogens (HQ = 1.0) (mg/kg)	Saturation (mg/kg)
Perfluorobutane sulfonate (PFBS-)	3.4E+01	noncarcinogenic effects		3.4E+01	3.4E+01	NA
Perfluoropentane sulfonate (PFPeS-)	1.8E+01	noncarcinogenic effects		1.8E+01	1.8E+01	NA
Perfluorohexane sulfonate (PFHxS-)	2.3E+00	noncarcinogenic effects		2.3E+00	2.3E+00	NA
Perfluoroheptane sulfonate (PFHpS-)	1.1E+00	noncarcinogenic effects		1.1E+00	1.1E+00	NA
Perfluorooctane sulfonate (PFOS-)	2.3E-01	noncarcinogenic effects		2.3E-01	2.3E-01	NA
Perfluorodecane sulfonate (PFDS-)	1.1E+00	noncarcinogenic effects		1.1E+00	1.1E+00	NA
Perfluoro propanoate (PFPrA-)	3.7E+01	noncarcinogenic effects		3.7E+01	3.7E+01	3.3E+03
Perfluoro butanoate (PFBA-)	4.3E+02	noncarcinogenic effects		4.3E+02	4.3E+02	NA
Perfluoro pentanoate (PFPeA-)	4.5E+01	noncarcinogenic effects		4.5E+01	4.5E+01	NA
Perfluoro hexanoate (PFHxA-)	5.6E+01	noncarcinogenic effects		5.6E+01	5.6E+01	NA
Perfluoro heptanoate (PFHpA-)	2.3E+00	noncarcinogenic effects		2.3E+00	2.3E+00	NA
Perfluoro octanoate (PFOA-)	3.4E-01	noncarcinogenic effects		3.4E-01	3.4E-01	NA
Perfluoro nonanoate (PFNA-)	3.4E-01	noncarcinogenic effects		3.4E-01	3.4E-01	NA
Perfluoro decanoate (PFDA-)	2.3E-01	noncarcinogenic effects		2.3E-01	2.3E-01	NA
Perfluoro undecanoate (PFUnDA-)	5.6E-01	noncarcinogenic effects		5.6E-01	5.6E-01	NA
Perfluoro dodecanoate (PFDoDA-)	7.6E-01	noncarcinogenic effects		7.6E-01	7.6E-01	NA
Perfluoro tridecanoate (PFTrDA-)	7.6E-01	noncarcinogenic effects		7.6E-01	7.6E-01	NA
Perfluoro tetradecanoate (PFTeDA-)	7.6E+00	noncarcinogenic effects		7.6E+00	7.6E+00	NA
Perfluorooctane sulfonamide (PFOSA)	1.4E+00	noncarcinogenic effects		1.4E+00	1.4E+00	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	4.8E-01	noncarcinogenic effects		4.8E-01	4.8E-01	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.4E+01	noncarcinogenic effects		4.4E+01	4.4E+01	NA
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	3.4E+01	noncarcinogenic effects		3.4E+01	3.4E+01	NA
6:2 Fluorotelomer alcohol (6:2 FTOH-)	1.5E+02	noncarcinogenic effects		1.5E+02	1.5E+02	NA
8:2 Fluorotelomer alcohol (8:2 FTOH-)	1.2E+02	noncarcinogenic effects		1.2E+02	1.2E+02	NA
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	5.6E+01	noncarcinogenic effects		5.6E+01	5.6E+01	NA

Primary source: Refer to accompanying PFAS Technical Memorandum.

Notes:

1. Based on assumed residential exposure scenario. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
2. Carcinogens: Default target excess cancer risk = 10⁻⁶.
3. Noncarcinogens: Final action level based on Relative Source Contribution of 20% and target Hazard Quotient = 1.0.
4. NA = Toxicity factors not available.

See text for equations and assumptions used in models.

Final action level is lowest of individual screening levels for carcinogenic effects and noncarcinogenic effects or action level for construction/trench workers if lower (see Table I-3). Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

