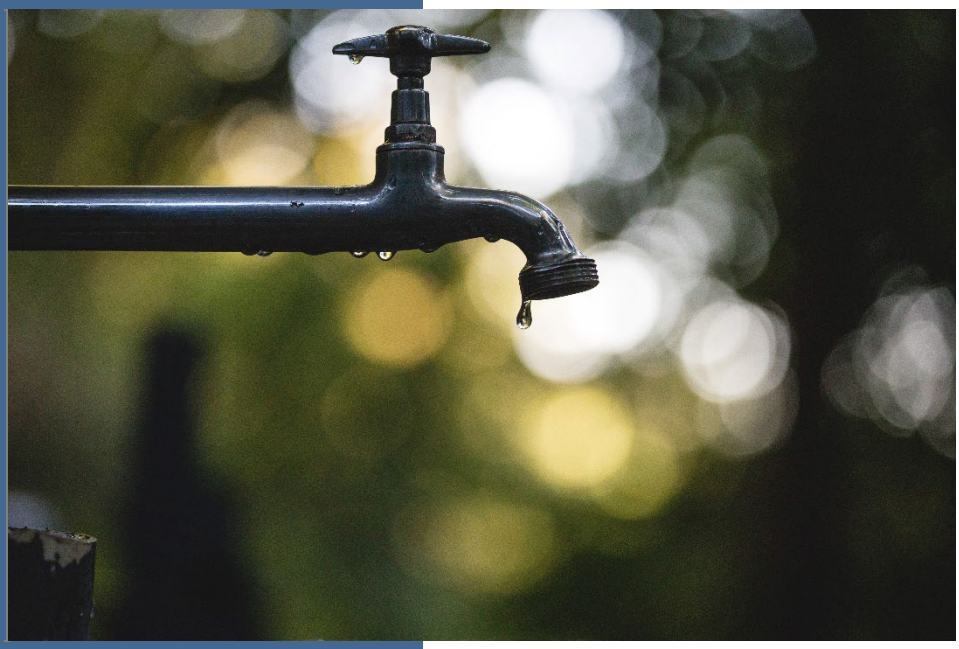

Guidance for Investigating and Remediating PFAS Contamination in Washington State

Toxics Cleanup Program

Washington State Department of Ecology
Olympia, Washington

June 2023 | Publication No. 22-09-058

DEPARTMENT OF ECOLOGY
State of Washington

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Related publications:

- Focus on: PFAS (Publication No. 21-09-060) at https://apps.ecology.wa.gov/publications/SummaryPages/2109060.html (2021)
- Focus on: PFAS Cleanup Levels (Publication No. 22-09-075) at https://apps.ecology.wa.gov/publications/SummaryPages/2209075.html (2022)

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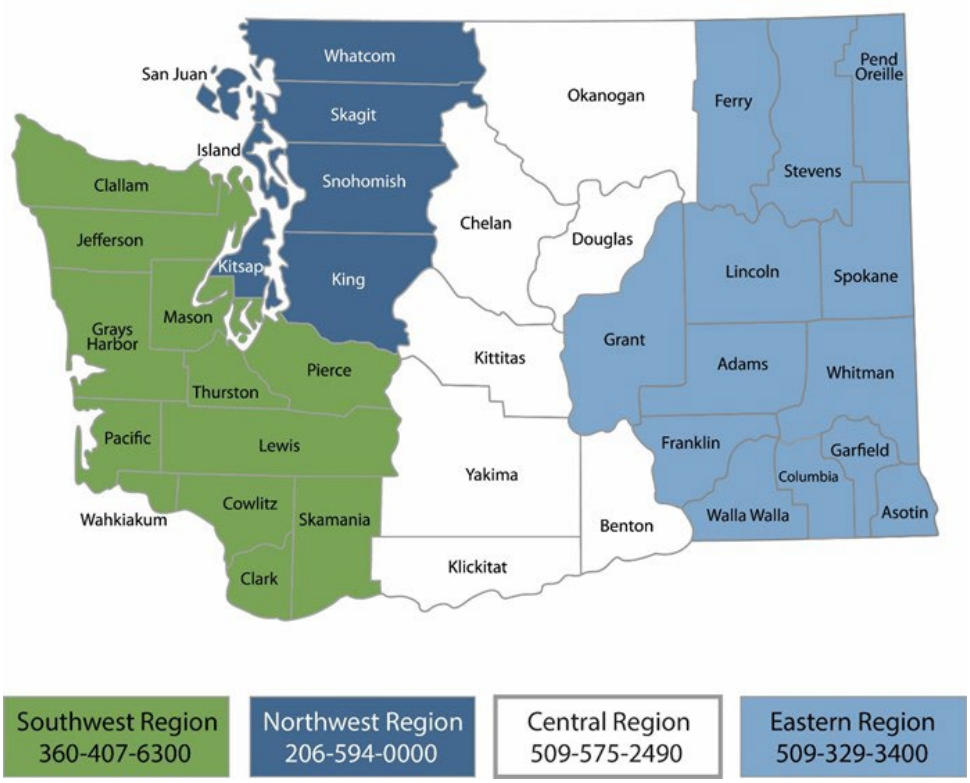
Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	P.O. Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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ECOLOGY
State of Washington

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Acronyms and Abbreviations

Acronym or abbreviation	Definition
µg/L	microgram per liter
AB1	gastrointestinal absorption fraction
ABW	average body weight
ADD	California acceptable daily dose
AFFF	Aqueous Film Forming Foam
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
AT_{nc}	averaging time – noncancer
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	ambient water quality criteria
BCF	bioconcentration factor
Board	Washington State Board of Health
BW	body weight
CAP	Chemical Action Plan
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CLARC	Cleanup Levels and Risk Calculations
COC	chemical of concern
CPF	carcinogenic potency factor (CPF and CSF have the same meaning)
CPHEA	Center for Public Health and Environmental Assessment (EPA)
CSF	cancer slope factor
CWB	State of California Water Board
DAF	dosimetric adjustment factor
DF	dilution factor
DOD	United States Department of Defense
DOH	Washington State Department of Health
DWF	drinking water fraction
DWIR	drinking water ingestion rate
Ecology	Washington State Department of Ecology
ED	exposure duration
EF	exposure frequency
EPA	United States Environmental Protection Agency
ESA	ASTM Environmental Site Assessment
foc	soil fraction of organic carbon
GenX	Trade name for a polymerization processing aid formulation that contains ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate
HA, HAL	health advisory, health advisory level (EPA)

Acronym or abbreviation	Definition
Hcc	Henry's law dimensionless constant
Hcp	Henry's law constant in atm-m^3/mol
HEAST	Health Effects Assessment Summary Tables (EPA)
HFPO-DA	Hexafluoropropylene oxide [HFPO] dimer acid (a GenX chemical)
HQ	hazard quotient
IARC	International Agency for Research on Cancer
IL	Investigatory Level
INH	inhalation correction factor
IRIS	Integrated Risk Information System (EPA)
ITRC	Interstate Technology and Regulatory Council
JBLM	Joint Base Lewis McCord
Kd	soil water distribution coefficient
Koc	organic carbon-water partitioning coefficients
L/day	liters per day
L/kg	liters per kilogram
LC/MS/MS	Liquid Chromatography Tandem Mass Spectrometry
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDEQ	Michigan Department of Environmental Quality
MDH	Minnesota Department of Health
MDHHS	Michigan Department of Health and Human Services
mg/kg	milligram per kilogram
mg/L	milligram per liter
MRL	Minimal Risk Level
MTCA	Model Toxics Control Act (Ecology)
NCEA	National Center for Environmental Assessment (EPA)
ng/kg	nanogram per kilogram
ng/L	nanogram per liter
NHDES	New Hampshire Department of Environmental Services
Nm	not measurable
NPDWR	National Primary Drinking Water Regulation (EPA)
ORD	Office of Research and Development (EPA)
ORNL	Oak Ridge National Labs
PFAA	Perfluoroalkyl acids
PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic Acid
PFBS	Perfluorobutane Sulfonic Acid
PFDA	Perfluorodecanoic Acid

