JOSH GREEN, M.D.
GOVERNOR OF HAWAI'I
KE KIA'ĀINA O KA MOKU'ĀINA 'O HAWAI'I

ELIZABETH A. CHAR, M.D.
DIRECTOR OF HEALTH
KA LUNA HO'OKELE

STATE OF HAWAI'I
DEPARTMENT OF HEALTH
KA 'OIHANA OLAKINO
P. O. BOX 3378
HONOLULU, HI 96801-3378

In reply, please refer to:
File: RB 116-2022

Date: December 29, 2022

To: Interested Parties

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

Diana Felton, MD, State Toxicologist
Hazard Evaluation and Emergency Response

Fenix Grange, Supervisor
Site Discovery, Assessment and Remediation
Hazard Evaluation and Emergency Response

From: Roger Brewer, PhD
Hazard Evaluation and Emergency Response

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

December 2022 Update: Soil and groundwater action levels added for 6:2 Fluorotelomer sulfonate (6:2 FTS^-). Action levels for $HFPO^-$ 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 (still dated April 2021, in Attachment 1).

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 2017a). A separate, Excel-based "EAL Surfer" of electronic lookup tables specific to PFASs is available for download from the EHE guidance webpage (HIDOH 2017a; 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/).

Terminology, Chemistry, Manufacture and Use

The singular and plural acronyms "PFAS" and "PFASs" are used in this memorandum, following the naming convention recommended by Buck et al. (2011). Specific compounds presented in this technical memorandum are listed in Table 1. The table notes both the protonated, acid form ("acid form") of the compound and the dissociated, anion form more common in the environment. The same abbreviation is confusingly 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. Examples of the nomenclature and abbreviations are noted in Figure 1.

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

PFASs can be divided into two, broad families of chemicals: 1) Perfluoroalkyl substances in which all of the hydrogen atoms attached to carbon atoms have been replaced with fluorine atoms, except for hydrogen atoms associated with attached, functional groups and 2) Polyfluoroalkyl substances in which some but not all of the hydrogen atoms have been replaced. As discussed below, toxicity factors are primarily available for a short list of perfluoroalkyl substances. PFASs used in industrial processes can be further categorized as sulfonic acids, characterized by the functional group -SO2OH, and carboxylic acids, characterized by the functional group –COOH. Examples include perfluorooctane sulfonic acid or "PFOS" and perfluorooctanoic acid or "PFOA" (Figure 1).

PFASs produced or used by industries are normally present in a salt or acid form (ITRC 2020). When these compounds are released to soil or water, the hydrogen atom dissociates, leaving the anion form. Anion forms of the compounds, such as perfluorooctane sulfonate ($PFOS^-$) and perfluorooctanoate ($PFOA^-$) are assumed to dominate in contaminated soil and water and are the focus of 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.

Related compounds used in industrial processes can eventually degrade to "terminal" perfluoroalkyl substances listed in this technical memorandum (see ITRC 2020). An example depicted in Figure 2 is the degradation of perfluorooctane sulfonamide (PFOSA), used in the past as a grease and water repellant and for which toxicity factors are also available, to perfluorooctane sulfonate ($PFOS^-$). The timeframe for degradation is unclear, however, and PFOSA should be independently tested for and assessed if potentially present.

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 (OECD 2013, ITRC 2020).

As of the date of this memorandum, contamination of groundwater in Hawai´i has been identified at a small number of firefighting training operations. The sites do not threaten drinking water but could pose a risk to nearby shorelines and aquatic habitats. Data for landfills are not currently available. In most cases, landfills are not located in areas that could threaten a drinking water supply.

There are no registered, PFAS manufacturing facilities in Hawai′i, although large amounts of PFAS containing, firefighting chemicals might be maintained at jet fuel storage areas. Effluent from wastewater treatment plants is reportedly used for irrigation at golf courses and road medians in some municipalities. Biosolids from treatment plants have also reportedly been used as a soil amendment at golf courses. Biosolids have not been routinely applied to agricultural fields to the knowledge of the HEER Office, although the extent to which this occurs is still being evaluated.

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 $PFNA^-$, based largely on PFASs reported under Method 537 (Tsitonaki et al. 2014). The relative proportions of these compounds can vary from site to site, depending on the types of firefighting foam used over time. Testing of water supply wells in California (CAEPA 2020) identified nine, primary PFASs, including $PFHxS^-$, $PFOS^-$, $PFOA^-$, $PFBS^-$, $PFHxA^-$, $PFHpA^-$, $PFNA^-$, $PFDA^-$ and $ADONA^-$. 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 alcohols 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 carboxylic acids. These compounds can form from the biodegradation of other fluorotelomer compounds (Buck et al. 2011, OECD 2013, ITRC 2020). Published toxicity studies for fluorotelomer alcohols have not been identified and action levels cannot be developed at this time. Contact the HEER Office for further assistance if these compounds are identified in groundwater.

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 such as $PFOS^-$ 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 PFASs precursors.

Testing for PFASs has only recently been undertaken in Hawai´i. PFASs have been identified in groundwater at former and active firefighting training areas. PFASs have not been detected in drinking water systems in Hawai′i to date above action levels noted in this memorandum. Data for wastewater treatment plant influent, effluent and sludge/biosolids are not currently available.

Laboratory Test Methods

Methods for testing of PFASs in water and other media are still evolving. A summary of the most common laboratory methods currently in use and examples PFASs reported is presented in Table 2. This includes U.S. Environmental Protection Agency (USEPA), Method 1633 (USEPA 2021c), Method 533 (USEPA 2019a) and Method 537.1 (USEPA 2020). 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 2 (DOD-DOE 2019; refer to Table B-15 and Table C-44 in manual). Testing for PFASs reportable under both Method 537.1 and 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 the need for sample collection and processing requirements with the laboratory prior to the collection and submittal of samples for analysis.

Sample Collection and Processing

A detailed review of sample collection methods specific to PFASs is beyond the scope of this technical memorandum. A brief overview is provided below. Refer to the HEER Office *Technical Guidance Manual* (TGM) for general guidance on the collection of particulate matter (e.g., soil) and water samples (HIDOH 2021; see Sections 3, 4, 5 and 6). Additional guidance on the collection of samples to be tested for PFASs will be incorporated into the HEER TGM as needed as more experience is gained in the field.

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 2020a,b; MADEP 2019; MIDEQ 2019). Research has not, however, 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 and perfluoroalkyl substances 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, used for the collection of groundwater samples (Ciomek 2020).].

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.

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).

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 the collection of a minimum 1-2kg of material composed of at least 50 increments collected in a systematic, random manner. 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 known to be used in the production of bags. Significant, cross contamination of large, Multi Increment samples from equipment or containers is unlikely provided that sample collection and processing steps noted in the TGM are adhered to. 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 2021). 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 2021).

Extraction and testing of a minimum, five-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.

PFASs Physiochemical Constants

A summary of physiochemical constants used to predict the fate and transport of the targeted PFASs and generate EALs is provided in Table 3a. References for physiochemical constants assigned to individual compounds are summarized in Table 3b. 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;
4. European Chemicals Agency.

Physiochemical constants published by ORNL are used to generate USEPA Regional Screening Levels and were selected if available (USEPA 2019b). As noted in Table 3b, many of the constants were taken from the USEPA CompTox Chemistry Dashboard. Limited, additional constants were available in PFAS-specific guidance published by ATSDR and the European Chemical Agency. Although not specifically referenced in the table, Henry's Constants for a number of PFASs are also available from Sander (2015).

The mobility of PFASs in the environment is governed by each chemical's solubility, volatility and tendency to sorb to organic carbon and clay. The solubility of PFASs varies widely between compounds and can be dependent on site-specific conditions that promote degradation and transformation into other compounds. Values for the solubility of the PFASs listed in Table 1 were obtained from the USEPA CompTox Chemical Dashboard (USEPA 2017). All of the values are predicted from models rather than directly measured. Confidence in the reliability of the values is moderate to low.

Volatility can be categorized in terms of both a chemicals Henry's Law Constant and vapor pressure. By default in HEER Office EHE guidance, a chemical is considered to be volatile and subject to emission to ambient air if the Henry's number is greater than >0.00001 atm m3/mole and molecular weight is less than 200 (HIDOH 2017; USEPA 2019b), and "semi-volatile" if the molecular weight is greater than 200. With the exception of perfuorobutanoate ($PFBA^-$), all of the listed PFASs can be classified as nonvolatile. Perfuorobutanoate is classified as semivolatile (see Table 1). This initially suggests that samples to be tested for $PFBA^-$ should be subsampled for testing 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 for the PFASs listed in Table 1 were obtained from the USEPA CompTox Chemical Dashboard. Values presented are modeled rather than directly measured, however, decreasing confidence in their accuracy. Vapor pressures are also presented for anion forms of PFASs in the CompTox Chemical Dashboard. Vapor pressures presented for the anion forms of three compounds $PFPeA^-$ and $PFHxA^-$, exceed 1 mm Hg and, under HIDOH guidance, would likewise be classified "semi-volatile" (HIDOH 2017a). This again suggests that samples to be tested for these chemicals should be subsampled for testing prior to processing.

Confidence in the modeled vapor pressures is again low, however. Vapor pressure can also be estimated based on the chemicals molecular weight, Henry's constant and solubility (after ECHA 2016, Equation r.16-4):

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

Using this approach and the values for the noted parameters listed in Table 1, 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 $PFBA^-$ following discussions with laboratory chemists familiar with testing for PFASs in soil samples. The applicability of the Henry's Constant in the CompTox Chemical Dashboard is questionable and significant loss of $PFBA^-$ during air drying is not anticipated.

For the purposes of this guidance, soil, sediment and other particulate samples to be tested for $PFBA^-$, $PFPeA^-$ and $PFHxA^-$ can therefore be processed in accordance with methods described in the HEER Office TGM for non-volatile chemicals. 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.

The potential for a compound to leach from soil and contaminate underlying groundwater is traditionally evaluated in terms of the chemicals "sorption coefficient (Koc)," (McCall et al. 1981; refer also to HIDOH 2017a). 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 cm^3/g are considered to be highly mobile. Chemicals with a Koc value greater than 500 cm^3/g are considered to have low mobility. Chemicals with Koc values greater than 5,000 cm^3/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 HIDOH EAL models allows prediction of the initial fate of a PFAS when released to soil (Figure 3). 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 over predict 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 (HIDOH 2017b).

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 $PFHxA^-$, $PFBS^-$ and $PFHxS^-$ characterizing the forward, leading edge of the plume (Figure 4). This likely in part 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.

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 especially needed.

The breakdown and transformation of PFASs in the environment can be very complex (see ITRC 2018). 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.

Human Toxicity

A summary of toxicity factors compiled for individual PFASs is provided in Table 4a. Final toxicity factors selected to generate EALs are noted in Table 4b. The studies reflect a mix of toxicity associated with protonated acid and anion forms of the compounds (see Table 4a). 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 5. An abbreviated summary is provided in Table J of Attachment 2. 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 2016a,b; Zeilmaker 2018; ATSDR 2018; Kirk et al. 2018). Refer to the references provided with Table 3b and Table 4b 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 a decrease of the action levels presented in this document.

Primary sources referred to for selection of toxicity factors presented in Table 4 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, 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.
8. 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.
9. USEPA, 2022, Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts (external review draft): US Environmental Protection Agency, Office of Research and Development, EPA/635/R-21/312a, February 2022.
10. 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 19 PFASs.

If available, toxicity factors published by the USEPA normally take priority. 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 for PFASs published by The Netherlands in 2018 and based on the reference potency of PFOA (acid form) were used to select RfDs for $PFHpS^-$, $PFDS^-$, $PFPeA^-$, $PFHpA^-$, $PFDA^-$, $PFUnDA^-$, $PFDoDA^-$, $PFTrDA^-$ 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 and/or perfluorooctanoic acid and proposed a cancer slope factor of 0.07 mg/kg-day (USEPA 2016b; 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.

As discussed below, higher confidence is placed in noncancer studies for generation of risk-based action levels for these compounds. The resulting action levels are intended to be protective of young, developing children. The action levels fall within the range of action levels based on an acceptable, excess cancer risk of 10^{-4} to 10^{-6} and are assumed to be adequately protective of both noncancer risks (hazards) to children as well cancer risk to adults. The same conclusion was reached in the USEPA assessment of toxicity (USEPA 2016b)

Figure 5 compares the hypothetical mobility of individual PFASs in terms of the sorption coefficient to the compounds toxicity. This can be useful to predict highly toxic and recalcitrant compounds that could remain immobile trapped in soil or taken up in the food chain and pose similar risk to PCBs. More mobile compounds could drive risk for uptake into food crops or livestock feed, such as $PFHxS^-$, $PFOS^-$, $PFOA^-$ and $PFNA^-$, although little research is currently available on this subject. The least sorptive compounds that pose a greater leaching risk to groundwater, such as $PFBS^-$ and $PFHxA^-$, are fortunately also of relatively lower toxicity.

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 2017a). 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.

PFAS Environmental Action Levels

Interim soil and water action levels for PFASs are provided in Tables A and B in Attachment 1. Detailed tables for derivation of the EALs are provided in Attachment 2. These tables represent an addendum to the 2017 EHE guidance document and are presented in the same format (HIDOH 2017a). 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.

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 2017a). 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 (non-volatile)
Leaching to Groundwater	X	All PFASs with available toxicity factors
[1]Gross Contamination	-	Odor thresholds not identified
Groundwater		
Drinking Water Ingestion	X	All PFASs with available toxicity factors
Vapor Intrusion	-	(non-volatile)
Aquatic Toxicity	X	Limited; drinking water action levels applied for initial screening if aquatic toxicity action levels not available
[1]Gross Contamination	-	Taste and odor thresholds not identified
Ambient Air and Subslab Vapor		
Vapor Intrusion	-	(non-volatile)

1. "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 2017a). Action levels currently not available for PFAS compounds and anticipated to be significantly higher than action levels based on direct exposure risks.

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 6). 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 6). Exceptions are discussed in the 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 6). 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*).

Drinking Water Ingestion

Two methods have been used by the USEPA to develop drinking water action levels for PFASs. The first method, used to develop Drinking Water Advisories for PFOS and PFOA, is intended to ensure that PFASs in blood serum of nursing women do not exceed a target level (USEPA 2016a,b). The second method, used to generate tapwater screening levels in the USEPA Regional Screening Level (RSL) guidance, is intended to ensure that the mean, daily exposure of young children to PFASs in drinking water does not exceed a target level (USEPA 2019b).

The drinking water advisory method utilizes the following equation (USEPA 2016a,b):

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

Where:
RfD: Chemical-specific, chronic, oral Reference Dose;
DWIR: Drinking water ingestion rate per kilogram of body weight (default 0.054 L/kg-day);
RSC: Relative Source Concentration (default 0.2).

Noted, default parameter values are taken directly from the USEPA documents. The default drinking water ingestion rate is based on data for lactating women. Inserting the default values allows the equation to be simplified to:

$$\text{Health Advisory } (\mu g/L) = \left(\frac{\text{RfD (mg/kg day)}}{0.054\ \text{(L/kg day)}}\right) \times \frac{1000\mu g}{mg} \times 0.2 \qquad \text{Eq 3}$$

This approach generated health advisories for PFOS and PFOA of 0.07 µg/L (USEPA 2016a,b). The advisories only consider the ingestion pathway. Additional exposure via dermal uptake is assumed to be negligible. The advisory notes that the sum of PFOS and PFOA should not exceed a concentration of 0.07 µg/L. The advisories otherwise do not consider cumulative health hazard posed by the presence of multiple other PFASs in the drinking water.

An alternative method to develop "Preliminary Remediation Goals (PRGs)" for PFASs in drinking water has been used by other offices within the USEPA (USEPA 2019b):

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

Where:
THQ: Target Hazard Quotient (default = 0.1);
AT: Averaging Time (default = 365 days/year x 6 years);
$BW_{res\text{-}c}$: 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 noted document. Inserting these values allows the equation to be simplified to:

$$\text{PRG } (\mu g/L) = 0.1 \times 0.96 \times \left(\frac{\text{RfD (mg/kg day)}}{0.052 \text{ (L/kg day)}}\right) \times \frac{1000 \mu g}{mg} \quad \text{Eq 5}$$

The PRG methodology is similar to the method used to develop tapwater screening levels published as part of the USEPA Regional Screening Levels (RSLs) guidance (USEPA 2019b) and to the approach used to derive drinking water action levels in the HIDOH EAL guidance (HIDOH 2017a). The PRG model again only considers the ingestion pathway, with additional exposure via dermal uptake assumed to be negligible. The Relative Source Contribution from dietary and other potential sources of PFASs is not taken into account.