**TABLE I-3. DIRECT-EXPOSURE ACTION LEVELS
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

CHEMICAL	Final Action Level (mg/kg)	Basis	¹ Carcinogens (Risk = 10 ⁻⁵) (mg/kg)	² Noncarcinogens (Final) (mg/kg)	² Noncarcinogens (HQ = 1.0) (mg/kg)	Saturation (mg/kg)
Perfluorobutane sulfonate (PFBS-)	6.8E+01	noncarcinogenic effects		6.8E+01	6.8E+01	NA
Perfluoropentane sulfonate (PFPeS-)	3.6E+01	noncarcinogenic effects		3.6E+01	3.6E+01	NA
Perfluorohexane sulfonate (PFHxS-)	4.4E+00	noncarcinogenic effects		4.4E+00	4.4E+00	NA
Perfluoroheptane sulfonate (PFHpS-)	2.3E+00	noncarcinogenic effects		2.3E+00	2.3E+00	NA
Perfluorooctane sulfonate (PFOS-)	4.5E-01	noncarcinogenic effects		4.5E-01	4.5E-01	NA
Perfluorodecane sulfonate (PFDS-)	2.3E+00	noncarcinogenic effects		2.3E+00	2.3E+00	NA
Perfluoro propanoate (PFPrA-)	6.5E+01	noncarcinogenic effects		6.5E+01	6.5E+01	3.3E+03
Perfluoro butanoate (PFBA-)	8.6E+02	noncarcinogenic effects		8.6E+02	8.6E+02	NA
Perfluoro pentanoate (PFPeA-)	9.0E+01	noncarcinogenic effects		9.0E+01	9.0E+01	NA
Perfluoro hexanoate (PFHxA-)	1.1E+02	noncarcinogenic effects		1.1E+02	1.1E+02	NA
Perfluoro heptanoate (PFHpA-)	4.6E+00	noncarcinogenic effects		4.6E+00	4.6E+00	NA
Perfluoro octanoate (PFOA-)	6.7E-01	noncarcinogenic effects		6.7E-01	6.7E-01	NA
Perfluoro nonanoate (PFNA-)	6.8E-01	noncarcinogenic effects		6.8E-01	6.8E-01	NA
Perfluoro decanoate (PFDA-)	4.5E-01	noncarcinogenic effects		4.5E-01	4.5E-01	NA
Perfluoro undecanoate (PFUnDA-)	1.1E+00	noncarcinogenic effects		1.1E+00	1.1E+00	NA
Perfluoro dodecanoate (PFDoDA-)	1.5E+00	noncarcinogenic effects		1.5E+00	1.5E+00	NA
Perfluoro tridecanoate (PFTrDA-)	1.5E+00	noncarcinogenic effects		1.5E+00	1.5E+00	NA
Perfluoro tetradecanoate (PFTeDA-)	1.5E+01	noncarcinogenic effects		1.5E+01	1.5E+01	NA
Perfluorooctane sulfonamide (PFOSA)	2.7E+00	noncarcinogenic effects		2.7E+00	2.7E+00	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)	1.0E+00	noncarcinogenic effects		1.0E+00	1.0E+00	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	8.8E+01	noncarcinogenic effects		8.8E+01	8.8E+01	NA
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)	6.8E+01	noncarcinogenic effects		6.8E+01	6.8E+01	NA
6:2 Fluorotelomer alcohol (6:2 FTOH-)	2.9E+02	noncarcinogenic effects		2.9E+02	2.9E+02	NA
8:2 Fluorotelomer alcohol (8:2 FTOH-)	2.5E+02	noncarcinogenic effects		2.5E+02	2.5E+02	NA
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)	1.1E+02	noncarcinogenic effects		1.1E+02	1.1E+02	NA

Primary source: Refer to accompanying PFAS Technical Memorandum.

Notes:

1. Based on assumed residential exposure scenario. Considered adequate for residential housing, schools, medical facilities, day-care centers, parks and other sensitive uses.
2. Carcinogens: Default target excess cancer risk = 10⁻⁵.
3. Noncarcinogens: Final action level based on Relative Source Contribution of 20% and target Hazard Quotient = 1.0.
4. NA = Toxicity factors not available.

See text for equations and assumptions used in models.

Final action level is lowest of individual screening levels for carcinogenic effects and noncarcinogenic effects or action level for construction/trench workers if lower (see Table I-3). Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS

(For general reference only. May not be adequately comprehensive for some chemicals. Aggregate or cumulative exposures may have different or increased health effects. Available information on some chemicals is very limited. Some noted effects may be insignificant. Refer to original documents for additional information.)