Acronym or abbreviation	Definition
PFDoDA	Perfluorododecanoic Acid
PFHpA	Perfluoroheptanoic Acid
PFHxA	Perfluorohexanoic Acid
PFHxS	Perfluorohexane Sulfonic Acid
PFNA	Perfluorononanoic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonic Acid
PFUnDA	Perfluoroundecanoic Acid
PPRTV	Provisional Peer-Reviewed Toxicity Value (EPA)
ppt	parts per trillion
PQL	practical quantitation limit
PRG	Preliminary Remediation Goal
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
QSM	Quality Systems Manual
qTOF	quadropole time-of-flight
RAIS	Risk Assessment Information System (maintained by ORNL)
RCW	Revised Code of Washington (Washington statute)
RfD	reference dose
RSC	relative source contribution
RSL	Regional Screening Level (EPA)
SAL	State Action Level (DOH)
SAP	Sampling and Analysis Plan
SCUM	Sediment Cleanup User's Manual (Ecology)
SIR	soil ingestion rate
SL	screening level
SMS	Sediment Management Standards (Ecology)
STSC	Superfund Health Risk Technical Support Center (EPA)
TCP	Toxics Cleanup Program (Ecology)
TDS	total dissolved solids
Tgw	target potable groundwater level
TOP	Total Oxydizable Precursors
TSS	total suspended solids
TT	treatment technique
U.S.	United States
UCF	unit conversion factor
UCMR3	Third Unregulated Contaminant Monitoring Rule (EPA)

Acronym or abbreviation	Definition
VOC	volatile organic compound
WAC	Washington Administrative Code (rule, regulation)
θa	air-filled soil porosity
θw	water-filled soil porosity
ρb	dry soil bulk density

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Chapter 1: Introduction

1.0 A brief history of PFAS

Per- and polyfluoroalkyl substances are collectively known as PFAS. The group comprises thousands of unique synthetic organic chemicals that are extremely stable and persistent. Commercially manufactured since the 1940s, PFAS compounds have been used in manufacturing common consumer products, such as carpeting, clothing, furniture, outdoor equipment, and food packaging. Many industries have also used PFAS, including aerospace, automotive, aviation, electronics, and medical industries. One major source of PFAS contamination is Aqueous Film Forming Foam (AFFF), which is used for fire training and extinguishing petroleum fires and other flammable liquids.[2]

The Interstate Technology Regulatory Council (ITRC) has much more background information about PFAS on their webpage. Access focus sheets, databases, and their online PFAS guidance (June 2022) at https://pfas-1.itrcweb.org/.

PFAS compounds have been extensively studied since the 1990s. Testing finds PFAS present throughout all environmental media such as groundwater, soil, sediments, and surface water, and in rainwater, snow, and ice worldwide. At the time this guidance was published, however, no legally enforceable Federal environmental standards had yet been established for any of these chemicals. While numerous studies are underway to determine how to limit the distribution of these compounds and successfully mitigate their environmental impacts, much work remains to be done.

Information related to PFAS investigation and remediation is rapidly evolving. This guidance is current as of the date of publication.

1.1 Purpose and applicability

The purpose of this guidance is to provide direction for investigating and cleaning up PFAS contamination in Washington state. The guidance is intended for people who are cleaning up a contaminated property, including property owners, potentially liable parties, and cleanup professionals. It is applicable for formal cleanups (those that are supervised by or conducted by the Washington State Department of Ecology (Ecology)), or independent cleanups conducted by the property owner on their own or with technical assistance from Ecology. For persons interested in obtaining information about the potential for a property to be impacted by PFAS, see the ITRC guidance referenced above.

[2] Washington state law (Chapter 70A.400 RCW) restricts AFFF because of the PFAS danger. AFFF can no longer be manufactured, sold, or used for fire training, although it can still be used for emergencies and actual fire situations when mandated by Federal law.

A considerable volume of literature has already been published about PFAS, so we provide only a general overview of most topics here, with links to references that offer more comprehensive discussions. However, we do provide detail about **state-specific issues** such as:

- PFAS impacts in Washington state,
- Regulatory authority under the Model Toxics Control Act (MTCA),
- How the Washington State Department of Health (DOH) established State Action Levels (SALs) for five PFAS compounds, and
- How Ecology established MTCA cleanup levels.

We also provide recommendations on which PFAS compounds to analyze for, and factors to consider when evaluating which media should be investigated.

There are thousands of PFAS, but this guidance focusses on those PFAS compounds where sufficient information exists to derive cleanup levels. Specifically, Chapter 3 provides levels protective of human health for eight PFAS compounds, while Chapter 5 provides levels for ten PFAS compounds that are protective of ecological receptors. Ecology expects that cleanup levels will become available for additional PFAS compounds as EPA develops more toxicity data.

1.2 Chemical structure and terminology

The PFAS family includes thousands of chemicals. Many of the chemicals are considered "precursors" that can continue to degrade in the environment until they reach end products known as perfluoroalkyl acids (PFAAs), which are resistant to further degradation. The structure of a PFAA has a carbon chain backbone with all carbons fully fluorinated, except functional "head groups" that are typically a carboxyl or a sulfonyl group. Because PFAAs are persistent and mobile in the environment, as well as some being bio-accumulative and highly toxic, they tend to be the focus of environmental investigations. For more information about this and other classes of PFAS, see Section 2.2 of the online ITRC guidance (ITRC 2022).

PFAS compounds can exist in various ionic states. Most PFAAs are present in the environment in their anionic form because the acid form typically dissociates (i.e., loses a hydrogen ion) in contact with water and other environmental media at environmentally relevant pH (e.g., >4). The acid and anionic forms of the compound have different physical and chemical properties and different CAS numbers (see Table 1).

This guidance document uses the acid form of the names. This is consistent with the naming convention found in most of the studies we evaluated during the literature review, and consistent with Ecology's Cleanup Levels and Risk Calculations (CLARC)[3] database. In

[3] https://ecology.wa.gov/CLARC

addition, most labs report analytical results using the acidic form. The protective concentrations established in this document are applicable to either the acid or the anionic form of the molecule.

Table 1: Test form of acid vs. anion form found in the environment. The Washington State Department of Ecology uses the acid form of these chemical names.

Acid compound	Acronym	CAS#		Anion found in the environment	CAS#
Perfluorobutanoic Acid	PFBA	375224	→	Perfluorobutanoate	45048622
Perfluorobutane Sulfonic Acid	PFBS	375735	→	Perfluorbutanesulfonate	45187153
Perfluorodecanoic Acid	PFDA	335762	→	Perfluorodecanoate	73829364
Perfluorododecanoic Acid	PFDoDA	307551	→	Perfluorododecanoate	171978953
Perfluoroheptanoic Acid	PFHpA	375859	→	Perfluoroheptanoate	120885292
Perfluorohexanoic Acid	PFHxA	307244	→	Perfluorohexanoate	92612527
Perfluorohexane Sulfonic Acid	PFHxS	355464	→	Perfluorohexanesulfonate	108427538
Perfluorononanoic Acid	PFNA	375951	→	Perfluorononanoate	72007682
Perfluorooctanoic Acid	PFOA	335671	→	Perfluorooctanoate	45285516
Perfluorooctane Sulfonic Acid	PFOS	1763231	→	Perfluorooctanesulfonate	45298906
Perfluoroundecanoic Acid	PFUnDA	2058948	→	Perfluoroundecanoate	196859548
Hexafluoropropylene Oxide – Dimer Acid	HFPO-DA	13252136	→	HFPO Carboxylate Anion	62037803

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Chapter 2: Potential Human Health Effects, Groundwater Impacts, and Regulation

2.0 Potential human health effects

To date, the potential human health effects of PFOS and PFOA have been the most intensively studied of the PFAS chemicals, but there is also considerable toxicological information on PFNA, PFHxS, PFBS, PFBA, PFHxA and hexafluoropropylene oxide dimer acid (HFPO-DA; also known as GenX). Some PFAS chemicals can readily absorb into the human body, and national surveys have shown that nearly all people tested had detectable levels of PFAS in their blood serum (DOH, 2021a). Primary noncancer health effects that have been associated with PFAS are increases of serum cholesterol levels; liver toxicity; reproductive and developmental toxicity (e.g., lower birth weights); and immune toxicity (DOH, 2021a).