The USEPA PRG model for PFASs was modified to include a Relative Source Contribution Term in order to derive PFAS drinking water action levels for use in Hawaii:

$$\text{EAL } (\mu g/L) = \frac{\text{THQ} \times \text{AT}_{res-c} \times \text{BW}_{res-c} \times \frac{1000 \mu g}{mg}}{\text{EF}_{res-c} \times \text{ED}_{res-c} \times \frac{1}{\text{RfD}} \times \text{IRW}_{res-c}} \times \text{RSC} \quad \text{Eq 6}$$

The Relative Source Contribution of 0.2 (20%) used to calculate USEPA Drinking Water Advisories for PFOS and PFOA was retained for calculation of drinking water action levels. (Note that a Relative Source Contribution is not normally included in action levels intended for initial screening purposes. Consideration of the additional factor was considered appropriate in this case due to the high, dietary risk of exposure to PFASs chemicals). The resulting action levels are intended to be protective of young, developing children who consume the USEPA default 0.78 liters of water per day for 350 days per year for a period of six years.

An informal review of groundwater data being compiled in California suggests that health risk is typically driven by just one or two PFASs, even though several other PFASs might also be present in the water (Small 2019). This is due to a combination of the relatively high toxicity and high concentration of these PFASs in the water samples tested in comparison to other PFASs present. A target Hazard Quotient of 0.5 was therefore selected for use in the calculation of drinking water action levels. Site-specific calculation of cumulative risk should be carried out if more than two PFASs approach the action levels noted in the lookup tables.

This in effect generates action levels identical to those that would be calculated using the USEPA PRG model in Equation 6 with a target Hazard Quotient of 0.1. However, the technical justification of the approach utilized is considered to be stronger. The resulting drinking water action level of 0.04 µg/L for both $PFOS^-$ and $PFOA^-$ is lower by slightly less than half than the

USEPA drinking water advisory of 0.07 µg/L for these chemicals (USEPA 2016a,b). This is due to the inclusion of a target Hazard Quotient of 0.5, rather than 1.0, in the calculation as described above.

The cancer slope factor for perfluorooctanoic acid published by the USEPA (2016b) was used to calculate a cancer-based action level for $PFOA^-$ in drinking water following the approach used for the USEPA RSLs (see Table H in Attachment 2). A target excess cancer risk of 10^{-5} and Relative Source Contribution of 20% was applied, yielding a cancer based, drinking water action level of 2.0 µg/L (Table D-3b in Attachment 2). This is well above the noncancer action level of 0.04 µg/L and supports the conclusion in the USEPA document that the noncancer action level is a adequately protective of both noncancer risks (hazards) to children as well cancer risk to adults.

Impacts to Aquatic Habitats

Chronic and acute toxicity levels compiled and reviewed by the Washington Department of Ecology served as the primary reference for used in this technical memorandum (Table 6; WADOE 2020). Action levels were available for 11 of the 19 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 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 $PFOA^-$ presented in Table 6 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 and 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 2). HEER Office guidance calls for the use of toxicity-based, drinking water action levels when aquatic toxicity action levels are not available (HIDOH 2017a). 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 additional 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 is recommended to 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.

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

2017a). 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 2017a). 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 0.5, similar to the approach used to develop risk-based action levels for drinking water. The need to assess cumulative risk in more detail, for example due to the presence of more than two PFAS compounds at concentrations that approach their respective action levels, should be reviewed on a case-by-case basis or carried out as directed by the HEER Office. Refer to Section 2.10 in Volume 1 of the EHE guidance for additional guidance (HIDOH 2017a).

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 is discussed in Appendix 1 of the EHE guidance (HIDOH 2017a):

$$C_{soil} = DAF \times C_{gw} \times 0.001 \text{ mg/µg} \qquad \text{Eq 7}$$

$$DAF = (6207 \times H) + (0.166 \times Koc)$$

where: DAF = SESOIL-based dilution/attenuation factor;
H = Henry's Law Constant (atm-m^3/mol);
Koc = Organic carbon partition coefficient (cm^3/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 14 of the 19 PFASs listed in cases where underlying groundwater is a source of drinking water (refer to Attachment 2, 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 4 of the 19 PFASs in cases where underlying groundwater is not a source of drinking water and the latter was in turn selected as final, soil action level (Summary Table B; refer to Attachment 2, 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 2017b) 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 2017b). 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 cm^3/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 2). Soil saturation levels were calculated using the saturation equation presented in USEPA Regional Screening Levels guidance (USEPA 2019; see Appendix 2 of HDOH 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.

Vapor Intrusion

Targeted PFASs listed in the lookup tables are not volatile and are not anticipated to pose a significant vapor intrusion risk to existing or future buildings (refer to Table 2). Ingestion of PFASs via drinking water, soil, or other media is instead considered to be the primary exposure route of concern (USEPA 2016a,b).

Other Potential Concerns

Uptake of PFASs into produce might need to be considered on a case-specific basis. Risk posed to terrestrial ecological receptors due to exposure to PFAS-contaminated soil, sediment or surface water must likewise be assessed on a case-specific basis. Washington State's PFAS guidance includes a summary of currently available information on plant uptake and other factors pertinent to ecological risk. Plant uptake factors from different studies can vary by over an order of magnitude, reflecting variability soil chemistry (e.g., organic carbon and clay content, pH, soil microbiome, etc.) as well as the specific species of plants used in the studies.

This complicates development of default action levels for the uptake of PFASs into food crops and livestock feed and the need for site-specific studies. Detailed guidance on this topic has not been compiled by the HEER Office. Consult with the project manager for preparation of study designs and the collection of sample data representative of the investigation objective in question. Evaluation of uptake of PFASs from soil and sediment into terrestrial and aquatic flora and fauna should be based on the collection of Multi Increment-type data for all media (refer to Sections 3, 4 and 5 of the HEER Office Technical Guidance Manual; HIDOH 2021). Use of discrete sampling methods is not acceptable due to low reliability of the data.

Taste and odor thresholds and other factors used to develop action levels for "Gross Contamination" are currently not available for PFASs chemicals. Action levels based on taste and odor thresholds, when available, are anticipated to be significantly higher than action levels based on direct-exposure risk. This implies that exposure to potentially hazardous levels of PFASs could occur well before contamination of the subject media is noticeable.

Investigation of PFASs-Contaminated Soil and Groundwater

Investigations of PFASs-contaminated soil and groundwater should adhere to sampling protocols presented in the HEER Office *Technical Guidance Manual* (HIDOH 2021).This include the collection of Multi Increment samples for testing of soil, sediment and biosolids. Discrete soil sample data are not acceptable for final decision making. The collection of Multi Increment-type samples should also be considered for testing of surface water.

Enhanced, sample collection methods that incorporate Multi Increment sampling concepts have not been fully developed and incorporated in the *Technical Guidance Manual* but could be required for the collection of representative groundwater samples at high-risk sites on a case-by-case basis. This might include, for example, the continuous collection of a sample during purges

of large, risk-based volumes of water from a single well, rather than the collection of traditional, small-volume, “discrete” waters samples.

Precautions should be taken to avoid accidental contamination of samples with PFASs in sampling equipment, clothing and other articles. Refer to guidance published by the California EPA (CAEPA 2019b,c) and similar sources for additional information, until such time that PFASs-specific guidance is incorporated into the HEER Office *Technical Guidance Manual* (HIDOH 2021).

Attachments:

Attachment 1: Summary tables of PFASs Environmental Action Levels

Attachment 2: Detailed tables of PFASs Environmental Action Levels (supplement to Appendix 1 of EHE guidance)

References (refer also to references included with individual tables)

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.

ATSDR, 2018, Toxicological Profile for Perfluoroalkyls: Agency for Toxic Substances and Disease Registry, Division of Toxicology and Human Health Sciences, June 2018.

Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T. and P. de Voogt, 2011, Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins: Integrated Environmental Assessment and Management — Volume 7, Number 4—pp. 513–541.

CAEPA, 2019a, Notification Level Recommendations, Perfluorooctanoic Acid and Perfluorooctane Sulfonate in Drinking Water: California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, August 2019.

CAEPA, 2019b, *Drinking Water Sample Collection for Per- and Polyfluoronated Alkyl Substances* (PFASs): California Environmental Protection Agency, State Water Resources Control Board, April 2019.

CAEPA, 2019c, *Per- and Polyfluoroalkyl Substances Sampling Guidelines*: California Environmental Protection Agency, State Water Resources Control Board, March 2019.

CAEPA, 2020, *PFASs Water Board Investigation Summary*: California Environmental Protection Agency, State Water Resources Control Board, March 2020.

Cataldo, W., 2020, SC Johnson, email to Roger Brewer, Hawai´i Department of Health, December 17, 2020.

Ciomek, J., 2020, GeoInsight, email to Roger Brewer, Hawai´i Department of Health, November 25, 2020.

Denly, E., Occhialini, J., Bassignani, P., Eberle, M., and N. Rabah, 2019, Per- and polyfluoroalkyl substances in environmental sampling products: Fact or fiction?: Remediation. 2019;29:65–76, DOI: 10.1002/rem.21614.

DEPA, 2019, *Risk Assessment of Fluorinated Substances in Cosmetic Products*: Denmark Environmental Protection Agency, Ministry of Environment and Food, Survey of Chemical Substances in Consumer Products No. 169, October 2018.

ECHA, 2016, Guidance on information requirements and Chemical Safety Assessment Chapter R.16: Environmental exposure assessment: European Chemical Agency, February 2016.

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, 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).

Giesy, J.P., Naile, 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.

HIDOH, 2017a, *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater – Hawai'i Edition* (Fall 2017): Hawai´i Department of Health, Office of Hazard Evaluation and Emergency Response https://health.hawaii.gov/heer/guidance/ehe-and-eals/

HIDOH, 2017b, *Use of laboratory batch tests to evaluate potential leaching of contaminants from soil*: Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response, https://health.hawaii.gov/heer/guidance/ehe-and-eals/

HIDOH, 2021, *Technical Guidance Manual* (and updates): Hawai´i Department of Health, Office of Hazard Evaluation and Emergency Response, https://health.hawaii.gov/heer/tgm/

NASF, 2019, 6:2 FluorotelomerSulfonate (6:2 FTS), Toxicology at a Glance: National Association for Surface Finishing, March 2019.

ITRC, 2020, Per- and Polyfluoroalkyl Substances: Interstate Technology and Regulatory Council, April 2020.

Kaminski, D., 2020, PFAS: Dispelling Sampling Myths: QED Environmental Systems Inc., September 1, 2020 (webinar sponsored by Eurofins/Test America laboratory, https://www.testamericainc.com/)

Kathan, K., 2020, Vermont - PFAS Into and Out Of Landfills: Vermont Department of Environmental Conservation, Solid Waste Management Program, June 9, 2020 (webinar hosted by Northeast Waste Management Officials' Association, http://www.newmoa.org/cleanup/workshops.cfm)

Kirk, M., Smurthwaite, K., Bräunig, J., Trevenar, S., D'Este, C, Lucas, R., Lal, A., Korda, R., Clements, A., Mueller, J., and B. Armstrong, 2018, The PFAS Health Study: Systematic Literature Review. Canberra: The Australian National University.

Lang, J.R., Allred, B.M., Field, J.A., Levis, J.W. and M.A. Barlaz, 2017, National Estimate of Per- and Polyfluoroalkyl Substance Release to U.S. Municipal Landfill Leachate: Environmental Science and Technology, Vol 51, pp 2197−2205. DOI: 10.1021/acs.est.6b05005

MADEP, 1994, *Background Documentation for the Development of the MCP Numerical Standards:* Massachusetts Department of Environmental Protection, Bureau of Waste Site Cleanup and Office of Research and Standards, April 1994, www.state.ma.us/dep/ors/orspubs.htm.

MADEP, 2019, Interim Guidance on Sampling and Analysis for PFAS at Disposal Sites Regulated under the Massachusetts Contingency Plan: Massachusetts Department of Environmental Protection, Office of Energy and Environmental Affairs, December 27, 2019.

McCall, P.J., Laskowski, D.A., Swann, R.L. and H.J. Dishburger HJ, 1981, Measurement of sorption coefficients of organic chemicals and their use, in environmental fate analysis: in *Test Protocols for Environmental Fate and Movement of Toxicants*. Proceedings of Association of Official Analytical Chemists Symposium.

MIDEQ, 2019, *Fish Tissue PFAS Sampling Guidance*: Michigan Department of Environmental Quality, January 2019.

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.

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.

MISAW, 2019, *Health-Based Drinking Water Value Recommendations for PFAS in Michigan*: Michigan Science Advisory Workgroup, June 27, 2019.

MNDOH, 2017, *Toxicological Summary for: Perfluorobutane sulfonate*: Minnesota Department of Health, December 2017.

MNDOH, 2018, *Toxicological Summary for Perfluorobutanoate*: Minnesota Department of Health, August 2018.

MNDOH, 2019, *Toxicological Summary for: Perfluorohexane sulfonate*: Minnesota Department of Health, April 2019.

OECD, 2013, *Synthesis paper on per- and polyfluorinated chemicals (PFCs)*: Organization for Economic Cooperation and Development, Environment, Health and Safety Division, Environment Directorate, 2013.

ORNL, 2020, *Risk Assessment Information System*: Oak Ridge National Laboratories, Office of Environmental Management, accessed 5/5/20. https://rais.ornl.gov/

Roberson, K., 2020, California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board, personal communication, June 10, 2020.

Rodowa, A.E., Christie, E., Sedlak, J., Peaslee, G.F., Bogdan, D., DiGuiseppi, B. and J.A. Field, 2020, Field Sampling Materials Unlikely Source of Contamination for Perfluoroalkyl and Polyfluoroalkyl Substances in Field Samples: Environ. *Science and Technology Letters*, 2020/7, pp 156−163.

Sander, R. (2015) Compilation of Henry's law constants (version 4.0) for water as solvent, Atmos. Chem. Phys., 15, 4399-4981, doi:10.5194/acp-15-4399-2015

Small, M., 2019, Preliminary California PFAS Fingerprint Analysis: PFAS Datathon 2019, sponsored by California Environmental Protection Agency, December 4-5, 2019.

Tsitonaki, K., Jepsen, T.S. and T. Hauerberg, 2014, *Screening study of selected PFASs compounds as soil and groundwater contamination in connection with point sources*: The Danish Environmental Protection Agency, Environmental project No 1600, www.mst.dk

TXCEQ, 2016, T*oxicity Factor Derivation for Perfluoro Compounds Under the Texas Risk Reduction Program*: Texas Commission on Environmental Quality, January 4, 2016. https://www.tceq.texas.gov/toxicology

USDOD-USDOE, 2019, *Consolidated Quality Systems Manual (QSM) for Environmental Laboratories*: join Department of Defense-Department of Energy, Version 5.3, 2019.

USEPA, 1995, F*inal Water Quality Guidance for the Great Lakes System*: U.S. Environmental Protection Agency, Code of Federal Regulations, Title 40, Parts 9, 122, 123, 131 and 132, www.access.gpo.gov/nara/cfr/.

USEPA, 1996, *Soil Screening Guidance: Technical Background Document*: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Publication 9355.4-17A, May, 1996.

USEPA, 2002, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*: U.S. Environmental Protection Agency, Solid Waste and Emergency Response, OSWER 9355.4-24, December 2002, http://www.epa.gov/superfund/resources/soil/ssg_main.pdf

USEPA, 2011, *Exposure Factors Handbook*: U.S. Environmental Protection Agency, September 2011.

USEPA, 2014, *Provisional Peer-Reviewed Toxicity Values for Perfluorobutane Sulfonate (PFBS)*: U.S. Environmental Protection Agency, Washington, DC, EPA/690/R-14/012F, 2014.

USEPA, 2016a, D*rinking Water Health Advisory for Perfluorooctanoic Acid (PFOS)*: U.S. Environmental Protection Agency, Office of Water, EPA 822-R-16-004. May 2016.

USEPA, 2016b, *Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA)*: U.S. Environmental Protection Agency, Office of Water, EPA 822-R-16-005. May 2016.

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

USEPA, 2019a, *Method 533: Determination of Per- and Polyfluoroalkyl Substances in Drinking Water by Isotope Dilution Anion Exchange Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry*: U.S. Environmental Protection Agency, Office of Water, EPA 815-B-19-020, November 2019.

USEPA, 2019b, *Interim Recommendations to Address Groundwater Contaminated with Perfluorooctanoic Acid and Perfluorooctanesulfanate*: U.S. Environmental Protection Agency, Office of Land and Emergency Management, December 19. 2019.