CHEMICAL PARAMETER	Mutagen	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
Perfluorobutane sulfonate (PFBS-)						15 ^A	15 ^A			15 ^A				
Perfluoropentane sulfonate (PFPeS-)														
Perfluorohexane sulfonate (PFHxS-)				1 ^H ,4 ^A		1 ^A ,9 ^H	4 ^A		1 ^H ,2 ^H ,9 ^H		11 ^A	10 ^H		5 ^H
Perfluoroheptane sulfonate (PFHpS-)														
Perfluorooctane sulfonate (PFOS-)		13 ^A ,17	1 ^H ,2 ^H	1 ^H ,1 ^A ,5 ^H	1 ^H	1 ^H ,1 ^A ,9 ^H	1 ^H		1 ^H ,1 ^A ,2 ^H ,9 ^H ,13 ^A	2 ^H ,5 ^H	11 ^A	1 ^H ,10 ^H		5 ^H
Perfluorodecane sulfonate (PFDS-)														
Perfluoro propanoate (PFPrA-)			23 ^A	23 ^A				23 ^A		23 ^A				
Perfluoro butanoate (PFBA-)				3 ^A		1 ^A ,3 ^A	3 ^A	3 ^A						
Perfluoro pentanoate (PFPeA-)														
Perfluoro hexanoate (PFHxA-)				1 ^A , 21 ^A	1 ^H	1 ^A , 21 ^A	1 ^A	1 ^A , 21 ^A		1 ^A				
Perfluoro heptanoate (PFHpA-)				1 ^A										
Perfluoro octanoate (PFOA-)		6 ^H ,7 ^H ,13 ^A ,16,	1 ^H ,2 ^H ,6 ^H ,7 ^H	1 ^H ,1 ^A ,5 ^H ,6 ^H	1 ^H ,5 ^H ,6 ^H ,7 ^H	1 ^H ,1 ^A ,5 ^H ,6 ^H	1 ^H ,5 ^H ,7 ^H	8 ^A	1 ^H ,1 ^A ,2 ^H ,5 ^H	2 ^H ,5 ^H ,6 ^H	11 ^A ,5 ^H	1 ^H ,1 ^A ,8 ^A ,10 ^H	1 ^H	5 ^H
Perfluoro nonanoate (PFNA-)			1 ^H ,10 ^H			1 ^A								5 ^H
Perfluoro decanoate (PFDA-)			1 ^H			1 ^A			1 ^H ,2 ^H					
Perfluoro undecanoate (PFUnDA-)						1 ^A								
Perfluoro dodecanoate (PFDoDA-)														
Perfluoro tridecanoate (PFTrDA-)														
Perfluoro tetradecanoate (PFTeDA-)														
Perfluorooctane sulfonamide (PFOSA)														
2,3,3,3-tetrafluoro-2-(heptafluoroproxy) propanoate (HFPO DA-)		14 ^A		14 ^A		14 ^A		14 ^A	14 ^A					
6:2 Fluorotelomer sulfonate (6:2 FTS-)				19 ^A , 20 ^A	19 ^A					20 ^A				20 ^A
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)			12 ^A			12 ^A		12 ^A						
6:2 Fluorotelomer alcohol (6:2 FTOH-)				22 ^A		22 ^A	22 ^A							22 ^A
8:2 Fluorotelomer alcohol (8:2 FTOH-)				22 ^A		22 ^A				22 ^A				
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)						22 ^A			22 ^A					

Notes:

Refer to accompanying Technical Memorandum. "A" = Animal study; "H" = Human epidemiological study. Primary health risk long-term exposure to PFASs considered to be potential impacts to liver function and immune system toxicity.

References

1 ^H : Human Epi Studies correlation in ATSDR 2018 Toxicological Profile for Perfluoroalkyls, Updated May 2020 (https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf)				increased liver enzymes	increased risk PIH	small decreases in birth weight	thyroid alterations		decreased Ab response to vaccines			decreased fertility	increased asthma	
1 ^A : Animal Studies correlation in ATSDR 2018 Toxicological Profile for Perfluoroalkyls, Updated May 2020 (https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf)			increased total cholesterol	degenerative & necrotic effects likely relevant to humans		decreased pup body weight and survival. locomotor problems	thyroid alterations	Decreases in RBC count, Hb, and HCT levels	impaired response to antigens	renal tubular degeneration, papillary necrosis		decreased mammary gland development		
2 ^H : Kirk M et al 2018 The PFAS Health Study: Systematic Literature Review		kidney CA , testicular CA							ab response to diphtheria and rubella vaccines	impaired GFR, hyperuricemia, CKD				
3 ^A : MDH 2018 Toxicological Summary for PFBA (https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfba2summ.pdf), animal studies only				increased liver weights and morph changes		developmental delays in offspring of mice exp during pregnancy	decreased serum total T4	decreased RBCs, HCT, Hb						

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS

(For general reference only. May not be adequately comprehensive for some chemicals. Aggregate or cumulative exposures may have different or increased health effects. Available information on some chemicals is very limited. Some noted effects may be insignificant. Refer to original documents for additional information.)