According to the United States Environmental Protection Agency's (EPA) Interim Health Advisories (HAs), and consistent with EPA's hazard descriptors in Guidelines for Carcinogen Risk Assessment[4] (EPA, 2005), PFOA is classified as likely to be carcinogenic to humans based on evidence of increased risk of kidney and testicular cancer. There is also suggestive evidence that PFOS may be linked to human carcinogenicity (EPA, 2022a). However, at this time, EPA has not derived a cancer slope factor (CSF) for PFOS, and a preferred CSF has not been identified for derivation of a cancer-based drinking water HA level for PFOA.

EPA's initial evaluation of candidate CSFs suggests that the human health protective level in drinking water for PFOA based on noncancer effects is protective of a 1 in a million (1×10^{-6}) excess cancer risk (EPA, 2016b; 2022a). EPA is evaluating available toxicity data to derive a CSF for PFOA as part of the National Primary Drinking Water Regulation (NPDWR) (EPA, 2022a).

Based on the discussion in this section, therefore, Ecology used noncancer endpoints to provide the foundation for the human health-based protective levels developed for and described in this guidance. Noncancer toxicity values were determined based on available reference doses (RfDs). The process for selecting reference doses is discussed in Chapter 3.

2.1 Impacts to groundwater and drinking water

The widespread use of PFAS chemicals, and their persistence and mobility in the environment, have impacted groundwater and drinking water systems. EPA sampled and detected PFAS chemicals in drinking water systems across the United States as part of a national survey conducted between 2013 and 2015 called the Unregulated Contaminant Monitoring Rule

[4] https://archive.epa.gov/raf/web/html/guidelines-carcinogen-risk-assessment.html#:~:text=Guidelines%20for%20Carcinogen%20Risk%20Assessment%20%282005%29%201%20Background,July%201999%20interim%20guidance.%20...%203%20Citation%20

(UCMR3) sampling event.[5] As part of this event, 132 public water systems in Washington state conducted monitoring that covered approximately 94% of Washington residents served by public water systems. This monitoring included sampling for six PFAS compounds:

- Perfluorooctane sulfonic acid (PFOS)
- Perfluorooctanoic acid (PFOA)
- Perfluorononanoic acid (PFNA)
- Perfluorohexane sulfonic acid (PFHxS)
- Perfluoroheptanoic acid (PFHpA)
- Perfluorobutane sulfonic acid (PFBS)

PFOA and PFOS were detected above the laboratory reporting limits in three public water systems: City of Issaquah, City of DuPont, and Joint Base Lewis-McChord (JBLM). At that time, only the City of Issaquah had exceedances of EPA's 2016 Health Advisory Level (HAL), which was 70 nanograms/liter (ng/L or parts per trillion [ppt]). In June 2022, EPA issued lower interim health advisories for PFOA and PFOS that are 0.004 ng/L and 0.02 ng/L, respectively. (See 3.3.1 Health advisories for timeline and more information).

Since the UCMR3 sampling event of 2013–15, several military bases in Washington state have tested drinking water sources both on and off the base in response to a directive from the U.S. Department of Defense (DOD). PFAS were discovered at McChord Airfield and Fort Lewis (located between Olympia and Tacoma), Naval Air Station Whidbey Island (located near Oak Harbor); Naval Base Kitsap-Bangor (located near Poulsbo and Silverdale); Fairchild Air Force Base (located near Airway Heights and Spokane), and the Yakima Training Center (located near Yakima), which is part of JBLM. Additional investigations are ongoing to determine the degree and extent of PFAS contamination in drinking water wells both on- and off-base.

As of May 2022, PFOA and PFOS were identified above the 2016 EPA HAL of 70 ng/L in 6 locations across Washington:

1. Joint Base Lewis McChord
2. Naval Air Station Whidbey Island, including the Coupeville and Oak Harbor areas
3. Fairchild Air Force Base and the City of Airway Heights
4. Naval Base Kitsap-Bangor
5. City of Issaquah
6. Yakima Training Center (part of JBLM).

AFFF used for fire suppression and training appears to be the primary source of contamination in all six locations.

The City of Issaquah and Eastside Fire and Rescue are voluntarily investigating the source of PFAS in the lower Issaquah Valley. EPA is overseeing the investigation and cleanup of PFAS

[5] EPA's Third Unregulated Contaminant Monitoring Rule (UCMR3) for monitoring emerging contaminants in drinking water (https://www.epa.gov/dwucmr/third-unregulated-contaminant-monitoring-rule).

at most of the federal military facilities with assistance from Ecology. Ecology's Hazardous Waste and Toxics Reducton Program is overseeing Yakima Training Center's investigation and cleanup. You can find more information for many of these locations in Ecology's Per- and Polyfluoroalkyl Substances Chemical Action Plan[6].

2.2 Regulatory authority

As of the date we published this guidance, EPA had not identified any PFAS compounds as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and no maximum contaminant levels (MCLs) for PFAS comounds have been established under the federal Safe Drinking Water Act. EPA's Strategic Roadmap[7] released in October 2021 identifies a number of actions they plan to complete over the next several years (EPA, 2021c). These include but are not limited to: 1) proposing to list PFOA, PFOS, and possibly other PFAS compounds as hazardous substances under CERCLA, and 2) establishing final National Drinking Water Standards for PFOA and PFOS. The U.S. Congress is considering the PFAS Action Act (HR 2467) to address both goals, but the fate of the bill is uncertain.

The Toxics Cleanup Program (TCP) evaluated Ecology's legal authority to regulate PFAS and concluded that PFAS compounds meet the definition of a hazardous substance under the Model Toxics Control Act (MTCA). We accounced this conclusion on October 21, 2021, in Ecology's *Site Register* at https://apps.ecology.wa.gov/publications/SummaryPages/2109041U.html.

Just prior to this announcement, TCP presented our regulatory conclusion during the keynote address at the Northwest Environmental Business Council's (NEBC's) Remediation Conference on October 14, 2021. The purpose of the presentation was to:

a. Explain the authority we used to reach the conclusion that PFAS are a hazardous substance;
b. Discuss the anticipated implications for investigation and cleanup of PFAS contamination; and
c. Answer questions and obtain feedback from participants.

Since TCP's 2021 announcement, Ecology has received a number of questions about reporting requirements for PFAS releases. In July 2022, we published a PFAS Cleanup Levels focus sheet[8] (Ecology Publication No. 22-09-075) that provides preliminary soil and groundwater cleanup levels for the same five PFAS compounds for which the Washington Department of Health promulgated State Action Levels, as well as cleanup levels for HFPO-DA. The PFAS focus sheet served as interim guidance until this comprehensive guidance was finalized.

[6] https://apps.ecology.wa.gov/publications/summarypages/2104048.html
[7] https://www.epa.gov/pfas/pfas-strategic-roadmap-epas-commitments-action-2021-2024
[8] https://apps.ecology.wa.gov/publications/SummaryPages/2209075.html

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Chapter 3: Human Health Advisory, Action, and Cleanup Levels

3.0 Overview

This chapter discusses regulatory levels. We outline the State Action Levels (SALs) developed by the Washington State Department of Health (DOH). We provide preliminary MTCA cleanup levels developed by Ecology, and the methods used for calculating those levels. We discuss the human health-based protective levels developed by EPA, then conclude with a brief discussion of PFAS investigatory levels Ecology developed in 2018 but no longer use.

Even when protective concentrations for PFAS in environmental media are developed for similar scenarios (e.g. drinking water and groundwater that could be used as drinking water), the concentrations can differ because of differences in exposure assumptions and toxicity values. Some regulatory levels for drinking water, for example, include relative source contribution (RSC) factors that account for potential exposures from sources other than drinking water (such as diet), whereas other regulatory levels do not include RSCs.

The toxicology of PFAS is currently an area of intense research. Regulatory agencies develop toxicity values using the best available information at the time. As new toxicological information emerges, the regulatory levels discussed in this chapter may change and regulatory levels for other PFAS compounds may become available.