USEPA, 2019c. *Leaching Environmental Assessment Framework (LEAF) How-To Guide*: U.S. Environmental Protection Agency, SW-846 Update VII, May 2019.

USEPA, 2019d, *EPA Analytical Methods for PFAS in Drinking Water*: U.S. Environmental Protection Agency, Office of Water, EPA 815-B-19-021 December 2019.

USEPA, 2020, Method 537.1: *Determination of Selected Per- and Polyfluoroalkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry*: U.S. Environmental Protection Agency, Office of Water, EPA/600/R-20/006, March 2020.

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, 2021c, *Draft Method 1633 Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS*: US Environmental Protection Agency, Office of Water, August 2021.

USEPA, 2022a, *Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts* (external review draft): US Environmental Protection Agency, Office of Research and Development, February 2022.

USEPA, 2022b, *Screening Levels for Chemical Contaminants*: U.S. Environmental Protection Agency, November 2022, prepared by Oak Ridge National Laboratories, http://www.epa.gov/region09/waste/sfund/prg/

USEPA, 2022c, Lifetime Drinking Water Health Advisories for Four Perfluoroalkyl Substances: US Environmental Protection Agency, Federal Register, Vol. 87, No. 118, Tuesday, June 21, 2022, Notices.

WADOE, 1993, *Whole Effluent Toxicity Testing and Limits*: Washington Department of Ecology, Washington Administrative Code, Chapter 173-205.

WADOE, 2020, *PFAS Ecological Receptors - Concentrations Protective of Surface Water and Upland Soil* (Draft): Washington Department of Ecology, December 2020.

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

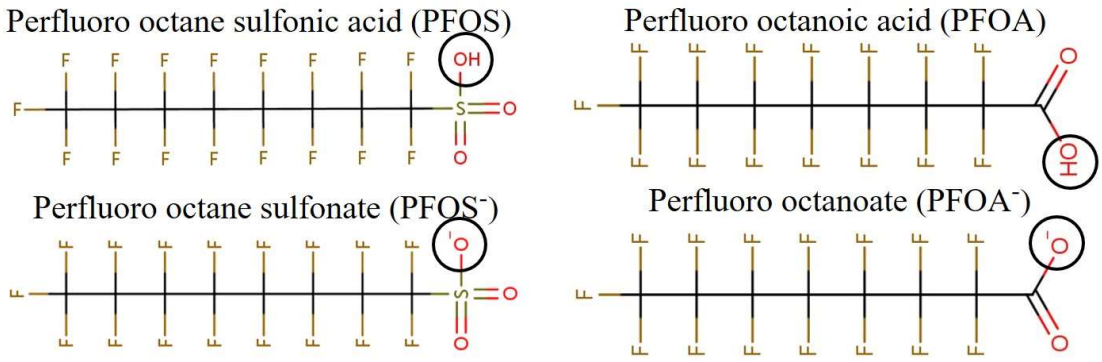

Figure 1. Protonated acid versus anion molecular structures of perfluorooctane sulfonic acid and perfluorooctane sulfonate compared to perfluorooctanoic acid and perfluorooctanoate. Anion form noted in lower pictures is more common in contaminated soil, sediment and water.

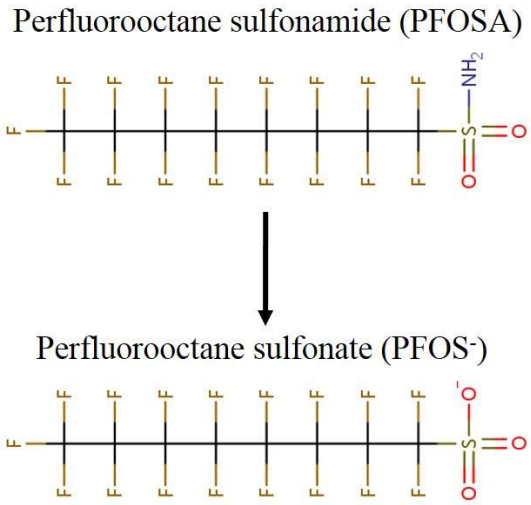

Figure 2. Degradation of to perfluorooctane sulfonamide to perfluorooctane sulfonate in the environment.

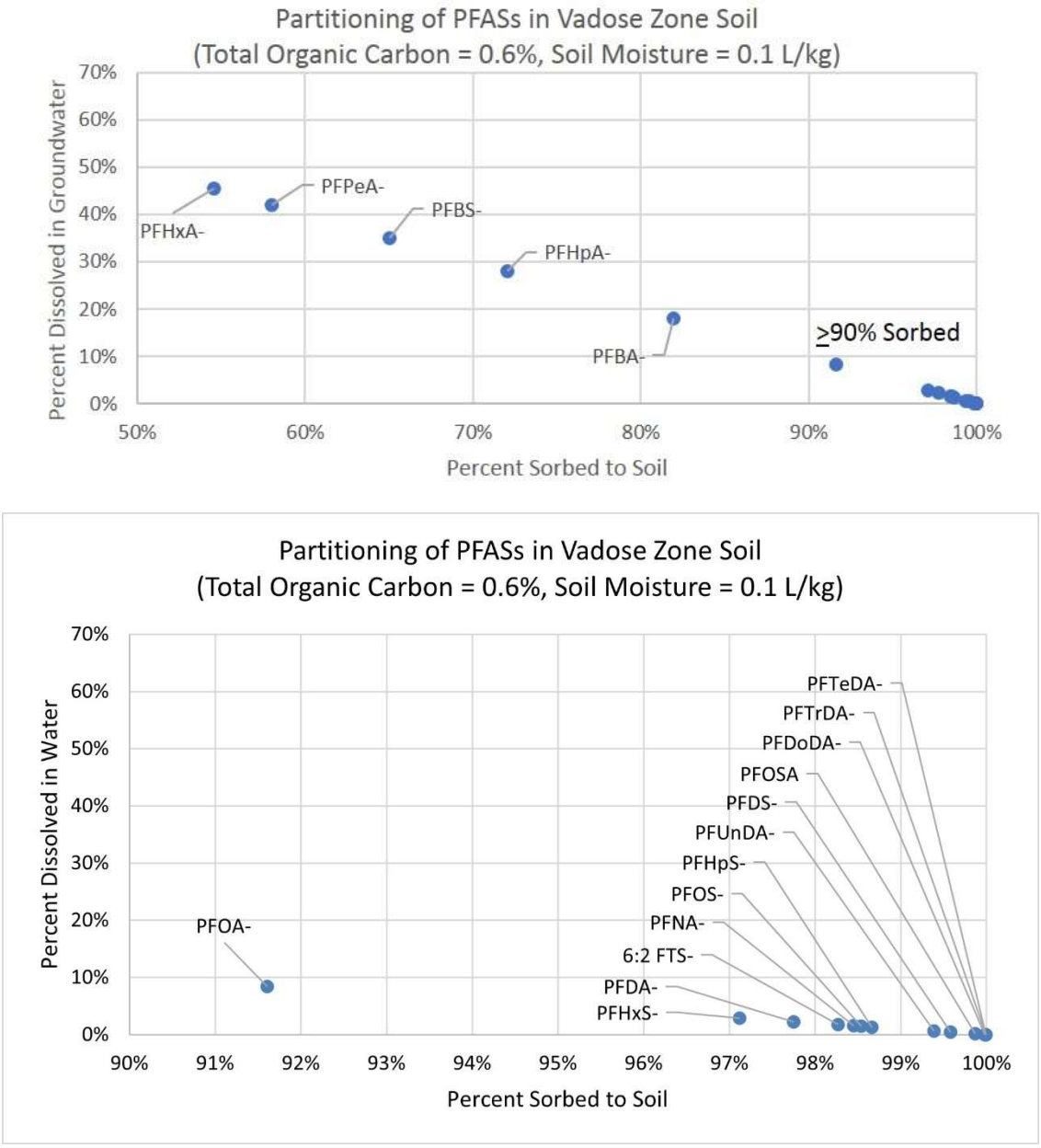

Figure 3. Predicted partitioning of PFASs upon initial release to vadose zone soil based on the chemical's solubility, sorption coefficient and volatility and default soil parameter values used in HIDOH EAL models.

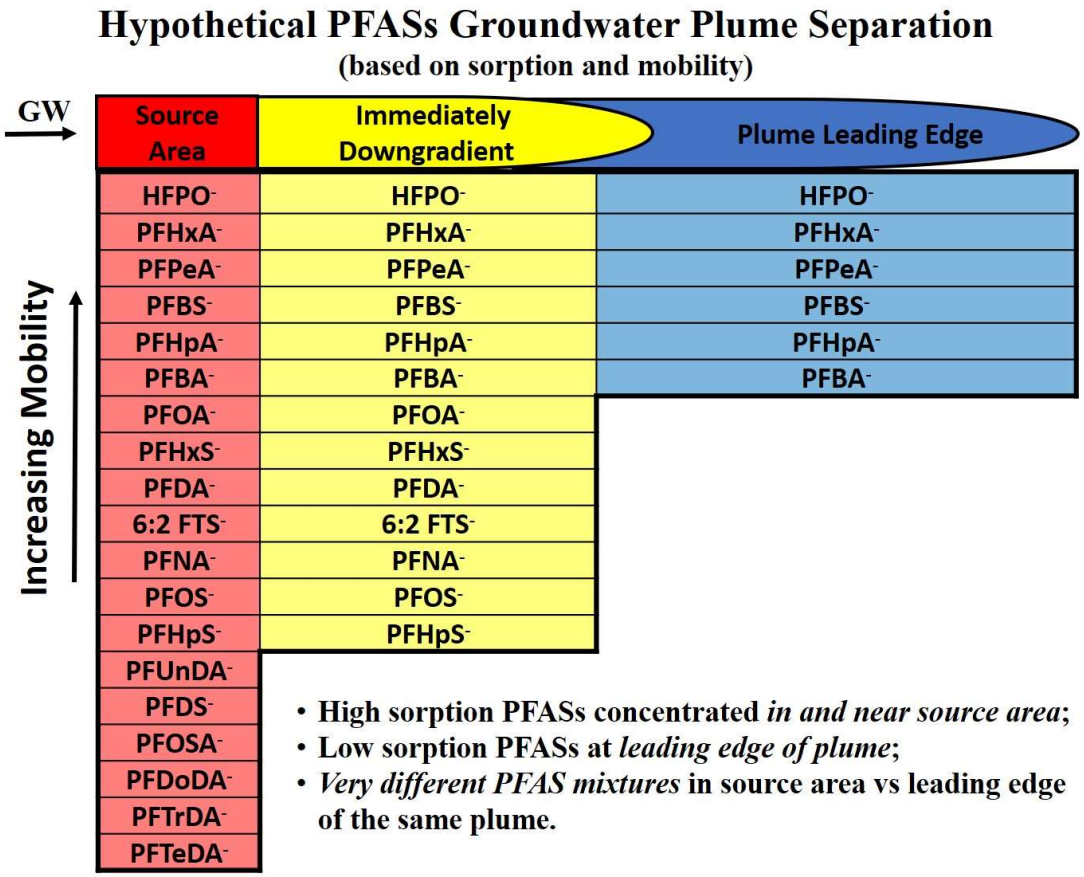

Figure 4. Hypothetical PFASs groundwater plume separation based on sorption coefficients for individual compounds.

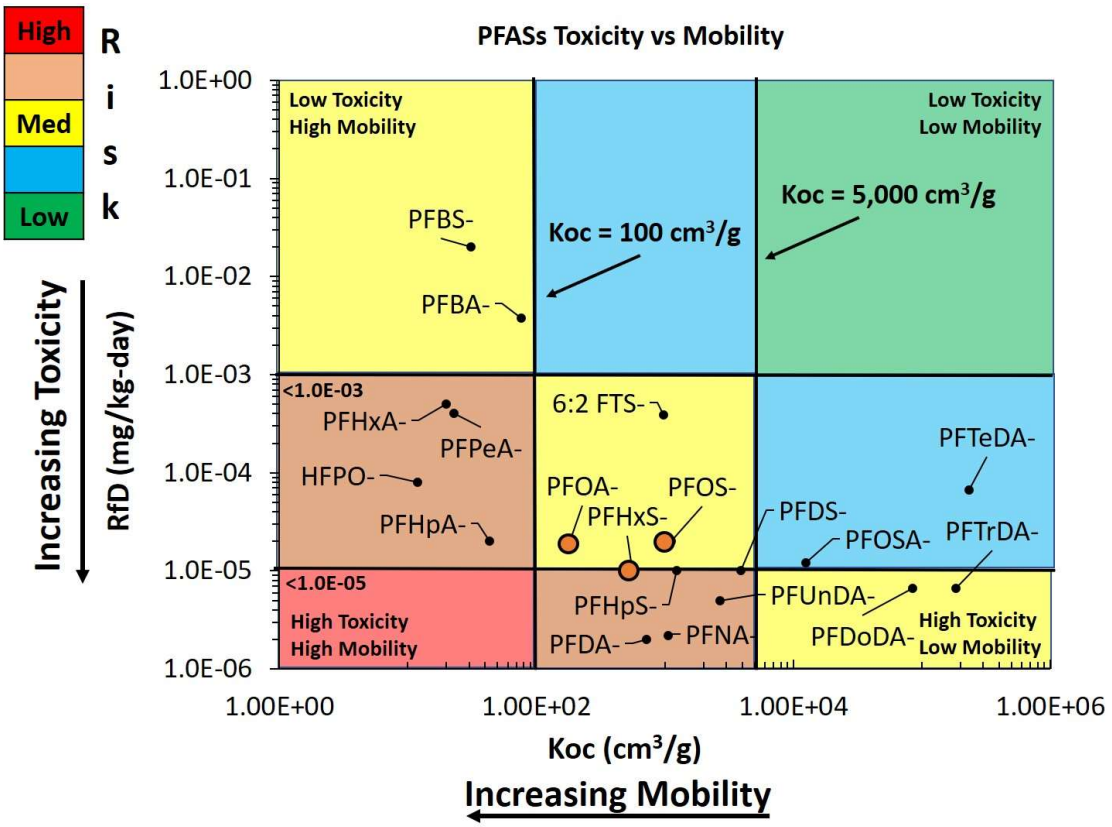

Figure 5. Comparison of PFASs mobility versus toxicity.

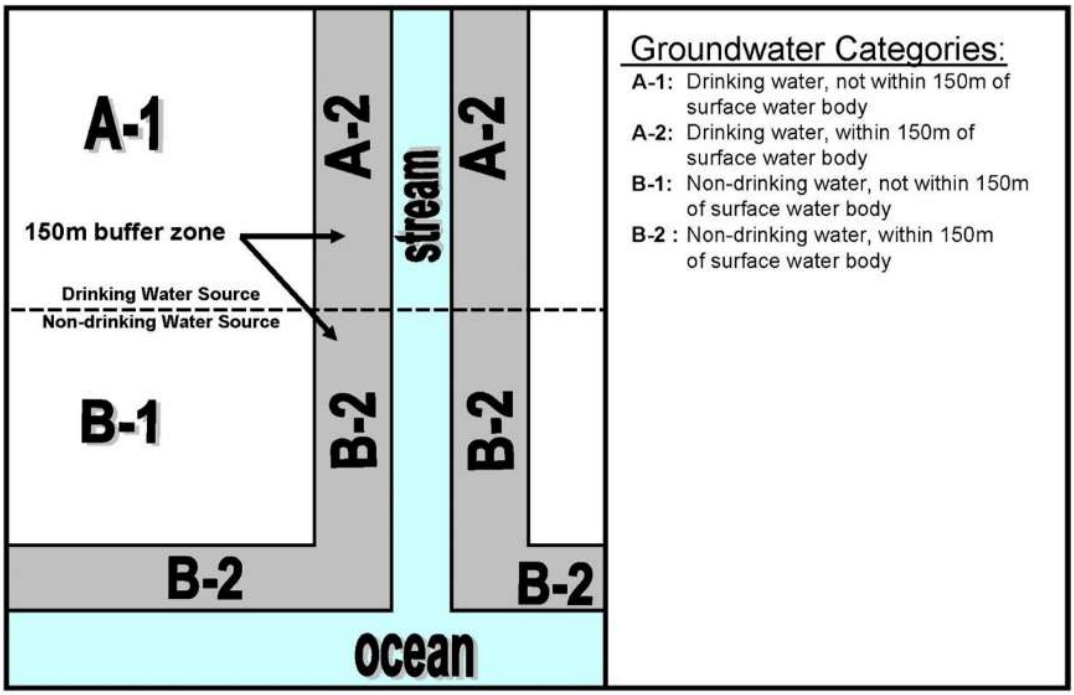

Figure 6. Groundwater categories used to develop the Tier 1 EAL lookup tables (HIDOH 2017a).