CHEMICAL PARAMETER	Mutagen	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
4^A : MDH 2019 Toxicological Summary for PFHxS (https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfhxs.pdf). Animal studies only			increased cholesterol	focal hepatic necrosis			decreased free T4							
5^H : Expert Health Panel for Per- and Poly- Fluoroalkyl Substances (PFAS) 2018 Australian Report to the Minister (https://www1.health.gov.au/internet/main/publishing.nsf/Content/C9734ED6BE238EC0CA2581BD00052C03/%24File/expert-panel-report.pdf)		possible increased risk of kidney & testicular CA	increased total cholesterol	increased ALT (may not be clinically significant)	increased risk of PIH	low birth weights	thyroid dysfunction in women		decreased immune response	decreased uric acid clearance				
6^H : Rijs et al RIVM Dutch National Institute for Public Health and the Environment 2017 PFOA exposure and Health: A review of scientific literature. (https://www.rivm.nl/bibliotheek/rapporten/2017-0086.pdf)		association with testicular and kidney cancer	probable link with high cholesterol	increased ALT and other liver enzymes	increased PIH	decreased birth weight			decreased response to vaccines	increased uric acid				
7^H : C8 Science Panel 2012 Probable Link Reports (http://www.c8sciencepanel.org/prob_link.html)		probable link with kidney & testicular CAs			probable link with PIH		probable link with thyroid disease		probable link with ulcerative colitis					
8^{H,A} : Sunderland et al 2018 A review of pathways of human exposure to PFAS and present understanding of health effects		carcinogenic in rats						changes in leukocyte counts	immune problems			male repo hormone alteration		
9^H : Liew Z et al 2018 Developmental exposures to PFAS: an update of associated health outcomes			increased risk of hyperglycemia			low birth weights			modulates immune responses in children					
10^H : Lin CY et al 2009 Association among serum PFAS chemicals, glucose homeostasis risk, and metabolic syndrome												increased risk of gestational DM		
11^A : Johansson et al 2008 Neonatal Exposures to PFOS and PFOA causes neurobehavioral defects in adult mice			weight loss, reduced food consumption								inability to habituate to new environment			
12^A : Gordon SC 2011 Toxicological evaluation of ADONA			decreased total cholesterol			decreased litter size		increased WBC, decreased RBC, HCT, Hb		Decreased calcium excretion				
13^A : National Toxicology Program 2019 Technical Report on the toxicology and carcinogenic studies of PFOA administered in feed to Sprague-Dawley Rats		clear evidence of carcinogenic activity in rats (liver and pancreatic)							presumed immune hazard					

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS

(For general reference only. May not be adequately comprehensive for some chemicals. Aggregate or cumulative exposures may have different or increased health effects. Available information on some chemicals is very limited. Some noted effects may be insignificant. Refer to original documents for additional information.)

CHEMICAL PARAMETER	Mutagen	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
14^A: USEPA 2018 Draft human toxicity values for HFPO (GenX) (https://www.epa.gov/sites/production/files/2018-11/documents/genx_public_comment_draft_toxicity_assessment_nov2018-508.pdf)		liver, pancreatic, testicular tumors		increased liver enzymes and hepatic necrosis		low birth weights		decreased RBCs, Hb, HCT	immune alterations					
15^A: USEPA 2018 Draft human toxicity values for PFBS (https://www.epa.gov/sites/production/files/2018-11/documents/pfbs_public_comment_draft_toxicity_assessment_nov2018-508.pdf)						evidence support a hazard	evidence support a hazard			evidence support a hazard				
16^{AH}: USEPA 2016 Drinking water health advisory for PFOA (https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final_508.pdf)		suggestive evidence of carcinogenic potential												
17^{AH}: USEPA 2016 Drinking water health advisory for PFOS (https://www.epa.gov/sites/production/files/2016-05/documents/pfos_health_advisory_final_508.pdf)		suggestive evidence of carcinogenic potential												
18: IARC 2016 Monograph 110: PFOA (https://monographs.iarc.fr/wp-content/uploads/2018/06/mono110-01.pdf)		limited evidence of carcinogenicity (kidney and testis), possible human carcinogen 2B												
19^A: Michigan Dept of Environment, Great Lakes and Energy Interoffice Communication on 6:2 FTSA, September 2020				AST elevation, increased liver weight	Decrease in Cardiac weight									
20^A: NASF, 6:2 FluorotelomerSulfonate (6:2 FTS), Toxicology at a Glance: National Association for Surface Finishing, March 2019				Increased liver weight, necrosis						Increased kidney weight, altered Cr				Skin irritation
21^A: USEPA DRAFT Toxicological Review of Perfluorohexanoic Acid and Related Salts February 2022				Increased liver weight, necrosis, increased liver enzymes		decreased birth weight	thyroid alterations	Decreased RBCs, Hb, HCT						