3.1 Department of Health Drinking Water State Action Levels

In July 2017, the Department of Health received requests to establish drinking water standards for PFAS chemicals due to concerns over concentrations of PFAS identified in the drinking water supplies of several Washington state communities. In October 2017, the Washington State Board of Health (Board) authorized DOH to initiate a rulemaking process to amend Chapter 246-290 WAC,[9] Washington's regulations for Group A Public Water Supplies, to address PFAS in drinking water. The final rule set State Action Levels (SALs) for five PFAS chemicals. It also set requirements for monitoring and reporting, follow-up actions, and public notice for contaminants without an MCL (DOH, 2021b).

In support of the Board and as part of the rulemaking, DOH developed recommendations for SAL values for PFOA, PFOS, PFNA, PFHxS, and PFBS. DOH identified these compounds for SAL development because they have been detected in Washington state drinking water supplies, had available toxicological information, and may be good indicators of PFAS occurrence in drinking water (DOH, 2021a; WAC 246-290-315[10]). The Group A Drinking Water

[9] https://app.leg.wa.gov/WAC/default.aspx?cite=246-290 (Group A public water supplies)
[10] https://app.leg.wa.gov/WAC/default.aspx?cite=246-290-315 (State action levels (SALs) and state maximum contaminant levels (MCLs))

Rule with SALs for the five PFAS substances was adopted on November 17, 2021, and became effective on January 1, 2022.

Similar to the EPA 2016 health advisory levels for PFOS and PFOA, the Department of Health established the five PFAS State Action Levels to be protective of noncancer effects assuming a lifetime exposure to drinking water. Some PFAS such as PFOA, PFOS, PFHxS and PFNA are readily absorbed into the human body when ingested with food and water, but only slowly eliminated. For more information, see PFAS in the U.S. population[11] (ATSDR). They can accumulate in blood serum and other locations in the body and because of this, the SALs are designed to protect the most sensitive subpopulations including pregnant mothers, developing fetuses, and infants. During pregnancy, for instance, PFAS that accumulated in the mother's serum can cross the placenta and accumulate in the developing fetus. Another example: PFAS serum levels can quickly increase in infants who are breast-fed and bottle-fed due to their high intake of milk or formula (prepared with tap- water) compared to their body weight (DOH, 2021a).

3.1.1 How DOH developed State Action Levels

The Department of Health considered key elements when deriving the SALs including: a) derivation of noncancer toxicity values, b) an estimation of the RSC from drinking water, and c) development of water ingestion rates. These are the same elements used by EPA to develop their Health Advisories and are discussed below.

Noncancer Toxicity Data

When DOH was identifying noncancer toxicity values to use for developing the SALs, they relied on values that had already been selected by U.S. federal and state governments based on reviews of existing, high-quality peer-reviewed toxicity studies. The noncancer toxicity values produced from these reviews included reference doses (RfDs) set by EPA and U.S. states; minimal risk levels (MRLs[12]) set by the Agency for Toxic Substances and Disease Registry (ATSDR); and California Acceptable Daily Doses (ADD; DOH, 2021a). DOH selected toxicity values that were based on noncancer effects in laboratory animals, particularly effects on immune function, offspring development, and thyroid hormones.

Relative Source Contribution (RSC)

Like EPA did with health advisories (Section 3.3.1), DOH applied an RSC when developing the SALs to account for other potentially significant exposure sources (that is, besides consuming contaminated drinking water). To do this, DOH first used EPA's Exposure Decision Tree to identify appropriate RSCs for each PFAS (EPA, 2000). With the exception of PFBS, DOH then applied an RSC of 50% to infants who breast- or bottle-feed since it was assumed these routes

[11] https://www.atsdr.cdc.gov/pfas/health-effects/us-population.html

[12] MRLs are developed by ATSDR and can be used as an RfD. An MRL is an estimate of the amount of a chemical a person can eat, drink, or breathe each day without a detectable risk to health. MRLs are developed for noncancer endpoints (DOH, 2021a).

of exposure dominate the PFAS intake in young children. Based on criteria that included the potential for additional sources of exposure and adequacy of available data, DOH used an RSC of 50% for PFOA, PFHxS, and PFNA for all age groups (Table 2). PFBS was assigned an RSC of 20% for all age groups. The RSCs for PFOS ranged from 50% for infants to 20% for adults (DOH, 2021a).

Water Ingestion

PFOA, PFOS, PFHxS, and PFNA can readily absorb into the human body and have much longer half-lives than PFBS. For the four chemicals, DOH applied a model developed by the Minnesota Department of Health (MDH model) that predicts blood serum levels. These levels are based on human exposure to PFAS contamination via placental transfer, breast-milk ingestion, and tap water ingestion, and includes infants who are bottle-fed. Upper-percentile (90^{th} to 95^{th}) breast-milk and drinking water ingestion rates were used in the model to predict drinking water levels needed to keep serum levels of adults and breast- or bottle-fed infants at or below the protective serum level. The serum level to protect mothers and children from PFAS exposure via tap water and breast-milk ingestion was determined by multiplying the target serum level identified in the toxicity study by the RSC (e.g., 20%, 50%; DOH, 2021a).

PFBS appears to clear from human serum much more rapidly than the other four PFAS chemicals evaluated and has a half-life of days compared to years (DOH, 2021a). Rather than apply the MDH model, DOH used a simple equation based on a standard residential drinking water intake scenario and an ingestion rate of 0.174 L/kg-day (Table 2 below). The ingestion rate selected by DOH is based on the 95^{th} percentile water intake for infants less than a year old (bottle-fed with formula mixed with tap water) as identified in EPA's 2011 Exposure Factors Handbook[13] (EPA, 2011).

[13] https://www.epa.gov/expobox/about-exposure-factors-handbook

Table 2: Drinking water State Action Levels (SALs) developed by the Washington State Department of Health.

PFAS chemical	Source for toxicity value	RfD or MRL[14] (ng/kg-day)	Relative Source Contribution (RSC)	Ingestion Rate	State Action Level (SAL)
PFOA	ATSDR, 2021	3	50%	MDH model[15]	10 ng/L
PFOS	MDH, 2020a; NHDES, 2019	3	20% adults 50% infants	MDH model	15 ng/L
PFNA	ATSDR, 2021[16]	2.5	50%	MDH model	9 ng/L
PFHxS	MDH, 2020b	9.7	50%	MDH model	65 ng/L
PFBS	EPA, 2021a	300	20%	0.174 L/kg-day	345 ng/L[17]

The chemical-by-chemical approach to developing action levels for PFAS should be considered an interim solution due to the number of PFAS chemicals and the frequent detections of PFAS mixtures in environmental media. As more information becomes available, it may be possible to evaluate PFAS as a complex mixture according to subclasses based on key characteristics such as chemical structure, bioavailability, bioaccumulation potential, toxicity, or mechanism of action (DOH, 2021a).

3.1.2 State Action Level requirements

Under the DOH rulemaking, monitoring for PFAS will be required by community and nontransient noncommunity Group A water systems (DOH, 2021c). Transient noncommunity water systems located near known or suspected PFAS contamination will also be required to sample for PFAS and meet follow-up requirements if PFAS are detected (see WAC 246-290-320(8)).[18] Initial monitoring of systems must be completed no later than December 31, 2025.

[14] RfD = Oral Reference Dose. ATSDR uses the term minimal risk level or MRL rather than RfD.

[15] MDH = Minnesota Department of Health toxicokinetic model for infant intake of bioaccumulative PFAS in drinking water.

[16] DOH adjusted the ATSDR MRL from 3ng/kg-day to 2.5 ng/kg-day based on an updated half-life estimate of 3.52 years.

[17] PFBS SAL (ng/L) = (300 ng/kg-day x 20%) ÷ 0.174 L/kg-day.

[18] https://apps.leg.wa.gov/WAC/default.aspx?cite=246-290 (Group A public water supplies.)

Ongoing monitoring will be required once every three years, unless the utility qualifies for a waiver as determined by DOH.

Water systems that have PFAS above the level of detection will be required to continue monitoring on a more frequent schedule. Public notice to inform customers will be required if a system has PFAS levels exceeding a SAL (DOH, 2021c).