Table 1. Acid versus anion nomenclature for targeted Perfluoroalky substances.

Group	Industrial Protonated Acid Form	CAS Number	Abbreviation	Anion Form Found in the Environment	CAS Number	[1]Abbreviation
Perfluoroalkyl sulfonic acids & sulfonates	Perfluoro butane sulfonic acid	375-73-5	PFBS	Perfluoro butane sulfonate	45187-15-3	$PFBS^-$
	Perfluoro hexane sulfonic acid	355-46-4	PFHxS	Perfluoro hexane sulfonate	108427-53-8	$PFHxS^-$
	Perfluoro heptane sulfonic acid	375-92-8	PFHpS	Perfluoro heptane sulfonate	146689-46-5	$PFHpS^-$
	Perfluoro octane sulfonic acid	1763-23-1	PFOS	Perfluoro octane sulfonate	45298-90-6	$PFOS^-$
	Perfluoro decane sulfonic acid	335-77-3	PFDS	Perfluoro decane sulfonate	126105-34-8	$PFDS^-$
Perfluoroalkyl carboxylic acides and carboxylates	Perfluoro butanoic acid	375-22-4	PFBA	Perfluoro butanoate	45048-62-2	$PFBA^-$
	Perfluoro pentanoic acid	2706-90-3	PFPeA	Perfluoro pentanoate	45167-47-3	$PFPeA^-$
	Perfluoro hexanoic acid	307-24-4	PFHxA	Perfluoro hexanoate	92612-52-7	$PFHxA^-$
	Perfluoro heptanoic acid	375-85-9	PFHpA	Perfluoro heptanoate	120885-29-2	$PFHpA^-$
	Perfluoro octanoic acid	335-67-1	PFOA	Perfluoro octanoate	45285-51-6	$PFOA^-$
	Perfluoro nonanoic acid	375-95-1	PFNA	Perfluoro nonanoate	72007-68-2	$PFNA^-$
	Perfluoro decanoic acid	335-76-2	PFDA	Perfluoro decanoate	73829-36-4	$PFDA^-$
	Perfluoro undecanoic acid	2058-94-8	PFUnDA	Perfluoro undecanoate	196859-54-8	$PFUnDA^-$
	Perfluoro dodecanoic acid	307-55-1	PFDoDA	Perfluoro dodecanoate	171978-95-3	$PFDoDA^-$
	Perfluoro tridecanoic acid	72629-94-8	PFTrDA	Perfluoro tridecanoate	862374-87-6	$PFTrDA^-$
	Perfluoro tetradecanoic acid	376-06-7	PFTeDA	Perfluoro tetradecanoate	365971-87-5	$PFTeDA^-$
Other	[2]Perfluoro octane sulfonamide	754-91-6	PFOSA	[2]Perfluoro octane sulfonate	45298-90-6	$PFOS^-$
	Hexafluoropropylene oxide dimer acid	13252-13-6	HFPO	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate	122499-17-6	$HFPO^-$
	6:2 Fluorotelomer sulfonic acid	27619-97-2	6:2 FTS	6:2 Fluorotelomer sulfonate	425670-75-3	$6:2\ FTS^-$

1. Superscript "-" after abbreviation used to indicate anion form of compound.
2. Perfluorooctane sulfonamide degrades to perfluorooctane sulfonate in the environment (see Figure 2).

Table 2. PFASs included in HDOH EALs and reported under example laboratory methods (after USEPA 2019d; lab methods and list of compounds reported continually evolving).

Analyte	CAS #	[1]Method 1633	Method 537.1	Method 533	DoD QSM 5.3
PFBS$^-$	45187-15-3	X	X	X	X
PFHxS$^-$	108427-53-8	X	X	X	X
PFHpS$^-$	146689-46-5	X		X	X
PFOS$^-$	45298-90-6	X	X	X	X
PFDS$^-$	126105-34-8	X			X
PFBA$^-$	45048-62-2	X		X	X
PFPeA$^-$	45167-47-3	X		X	X
PFHxA$^-$	92612-52-7	X	X	X	X
PFHpA$^-$	120885-29-2	X	X	X	X
PFOA$^-$	45285-51-6	X	X	X	X
PFNA$^-$	72007-68-2	X	X	X	X
PFDA$^-$	73829-36-4	X	X	X	X
PFUnDA$^-$	196859-54-8	X	X	X	X
PFDoDA$^-$	171978-95-3	X	X	X	X
PFTrDA$^-$	862374-87-6	X	X		X
PFTeDA$^-$	365971-87-5	X	X		X
PFOSA	754-91-6	X			X
HFPO$^-$	13252-13-6	X	X	X	
6:2 FTS$^-$	425670-75-3	X			

1. Additional compounds reported under USEPA Method 1633 (toxicity factors not available): NMeFOSAA, NEtFOSAA, NEtFOSAA, 8:2 FTS, NEtFOSA, NMeFOSA, NMeFOSE, NEtFOSE, 9Cl-PF3ONS, 11Cl-PF3OUdS, ADONA, 3:3 FTCA, 5:3 FTCA, 7:3 FTCA, NFDHA, PFMBA, PFMPA, PFEESA.

.

Table 3a. PFAS physiochemical constants and absorption factors used in EAL Models.

[1]CAS #	[1]PFAS	[2]Physical State		Molecular Weight	Organic Carbon Partition coefficient, K_{oc}	Diffusivity in Air D_a	Diffusivity in Water D_w	Pure Component Solubility in Water S	Henry's Law Constant H	Henry's Law Constant H'	GI Tract Absorption Factor GIABS	Skin Absorption Factor ABS
				MW	(cm^3/g)	(cm^2/s)	(cm^2/s)	(mg/L)	(atm-m^3/mol)	(unitless)	(unitless)	(unitless)
45187-15-3	$PFBS^-$	NV	S	299	3.10E+01	2.70E-02	7.17E-06	2.17E+03	2.95E-10	1.21E-08	1.00E+00	1.00E-01
108427-53-8	$PFHxS^-$	NV	S	399	5.62E+02	3.50E-02	4.09E-06	1.70E+05	1.94E-10	7.93E-09	1.00E+00	1.00E-01
146689-46-5	$PFHpS^-$	NV	S	449	1.23E+03			3.53E+05	1.79E-10	7.32E-09	1.00E+00	1.00E-01
45298-90-6	$PFOS^-$	NV	S	499	1.12E+03	2.07E-02	5.26E-06	5.64E+05	1.80E-11	7.36E-10	1.00E+00	1.00E-01
126105-34-8	$PFDS^-$	NV	S	599	3.94E+03			1.08E+06	3.31E-10	1.35E-08	1.00E+00	1.00E-01
45048-62-2	$PFBA^-$	SV	L	213	7.60E+01			1.46E+05	5.01E-05	2.05E-03	1.00E+00	1.00E-01
45167-47-3	$PFPeA^-$	NV	L	263	2.30E+01			2.43E+05	2.97E-10	1.21E-08	1.00E+00	1.00E-01
92612-52-7	$PFHxA^-$	NV	L	313	2.00E+01			3.44E+05	2.35E-10	9.61E-09	1.00E+00	1.00E-01
120885-29-2	$PFHpA^-$	NV	S	363	4.30E+01			5.30E+05	2.09E-10	8.54E-09	1.00E+00	1.00E-01
45285-51-6	$PFOA^-$	NV	S	413	1.82E+02			6.24E+05	1.92E-10	7.85E-09	1.00E+00	1.00E-01
72007-68-2	$PFNA^-$	NV	S	463	1.06E+03			7.78E+05	1.18E-09	4.82E-08	1.00E+00	1.00E-01
73829-36-4	$PFDA^-$	NV	S	513	7.24E+02			9.54E+05	1.50E-10	6.13E-09	1.00E+00	1.00E-01
196859-54-8	$PFUnDA^-$	NV	S	563	2.69E+03			1.16E+06	3.34E-10	1.37E-08	1.00E+00	1.00E-01
171978-95-3	$PFDoDA^-$	NV	S	613	8.54E+04			1.40E+06	3.40E-10	1.39E-08	1.00E+00	1.00E-01
862374-87-6	$PFTrDA^-$	NV	S	663	1.84E+05			1.69E+06	3.48E-10	1.42E-08	1.00E+00	1.00E-01
365971-87-5	$PFTeDA^-$	NV	S	713	2.33E+05			2.03E+06	3.55E-10	1.45E-08	1.00E+00	1.00E-01
754-91-6	PFOSA	NV	S	499	1.26E+04	3.02E-02	3.53E-06	6.64E-01	1.26E-09	5.15E-08	1.00E+00	1.00E-01
122499-17-6	$HFPO^-$	NV	S	329	1.20E+01			1.00E+06	4.06E-06	1.66E-04	1.00E+00	1.00E-01
425670-75-3	6:2 FTS^-	NV	S	427	9.47E+02			5.72E+05	1.83E-10	7.48E-09	1.00E+00	1.00E-01

Table 3a (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 (atm m^3/mole) >0.00001 and molecular weight <200, and "semi-volatile" if molecular weight >200.
3. Confidence in modeled vapor pressures is low; not considered in determination of a compound as volatile or semivolatile.
References:
Refer to Table 3b in accompanying technical memorandum for reference documents used to compile physiochemical constants for individual PFAS.
Refer to Table 4a in accompanying technical memorandum for reference documents used to compile toxicity factors for individual PFAS.

Table 3b. References for PFAS physiochemical constants.

CAS #	PFAS	[1]Physical State		Molecular Weight MW	Organic Carbon Partition Coefficient K_{oc} (cm^3/g)	Diffusivity in Air D_a (cm^2/s)	Diffusivity in Water D_w (cm^2/s)	Pure Component Solubility in Water S (mg/L)	Henry's Law Constant H ($atm-m^3/mol$)	[2]Henry's Law Constant H' (unitless)	GI Tract Absorption Factor GIABS (unitless)	Skin Absorption Factor ABS (unitless)
45187-15-3	$PFBS^-$	*	1	1	3	2	2	1	1	1 (calc)	2	2
108427-53-8	$PFHxS^-$	*	1	1	3	2	2	1	1	1 (calc)	2	2
146689-46-5	$PFHpS^-$	*	1	1	1	-	-	1	1	1 (calc)	after 2	*after 2*
45298-90-6	$PFOS^-$	*	1	1	3	2	2	1	1	1 (calc)	2	2
126105-34-8	$PFDS^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
45048-62-2	$PFBA^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
45167-47-3	$PFPeA^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
92612-52-7	$PFHxA^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
120885-29-2	$PFHpA^-$	*	1	1	3	-	-	1	1	1 (calc)	2	2
45285-51-6	$PFOA^-$	*	1	1	3	-	-	1	1	1 (calc)	2	2
72007-68-2	$PFNA^-$	*	1	1	3	-	-	1	1	1 (calc)	2	2
73829-36-4	$PFDA^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
196859-54-8	$PFUnDA^-$	*	1	1	3	-	-	1	1	1 (calc)	after 2	*after 2*
171978-95-3	$PFDoDA^-$	*	1	1	1	-	-	1	1	1 (calc)	after 2	*after 2*
862374-87-6	$PFTrDA^-$	*	1	1	1	-	-	1	1	1 (calc)	after 2	*after 2*
365971-87-5	$PFTeDA^-$	*	1	1	1	-	-	1	1	1 (calc)	after 2	*after 2*
754-91-6	PFOSA	*	1	1	3	2	2	1	1	1 (calc)	after 2	*after 2*
13252-13-6	$HFPO^-$	*	4	4	4	-	-	4	4	4 (calc)	after 2	*after 2*
425670-75-3	6:2 FTS^-	*	1	1	1	-	-	1	1	1 (calc)	after 2	*after 2*

1. Volatility determined based on Molecular Weight and Henry's Constant (see Table 3a).
2. Dimensionless Henry's Law constant calculated based on Sander (2015) assuming a temperature of 25°C.

Table 3b (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/Acly Halides as Substances of Very High Concern: European Chemicals Agency, Adopted on 26 June 2019.

Table 4a. Selection of PFASs toxicity factors.

		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	
[1]PFAS	[1]CAS	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	1.4E-03	Anion	RfD (mg/kg-d)	[2]Primary Study Form
$PFBS^-$	45187-15-3	3.0E-04	H+ Acid			3.00E-04	Anion	0.001	2.0E-02	Anion	3.8E-06	Anion	1.3E-03	Anion
$PFHxS^-$	108427-53-8			2,00E-05	H+ Acid	9.70E-06	Anion	0.6	3.3E-05	Anion			9.7E-06	Anion
$PFHpS^-$	146689-46-5							2.0	1.0E-05	H+ Acid	2.3E-05	Anion		
$PFOS^-$	45298-90-6	2.0E-05	Anion	2,00E-06	H+ Acid	2.89E-06	Anion	2.0	1.0E-05	Anion	1.2E-05	Anion	3.1E-06	Anion
$PFDS^-$	126105-34-8							2.0	1.0E-05	H+ Acid	2.9E-03	H+ Acid		
$PFBA^-$	45048-62-2							0.05	4.0E-04	Anion	3.8E-06	H+ Acid	3.8E-03	Anion
$PFPeA^-$	45167-47-3							0.05	4.0E-04	H+ Acid	3.8E-06	H+ Acid		
$PFHxA^-$	92612-52-7	5.0E-04	H+ Acid			8.3E+00	H+ Acid	0.01	2.0E-03	Anion	2.3E-05	H+ Acid		
$PFHpA^-$	120885-29-2							1.0	2.0E-05	H+ Acid	1.2E-05	H+ Acid		
$PFOA^-$	45285-51-6	2.0E-05	H+ Acid	3,00E-06	H+ Acid	3.90E-06	H+ Acid	1.0	2.0E-05	H+ Acid	1.2E-05	H+ Acid	1.8E-05	Anion
$PFNA^-$	72007-68-2			3.00E-06	H+ Acid	2.20E-06	H+ Acid	10	2.0E-06	H+ Acid	1.5E-05	H+ Acid		
$PFDA^-$	73829-36-4							10	2.0E-06	H+ Acid	1.2E-05	H+ Acid		
$PFUnDA^-$	196859-54-8							4.0	5.0E-06	H+ Acid	1.2E-05	H+ Acid		
$PFDoDA^-$	171978-95-3							3.0	6.7E-06	H+ Acid	1.2E-05	H+ Acid		
$PFTrDA^-$	862374-87-6							3.0	6.7E-06	H+ Acid	1.2E-05	H+ Acid		
$PFTeDA^-$	365971-87-5							0.3	6.7E-05	H+ Acid	1.2E-05	H+ Acid		
PFOSA	754-91-6										1.4E-03	Anion		
$HFPO^-$	13252-13-6	3.0E-06	H+ Acid	7.70E-05	H+ Acid									
$6:2\ FTS^-$	425670-75-3			3.9E-04	H+ Acid									

Table 4a (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.
4. 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.

MNDOH, 2018, Toxicological Summary for Perfluorobutanoate: Minnesota Department of Health, August 2018.

TXCEQ, 2016, Toxicity Factor Derivation for Perfluoro Compounds (PFCs) Under the Texas Risk Reduction Program: Texas Commission on Environmental Quality, January 4, 2016.

USEPA, 2016a, Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA). U.S. Environmental Protection Agency, Office of Water, EPA 822-R-16-005. May 2016.

USEPA, 2016b, Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOS). U.S. Environmental Protection Agency, Office of Water, EPA 822-R-16-004. May 2016.

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, 2022, *Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts* (external review draft): US Environmental Protection Agency, Office of Research and Development, EPA/635/R-21/312a, February 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 4b. Final noncancer toxicity factors used for development of action levels and assessment of risk.