TABLE K. *ANTHROPOGENIC BACKGROUND CONCENTRATIONS OF PFASs IN URBAN SOIL

CHEMICAL PARAMETER	Range (mg/kg)	² Upper Bound (mg/kg)	³ Background Threshold Value (mg/kg)	⁴ Selected Action Level (mg/kg)
Perfluorobutane sulfonate (PFBS-)				
Perfluoropentane sulfonate (PFPeS-)				
Perfluorohexane sulfonate (PFHxS-)				
Perfluoroheptane sulfonate (PFHpS-)				
Perfluorooctane sulfonate (PFOS-)				
Perfluorodecane sulfonate (PFDS-)				
Perfluoro propanoate (PFPrA-)				
Perfluoro butanoate (PFBA-)				
Perfluoro pentanoate (PFPeA-)				
Perfluoro hexanoate (PFHxA-)				
Perfluoro heptanoate (PFHpA-)				
Perfluoro octanoate (PFOA-)				
Perfluoro nonanoate (PFNA-)				
Perfluoro decanoate (PFDA-)				
Perfluoro undecanoate (PFUnDA-)				
Perfluoro dodecanoate (PFDoDA-)				
Perfluoro tridecanoate (PFTrDA-)				
Perfluoro tetradecanoate (PFTeDA-)				
Perfluroroctane sulfonamide (PFOSA)				
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)				
6:2 Fluorotelomer sulfonate (6:2 FTS-)				
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)				
6:2 Fluorotelomer alcohol (6:2 FTOH-)				
<p>Primary Reference: Pending - Compilation of anthropogenic background levels of PFASs in soil to be prepared as data become available.</p> <p>Notes:</p> <p>1. Upper Bound concentration selected based on evaluation of univariate sample data plots.</p> <p>2. Background Threshold Value set to maximum-reported concentration, excluding samples with suspected anthropogenic contamination.</p> <p>3. Selected action level based on Upper Bound concentration unless otherwise noted.</p>				

TABLE L. SOIL ECOTOXICITY ACTION LEVELS

CHEMICAL PARAMETER	Urban Area Ecotoxicity Criteria (mg/kg)	
	Residential Areas	Commercial/ Industrial areas
Perfluorobutane sulfonate (PFBS-)		
Perfluoropentane sulfonate (PFPeS-)		
Perfluorohexane sulfonate (PFHxS-)		
Perfluoroheptane sulfonate (PFHpS-)		
Perfluorooctane sulfonate (PFOS-)		
Perfluorodecane sulfonate (PFDS-)		
Perfluoro propanoate (PFPrA-)		
Perfluoro butanoate (PFBA-)		
Perfluoro pentanoate (PFPeA-)		
Perfluoro hexanoate (PFHxA-)		
Perfluoro heptanoate (PFHpA-)		
Perfluoro octanoate (PFOA-)		
Perfluoro nonanoate (PFNA-)		
Perfluoro decanoate (PFDA-)		
Perfluoro undecanoate (PFUnDA-)		
Perfluoro dodecanoate (PFDoDA-)		
Perfluoro tridecanoate (PFTrDA-)		
Perfluoro tetradecanoate (PFTeDA-)		
Perflurooctane sulfonamide (PFOSA)		
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO DA-)		
6:2 Fluorotelomer sulfonate (6:2 FTS-)		
Ammonium 4,8-Dioxa-3H-perfluoro nonanoate (ADONA-)		
6:2 Fluorotelomer alcohol (6:2 FTOH-)		
8:2 Fluorotelomer alcohol (8:2 FTOH-)		
6:2 Fluorotelomer thioether amido sulfonate (6:2 FTTAoS-)		

Attachment 4

Total PFAS Risk Fact Sheet (HIDOH March 2024)



Assessment of Total PFAS Risk

This fact sheet is an accompaniment to the HDOH Technical Memorandum *Interim Soil and Water Environmental Action Levels (EALs) for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs)* (HDOH 2024a) and summarizes a method to calculate the cumulative health risk posed by exposure to different groupings of PFAS compounds. The approach described is intended to be used by environmental professionals familiar with the collection of samples and basic methods used to quantify the health risk posed by exposure to contaminants in environmental media.

What are PFASs?

Per- and polyfluoroalkyl substances (PFASs) are manmade chemicals used in many industries since the 1940s to make things waterproof, non-stick, and stain resistant. Examples of materials that may contain PFASs include firefighting foam, carpet, furniture, waterproof clothing, and certain types of food packaging. Similar compounds are also found in influent, effluent and biosolids associated with municipal and industrial wastewater treatment plants as well as leachate from landfills. These chemicals are often described as “forever chemicals” because they do not breakdown over time and can build up in the environment and our bodies. Additional information can be found on the Hawai‘i Department of Health PFAS webpage (HDOH 2024).

Toxicological studies have demonstrated that exposure to even low levels of PFASs over many years in food, water and other media can pose health risks. The primary PFASs of interest within these groups are referred to as “Terminal Endpoint” compounds (“Terminal PFASs;” Figure 2). These are the final breakdown products of PFASs compounds assumed to cause the greatest health risk and for which extensive toxicological studies have been carried out. PFASs are named in part based on the number of carbons in the compound. Long-chain compounds are generally more toxic than shorter chain compounds.

What are Environmental Action Levels?