3.2 Establishing MTCA cleanup levels

The MTCA Cleanup Regulations (WAC 173-340-200),[19] define a cleanup level as the concentration of a hazardous substance in water, soil, air, or sediment[20] that is determined to be protective of human health and the environment under specified exposure conditions. Since Ecology requires that remedial actions under MTCA address a threat to human health or the environment, a preliminary cleanup level gauges whether a hazardous substance is present at a concentration that may warrant a cleanup action. While final cleanup levels for a site will be established in the Cleanup Action Plan, it helps to set preliminary cleanup levels early in the cleanup process so all parties have a common understanding of the potential severity of contamination that might be found during the site investigation.

MTCA cleanup levels may be established using Method A[21] (Applicable Laws and Tables), Method B[22] (Unrestricted), or Method C[23] (Industrial). Since Method A table values are not available for any PFAS chemicals, this guidance addresses establishing MTCA cleanup levels under Methods B and C.

Cleanup levels under Method B are established using applicable state and federal laws (referred to as ARARs) and the risk-based equations and other requirements specified for each medium (i.e., groundwater, surface water, soil, and air). The lifetime excess cancer risk[24] under Method B is set at 1 in a million (1×10^{-6}) for individual substances, and 1 in 100,000 (1×10^{-5}) for the total cancer risk from all carcinogenic chemicals of concern (COCs) and pathways of exposure at a site.

Cleanup levels are also determined using reference doses for compounds having noncancer

[19] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-200 (Definitions)

[20] Cleanup levels for PFAS chemicals in sediment are managed under a separate rule, the Sediment Management Standards (Chapter 173-204 WAC) and its associated guidance, the Sediment Cleanup User's Manual (SCUM) (Ecology Publication No. 12-09-057).

[21] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-704 (Method A)
[22] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-705 (Method B)
[23] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-706 (Method C)

[24] Risk is expressed in terms of lifetime excess cancer risk (in excess of one's background risk of developing cancer). For example, a risk of 1×10^{-6} equates to approximately one excess cancer case in a population of one million individuals due to exposure to the cancer-causing substance over a lifetime.

health effects. However, when toxicity data are available to determine a carcinogenic risk, the calculated level is typically more stringent than noncancer levels, and MTCA requires the most stringent cleanup level to be used. Further discussion on noncancer risk levels is provided in Section 3.2.1.

Method C is similar to Method B. However, Method C cleanup levels are based on less stringent exposure assumptions, and the lifetime excess cancer risk is set at 1×10^{-5} for both individual substances and for the total cancer risk caused by all COCs and pathways of exposure. In the following sections, we discuss how we developed (or will develop) MTCA cleanup levels for PFAS chemicals for each media (groundwater, surface water, soil, and air).

3.2.1 Developing MTCA risk-based cleanup levels

Calculating MTCA risk-based cleanup levels requires establishing chemical-specific human health toxicity criteria (e.g., noncancer RfDs and carcinogenic potency factors [CPFs]) that are used in combination with MTCA's default exposure parameters. Noncancer RfDs are used to evaluate potential noncancer health effects, and CPFs are used to evaluate the probability of cancer risk. Since data are limited to support quantitative assessment of cancer risk for PFAS chemicals (DOH, 2021a), and because using EPA's noncancer RfD is protective of potential cancer risks, Ecology has determined the use of noncancer RfDs to derive cleanup levels is appropriate.

MTCA risk-based equations to evaluate noncancer health effects require using an RfD established in accordance with WAC 173-340-708(7)(d).[25] The MTCA Cleanup Regulations provide a hierarchy of human health toxicity databases where EPA's Integrated Risk information System (IRIS) is the preferred source, followed by EPA's Health Effects Assessment Summary Tables (HEAST), followed by EPA's National Center for Environmental Assessment (NCEA). Details about the toxicity sources:

IRIS. Final toxicity data are currently only available for PFBA and PFHxA in EPA's IRIS database. EPA is conducting toxicity assessments for several PFAS in IRIS as discussed in Section 3.3.2.

HEAST. No toxicity data are available for PFAS chemicals in EPA's HEAST database. EPA has not updated chemical toxicity values in HEAST since 1997. Values in HEAST are archived when an IRIS or EPA Provisional Peer-Reviewed Toxicity Value (PPRTV) is released (see NCEA below). For more information, see Section 2.3 of EPA's Regional Screening Level (RSL) user's guide.[26]

[25] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-708 (Human health risk assessment procedures.)
[26] https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide#toxicity

NCEA. The NCEA develops toxicity data in support of EPA's PPRTV program. NCEA is now known as the Center for Public Health and Environmental Assessment (CPHEA) and is part of EPA's Office of Research and Development (ORD). PPRTV assessments are developed in response to requests from EPA's Superfund Program to the Superfund Health Risk Technical Support Center (STSC) located within the CPHEA. EPA published a PPRTV oral RfD of 300 ng/kg-day for PFBS based on thyroid effects in 2021 (EPA, 2021a).

Ecology will follow the procedures set forth in WAC 173-340-708 when assessing how new or updated toxicity data will be used to determine applicable cleanup levels. In accordance with the MTCA Cleanup Regulations: if an RfD is not available from IRIS, HEAST, or NCEA, or is demonstrated to be inappropriate, Ecology may determine that development of an alternate RfD is needed (WAC 173-340-708(7)(f)).[27] This is the case for four of the five PFAS chemicals evaluated by DOH, since all but PFBS[28] lack toxicity data in the MTCA sources listed above. For HFPO-DA (GenX), Ecology adopted the oral RfD developed by EPA's Office of Water (EPA, 2022c). Inhalation RfDs are not available for any PFAS compounds, so only oral RfDs were used to derive MTCA cleanup levels for soil and groundwater.

For the purpose of developing MTCA cleanup levels for PFAS chemicals, Ecology concludes that the RfDs identified by DOH in the development of their SALs are appropriate and represent the best and latest science. The toxicity studies that form the basis for the SALs are high quality, peer-reviewed, comprehensive, and based on current scientific research (DOH, 2021a; Ecology 2022). In addition, the techniques used to develop the RfDs are consistent with those recommended in MTCA (WAC 173-340-708(7)(f)). In accordance with MTCA, Ecology has consulted with both EPA and DOH on the selection of RfDs identified in this guidance for the development of MTCA cleanup levels (WAC 173-340-708(7)(g)) (Ecology 2022). The eight RfDs selected for developing MTCA cleanup levels are listed below. See Section 3.3.1 for more details on the Department of Health's RfDs.

- **PFOA** – 3 ng/kg-day (ATSDR, 2021)
- **PFOS** – 3 ng/kg-day (MDH 2020a; NHDES, 2019)
- **PFNA** – 2.5 ng/kg-day (ATSDR, 2021)
- **PFHxS** – 9.7 ng/kg-day (MDH, 2020b)
- **PFBS** – 300 ng/kg-day (EPA, 2021a)
- **PFBA** – 1000 ng/kg-day (EPA, 2022)
- **PFHxA** – 500 ng/kg-day (EPA, 2023)

[27] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-708 (Human health risk assessment procedures.)
[28] DOH applied EPA's published PPRTV oral RfD of 300 ng/kg-day to develop the SAL for PFBS (EPA, 2021a).

- **GenX** – 3 ng/kg-day (EPA, 2022)

3.2.2 Compliance with ARARs

Cleanup levels must comply with applicable local, state, and federal laws in addition to requirements Ecology has determined to be relevant and appropriate (WAC 173-340-710(4)).[29] These legally applicable, relevant and appropriate requirements are collectively referred to as ARARs. At the time we published this guidance, there were no legally applicable state or federal laws (such as MCLs or maximum contaminant levels) to apply when developing PFAS cleanup levels.

On March 14, 2023, EPA proposed a National Primary Drinking Water Regulation (NPDWR) to establish legally enforceable MCLs for six PFAS compounds in drinking water. The proposed rule would regulate two PFAS compounds (PFOA and PFOS) as individual contaminants, each with an MCL of 4 ng/L. In addition, four other PFAS compounds (PFBS, PFNA, PFHxS, and HFPO-DA (GenX)) will be regulated as a mixture. This mixture will be evaluated using a Hazard Index approach, with the MCL set at a hazard index of 1.0. When EPA promulgates a final MCL for a particular PFAS compound, Ecology will consider the level to be an applicable state and federal requirement under the provisions in WAC 173-340-720. In addition, a final MCL will replace a SAL, if one exists.