[1]PFAS	[1]CAS	[2]Selected Reference Dose (RfD)				
		[2]Preliminary RfD-Oral mg/kg-day	Reference	[3]Requires Adjustment to Reflect Anion Form?	[3]Anion:H+ Acid Adjustment Factor	[3]Final RfD-Oral mg/kg-day
$PFBS^-$	45187-15-3	3.0E-04	USEPA 2021a	Yes	9.97E-01	3.0E-04
$PFHxS^-$	108427-53-8	2.0E-05	ATSDR (2021)	Yes	9.97E-01	9.7E-06
$PFHpS^-$	146689-46-5	1.0E-05	Zeilmaker et al. (2018)	Yes	9.98E-01	1.0E-05
$PFOS^-$	45298-90-6	2.0E-06	ATSDR (2021)	Yes	9.98E-01	2.0E-05
$PFDS^-$	126105-34-8	1.0E-05	Zeilmaker et al. (2018)	Yes	9.98E-01	1.0E-05
$PFBA^-$	45048-62-2	3.8E-03	MNDOH (2018)	No	9.95E-01	3.8E-03
$PFPeA^-$	45167-47-3	4.0E-04	Zeilmaker et al. (2018)	Yes	9.96E-01	4.0E-04
$PFHxA^-$	92612-52-7	5.0E-04	USEPA (2022)	Yes	9.97E-01	2.0E-03
$PFHpA^-$	120885-29-2	2.0E-05	Zeilmaker et al. (2018)	Yes	9.97E-01	2.0E-05
$PFOA^-$	45285-51-6	3.0E-06	ATSDR (2021)	Yes	9.98E-01	2.0E-05
$PFNA^-$	72007-68-2	3.0E-06	ATSDR (2021)	Yes	9.98E-01	2.2E-06
$PFDA^-$	73829-36-4	2.0E-06	Zeilmaker et al. (2018)	Yes	9.98E-01	2.0E-06
$PFUnDA^-$	196859-54-8	5.0E-06	Zeilmaker et al. (2018)	Yes	9.98E-01	5.0E-06
$PFDoDA^-$	171978-95-3	6.7E-06	Zeilmaker et al. (2018)	Yes	9.98E-01	6.7E-06
$PFTrDA^-$	862374-87-6	6.7E-06	Zeilmaker et al. (2018)	Yes	9.98E-01	6.7E-06
$PFTeDA^-$	365971-87-5	6.7E-05	Zeilmaker et al. (2018)	Yes	9.99E-01	6.7E-05
PFOSA	754-91-6	1.2E-05	Texas CEQ (2016)	No	NA	1.2E-05
$HFPO^-$	13252-13-6	3.0E-06	USEPA 2021b	Yes	NA	8.0E-05
6:2 FTS^-	425670-75-3	3.9E-04	MIDOE (2020, 2021)	Yes	9.99E-01	3.9E-04

Table 4b (cont.). Final noncancer toxicity factors used for development of action levels and assessment of risk.

Notes:
1. CAS number reflects anion form. 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 and for order of preference.
3. Selected Reference Dose (RfD) adjusted to reflect exposure to anion form of compound if primary study used in reference reflective of H+ acid-based dose (Anion RfD = H+ acid-based RfD x (H+ Acid Molecular Weight/Anion Molecular Weight). Results inconsequential in terms of RfD but more technically correct for development of risk-based action levels for anion forms of the compounds that typically dominate environmental samples.

References

ATSDR, 2021, Toxicological Profile for Perfluoroalkyls: Agency for Toxic Substances and Disease Registry, May 2021.

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, 2018, Toxicological Summary for Perfluorobutanoate: Minnesota Department of Health, August 2018.

TXCEQ, 2016, Toxicity Factor Derivation for Perfluoro Compounds (PFCs) Under the Texas Risk Reduction Program: Texas Commission on Environmental Quality, January 4, 2016.

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, 2022, Toxicological Review of Perfluorohexanoic Acid [CASRN 307244] and Related Salts (external review draft): US Environmental Protection Agency, Office of Research and Development, EPA/635/R-21/312a, February 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 5. *Chronic health effects of PFASs (refer to Attachment 2, Table J for additional information).

CHEMICAL	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
PFBS-					15[A]	15[A]			15[A]				
PFHxS-			1[H],4[A]		1[A],9[H]	4[A]		1[H],2[H],9[H]		11[A]	10[H]		5[H]
PFHpS-													
PFOS-	13[A],17	1[H],2[H]	1[H]1[A],5H	1[H]	1[H]1[A],9[H]	1[H]		1[H]1[A],2[H], 9[H],13A	2[H],5[H]	11[A]	1[H],10[H]		5[H]
PFDS-													
PFBA-			3[A]		1[A],3[A]	3[A]	3[A]						
PFPeA-													
PFHxA-			1[A], 21[A]	1[H]	1[A], 21[A]	1[A]	1[A], 21[A]		1[A]				
PFHpA-			1[A]										
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],7H,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]
PFNA-		1[H],10[H]			1[A]								5[H]
PFDA-		1[H]			1[A]			1[H],2[H]					
PFUnDA-					1[A]								
PFDoDA-													
PFTrDA-													
PFTeDA-													
PFOSA													
HFPO-	14[A]		14[A]		14[A]		14[A]	14[A]					
6:2 FTS-			19[A], 20[A]	19[A]					20[A]				20[A]

*For general reference only. 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.

Table 5 (cont.). *Chronic health effects of PFASs (refer to Attachment 2, Table J for additional information).

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 Spraugue-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 DRAFT Toxicological Review of Perfluorohexanoic Acid and Related Salts February 2022

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).

Symbol	Definition (units)	Default	References
CSFo	Cancer slope factor oral $(mg/kg\text{-}d)^{-1}$	--	Chemical specific – Table 4
CSFi	Cancer slope factor inhaled $(mg/kg\text{-}d)^{-1}$	--	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
TRr/o	Target cancer risk - residential, occupational/ industrial exposure scenario	10^{-6}	USEPA 2019b.
TRctw	Target cancer risk - construction/trench worker exposure scenario	10^{-5}	HIDOH (see Appendix 1)
THQs	Target hazard quotient (soil)	0.2	(refer to memorandum text)
THQdw	Target hazard quotient (drinking water)	0.5	(refer to memorandum text)
RSCdw	Relative Source Contribution (drinking water)	0.2	(refer to memorandum text)
BWa	Body weight, adult (kg)	70	HIDOH
BWc	Body weight, child (kg)	15	USEPA 2019b
ATc	Average time – carcinogens (days)	25,550	USEPA 2019b
ATn	Average time – noncarcinogens (days)	EDx365	USEPA 2019b
SAar	Exposed surface area, adult res. (cm^2/day)	6,032	USEPA 2019b
SAaw	Exposed surface area, adult occ. (cm^2/day)	2,373	USEPA 2019b
SAc	Exposed surface area, child (cm^2/day)	3,527	USEPA 2019b
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 2019b
AFaw	Adherence factor, occupational (mg/cm^2)	0.12	USEPA 2019b
AFctw	Adherence factor, construction/trench worker (mg/cm^2)	0.30	USEPA 2019b
AFc	Adherence factor, child (mg/cm^2)	0.20	USEPA 2019b
ABS	Skin absorption (unitless): chemical specific	--	USEPA 2019b
IRAa	Inhalation rate – adult (m^3/day)	20	USEPA 2019b
IRAc	Inhalation rate – child (m^3/day)	10	USEPA 2019b
IRActw	Inhalation rate – construction/trench worker (m^3/day)	20	USEPA 2011b
IRWa	Drinking water ingestion – adult (L/day)	2.5	USEPA 2019b
IRWc	Drinking water ingestion – child (L/day)	0.78	USEPA 2019b
IRSa	Soil ingestion – adult (mg/day)	100	USEPA 2019b
IRSc	Soil ingestion – child (mg/day)	200	USEPA 2019b)
IRSo	Soil ingestion – occupational (mg/day)	100	USEPA 2019b
IRSctw	Soil ingestion–construction/trench worker (mg/day)	330	USEPA 2002
EFr	Exposure frequency – residential (d/y)	350	USEPA 2019b
EFo	Exposure frequency – occupational (d/y)	250	USEPA 2019b
EFctw	Exposure frequency – construction/trench worker (d/y)	20	Massachusetts DEP (1994)
EDr	Exposure duration – residential (years)	26	USEPA 2019b
EDc	Exposure duration – child (years)	6	USEPA 2019b
EDo	Exposure duration – occupational (years)	25	USEPA 2019b
EDctw	Exposure duration – construction/trench worker (years)	7	modified from Massachusetts DEP (1994)

Attachment 1

Summary PFAS Lookup Tables
(HIDOH December 2022)

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

	>150m to Surface Water Body		≤150m to Surface Water Body	
CHEMICAL PARAMETER	**[1]Soil (mg/kg)**	**[2]Groundwater (ug/L)**	**[1]Soil (mg/kg)**	**[2]Groundwater (ug/L)**
Perfluorobutane sulfonate ($PFBS^-$)	3.1E-03	6.0E-01	3.1E-03	6.0E-01
Perfluorohexane sulfonate ($PFHxS^-$)	3.7E-03	4.0E-02	3.7E-03	4.0E-02
Perfluoroheptane sulfonate ($PFHpS^-$)	4.1E-03	2.0E-02	4.1E-03	2.0E-02
Perfluorooctane sulfonate ($PFOS^-$)	7.5E-04	4.0E-03	7.5E-04	4.0E-03
Perfluorodecane sulfonate ($PFDS^-$)	1.3E-02	2.0E-02	1.3E-02	2.0E-02
Perfluoro butanoate ($PFBA^-$)	9.9E-02	7.6E+00	9.9E-02	7.6E+00
Perfluoro pentanoate ($PFPeA^-$)	3.1E-03	8.0E-01	3.1E-03	8.0E-01
Perfluoro hexanoate ($PFHxA^-$)	3.3E-03	1.0E+00	3.3E-03	1.0E+00
Perfluoro heptanoate ($PFHpA^-$)	2.9E-04	4.0E-02	2.9E-04	4.0E-02
Perfluoro octanoate ($PFOA^-$)	1.8E-04	6.0E-03	1.8E-04	6.0E-03
Perfluoro nonanoate ($PFNA^-$)	1.1E-03	6.0E-03	1.1E-03	6.0E-03
Perfluoro decanoate ($PFDA^-$)	4.8E-04	4.0E-03	4.8E-04	4.0E-03
Perfluoro undecanoate ($PFUnDA^-$)	4.5E-03	1.0E-02	4.5E-03	1.0E-02
Perfluoro dodecanoate ($PFDoDA^-$)	8.4E-03	1.3E-02	8.4E-03	1.3E-02
Perfluoro tridecanoate ($PFTrDA^-$)	8.4E-03	1.3E-02	8.4E-03	1.3E-02
Perfluoro tetradecanoate ($PFTeDA^-$)	8.4E-02	1.3E-01	8.4E-02	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	2.4E-02	1.5E-02	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate ($HFPO^-$)	1.2E-05	6.0E-03	1.2E-05	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS^-)	1.2E-01	7.8E-01	1.2E-01	7.8E-01

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 Attachment 2, Tables A-1 and A-2.

Source of Groundwater Action Levels: Attachment 2, 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 HDOH 2017; 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

	>150m to Surface Water Body		≤150m to Surface Water Body	
CHEMICAL PARAMETER	**[1]Soil (mg/kg)**	**[2]Groundwater (ug/L)**	**[1]Soil (mg/kg)**	**[2]Groundwater (ug/L)**
Perfluorobutane sulfonate ($PFBS^-$)	3.8E-01	5.0E+04	3.8E-01	5.0E+04
Perfluorohexane sulfonate ($PFHxS^-$)	2.5E-02	1.0E+01	2.5E-02	1.0E+01
Perfluoroheptane sulfonate ($PFHpS^-$)	4.1E-03	2.0E-02	4.1E-03	2.0E-02
Perfluorooctane sulfonate ($PFOS^-$)	2.5E-03	3.1E+01	2.5E-03	1.1E+00
Perfluorodecane sulfonate ($PFDS^-$)	1.3E-02	2.0E-02	1.3E-02	2.0E-02
Perfluoro butanoate ($PFBA^-$)	4.8E+00	8.3E+02	4.8E+00	8.3E+02
Perfluoro pentanoate ($PFPeA^-$)	3.1E-03	8.0E-01	3.1E-03	8.0E-01
Perfluoro hexanoate ($PFHxA^-$)	6.3E-01	4.8E+04	6.3E-01	6.3E+03
Perfluoro heptanoate ($PFHpA^-$)	2.9E-04	4.0E-02	2.9E-04	4.0E-02
Perfluoro octanoate ($PFOA^-$)	3.8E-03	1.2E+02	3.8E-03	8.3E+00
Perfluoro nonanoate ($PFNA^-$)	3.8E-03	8.0E+00	3.8E-03	8.0E+00
Perfluoro decanoate ($PFDA^-$)	2.5E-03	1.0E+01	2.5E-03	1.0E+01
Perfluoro undecanoate ($PFUnDA^-$)	6.3E-03	1.0E+01	6.3E-03	1.0E+01
Perfluoro dodecanoate ($PFDoDA^-$)	8.4E-03	2.0E+01	8.4E-03	2.0E+01
Perfluoro tridecanoate ($PFTrDA^-$)	8.4E-03	1.3E-02	8.4E-03	1.3E-02
Perfluoro tetradecanoate ($PFTeDA^-$)	8.4E-02	1.3E-01	8.4E-02	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	2.4E-02	1.5E-02	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate ($HFPO^-$)	1.2E-05	6.0E-03	1.2E-05	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS^-)	4.9E-01	1.1E+04	4.9E-01	2.6E+02

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 discharge of groundwater into a freshwater, marine or estuary surface water system. Compare to *dissolved-phase* concentration.

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

Source of Groundwater Action Levels: Attachment 2, 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).

Attachment 2

Detailed PFAS Lookup Tables

(HIDOH December 2022; 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)

	(mg/kg)							
						[1]Human Health		Leaching & Groundwater Protection
CHEMICAL PARAMETER	Final EAL	Basis	[1]Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.1E-03	Groundwater Protection	1.0E+03			3.8E-01	(not volatile)	3.1E-03
Perfluorohexane sulfonate (PFHxS-)	3.7E-03	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	3.7E-03
Perfluoroheptane sulfonate (PFHpS-)	4.1E-03	Groundwater Protection	1.0E+03			1.3E-02	(not volatile)	4.1E-03
Perfluorooctane sulfonate (PFOS-)	7.5E-04	Groundwater Protection	1.0E+03			2.5E-03	(not volatile)	7.5E-04
Perfluorodecane sulfonate (PFDS-)	1.3E-02	Direct Exposure	1.0E+03			1.3E-02	(not volatile)	1.3E-02
Perfluoro butanoate (PFBA-)	9.9E-02	Groundwater Protection	1.0E+03			4.8E+00	(not volatile)	9.9E-02
Perfluoro pentanoate (PFPeA-)	3.1E-03	Groundwater Protection	1.0E+03			5.1E-01	(not volatile)	3.1E-03
Perfluoro hexanoate (PFHxA-)	3.3E-03	Groundwater Protection	1.0E+03			6.3E-01	(not volatile)	3.3E-03
Perfluoro heptanoate (PFHpA-)	2.9E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	2.9E-04
Perfluoro octanoate (PFOA-)	1.8E-04	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.8E-04
Perfluoro nonanoate (PFNA-)	1.1E-03	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.1E-03
Perfluoro decanoate (PFDA-)	4.8E-04	Groundwater Protection	1.0E+03			2.5E-03	(not volatile)	4.8E-04
Perfluoro undecanoate (PFUnDA-)	4.5E-03	Groundwater Protection	1.0E+03			6.3E-03	(not volatile)	4.5E-03
Perfluoro dodecanoate (PFDoDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.4E-02	Direct Exposure	1.0E+03			8.4E-02	(not volatile)	1.0E+06
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	Direct Exposure	1.0E+03			1.5E-02	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.2E-05	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.2E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.2E-01	Groundwater Protection	1.0E+03			4.9E-01	(not volatile)	1.2E-01

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)

	(mg/kg)							
						[1]Human Health		Leaching & Groundwater Protection
CHEMICAL PARAMETER	Final EAL	Basis	[1]Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.1E-03	Groundwater Protection	1.0E+03			3.8E-01	(not volatile)	3.1E-03
Perfluorohexane sulfonate (PFHxS-)	3.7E-03	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	3.7E-03
Perfluoroheptane sulfonate (PFHpS-)	4.1E-03	Groundwater Protection	1.0E+03			1.3E-02	(not volatile)	4.1E-03
Perfluorooctane sulfonate (PFOS-)	7.5E-04	Groundwater Protection	1.0E+03			2.5E-03	(not volatile)	7.5E-04
Perfluorodecane sulfonate (PFDS-)	1.3E-02	Direct Exposure	1.0E+03			1.3E-02	(not volatile)	1.3E-02
Perfluoro butanoate (PFBA-)	9.9E-02	Groundwater Protection	1.0E+03			4.8E+00	(not volatile)	9.9E-02
Perfluoro pentanoate (PFPeA-)	3.1E-03	Groundwater Protection	1.0E+03			5.1E-01	(not volatile)	3.1E-03
Perfluoro hexanoate (PFHxA-)	3.3E-03	Groundwater Protection	1.0E+03			6.3E-01	(not volatile)	3.3E-03
Perfluoro heptanoate (PFHpA-)	2.9E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	2.9E-04
Perfluoro octanoate (PFOA-)	1.8E-04	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.8E-04
Perfluoro nonanoate (PFNA-)	1.1E-03	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.1E-03
Perfluoro decanoate (PFDA-)	4.8E-04	Groundwater Protection	1.0E+03			2.5E-03	(not volatile)	4.8E-04
Perfluoro undecanoate (PFUnDA-)	4.5E-03	Groundwater Protection	1.0E+03			6.3E-03	(not volatile)	4.5E-03
Perfluoro dodecanoate (PFDoDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.4E-02	Direct Exposure	1.0E+03			8.4E-02	(not volatile)	1.0E+06
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	Direct Exposure	1.0E+03			1.5E-02	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.2E-05	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.2E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.2E-01	Groundwater Protection	1.0E+03			4.9E-01	(not volatile)	1.2E-01