“Environmental Action Levels (EALs)” prepared by HDOH reflect concentrations of PFASs in soil and drinking water that are not expected to pose a significant risk to young children or adults even after many years of exposure. Exceeding an action level does not necessarily indicate an imminent health risk, but it does indicate that additional evaluation is warranted. Additional information is provided in the main document to this fact sheet (HDOH 2024a) and in the main HDOH EAL guidance document (HDOH 2024).

The Technical Memorandum accompanying this Fact Sheet presents soil, water and in some cases indoor air action levels for each of the Terminal PFASs listed above and a short list of more complex, “precursor” PFASs. Precursor compounds are characterized by the addition of a functional group to a Terminal PFAS.

	Ultrashort	Terminal Endpoint Compound	# Carbons
	Short		
	Long		
Sulfonates		Perfluoro butane sulfonate	4
		Perfluoro pentane sulfonate	5
		Perfluoro hexane sulfonate	6
		Perfluoro heptane sulfonate	7
		Perfluoro octane sulfonate	8
		Perfluoro decane sulfonate	10
Carboxylates		Perfluoro propanoate	3
		Perfluoro butanoate	4
		Perfluoro pentanoate	5
		Perfluoro hexanoate	6
		Perfluoro heptanoate	7
		Perfluoro octanoate	8
		Perfluoro nonanoate	9
		Perfluoro decanoate	10
		Perfluoro undecanoate	11
		Perfluoro dodecanoate	12
	Perfluoro tridecanoate	13	
	Perfluoro tetradecanoate	14	

Figure 1. Terminal Endpoint PFASs.



PFASs Environmental Action Levels Total PFAS Risk Fact Sheet

This includes manufactured compounds and partial metabolites of these compounds. The latter are known to break down into terminal PFAS compounds in the environment and inside of the body. The action levels focus on the protection of young children. Potential long-term cancer risks are also considered for some PFASs, but noncancer-related risks and the protection of young children take precedence. Refer to the accompanying Technical Memorandum for additional information.

How are samples collected and tested for PFASs?

Samples of soil and water to be tested for PFASs should be collected in accordance with methods described in the HIDOH *Technical Guidance Manual* (TGM, HIDOH 2024). Samples of soil, sediment, biosolids and other particulate matter must be obtained using Decision Unit and Multi Increment® Sample (DU-MIS) investigation methods outlined in Sections 3 and 4 of the TGM. (Multi Increment® is registered trademarked of EnviroStat, Inc.) Methods for the collection of representative samples of surface water and groundwater are discussed in Section 6 of the TGM.

Assessment of Total PFAS Risk requires up to three separate laboratory analyses – analysis prior to sample oxidation, analysis following sample oxidation and analysis for Total Organic Fluorine. The method used to oxidize a sample is referred to as “Total Oxidizable Precursors” or “TOPs.” Sample data based on TOPs processing are most useful for assessment of risk. Analysis of a sample prior to sample oxidation is primarily useful for forensics purposes and determination of the origin of the PFAS contamination.

The same method is used for both pre-TOPs and post-TOPs analysis. Some laboratories have developed equivalent or improved methods. Check with the laboratory prior to the collection of samples to determine which method is most appropriate for your needs.

What is “TOPs” analysis?

Complex, PFAS precursor compounds are broken down to Terminal PFAS compounds through a laboratory sample processing method referred to as “Total Oxidizable Precursors” or “TOPs” (Houtz and Sedlak 2012, Ateia 2023, Pelch 2023). The sample is heated with an oxidizing agent under alkaline conditions. Much like pruning branches from a tree to expose the underlying trunk, this strips functional groups from complex, “precursor” PFAS compounds and generates a new set of Terminal PFASs compounds specific to the types of precursors originally present (Figure 1).

An example is the oxidation of 6:2 fluorotelomer thioether amido sulfonic acid (6:2 FtTAoS), the primary PFAS compound in aqueous firefighting foam (AFFF). TOPs effectively clips off the large, functional group attached to 6:2 FtTAoS, leaving behind the Terminal PFAS compound perfluoroheptanoate (PFHpA⁻). This simulates metabolism and breakdown of 6:2 FtTAoS in the body. For reasons that are not yet well understood, additional shorter-chain PFAS like perfluorohexanoate (PFHxA⁻) and perfluorobutanoate (PFBA⁻) can also be generated. Note that the anion forms of the compounds are typically found in nature.