However, Ecology can review each cleanup site to determine if there are relevant and appropriate requirements that, while not legally required, should be applied based on circumstances at the site. To make this determination, Ecology would need to evaluate the criteria identified in WAC 173-340-710(4) to establish whether the value under consideration was relevant and appropriate.

3.2.3 Potable groundwater cleanup levels

The process outlined in WAC 173-340-720[30] is for setting cleanup levels for potable and non-potable groundwater. MTCA groundwater cleanup levels for PFAS chemicals discussed in this section are based on the assumption that the highest beneficial use and the reasonable maximum exposure at the site is the ingestion of groundwater as a current or potential potable drinking water source. The Department of Health's SALs are expected to serve as the groundwater cleanup levels for most sites that have potable groundwater.

Under Method B, or Method C if applicable, groundwater cleanup levels must be a) as stringent as applicable state and federal laws, b) protective of human health, and c) protective of surface water beneficial uses. Additional requirements for establishing Method C cleanup levels for potable groundwater are found in WAC 173-340-706(1) but note that Method C groundwater cleanup levels are rarely used.

[29] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-710 (Applicable local, state and federal laws.)
[30] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-720 (Groundwater cleanup standards.)

Ecology applied the RfDs in Section 3.1.1 to calculate Method B and C cleanup levels using MTCA Equation 720-1. We used an inhalation correction factor of 1 for chemicals that are not volatile, and 2 for volatile PFAS compounds (PFBA and HFPO-DA), along with the other default exposure assumptions. Table 3 shows the three levels: calculated groundwater cleanup levels under Methods B and C, the DOH SALs, and Ecology's preliminary groundwater cleanup levels.

Table 3: Groundwater cleanup levels for PFAS using Method B and Method C in Washington state's MTCA Cleanup Regulations. **Note:** The levels provided below are current as of the release date of this guidance. Ecology recommends checking CLARC at Washington State Department of Ecology[31] to confirm the accuracy of these values, and to determine if cleanup levels have been developed for other PFAS compounds.

PFAS	Method B[32]	Method C[33]	DOH SAL[34]	Preliminary Groundwater Cleanup Levels	Units
PFOA	48	110	10	10	ng/L
PFOS	48	110	15	15	ng/L
PFNA	40	88	9	9	ng/L
PFHxS	160	340	65	65	ng/L
PFBS	4,800	11,000	345	345	ng/L
PFBA	8,000	18,000	---	8,000	ng/L
PFHxA	8,000	18,000	---	8,000	ng/L
HFPO-DA	24	53	---	24	ng/L

The calculated Method B and C groundwater equation values in this table are higher than the DOH SALs because the MTCA cleanup level equations do not account for relative source contribution or trans-lactational exposures to breast-fed children when contaminants accumulate in breast milk (see discussion in Sections 3.1.1, and 3.3.1). However, under MTCA the hazard index cannot exceed 1, so some downward adjustments would need to be made if there are multiple noncarcinogens that affect the same endpoint (target organ/critical effect). Since PFAS

[31] https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC

[32] Method B – Based on child exposure with a HQ of 1, body weight of 16 kg, and a drinking water ingestion rate of 1 liter/day.

[33] Method C – Based on adult exposure with a HQ of 1, body weight of 70 kg, and a drinking water ingestion rate of 2 liters/day.

[34] The development of DOH SALs is discussed in Section 3.3 of this guidance.

compounds all share liver effects as a target organ, adjustments would need to be made to the cleanup levels for multiple PFAS so that the total HI does not exceed 1.

The DOH SALs in Table 3 should be evaluated to determine if they constitute "relevant and appropriate requirements" as set forth in WAC 173-340-710(4). Ecology expects that the SALs will be considered ARARs and therefore applied as the cleanup levels at sites where groundwater is currently being used, or may be used in the future, as a potable drinking water source.[35] The SALs are sufficiently protective (Hazard Quotient (HQ) less than 1) and represent the most stringent ARAR currently available.

Until Ecology determines that the DOH SALs are an ARAR for a site, they should be considered preliminary cleanup levels. However, the Method B and C equation levels were calculated using reference doses established under the options set forth in WAC 173-340-708(7), and those values are applicable under MTCA. Seven PFAS compounds and their corresponding cleanup levels have been added to CLARC (Ecology's Cleanup Levels and Risk Calculation database), and PFHxA is expected to be added when CLARC is next updated.

As discussed in Section 3.3.2, EPA is conducting additional IRIS toxicity assessments and the number of PFAS compounds with available cleanup levels will increase over time. Until the Method B (or Method C, if applicable) levels are superseded by a site-specific determination that the DOH SALs are relevant and appropriate, compliance with the MTCA derived levels in Table 3 is required. For all contaminated sites, Ecology recommends using a laboratory that can achieve practical quantitation limits (PQLs) at or below the SALs listed in Table 3.

Note: Unless it can be demonstrated that the hazardous substances are not likely to reach surface water, the groundwater cleanup level must be at least as stringent as the surface water cleanup level established in accordance with WAC 173-340-730 (see Section 3.2.4 below).

3.2.4 Surface water cleanup levels

The process outlined in WAC 173-340-730 is for setting cleanup levels for surface water. Under Methods B and C, surface water cleanup levels must be a) as stringent as applicable state and federal laws, b) protective of human health and the environment, and c) protective of drinking water beneficial uses if surface water is suitable as a domestic water supply. Additional requirements for establishing Method C cleanup levels for surface water are the same as previously described for groundwater. Method C cleanup levels are rarely used.

[35] Each cleanup site should be reviewed to determine on a site-specific basis if there are relevant and appropriate requirements that should be applied, such as DOH's SALs.

Default standard Method B and C cleanup levels for PFAS chemicals in surface water that are based on consumption of fish may be calculated using MTCA Equation 730-1[36] for noncancer effects, in conjunction with a) the RfDs that formed the basis of the DOH SALs, b) chemical-specific bioconcentration factors (BCFs), and c) associated default exposure assumptions. However, these calculations can't be performed because chemical-specific BCFs are not available from EPA at this time for any PFAS. Ecology will seek to establish BCFs for PFAS chemicals in accordance with WAC 173-340-708(9) as new scientific data becomes available.

For sites where surface water is used or could be used in the future for drinking water, the most stringent level based on potable groundwater (see cleanup levels in Section 3.2.3) and the recommended surface water quality criteria based on protection of ecological risks provided in Table 6 (see Chapter 5) would apply as the surface water cleanup level. In cases where surface water is non-potable, Ecology recommends applying the surface water quality criteria in Table 6 for preliminary site screening. In the absence of available surface water quality criteria, Ecology recommends applying the potable groundwater cleanup levels for preliminary site screening in accordance with WAC 173-340-720(6)(b)(i). EPA is currently developing ambient water quality criteria for PFAS under Section 304 of the Clean Water Act,[37] and these may be applied as ARARs under MTCA once they are finalized.

3.2.5 Soil cleanup levels

WAC 173-340-740[38] is for setting unrestricted land use cleanup levels for soil (Method B).
WAC 173-340-745[39] is for setting cleanup levels at industrial properties (Method C).
WAC 173-340-747[40] is for setting soil cleanup levels for groundwater protection (both Method B and Method C). The MTCA soil cleanup levels for PFAS discussed in this section are based on direct human contact through incidental ingestion, and protection of groundwater as a potable drinking water source.

Under Methods B and C, soil cleanup levels must be a) as stringent as applicable state and federal laws, b) protective of human health (soil direct contact) and the environment (i.e., terrestrial ecological receptors[41]), and c) protective of groundwater. Additional requirements for establishing Method C cleanup levels for soil are: d) the site meets the definition of an industrial property under the MTCA Cleanup Regulations (WAC 173-340-745(1)(a)(i)), e) institutional

[36] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-730 (Surface water cleanup standards.)
[37] https://www.epa.gov/laws-regulations/summary-clean-water-act
[38] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-740 (Unrestricted land use soil cleanup standards.)
[39] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-745 (Soil cleanup standards for industrial properties.)
[40] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-747 (Deriving soil concentrations for groundwater protection.)

[41] Cleanup levels based on the protection of terrestrial ecological receptors are discussed in detail in Chapter 5 of this guidance.

controls are in place, and f) residual hazardous substances will not pose a threat to human health or the environment.