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)

	(mg/kg)							
						[1]Human Health		Leaching & Groundwater Protection
CHEMICAL PARAMETER	Final EAL	Basis	[1]Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	NON-Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.8E-01	Direct Exposure	1.0E+03			3.8E-01	(not volatile)	2.6E+02
Perfluorohexane sulfonate (PFHxS-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	4.1E-03	Groundwater Protection	1.0E+03			1.3E-02	(not volatile)	4.1E-03
Perfluorooctane sulfonate (PFOS-)	2.5E-03	Direct Exposure	1.0E+03			2.5E-03	(not volatile)	5.8E+00
Perfluorodecane sulfonate (PFDS-)	1.3E-02	Direct Exposure	1.0E+03			1.3E-02	(not volatile)	1.3E-02
Perfluoro butanoate (PFBA-)	4.8E+00	Direct Exposure	1.0E+03			4.8E+00	(not volatile)	1.1E+01
Perfluoro pentanoate (PFPeA-)	3.1E-03	Groundwater Protection	1.0E+03			5.1E-01	(not volatile)	3.1E-03
Perfluoro hexanoate (PFHxA-)	6.3E-01	Direct Exposure	1.0E+03			6.3E-01	(not volatile)	1.6E+02
Perfluoro heptanoate (PFHpA-)	2.9E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	2.9E-04
Perfluoro octanoate (PFOA-)	3.8E-03	Direct Exposure	1.0E+03			3.8E-03	(not volatile)	3.6E+00
Perfluoro nonanoate (PFNA-)	3.8E-03	Direct Exposure	1.0E+03			3.8E-03	(not volatile)	1.4E+00
Perfluoro decanoate (PFDA-)	2.5E-03	Direct Exposure	1.0E+03			2.5E-03	(not volatile)	1.2E+00
Perfluoro undecanoate (PFUnDA-)	6.3E-03	Direct Exposure	1.0E+03			6.3E-03	(not volatile)	4.5E+00
Perfluoro dodecanoate (PFDoDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.4E-02	Direct Exposure	1.0E+03			8.4E-02	(not volatile)	1.0E+06
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	Direct Exposure	1.0E+03			1.5E-02	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.2E-05	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.2E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E-01	Direct Exposure	1.0E+03			4.9E-01	(not volatile)	1.7E+03

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)

	(mg/kg)							
						[1]Human Health		Leaching & Groundwater Protection
CHEMICAL PARAMETER	Final EAL	Basis	[1]Gross Contamination (Odors, etc.) Table F-2	Terrestrial Ecotoxicity Table L	Background Table K	Direct Exposure Table I-1	Vapor Intrusion Into Buildings Table C-1b	NON-Drinking Water Resource Table E
Perfluorobutane sulfonate (PFBS-)	3.8E-01	Direct Exposure	1.0E+03			3.8E-01	(not volatile)	2.6E+02
Perfluorohexane sulfonate (PFHxS-)	2.5E-02	Direct Exposure	1.0E+03			2.5E-02	(not volatile)	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	4.1E-03	Groundwater Protection	1.0E+03			1.3E-02	(not volatile)	4.1E-03
Perfluorooctane sulfonate (PFOS-)	2.5E-03	Direct Exposure	1.0E+03			2.5E-03	(not volatile)	2.0E-01
Perfluorodecane sulfonate (PFDS-)	1.3E-02	Direct Exposure	1.0E+03			1.3E-02	(not volatile)	1.3E-02
Perfluoro butanoate (PFBA-)	4.8E+00	Direct Exposure	1.0E+03			4.8E+00	(not volatile)	1.1E+01
Perfluoro pentanoate (PFPeA-)	3.1E-03	Groundwater Protection	1.0E+03			5.1E-01	(not volatile)	3.1E-03
Perfluoro hexanoate (PFHxA-)	6.3E-01	Direct Exposure	1.0E+03			6.3E-01	(not volatile)	2.1E+01
Perfluoro heptanoate (PFHpA-)	2.9E-04	Groundwater Protection	1.0E+03			2.5E-02	(not volatile)	2.9E-04
Perfluoro octanoate (PFOA-)	3.8E-03	Direct Exposure	1.0E+03			3.8E-03	(not volatile)	2.5E-01
Perfluoro nonanoate (PFNA-)	3.8E-03	Direct Exposure	1.0E+03			3.8E-03	(not volatile)	1.4E+00
Perfluoro decanoate (PFDA-)	2.5E-03	Direct Exposure	1.0E+03			2.5E-03	(not volatile)	1.2E+00
Perfluoro undecanoate (PFUnDA-)	6.3E-03	Direct Exposure	1.0E+03			6.3E-03	(not volatile)	4.5E+00
Perfluoro dodecanoate (PFDoDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	8.4E-03	Direct Exposure	1.0E+03			8.4E-03	(not volatile)	1.0E+06
Perfluoro tetradecanoate (PFTeDA-)	8.4E-02	Direct Exposure	1.0E+03			8.4E-02	(not volatile)	1.0E+06
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	Direct Exposure	1.0E+03			1.5E-02	(not volatile)	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.2E-05	Groundwater Protection	1.0E+03			3.8E-03	(not volatile)	1.2E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E-01	Direct Exposure	1.0E+03			4.9E-01	(not volatile)	4.1E+01

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 (ug/L)	Commercial/ Industrial Land Use Only (ug/L)
Perfluorobutane sulfonate (PFBS-)	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 butanoate (PFBA-)	SV	L	(not volatile)	(not volatile)
Perfluoro pentanoate (PFPeA-)	NV	L	(not volatile)	(not volatile)
Perfluoro hexanoate (PFHxA-)	NV	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)
Perfluroroctane sulfonamide (PFOSA)	NV	S	(not volatile)	(not volatile)
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer sulfonate (6:2 FTS-)	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 = 0.2 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 (mg/kg)	Commercial/ Industrial Land Use Only (mg/kg)
Perfluorobutane sulfonate (PFBS-)	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 butanoate (PFBA-)	SV	L	(not volatile)	(not volatile)
Perfluoro pentanoate (PFPeA-)	NV	L	(not volatile)	(not volatile)
Perfluoro hexanoate (PFHxA-)	NV	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)
Perfluroroctane sulfonamide (PFOSA)	NV	S	(not volatile)	(not volatile)
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	NV	S	(not volatile)	(not volatile)
6:2 Fluorotelomer sulfonate (6:2 FTS-)	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 = 0.2 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. [1]SHALLOW 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 (ug/m^3)	Carcinogenic Effects (ug/m^3)	Noncarcinogenic Effects (ug/m^3)	Lowest C/I (ug/m^3)	Carcinogenic Effects (ug/m^3)	Noncarcinogenic Effects (ug/m^3)
Perfluorobutane sulfonate (PFBS-)	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 butanoate (PFBA-)	SV	L	(not volatile)			(not volatile)		
Perfluoro pentanoate (PFPeA-)	NV	L	(not volatile)			(not volatile)		
Perfluoro hexanoate (PFHxA-)	NV	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)		
Perfluroroctane sulfonamide (PFOSA)	NV	S	(not volatile)			(not volatile)		
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	NV	S	(not volatile)			(not volatile)		
6:2 Fluorotelomer sulfonate (6:2 FTS-)	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 = 0.2 for all chemicals except as noted.

Residential soil gas:indoor air attenuation factor = 0.001 (1/1000). Commercial/industrial soil gas:indoor air attenuation factor = 0.0005 (1/2000). 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 chemicals only)

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)	[1]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)				
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 butanoate (PFBA-)	SV	L	NA	1.0E+01	(not volatile)			(not volatile)				
Perfluoro pentanoate (PFPeA-)	NV	L	NA	NA	(not volatile)			(not volatile)				
Perfluoro hexanoate (PFHxA-)	NV	L	NA	NA	(not volatile)			(not volatile)				
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)				
Perfluroroctane sulfonamide (PFOSA)	NV	S	NA	NA	(not volatile)			(not volatile)				
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	NV	S	NA	NA	(not volatile)			(not volatile)				
6:2 Fluorotelomer sulfonate (6:2 FTS-)	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 = 0.2 for all chemicals except as noted. Target 10^{-5} risk applied to ethylbenzene, 1-methylnaphthalene and naphthalene. Target HQ of 1.0 applied to TPHg and TPHmd.

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.

Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2004, 2011).

Action levels calculated using spreadhseet 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).

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)

CONTAMINANT	[1]Final Groundwater Action Level	Basis	Gross Contamination (Taste & Odors, etc.) Table G-1	Drinking Water Toxicity Table D-3a	Vapor Intrusion Into Buildings Table C-1a	Aquatic Habitat Impacts (chronic) Table D-4a
Perfluorobutane sulfonate (PFBS-)	6.0E-01	Drinking Water Toxicity	5.0E+04	6.0E-01	(not volatile)	1.3E+05
Perfluorohexane sulfonate (PFHxS-)	4.0E-02	Drinking Water Toxicity	5.0E+04	4.0E-02	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	Drinking Water Toxicity	5.0E+04	2.0E-02	(not volatile)	2.0E-02
Perfluorooctane sulfonate (PFOS-)	4.0E-03	Drinking Water Toxicity	5.0E+04	4.0E-03	(not volatile)	1.1E+00
Perfluorodecane sulfonate (PFDS-)	2.0E-02	Drinking Water Toxicity	5.0E+04	2.0E-02	(not volatile)	2.0E-02
Perfluoro butanoate (PFBA-)	7.6E+00	Drinking Water Toxicity	5.0E+04	7.6E+00	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	8.0E-01	Drinking Water Toxicity	5.0E+04	8.0E-01	(not volatile)	8.0E-01
Perfluoro hexanoate (PFHxA-)	1.0E+00	Drinking Water Toxicity	5.0E+04	1.0E+00	(not volatile)	6.3E+03
Perfluoro heptanoate (PFHpA-)	4.0E-02	Drinking Water Toxicity	5.0E+04	4.0E-02	(not volatile)	4.0E-02
Perfluoro octanoate (PFOA-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	8.3E+00
Perfluoro nonanoate (PFNA-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	8.0E+00
Perfluoro decanoate (PFDA-)	4.0E-03	Drinking Water Toxicity	5.0E+04	4.0E-03	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	1.0E-02	Drinking Water Toxicity	5.0E+04	1.0E-02	(not volatile)	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	1.3E-02	Drinking Water Toxicity	5.0E+04	1.3E-02	(not volatile)	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	Drinking Water Toxicity	5.0E+04	1.3E-02	(not volatile)	1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	Drinking Water Toxicity	5.0E+04	1.3E-01	(not volatile)	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	Drinking Water Toxicity	3.3E+02	2.4E-02	(not volatile)	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS-)	7.8E-01	Drinking Water Toxicity	5.0E+04	7.8E-01	(not volatile)	2.6E+02

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	[1]Final Groundwater Action Level	Basis	Gross Contamination (Taste & Odors, etc.) Table G-1	Drinking Water Toxicity Table D-3a	Vapor Intrusion Into Buildings Table C-1a	Aquatic Habitat Impacts (acute) Table D-4a
Perfluorobutane sulfonate (PFBS-)	6.0E-01	Drinking Water Toxicity	5.0E+04	6.0E-01	(not volatile)	1.3E+05
Perfluorohexane sulfonate (PFHxS-)	4.0E-02	Drinking Water Toxicity	5.0E+04	4.0E-02	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	Drinking Water Toxicity	5.0E+04	2.0E-02	(not volatile)	2.0E-02
Perfluorooctane sulfonate (PFOS-)	4.0E-03	Drinking Water Toxicity	5.0E+04	4.0E-03	(not volatile)	3.1E+01
Perfluorodecane sulfonate (PFDS-)	2.0E-02	Drinking Water Toxicity	5.0E+04	2.0E-02	(not volatile)	2.0E-02
Perfluoro butanoate (PFBA-)	7.6E+00	Drinking Water Toxicity	5.0E+04	7.6E+00	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	8.0E-01	Drinking Water Toxicity	5.0E+04	8.0E-01	(not volatile)	8.0E-01
Perfluoro hexanoate (PFHxA-)	1.0E+00	Drinking Water Toxicity	5.0E+04	1.0E+00	(not volatile)	4.8E+04
Perfluoro heptanoate (PFHpA-)	4.0E-02	Drinking Water Toxicity	5.0E+04	4.0E-02	(not volatile)	4.0E-02
Perfluoro octanoate (PFOA-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	1.2E+02
Perfluoro nonanoate (PFNA-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	8.0E+00
Perfluoro decanoate (PFDA-)	4.0E-03	Drinking Water Toxicity	5.0E+04	4.0E-03	(not volatile)	1.0E+01
Perfluoro undecanoate (PFUnDA-)	1.0E-02	Drinking Water Toxicity	5.0E+04	1.0E-02	(not volatile)	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	1.3E-02	Drinking Water Toxicity	5.0E+04	1.3E-02	(not volatile)	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	Drinking Water Toxicity	5.0E+04	1.3E-02	(not volatile)	1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	Drinking Water Toxicity	5.0E+04	1.3E-01	(not volatile)	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	Drinking Water Toxicity	3.3E+02	2.4E-02	(not volatile)	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	Drinking Water Toxicity	5.0E+04	6.0E-03	(not volatile)	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS-)	7.8E-01	Drinking Water Toxicity	5.0E+04	7.8E-01	(not volatile)	1.1E+04

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	[1]Final Groundwater Action Level	Basis	Gross Contamination (Odors, etc.) Table G-2	Vapor Intrusion Into Buildings Table C-1a	Aquatic Habitat Impacts (chronic) Table D-4a
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Gross Contamination	5.0E+04	(not volatile)	1.3E+05
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.0E-02
Perfluorooctane sulfonate (PFOS-)	1.1E+00	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.1E+00
Perfluorodecane sulfonate (PFDS-)	2.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.0E-02
Perfluoro butanoate (PFBA-)	8.3E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	8.0E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.0E-01
Perfluoro hexanoate (PFHxA-)	6.3E+03	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.3E+03
Perfluoro heptanoate (PFHpA-)	4.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.0E-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-)	1.3E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	Aquatic Habitat Goal	3.3E+02	(not volatile)	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.6E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.6E+02

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	[1]Final Groundwater Action Level	Basis	Gross Contamination (Odors, etc.) Table G-2	Vapor Intrusion Into Buildings Table C-1a	Aquatic Habitat Impacts (acute) Table D-4a
Perfluorobutane sulfonate (PFBS-)	5.0E+04	Gross Contamination	5.0E+04	(not volatile)	1.3E+05
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.0E-02
Perfluorooctane sulfonate (PFOS-)	3.1E+01	Aquatic Habitat Goal	5.0E+04	(not volatile)	3.1E+01
Perfluorodecane sulfonate (PFDS-)	2.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	2.0E-02
Perfluoro butanoate (PFBA-)	8.3E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.3E+02
Perfluoro pentanoate (PFPeA-)	8.0E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	8.0E-01
Perfluoro hexanoate (PFHxA-)	4.8E+04	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.8E+04
Perfluoro heptanoate (PFHpA-)	4.0E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	4.0E-02
Perfluoro octanoate (PFOA-)	1.2E+02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.2E+02
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-)	1.3E-02	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	Aquatic Habitat Goal	3.3E+02	(not volatile)	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	Aquatic Habitat Goal	5.0E+04	(not volatile)	6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS-)	1.1E+04	Aquatic Habitat Goal	5.0E+04	(not volatile)	1.1E+04

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.) Table G-3	Drinking Water (Toxicity) Table D-3a	Fresh Water Aquatic Habitat Goal (Chronic Toxicity) Table D-4a	Bioaccumulation and Human Consumption Table D-4f
Perfluorobutane sulfonate (PFBS-)						
Perfluorohexane sulfonate (PFHxS-)						
Perfluoroheptane sulfonate (PFHpS-)						
Perfluorooctane sulfonate (PFOS-)						
Perfluorodecane sulfonate (PFDS-)						
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-)						
6:2 Fluorotelomer sulfonate (6:2 FTS-)						