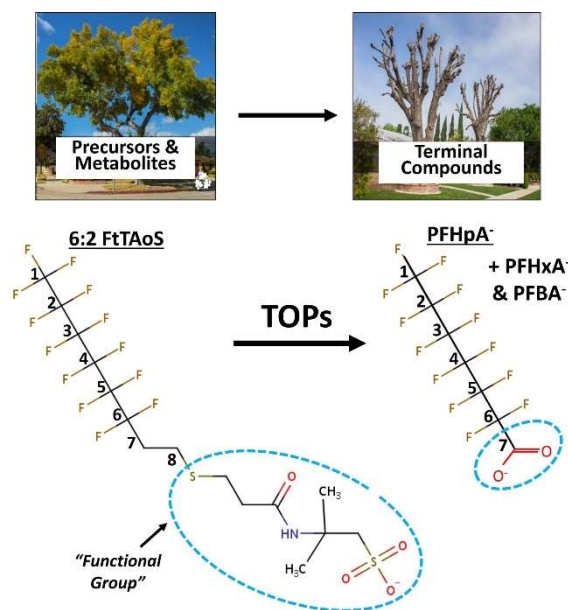


Figure 2. Oxidation of 6:2 FtTAoS to generate the Terminal Endpoint compound PFHpA⁻.



PFASs Environmental Action Levels Total PFAS Risk Fact Sheet

How is the total health risk posed by exposure to PFASs determined?

The cumulative health effects posed by PFASs is assessed with respect to three groups of Terminal PFASs that could be present in a sample (Figure 2), defined for use in this guidance as “Pre-TOPs PFASs,” “Post-TOPs Precursor PFASs” and “Excess Fluorine PFASs.” Pre-TOPs compounds represent Terminal PFAS compounds originally present in the sample. Post-TOPs Precursor PFASs represent Terminal PFAS compounds generated by oxidation of precursor compounds in the sample using TOPs analysis. Any additional PFASs in a sample are identified by comparing the concentration of TOF reported for the sample to the total concentration of fluorine predicted by concentrations Terminal PFASs reported by the TOPs analysis. The difference is referred to as “Excess Fluorine.” Detailed analysis of samples with excess fluorine typically identifies the associated compounds as “ultrashort” PFASs such as the three-carbon perfluoropropanoate (PFPrA⁻).

Post-TOPs data are especially important for soil, biosolids and other particulate media, where significant concentrations of precursor compounds might be present. Total Organic Fluorine data tend to be more important for PFAS-contaminated water, where significant concentrations of ultrashort compounds have been reported.

Total PFAS Risk is calculated by comparing concentrations of Pre-TOPs and Post-TOPs Precursor Terminal PFAS to corresponding action levels. The concentration of additional, ultrashort PFASs based on a review of the TOF data is compared to action levels for PFPrA⁻. The ratio of the reported concentration of a compound to the corresponding action level is referred to as the “Hazard Quotient (HQ).” The sum of the Hazard Quotients calculated for pre- and post-TOPs PFASs is referred to as a “Hazard Index (HI).” Adding the Hazard Indices for Pre-TOPs PFASs and Post-TOPs Precursor PFASs to the Hazard Quotient calculated for PFASs associated with Excess Fluorine generates a cumulative Hazard Index for Total PFASs Risk as a whole:

$$\text{Total PFAS Risk} = \text{Pre-TOPs HI} + \text{Post-TOPs Precursor HI} + \text{Excess Fluorine HQ.}$$

A Hazard Index greater than “1” indicates a potential health concern that requires additional evaluation.

An Excel-based spreadsheet that accompanies this Fact Sheet and Technical Memorandum makes calculation of a Hazard Index easy. Use of the spreadsheet is strongly recommended.

Where can I get more information?

Detailed information on the methods used to assess PFAS health risk can be found in the HIDOH Technical Memorandum that accompanies this Fact Sheet (HIDOH 2024a). Additional information can be found in the references noted below and by searching for specific topics on the internet.

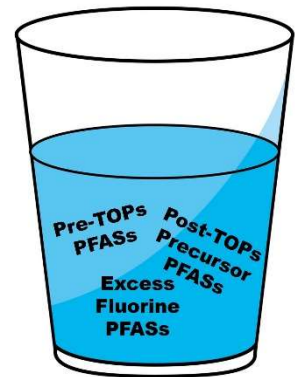


Figure 3. Three groups of PFASs potentially present in contaminated media.

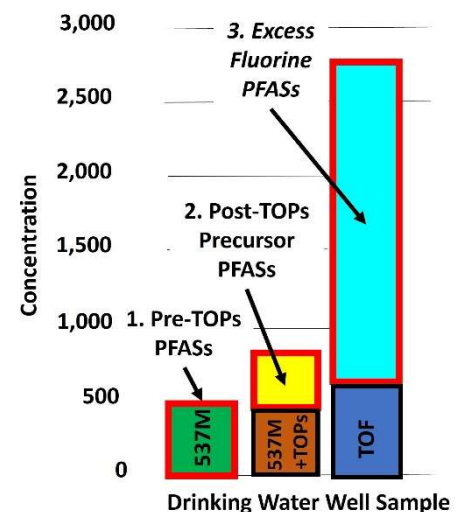


Figure 4. Three groups of PFAS-related compounds in contaminated media (Method 537M shown as an example).