Default standard Method B and C cleanup levels for PFAS in soil based on protection of noncancer effects from human direct contact were calculated using MTCA Equations 740-1 and 745-1, respectively (Table 4). Ecology calculated these levels using the RfDs that formed the basis of the Department of Health's SALs and EPA's RfD for HFPO-DA, in addition to using the associated default exposure assumptions found in WAC 173-340-740 (Method B), and WAC 173-340-745 (Method C).

Table 4: Method B and C soil direct contact cleanup levels for PFAS under Washington state's MTCA Cleanup Regulations. **Note:** The levels provided below are up to date as of the release date of this guidance. Ecology recommends checking CLARC at Washington State Department of Ecology[42] to confirm the accuracy of these values, and to determine if cleanup levels have been developed for other PFAS compounds.

PFAS	Method B[43]	Method C[44]	Units
PFOA	0.24	11	mg/kg
PFOS	0.24	11	mg/kg
PFNA	0.2	8.8	mg/kg
PFHxS	0.78	34	mg/kg
PFBS	24	1,100	mg/kg
PFBA	80	3,500	mg/kg
PFHxA	40	1,800	mg/kg
HFPO-DA	0.24	11	mg/kg

The cleanup levels in Table 5 are soil concentrations for both the vadose zone and saturated zone that are protective of potable groundwater. These levels were calculated using MTCA Equation 747-1 and the default soil characteristics listed in the MTCA Cleanup Regulations. Ecology used the Method B groundwater cleanup levels from Table 3, and the SALs when

[42] https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC

[43] Method B: Based on child exposure with a body weight of 16 kg and a soil ingestion rate of 200 mg/day.

[44] Method C: Based on adult exposure with a body weight of 70 kg and a soil ingestion rate of 50 mg/day.

available. Organic carbon-water partitioning coefficients (Koc) and Henry's Law constants (Hcp) were obtained from the Oak Ridge National Labs (ORNL) database of chemical-specific parameters in their Risk Assessment Information System (RAIS[45]; ORNL, 2022). Soil-water distribution coefficient (Kd) values were calculated from Koc values using MTCA Equation 747-2.

Table 5: PFAS soil concentrations protective of potable groundwater under Washington state's MTCA Cleanup Regulations. **Note:** The levels provided below are up to date as of the release date of this guidance. Ecology recommends checking CLARC at the Washington State Department of Ecology[46] to confirm the accuracy of these values, and to determine if cleanup levels have been developed for other PFAS compounds.

PFAS	Method B Vadose Zone	Method B Saturated Zone	Vadose zone – SAL Based	Saturated zone – SAL Based	Units
PFOA	3.0E-04	1.9E-05	6.3E-05	4.0E-06	mg/kg
PFOS	5.5E-04	3.2E-05	1.7E-04	9.9E-06	mg/kg
PFNA	3.6E-04	2.1E-05	8.0E-05	4.8E-06	mg/kg
PFHxS	9.7E-04	6.2E-05	4.1E-04	2.6E-05	mg/kg
PFBS	2.5E-02	1.7E-03	1.8E-03	1.2E-04	mg/kg
PFBA	4.4E-02	2.9E-03	---	---	mg/kg
PFHxA	3.5E-02	2.5E-03	---	---	mg/kg
HFPO-DA	1.0E-04	7.2E-06			mg/kg

MTCA Equation 747-1 does not account for some of the unique transport characteristics of PFAS. Because of their surfactant properties, PFAS tend to sorb preferentially to air-water and NAPL-water interfaces. Studies have shown that air-water interfaces can account for up to 100% of the PFOS and PFOA retained in soil. The Kd parameter in Equation 747-1 accounts for adsorption to organic matter in soil but does not account for interfacial sorption.

Other soil characteristics that influence PFAS sorption include pH, cation exchange capacity, and micropore volume. These characteristics are not accounted for in Equation 747-1. Soil leaching cleanup levels for PFAS are associated with a higher level of uncertainty than for other chemicals. However, soil leaching cleanup levels for PFAS will often be below practical quantitation limits, so an emphasis on attaining low quantitation limits will be more important than the accuracy of the leaching cleanup levels. WAC 173-340-707 contains the criteria to be used when evaluating analytical limitations. In most cases, sites will be in compliance with MTCA if the measured concentration is less than the practical quantitation limit. Another option

[45] https://rais.ornl.gov/
[46] https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC

for evaluating the leaching pathway would be to sample groundwater, then if appropriate, use an empirical demonstration in accordance with WAC 173-340-747(9).

3.2.6 Air cleanup levels

The process outlined in WAC 173-340-750[47] is for setting cleanup levels for air. Default standard Method B and C cleanup levels for inhalation of hazardous substances in air may be calculated using MTCA Equation 750-1 for noncancer effects, in conjunction with chemical-specific inhalation RfDs and the associated default exposure assumptions. Adjustments to Equation 750-1 for calculating Method C cleanup levels are discussed in WAC 173-340-750(4).

However, air cleanup levels could not be calculated because chemical-specific inhalation RfDs are not available at this time for any PFAS compounds. Ecology will seek to establish inhalation toxicity criteria for PFAS chemicals in accordance with WAC 173-340-708(7) as new scientific data becomes available.

3.3 EPA health advisory and screening levels

This section is primarily for informational purposes, since Washington state relies on levels calculated in accordance with requirements in the MTCA Cleanup Regulations. It provides a brief overview of the drinking water lifetime health advisories (HAs) and screening levels (SLs) that EPA established for several PFAS chemicals.

3.3.1 Health Advisories

EPA health advisories identify levels that are protective of noncancer effects over a lifetime exposure to contaminants in drinking water, including sensitive subpopulations and life stages. The HAs are non-enforceable and non-regulatory but provide technical information to drinking water system operators and officials in federal, state, tribal, and local governments about the health effects, analytical methods, and treatment technologies associated with contaminated drinking water (EPA, 2022c).

EPA initially developed provisional HAs for PFOS and PFOA in 2009 in response to levels detected in public drinking water systems (EPA, 2009). Developments since then:

- **May 2016.** Based on an assessment of newer science and toxicological data, EPA issued finalized lifetime HAs of 70 ng/L for PFOS and PFOA individually, as well as for the two chemicals combined (EPA, 2016a; 2016b).

- **June 2022.** EPA issued interim updated HAs for PFOS and PFOA, and final HAs for HFPO-DA (GenX) and PFBS (EPA, 2022c). The interim updated HAs for PFOS and PFOA are based on new studies and are several orders of magnitude lower than the

[47] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-750 (Cleanup standards to protect air quality.)

2016 HA (0.02 ng/L for PFOS, and 0.004 ng/L for PFOA). EPA's final HAs for HFPO-DA and PFBS are 10 ng/L and 2,000 ng/L, respectively.

EPA calculated the HAs for a drinking water exposure scenario using a chronic oral reference dose (RfD[48]) to affectively achieve a hazard quotient (HQ) of 1. Methods for deriving the oral RfDs are found in EPA's June 2022 technical fact sheet[49] that discusses HAs for four PFAS compounds (EPA, 2022c). In the HA calculation, EPA used their Exposure Decision Tree to determine appropriate relative source contribution (RSC) of 20% for drinking water ingestion to allow for exposure from other sources such as food, dust, and soil (EPA, 2000). Application of the RSCs assumes that exposure from contaminated drinking water accounts for only a portion (i.e., 20%) of the permissible dose (i.e., the oral RfD), and exposures from other sources account for 80% (EPA, 2022c). As a result, the protective drinking water level is lowered by 80% to generate the HAs. EPA uses the equation below to derive lifetime noncancer HAs.