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.) Table G-4	Marine Aquatic Habitat Goal (Chronic Toxicity) Table D-4a	Bioaccumulation and Human Consumption Table D-4F
Perfluorobutane sulfonate (PFBS-)					
Perfluorohexane sulfonate (PFHxS-)					
Perfluoroheptane sulfonate (PFHpS-)					
Perfluorooctane sulfonate (PFOS-)					
Perfluorodecane sulfonate (PFDS-)					
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-)					
6:2 Fluorotelomer sulfonate (6:2 FTS-)					

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)

CHEMICAL PARAMETER	[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
Perfluorobutane sulfonate (PFBS-)					
Perfluorohexane sulfonate (PFHxS-)					
Perfluoroheptane sulfonate (PFHpS-)					
Perfluorooctane sulfonate (PFOS-)					
Perfluorodecane sulfonate (PFDS-)					
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-)					
6:2 Fluorotelomer sulfonate (6:2 FTS-)					

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-)	6.0E-01	noncarcinogenic effects				6.0E-01	noncarcinogenic effects
Perfluorohexane sulfonate (PFHxS-)	4.0E-02	noncarcinogenic effects				4.0E-02	noncarcinogenic effects
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	noncarcinogenic effects				2.0E-02	noncarcinogenic effects
Perfluorooctane sulfonate (PFOS-)	4.0E-03	noncarcinogenic effects				4.0E-03	noncarcinogenic effects
Perfluorodecane sulfonate (PFDS-)	2.0E-02	noncarcinogenic effects				2.0E-02	noncarcinogenic effects
Perfluoro butanoate (PFBA-)	7.6E+00	noncarcinogenic effects				7.6E+00	noncarcinogenic effects
Perfluoro pentanoate (PFPeA-)	8.0E-01	noncarcinogenic effects				8.0E-01	noncarcinogenic effects
Perfluoro hexanoate (PFHxA-)	1.0E+00	noncarcinogenic effects				1.0E+00	noncarcinogenic effects
Perfluoro heptanoate (PFHpA-)	4.0E-02	noncarcinogenic effects				4.0E-02	noncarcinogenic effects
Perfluoro octanoate (PFOA-)	6.0E-03	noncarcinogenic effects				6.0E-03	noncarcinogenic effects
Perfluoro nonanoate (PFNA-)	6.0E-03	noncarcinogenic effects				6.0E-03	noncarcinogenic effects
Perfluoro decanoate (PFDA-)	4.0E-03	noncarcinogenic effects				4.0E-03	noncarcinogenic effects
Perfluoro undecanoate (PFUnDA-)	1.0E-02	noncarcinogenic effects				1.0E-02	noncarcinogenic effects
Perfluoro dodecanoate (PFDoDA-)	1.3E-02	noncarcinogenic effects				1.3E-02	noncarcinogenic effects
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	noncarcinogenic effects				1.3E-02	noncarcinogenic effects
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	noncarcinogenic effects				1.3E-01	noncarcinogenic effects
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	noncarcinogenic effects				2.4E-02	noncarcinogenic effects
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	noncarcinogenic effects				6.0E-03	noncarcinogenic effects
6:2 Fluorotelomer sulfonate (6:2 FTS-)	7.8E-01	noncarcinogenic effects				7.8E-01	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 0.5 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-)	6.0E-01	noncarcinogenic effects			6.0E-01
Perfluorohexane sulfonate (PFHxS-)	4.0E-02	noncarcinogenic effects			4.0E-02
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	noncarcinogenic effects			2.0E-02
Perfluorooctane sulfonate (PFOS-)	4.0E-03	noncarcinogenic effects			4.0E-03
Perfluorodecane sulfonate (PFDS-)	2.0E-02	noncarcinogenic effects			2.0E-02
Perfluoro butanoate (PFBA-)	7.6E+00	noncarcinogenic effects			7.6E+00
Perfluoro pentanoate (PFPeA-)	8.0E-01	noncarcinogenic effects			8.0E-01
Perfluoro hexanoate (PFHxA-)	1.0E+00	noncarcinogenic effects			1.0E+00
Perfluoro heptanoate (PFHpA-)	4.0E-02	noncarcinogenic effects			4.0E-02
Perfluoro octanoate (PFOA-)	6.0E-03	noncarcinogenic effects	2.0E+00		6.0E-03
Perfluoro nonanoate (PFNA-)	6.0E-03	noncarcinogenic effects			6.0E-03
Perfluoro decanoate (PFDA-)	4.0E-03	noncarcinogenic effects			4.0E-03
Perfluoro undecanoate (PFUnDA-)	1.0E-02	noncarcinogenic effects			1.0E-02
Perfluoro dodecanoate (PFDoDA-)	1.3E-02	noncarcinogenic effects			1.3E-02
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	noncarcinogenic effects			1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	noncarcinogenic effects			1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	noncarcinogenic effects			2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	noncarcinogenic effects			6.0E-03
6:2 Fluorotelomer sulfonate (6:2 FTS-)	7.8E-01	noncarcinogenic effects			7.8E-01

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 0.5 and a target Excess Cancer Risk of 10-6 (see Table D-3b). Refer to accompanying Technical Memorandum for additional details.

NA=Not available.

TABLE D-4a. SUMMARY OF AQUATIC HABITAT GOALS

	Estuarine		Freshwater		Marine	
CHEMICAL PARAMETER	**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
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-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-)	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02
Perfluoro butanoate (PFBA-)	8.3E+02	8.3E+02	8.3E+02	8.3E+02	8.3E+02	8.3E+02
Perfluoro pentanoate (PFPeA-)	8.0E-01	8.0E-01	8.0E-01	8.0E-01	8.0E-01	8.0E-01
Perfluoro hexanoate (PFHxA-)	6.3E+03	4.8E+04	6.3E+03	4.8E+04	4.8E+04	4.8E+04
Perfluoro heptanoate (PFHpA-)	4.0E-02	4.0E-02	4.0E-02	4.0E-02	4.0E-02	4.0E-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	8.0E+00	8.0E+00	8.0E+00	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	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	1.3E-01	1.3E-01	1.3E-01	1.3E-01	1.3E-01
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	6.0E-03	6.0E-03	6.0E-03	6.0E-03	6.0E-03
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

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

	[1]Aquatic Habitat Goals					
CHEMICAL PARAMETER	[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 LC0	5.0E+05	NOEC Daphnia Magna	1.3E+05	=acute LC0
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	=freshwater chronic	1.0E+01	infection risk	1.0E+01	=freshwater chronic
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	=Drinking Water Toxicity	2.0E-02	=Drinking Water Toxicity)	2.0E-02	=Drinking Water Toxicity
Perfluorooctane sulfonate (PFOS-)	1.1E+00	PNOEC	2.3E+00	NOEC	1.1E+00	PNOEC
Perfluorodecane sulfonate (PFDS-)	2.0E-02	=Drinking Water Toxicity	2.0E-02	=Drinking Water Toxicity)	2.0E-02	=Drinking Water Toxicity
Perfluoro butanoate (PFBA-)	8.3E+02	=freshwater chronic	8.3E+02	NOEC	8.3E+02	=freshwater chronic
Perfluoro pentanoate (PFPeA-)	8.0E-01	=Drinking Water Toxicity	8.0E-01	=Drinking Water Toxicity)	8.0E-01	=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-)	4.0E-02	=Drinking Water Toxicity	4.0E-02	=Drinking Water Toxicity)	4.0E-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	=freshwater chronic	1.0E+01	NOEC	1.0E+01	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	=freshwater chronic	2.0E+01	NOEC	2.0E+01	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	=Drinking Water Toxicity	1.3E-02	=Drinking Water Toxicity)	1.3E-02	=Drinking Water Toxicity
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	=Drinking Water Toxicity	1.3E-01	=Drinking Water Toxicity)	1.3E-01	=Drinking Water Toxicity
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	=Drinking Water Toxicity	2.4E-02	=Drinking Water Toxicity)	2.4E-02	=Drinking Water Toxicity
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	=Drinking Water Toxicity	6.0E-03	=Drinking Water Toxicity)	6.0E-03	=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)

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
Perfluorohexane sulfonate (PFHxS-)	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic
Perfluoroheptane sulfonate (PFHpS-)	2.0E-02	=Drinking Water Toxicity	2.0E-02	=Drinking Water Toxicity	2.0E-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-)	2.0E-02	=Drinking Water Toxicity	2.0E-02	=Drinking Water Toxicity	2.0E-02	=Drinking Water Toxicity
Perfluoro butanoate (PFBA-)	8.3E+02	=freshwater chronic	8.3E+02	=freshwater chronic	8.3E+02	=freshwater chronic
Perfluoro pentanoate (PFPeA-)	8.0E-01	=Drinking Water Toxicity	8.0E-01	=Drinking Water Toxicity	8.0E-01	=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-)	4.0E-02	=Drinking Water Toxicity	4.0E-02	=Drinking Water Toxicity	4.0E-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-)	8.0E+00	=freshwater chronic	8.0E+00	=freshwater chronic	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-)	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)	2.0E+01	=freshwater chronic	2.0E+01	=freshwater chronic	2.0E+01	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)	1.3E-02	=Drinking Water Toxicity	1.3E-02	=Drinking Water Toxicity	1.3E-02	=Drinking Water Toxicity
Perfluoro tetradecanoate (PFTeDA-)	1.3E-01	=Drinking Water Toxicity	1.3E-01	=Drinking Water Toxicity	1.3E-01	=Drinking Water Toxicity
Perfluroroctane sulfonamide (PFOSA)	2.4E-02	=Drinking Water Toxicity	2.4E-02	=Drinking Water Toxicity	2.4E-02	=Drinking Water Toxicity
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	6.0E-03	=Drinking Water Toxicity	6.0E-03	=Drinking Water Toxicity	6.0E-03	=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

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

	Freshwater (ug/L)		Saltwater (ug/L)	
CONTAMINANT	**Chronic**	**Acute**	**Chronic**	**Acute**
Perfluorobutane sulfonate (PFBS-)				
Perfluorohexane sulfonate (PFHxS-)				
Perfluoroheptane sulfonate (PFHpS-)				
Perfluorooctane sulfonate (PFOS-)				
Perfluorodecane sulfonate (PFDS-)				
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-)				
6:2 Fluorotelomer sulfonate (6:2 FTS-)				

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)

	Freshwater						Marine					
CONTAMINANT	**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
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 butanoate (PFBA-)			8.3E+02	NOEC	8.3E+02	=freshwater chronic			8.3E+02	=freshwater chronic	8.3E+02	=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	8.0E+00	=freshwater chronic			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	1.0E+01	=freshwater chronic			1.0E+01	=freshwater chronic	1.0E+01	=freshwater chronic
Perfluoro dodecanoate (PFDoDA-)			2.0E+01	NOEC	2.0E+01	=freshwater chronic			2.0E+01	=freshwater chronic	2.0E+01	=freshwater chronic
Perfluoro tridecanoate (PFTrDA-)												
Perfluoro tetradecanoate (PFTeDA-)												
Perflurooctane sulfonamide (PFOSA)												
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)												
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

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., Naile, 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.

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)

	Freshwater		Marine		Freshwater			Marine		
CONTAMINANT	**Selected Criteria**	**Basis**	**Selected Criteria**	**Basis**	**[1]ACRC 2018**	**[2]Other**	**Other Ref**	**[1]ACRC 2018**	**[2]Other**	**Other Ref**
Perfluorobutane sulfonate (PFBS-)										
Perfluorohexane sulfonate (PFHxS-)										
Perfluoroheptane sulfonate (PFHpS-)										
Perfluorooctane sulfonate (PFOS-)	2.3E-04	Australia CRC 2018	2.9E-01	Australia CRC 2018	2.3E-04			2.9E-01		
Perfluorodecane sulfonate (PFDS-)										
Perfluoro butanoate (PFBA-)										
Perfluoro pentanoate (PFPeA-)										
Perfluoro hexanoate (PFHxA-)										
Perfluoro heptanoate (PFHpA-)										
Perfluoro octanoate (PFOA-)	1.9E+01	Australia CRC 2018	3.0E+00	Australia CRC 2018	1.9E+01			3.0E+00		
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-)										

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-)	
Perfluorohexane sulfonate (PFHxS-)	
Perfluoroheptane sulfonate (PFHpS-)	
Perfluorooctane sulfonate (PFOS-)	
Perfluorodecane sulfonate (PFDS-)	
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-)	
6:2 Fluorotelomer sulfonate (6:2 FTS-)	

References:

Notes:
Addresses use of water (including groundwater) for agricultural/irrigation purposes.

TABLE E-1. SOIL ACTION LEVELS FOR LEACHING CONCERNS

					Target Groundwater Concentrations				Soil Leaching Action Levels			
					Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
Chemical	Organic Carbon Coefficient (Koc) (cm^3/g)	Henry's Law Constant (H) ($atm\text{-}m^3/mol$)	Dilution/ Atenuation Factor (DAF)	Saturation Limit (mg/kg)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1a) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b) (ug/L)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d) (ug/L)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)
Perfluorobutane sulfonate (PFBS-)	3.10E+01	2.95E-10	5.15E+00	6.2E+02	6.0E-01	6.0E-01	5.0E+04	5.0E+04	3.1E-03	3.1E-03	2.6E+02	2.6E+02
Perfluorohexane sulfonate (PFHxS-)	5.62E+02	1.94E-10	9.33E+01	5.9E+05	4.0E-02	4.0E-02	1.0E+01	1.0E+01	3.7E-03	3.7E-03	9.3E-01	9.3E-01
Perfluoroheptane sulfonate (PFHpS-)	1.23E+03	1.79E-10	2.04E+02	1.0E+06	2.0E-02	2.0E-02	2.0E-02	2.0E-02	4.1E-03	4.1E-03	4.1E-03	4.1E-03
Perfluorooctane sulfonate (PFOS-)	1.12E+03	1.80E-11	1.86E+02	1.0E+06	4.0E-03	4.0E-03	1.1E+00	3.1E+01	7.5E-04	7.5E-04	2.0E-01	5.8E+00
Perfluorodecane sulfonate (PFDS-)	3.94E+03	3.31E-10	6.53E+02	1.0E+06	2.0E-02	2.0E-02	2.0E-02	2.0E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02
Perfluoro butanoate (PFBA-)	7.60E+01	5.01E-05	1.29E+01	8.1E+04	7.6E+00	7.6E+00	8.3E+02	8.3E+02	9.9E-02	9.9E-02	1.1E+01	1.1E+01
Perfluoro pentanoate (PFPeA-)	2.30E+01	2.97E-10	3.82E+00	5.8E+04	8.0E-01	8.0E-01	8.0E-01	8.0E-01	3.1E-03	3.1E-03	3.1E-03	3.1E-03
Perfluoro hexanoate (PFHxA-)	2.00E+01	2.35E-10	3.32E+00	7.6E+04	1.0E+00	1.0E+00	6.3E+03	4.8E+04	3.3E-03	3.3E-03	2.1E+01	1.6E+02
Perfluoro heptanoate (PFHpA-)	4.30E+01	2.95E-10	7.14E+00	1.9E+05	4.0E-02	4.0E-02	4.0E-02	4.0E-02	2.9E-04	2.9E-04	2.9E-04	2.9E-04
Perfluoro octanoate (PFOA-)	1.82E+02	1.92E-10	3.02E+01	7.4E+05	6.0E-03	6.0E-03	8.3E+00	1.2E+02	1.8E-04	1.8E-04	2.5E-01	3.6E+00
Perfluoro nonanoate (PFNA-)	1.06E+03	1.18E-09	1.76E+02	1.0E+06	6.0E-03	6.0E-03	8.0E+00	8.0E+00	1.1E-03	1.1E-03	1.4E+00	1.4E+00
Perfluoro decanoate (PFDA-)	7.24E+02	1.50E-10	1.20E+02	1.0E+06	4.0E-03	4.0E-03	1.0E+01	1.0E+01	4.8E-04	4.8E-04	1.2E+00	1.2E+00
Perfluoro undecanoate (PFUnDA-)	2.69E+03	3.34E-10	4.47E+02	1.0E+06	1.0E-02	1.0E-02	1.0E+01	1.0E+01	4.5E-03	4.5E-03	4.5E+00	4.5E+00
Perfluoro dodecanoate (PFDoDA-)	8.54E+04	3.40E-10	1.42E+04	1.0E+06	1.3E-02	1.3E-02	2.0E+01	2.0E+01	1.0E+06	1.0E+06	1.0E+06	1.0E+06
Perfluoro tridecanoate (PFTrDA-)	1.84E+05	3.48E-10	3.05E+04	1.0E+06	1.3E-02	1.3E-02	1.3E-02	1.3E-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	1.3E-01	1.3E-01	1.3E-01	1.3E-01	1.0E+06	1.0E+06	1.0E+06	1.0E+06
Perfluoroctane sulfonamide (PFOSA)	1.26E+04	1.26E-09	2.09E+03	5.0E+01	2.4E-02	2.4E-02	2.4E-02	2.4E-02	5.0E+01	5.0E+01	5.0E+01	5.0E+01
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.20E+01	4.06E-06	2.02E+00	1.7E+05	6.0E-03	6.0E-03	6.0E-03	6.0E-03	1.2E-05	1.2E-05	1.2E-05	1.2E-05
6:2 Fluorotelomer sulfonate (6:2 FTS-)	9.47E+02	1.83E-10	1.57E+02	1.0E+06	7.8E-01	7.8E-01	2.6E+02	1.1E+04	1.2E-01	1.2E-01	4.1E+01	1.7E+03

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. [1]SOIL VAPOR ACTION LEVELS FOR EVALUATION OF VADOSE-ZONE LEACHATE AND PROTECTION OF DRINKING WATER AQUIFERS

([2]volatile 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	-	-	-
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 butanoate (PFBA-)	SV	L	No	-	-	-
Perfluoro pentanoate (PFPeA-)	NV	L	No	-	-	-
Perfluoro hexanoate (PFHxA-)	NV	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	-	-	-
Perfluroroctane sulfonamide (PFOSA)	NV	S	No	-	-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	NV	S	No	-	-	-
6:2 Fluorotelomer sulfonate (6:2 FTS-)	NV	S	No	-	-	-

Notes:

1. 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.