PFASs Environmental Action Levels Total PFAS Risk Fact Sheet

References:

Ateia, M., Chiang, D., Cashman, M and C. Acheson, 2023, Total Oxidizable Precursor (TOP) Assay - Best Practices, Capabilities and Limitations for PFAS Site Investigation and Remediation: Environmental Science and Technology Letters, Vol. 10, pp 292–301.

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Pelch, K.E., McKnight, T. and A. Anna Read, 2023, 70 analyte PFAS test method highlights need for expanded testing of PFAS in drinking water: Science of the Total Environment, Vol. 876, 10 June 2023, 162978.

Attachment 5

Total Risk Calculator (separate Excel file)

Attachment 6

Summary of Previous Updates

April 2023 Update:

- Toxicity factors and EALs for ADONA added;
- Updated reference for PFHxA toxicity;
- Tapwater action levels updated to reflect a target noncancer Hazard Quotient of 1 versus 0.5 (used in previous editions) to match the anticipated approach for calculation of USEPA Maximum Contaminant Levels Goals for PFASs (refer to Section 8.0);
- Section added to discuss calculation of cumulative, noncancer hazard for drinking water resources impacted by multiple PFASs (refer to Section 9.0);
- Discussion of volatile PFASs added, although toxicity factors for the subject compounds are not currently available;
- Summary of Method 8327 for testing of PFASs in groundwater, surface water, and wastewater samples added;
- Table 4b revised to note correct final RfDs used to generate EALs (EALs not affected);
- Direct exposure soil action levels for unrestricted (e.g., residential) land use revised to correct calculation error (Appendix 1, Table I-1).

December 2022 Update: Soil and groundwater action levels added for 6:2 Fluorotelomer sulfonate (6:2 FTS⁻). Action levels for HFPO DA⁻ and PFHxA⁻ revised to reflect toxicity factors published by USEPA (USEPA 2021, 2022a). Action levels for PFOS⁻, PFOA⁻, PFHxS⁻ and PFNA⁻ were updated to reflect toxicity factors published by ATSDR (ATSDR 2021). The ATSDR toxicity factors have also been incorporated into the USEPA Regional Screenings Levels (RSL) guidance (USEPA 2022b).

Additional updates to EALs are anticipated in 2023 as new guidance on key compounds of interest, laboratory methods, toxicity studies and related information is compiled and reviewed by HDOH staff. This includes review of interim drinking water advisory levels for PFOS and PFOA published by the USEPA in June 2022 (USEPA 2022c). Draft Maximum Contaminant Levels (MCLs) for the same compounds anticipated to be published by the USEPA in 2023. The understanding of health impacts from exposure to individual PFASs continues to evolve as new studies are conducted and published. Further updates will incorporate additional health effects data as available.

August 2021 Update: Equation 1 was reorganized and revised to correct the parameter units. No changes were made to the EALs.

April 2021 Updates: Action levels for PFBS⁻ were updated to reflect a revised oral Reference Dose toxicity factor for PFBS⁻ published by the USEPA (USEPA 2021a). This resulted in a reduction of tapwater and soil direct exposure and leaching action levels for PFBS⁻. Default, acute aquatic toxicity action levels for PFHxS⁻, PFBA⁻, PFHxA⁻, PFUnDA⁻ and PFDODA⁻ and associated soil leaching action levels revised to correct error in Fall 2020 tables. The updates affect soil and groundwater action levels for these chemicals at sites where groundwater is not a source of drinking water and is situated >150m from a body of surface water (Table B). Action levels for other site scenarios and other PFASs were not affected. The updated action levels replace and take precedence over action levels presented in the previous, December 2020 technical memorandum. (Revised to add Table 4b.)

This memorandum presents interim, soil and groundwater Environmental Action Levels (EALs) for screening of sites contaminated with perfluoroalkyl and polyfluoroalkyl substances (PFASs). Brief overviews of key

topics are presented with references provided for additional details. The action levels represent a supplement to the Hawai'i Department of Health (HIDOH), Hazard Evaluation and Emergency Response (HEER) Office guidance document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* ("EHE guidance;" HIDOH 2024a). A separate, Excel-based "EAL Surfer" of electronic lookup tables specific to PFASs is available for download from the EHE guidance webpage (HIDOH 2024a; refer to weblink included with reference). Guidance in this memorandum updates and replaces guidance presented in a July 2020 draft, technical memorandum posted for public review.

Updates to the PFASs guidance are anticipated in the future as new information and additional experience is obtained. Comments and suggestions for edits are welcome and should be submitted to Roger Brewer with the HEER Office (roger.brewer@doh.hawaii.gov). A recorded presentation on the PFASs guidance is posted to the HEER Office webinar webpage (made prior to December 2020 update; <https://health.hawaii.gov/heer/guidance/heer-webinars/>)