2. 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.

3. 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 ≥ 100 OR no Odor Index and Vapor Pressure ≥ 1 Torr OR no data	100
	0.1 ≤ 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 ≥ 100 OR no Odor Index and Vapor Pressure ≥ 1 Torr OR no data	500
	0.1 ≤ 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 ≥ 100 OR no Odor Index and Vapor Pressure ≥ 1 Torr OR no data	500
	0.1 ≤ 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 ≥ 100 OR no Odor Index and Vapor Pressure ≥ 1 Torr OR no data	1000
	0.1 ≤ 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 [1]EXPOSED 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			-	-
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 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			-	-
Perfluroroctane sulfonamide (PFOSA)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA			-	-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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			-	-

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 [1]DEEP 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				-
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 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				-
Perfluroroctane sulfonamide (PFOSA)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA				-
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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				-

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
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 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	1.1E+06			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
Perfluroroctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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

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
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 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	1.1E+06			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
Perfluroroctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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

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
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 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	1.1E+06			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
Perfluroroctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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

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
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 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	1.1E+06			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
Perfluroroctane sulfonamide (PFOSA)	3.3E+02	Solubility	3.3E+02			5.0E+04
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	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

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.

[1]CAS #	[1]Chemical	[2]Physical State		Molecular Weight	Organic Carbon Partition coefficient,	Diffusivity in Air	Diffusivity in Water	Pure Component Solubility in Water	[4]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	(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	3.10E+01	2.70E-02	7.17E-06	2.17E+03		2.95E-10	1.21E-08	1.00E+00	1.00E-01			3.0E-04	4.90E-03
108427-53-8	Perfluorohexane sulfonate (PFHxS$^-$)	NV	S	399	5.62E+02	3.50E-02	4.09E-06	1.70E+05		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	1.23E+03			3.53E+05		1.79E-10	7.32E-09	1.00E+00	1.00E-01			1.0E-05	
45298-90-6	Perfluorooctane sulfonate (PFOS$^-$)	NV	S	499	1.12E+03	2.07E-02	5.26E-06	5.64E+05		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	3.94E+03			1.08E+06		3.31E-10	1.35E-08	1.00E+00	1.00E-01			1.0E-05	
45048-62-2	Perfluoro butanoate (PFBA$^-$)	SV	L	213	7.60E+01			1.46E+05		5.01E-05	2.05E-03	1.00E+00	1.00E-01			3.8E-03	1.00E-02
45167-47-3	Perfluoro pentanoate (PFPeA$^-$)	NV	L	263	2.30E+01			2.43E+05		2.97E-10	1.21E-08	1.00E+00	1.00E-01			4.0E-04	
92612-52-7	Perfluoro hexanoate (PFHxA$^-$)	NV	L	313	2.00E+01			3.44E+05		2.35E-10	9.61E-09	1.00E+00	1.00E-01			5.0E-04	
120885-29-2	Perfluoro heptanoate (PFHpA$^-$)	NV	S	363	4.30E+01			5.30E+05		2.09E-10	8.54E-09	1.00E+00	1.00E-01			2.0E-05	
45285-51-6	Perfluoro octanoate (PFOA$^-$)	NV	S	413	1.82E+02			6.24E+05		1.92E-10	7.85E-09	1.00E+00	1.00E-01	7.00E-02		3.0E-06	4.10E-06
72007-68-2	Perfluoro nonanoate (PFNA$^-$)	NV	S	463	1.06E+03			7.78E+05		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	7.24E+02			9.54E+05		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	2.69E+03			1.16E+06		3.34E-10	1.37E-08	1.00E+00	1.00E-01			5.0E-06	
171978-95-3	Perfluoro dodecanoate (PFDoDA$^-$)	NV	S	613	8.54E+04			1.40E+06		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	1.84E+05			1.69E+06		3.48E-10	1.42E-08	1.00E+00	1.00E-01			6.7E-06	
365971-87-5	Perfluoro tetradecanoate (PFTeDA$^-$)	NV	S	713	2.33E+05			2.03E+06		3.55E-10	1.45E-08	1.00E+00	1.00E-01			6.7E-05	
754-91-6	Perfluroroctane sulfonamide (PFOSA)	NV	S	499	1.26E+04	3.02E-02	3.53E-06	6.64E-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$^-$)	NV	S	329	1.20E+01			1.00E+06		4.06E-06	1.66E-04	1.00E+00	1.00E-01			3.0E-06	
425670-75-3	6:2 Fluorotelomer sulfonate (6:2 FTS$^-$)	NV	S	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	5.85E-04

General 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 (atm m3/mole) >0.00001 and molecular weight <200, and "semi-volatile" if molecular weight >200.

3. Confidence in Kow values low (USEPA CompTox database - modeled).

4. Confidence in pubished, modeled vapor pressures is low (e.g., USEPA 2017); not considered in determination of a compound as volatile or semivolatile.

5. 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
[1]UNRESTRICTED 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-01	noncarcinogenic effects			3.8E-01	7.6E-01	NA
Perfluorohexane sulfonate (PFHxS-)	2.5E-02	noncarcinogenic effects			2.5E-02	5.1E-02	NA
Perfluoroheptane sulfonate (PFHpS-)	1.3E-02	noncarcinogenic effects			1.3E-02	2.5E-02	NA
Perfluorooctane sulfonate (PFOS-)	2.5E-03	noncarcinogenic effects			2.5E-03	5.1E-03	NA
Perfluorodecane sulfonate (PFDS-)	1.3E-02	noncarcinogenic effects			1.3E-02	2.5E-02	NA
Perfluoro butanoate (PFBA-)	4.8E+00	noncarcinogenic effects			4.8E+00	9.6E+00	NA
Perfluoro pentanoate (PFPeA-)	5.1E-01	noncarcinogenic effects			5.1E-01	1.0E+00	NA
Perfluoro hexanoate (PFHxA-)	6.3E-01	noncarcinogenic effects			6.3E-01	1.3E+00	NA
Perfluoro heptanoate (PFHpA-)	2.5E-02	noncarcinogenic effects			2.5E-02	5.1E-02	NA
Perfluoro octanoate (PFOA-)	3.8E-03	noncarcinogenic effects	1.4E+01		3.8E-03	7.6E-03	NA
Perfluoro nonanoate (PFNA-)	3.8E-03	noncarcinogenic effects			3.8E-03	7.6E-03	NA
Perfluoro decanoate (PFDA-)	2.5E-03	noncarcinogenic effects			2.5E-03	5.1E-03	NA
Perfluoro undecanoate (PFUnDA-)	6.3E-03	noncarcinogenic effects			6.3E-03	1.3E-02	NA
Perfluoro dodecanoate (PFDoDA-)	8.4E-03	noncarcinogenic effects			8.4E-03	1.7E-02	NA
Perfluoro tridecanoate (PFTrDA-)	8.4E-03	noncarcinogenic effects			8.4E-03	1.7E-02	NA
Perfluoro tetradecanoate (PFTeDA-)	8.4E-02	noncarcinogenic effects			8.4E-02	1.7E-01	NA
Perfluroroctane sulfonamide (PFOSA)	1.5E-02	noncarcinogenic effects			1.5E-02	3.0E-02	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	3.8E-03	noncarcinogenic effects			3.8E-03	7.6E-03	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.9E-01	noncarcinogenic effects			4.9E-01	9.9E-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 = 0.5.
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-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-)	1.7E+01	noncarcinogenic effects		1.7E+01	3.4E+01	NA
Perfluorohexane sulfonate (PFHxS-)	1.1E+00	noncarcinogenic effects		1.1E+00	2.3E+00	NA
Perfluoroheptane sulfonate (PFHpS-)	5.6E-01	noncarcinogenic effects		5.6E-01	1.1E+00	NA
Perfluorooctane sulfonate (PFOS-)	1.1E-01	noncarcinogenic effects		1.1E-01	2.3E-01	NA
Perfluorodecane sulfonate (PFDS-)	5.6E-01	noncarcinogenic effects		5.6E-01	1.1E+00	NA
Perfluoro butanoate (PFBA-)	2.1E+02	noncarcinogenic effects		2.1E+02	4.3E+02	NA
Perfluoro pentanoate (PFPeA-)	2.3E+01	noncarcinogenic effects		2.3E+01	4.5E+01	NA
Perfluoro hexanoate (PFHxA-)	2.8E+01	noncarcinogenic effects		2.8E+01	5.6E+01	NA
Perfluoro heptanoate (PFHpA-)	1.1E+00	noncarcinogenic effects		1.1E+00	2.3E+00	NA
Perfluoro octanoate (PFOA-)	1.7E-01	noncarcinogenic effects	4.5E+01	1.7E-01	3.4E-01	NA
Perfluoro nonanoate (PFNA-)	1.7E-01	noncarcinogenic effects		1.7E-01	3.4E-01	NA
Perfluoro decanoate (PFDA-)	1.1E-01	noncarcinogenic effects		1.1E-01	2.3E-01	NA
Perfluoro undecanoate (PFUnDA-)	2.8E-01	noncarcinogenic effects		2.8E-01	5.6E-01	NA
Perfluoro dodecanoate (PFDoDA-)	3.8E-01	noncarcinogenic effects		3.8E-01	7.5E-01	NA
Perfluoro tridecanoate (PFTrDA-)	3.8E-01	noncarcinogenic effects		3.8E-01	7.5E-01	NA
Perfluoro tetradecanoate (PFTeDA-)	3.8E+00	noncarcinogenic effects		3.8E+00	7.5E+00	NA
Perfluroroctane sulfonamide (PFOSA)	6.8E-01	noncarcinogenic effects		6.8E-01	1.4E+00	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	1.7E-01	noncarcinogenic effects		1.7E-01	3.4E-01	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	2.2E+01	noncarcinogenic effects		2.2E+01	4.4E+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 = 0.5.
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-)	3.4E+01	noncarcinogenic effects		3.4E+01	6.8E+01	NA
Perfluorohexane sulfonate (PFHxS-)	2.2E+00	noncarcinogenic effects		2.2E+00	4.4E+00	NA
Perfluoroheptane sulfonate (PFHpS-)	1.1E+00	noncarcinogenic effects		1.1E+00	2.3E+00	NA
Perfluorooctane sulfonate (PFOS-)	2.3E-01	noncarcinogenic effects		2.3E-01	4.5E-01	NA
Perfluorodecane sulfonate (PFDS-)	1.1E+00	noncarcinogenic effects		1.1E+00	2.3E+00	NA
Perfluoro butanoate (PFBA-)	4.3E+02	noncarcinogenic effects		4.3E+02	8.6E+02	NA
Perfluoro pentanoate (PFPeA-)	4.6E+01	noncarcinogenic effects		4.6E+01	9.1E+01	NA
Perfluoro hexanoate (PFHxA-)	5.7E+01	noncarcinogenic effects		5.7E+01	1.1E+02	NA
Perfluoro heptanoate (PFHpA-)	2.3E+00	noncarcinogenic effects		2.3E+00	4.6E+00	NA
Perfluoro octanoate (PFOA-)	3.4E-01	noncarcinogenic effects	3.3E+02	3.4E-01	6.7E-01	NA
Perfluoro nonanoate (PFNA-)	3.4E-01	noncarcinogenic effects		3.4E-01	6.8E-01	NA
Perfluoro decanoate (PFDA-)	2.3E-01	noncarcinogenic effects		2.3E-01	4.5E-01	NA
Perfluoro undecanoate (PFUnDA-)	5.7E-01	noncarcinogenic effects		5.7E-01	1.1E+00	NA
Perfluoro dodecanoate (PFDoDA-)	7.6E-01	noncarcinogenic effects		7.6E-01	1.5E+00	NA
Perfluoro tridecanoate (PFTrDA-)	7.6E-01	noncarcinogenic effects		7.6E-01	1.5E+00	NA
Perfluoro tetradecanoate (PFTeDA-)	7.6E+00	noncarcinogenic effects		7.6E+00	1.5E+01	NA
Perfluroroctane sulfonamide (PFOSA)	1.4E+00	noncarcinogenic effects		1.4E+00	2.7E+00	NA
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)	3.4E-01	noncarcinogenic effects		3.4E-01	6.8E-01	NA
6:2 Fluorotelomer sulfonate (6:2 FTS-)	4.4E+01	noncarcinogenic effects		4.4E+01	8.7E+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^{-5}.
3. Noncarcinogens: Final action level based on Relative Source Contribution of 20% and target Hazard Quotient = 0.5.
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	[a]Mutagen	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
Perfluorobutane sulfonate (PFBS-)						15[A]	15[A]			15[A]				
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],5H	1[H]	1[H]1[A],9[H]	1[H]		1[H]1[A],2[H], 9[H],13A	2[H],5[H]	11[A]	1[H],10[H]		5[H]
Perfluorodecane sulfonate (PFDS-)														
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], 6[H],7H,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-)														
Perfluroroctane sulfonamide (PFOSA)														
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (HFPO-)		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]

Notes:

Refer to accompanying Technical Memorandum. 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 diptheria 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[a]	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-Flouroalkyl Substances (PFAS) 2018 Austrailian 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 & testicualr 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 reponse 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 and testicular CAs			probable link with PIH		probable link with thyroid disease		probable link with ulcerative collitis					
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			

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	[a]Mutagen	Carcinogen	Metabolic	Hepatic	Cardiovascular	Developmental	Endocrine	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Other
12[A]: Gordon SC 2011 Toxicological evaluation of ADONA								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 activitiy in rats (liver and pancreatic)							presumed immune hazard					
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												

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
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. [1]NATURAL BACKGROUND CONCENTRATIONS OF METALS IN 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-)				
Perfluorohexane sulfonate (PFHxS-)				
Perfluoroheptane sulfonate (PFHpS-)				
Perfluorooctane sulfonate (PFOS-)				
Perfluorodecane sulfonate (PFDS-)				
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-)				
6:2 Fluorotelomer sulfonate (6:2 FTS-)				

Primary Reference:

Notes:

1. Excludes samples with known or suspected anthropogenic contamination (see primary reference).
2. Upper Bound concentration selected based on evaluation of univariate sample data plots.
3. Background Threshold Value set to maximum-reported concentration, excluding samples with suspected anthropogenic contamination.
4. Selected action level based on Upper Bound concentration unless otherwise noted.

TABLE L. SOIL ECOTOXICITY ACTION LEVELS

	Urban Area Ecotoxicity Criteria (mg/kg)	
CHEMICAL PARAMETER	**Residential Areas**	**Commercial/ Industrial areas**
Perfluorobutane sulfonate (PFBS-)		
Perfluorohexane sulfonate (PFHxS-)		
Perfluoroheptane sulfonate (PFHpS-)		
Perfluorooctane sulfonate (PFOS-)		
Perfluorodecane sulfonate (PFDS-)		
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-)		
6:2 Fluorotelomer sulfonate (6:2 FTS-)		