HA Equation

$$Lifetime\ HA = \frac{RfD_o \times RSC}{DWIR/BW}$$

Definitions

HA = Drinking Water Health Advisory (mg/L)
RfD_o = Oral Reference Dose (mg/kg-day)
RSC = Relative Source Contribution (20%)
BW = Average Body Weight (kg)
DWIR = Drinking Water Ingestion Rate (liters/day)
DWIR/BW = Liters/kilogram-day[50]

In December 2019, EPA issued Interim recommendations for addressing groundwater contaminated with PFOA and PFOS[51] at sites that were being evaluated and managed by federal cleanup programs (EPA, 2019a). Their guidance used the 2016 HA of 70 ng/L as the recommended Preliminary Remediation Goal (PRG)[52] for both PFOS and PFOA in groundwater that is a current or potential source of drinking water, where no state or tribal MCL, or other applicable or relevant and appropriate requirements (ARARs), are available or sufficiently

[48] An oral reference dose is an estimate of a daily oral intake not anticipated to cause adverse health effects over a lifetime (including sensitive subgroups). RfDs are developed for noncancer endpoints (DOH, 2021a).

[49] https://www.epa.gov/sdwa/drinking-water-health-advisories-has#health

[50] EPA uses a 90th percentile drinking water ingestion rate that is adjusted for body weight (in units of L/kg-day). Values are provided in the June 2022 HA Fact sheet (EPA, 2022c).

[51] https://www.epa.gov/pfas/interim-recommendations-addressing-groundwater-contaminated-pfoa-and-pfos

[52] PRGs are generally initial targets for cleanup under federal cleanup programs, which may be adjusted on a site-specific basis as more information becomes available (EPA, 2019a).

protective. EPA is currently evaluating how the issuance of interim health advisories for PFOA and PFOS impact the recommendations in the December 2019 memo.

In March 2020, EPA published its proposed *Preliminary regulatory determinations for PFOS and PFOA in drinking water* under the Safe Drinking Water Act.[53] EPA made a final determination in March 2021 to regulate PFOS and PFOA, and is moving forward to develop a National Primary Drinking Water Regulation (NPDWR) for these two PFAS chemicals.[54] An NPDWR sets a maximum contaminant level or MCL. This regulation can also specify a certain treatment technique (TT) for public water systems for a specific contaminant or group of contaminants.

EPA published a Notice of Proposed Rulemaking to designate PFOS and PFOA as CERCLA hazardous substances in September 2022. The final rule is expected in 2023 (EPA, 2021c).

Note: Ecology is not using the EPA HALs as preliminary cleanup levels because: 1) the levels for PFOA and PFOS are interim and subject to change, 2) the PFBS level exceeds the DOH SAL, and 3) the approach used to determine the level for HFPO-DA is not consistent with the process set out in the MTCA Cleanup Regulations.

3.3.2 Screening Levels

Federal programs such as Superfund incorporate the use of risk-based Screening Levels (SLs). EPA established SLs for six PFAS compounds: PFOS, PFOA, PFNA, PFHxS, PFBS, and HFPO-DA (GenX). The SLs are maintained in EPA's Regional Screening Level (RSL) tables,[55] and are primarily used at CERCLA sites for screening chemicals to determine whether levels of contamination in site media may warrant further investigation or cleanup.

EPA provides SLs that are based on a cancer risk of 1×10^{-6}, and noncancer HQs of 1 and 0.1.[56] In the case of PFAS compounds, EPA recommends using a noncancer HQ of 0.1 for screening to account for cumulative effects from multiple PFAS compounds that may be present (EPA, 2019a).

[53] Announcement of Preliminary Regulatory Determinations for Contaminants on the Fourth Drinking Water Contaminant Candidate List, Vol. 85 Fed. Reg. No. 47, pg. 14098 (March 10, 2020).

[54] Announcement of Final Regulatory Determinations for Contaminants on the Fourth Drinking Water Contaminant Candidate List, Vol. 86 Fed. Reg. No. 40, pg. 12272 (March 3, 2021).

[55] https://www.epa.gov/risk/regional-screening-levels-rsls

[56] A noncancer SL @ HQ 0.1 is derived by dividing the SL @ HQ 1 by 10.

All PFAS compounds listed in EPA's RSL table have SLs based on noncancer effects. PFOA also has an SL based on cancer risk. The cancer-based SL for PFOA is based on an oral CSF of 0.07 kg-day/mg. This CSF and several other candidate CSFs were derived by EPA's Office of Water in 2016, and at the time it was determined that the HA based on noncancer effects is protective for the cancer endpoint (EPA, 2016b).

As a result, EPA did not select one overall CSF for developing a cancer-based PFOA HA (based on a 1 x 10^{-6} cancer risk) (EPA, 2022a). As of the date of this document, the PFOA noncancer-based tap water SL of 60 ng/L (at an HQ = 1) is more than an order of magnitude lower than its corresponding cancer-based SL of 1,100 ng/L (at a risk level = 1 x 10^{-6}). As previously noted, EPA is evaluating available toxicity data to derive a CSF for PFOA as part of the National Primary Drinking Water Regulation (EPA, 2022a).

EPA's RSL table contains PFAS SLs based on a) human direct contact with residential and industrial soil, b) soil concentrations that are protective of groundwater, and c) human exposure to tap water. PFAS soil and tap water SLs consider cumulative exposure via ingestion and dermal contact. Equations and exposure assumptions for calculating the SLs are provided in Section 4 of EPA's RSL User's Guide.[57]

Note: Unlike for the development of health advisories, risk-based EPA screening levels assume that all of the exposure is from tap water ingestion (i.e., the relative source contribution is 100%). This is the same assumption used in MTCA cleanup level equations for drinking water ingestion.

IRIS assessments currently underway

EPA is currently conducting IRIS toxicity assessments on perfluorodecanoic acid (PFDA), perfluorononanoic acid (PFNA), and perfluorohexane sulfonic acid (PFHxS). The IRIS assessments will identify the potential human health effects from exposure to each PFAS chemical, and will derive toxicity values that may be used for developing EPA SLs and MTCA cleanup levels. The IRIS assessments will evaluate both cancer and noncancer effects. For information about the PFAS chemicals identified for assessment in IRIS, visit https://iris.epa.gov/AtoZ/?list_type=erd

[57] https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide

3.4 Ecology's historical PFAS Investigatory Levels (now superseded)

In 2018, local agencies in Issaquah wanted to proactively clean up PFAS identified in a drinking water well and asked for guidance from Ecology to inform their decision-making. Ecology's Northwest Regional Office assisted Headquarters staff by calculating Investigatory Levels (ILs) for PFOS and PFOA. Following the promulgation of the Department of Health's SALs Ecology no longer uses investigatory levels.

Chapter 4: Sampling for PFAS

4.0 Overview

Sampling and analysis of PFAS in environmental media have many challenges due to their ubiquitous nature and low screening/cleanup levels (sometimes in the low parts per trillion range). Methods for analyzing PFAS are still evolving, as well. This chapter summarizes sampling approaches for PFAS and provides analytical methods for environmental media, best practices for collecting representative samples and minimizing cross-contamination, and recommendations for when to sample for PFAS at a MTCA site.

4.1 General sampling approaches

Sampling for PFAS follows the same general approach as for other chemicals, but with additional considerations based on the challenges noted above. General protocols for PFAS sampling are summarized in Sections 11.1.1 through 11.1.7 of the Interstate Technology and Regulatory Council (ITRC) PFAS guidance[58] (ITRC, 2022), as well as in their fact sheets about site characterization, sampling precautions, and laboratory analytical methods (ITRC, 2022a; 2022b). ITRC intends to update their PFAS guidance as new data becomes available, so check their documents periodically for recent information and direction. Two other good sampling resources are:

1. **General PFAS Sampling Guidance** developed by the Michigan Department of Environmental Quality (MDEQ, 2018), along with media-specific PFAS sampling guidance located on their website: https://www.michigan.gov/pfasresponse/investigations/sampling-guidance.

2. **PFAS sampling guidance** developed by the State of California Water Boards (CWB) for drinking water[59] and non-drinking water sources[60] (CWB, 2020a; 2020b).

Consistent with standard protocols for environmental investigation and WAC 173-340-820,[61] a sampling and analysis plan (SAP) and a site-specific Quality Assurance Project Plan (QAPP) need to be developed before conducting PFAS sampling. The QAPP and SAP should address any PFAS-specific considerations in addition to requirements surrounding analytical methods and quality control (QC). Ecology's Quality Assurance[62] webpage has guidance on developing

[58] https://pfas-1.itrcweb.org/
[59] https://www.waterboards.ca.gov/pfas/drinking_water.html
[60] https://www.waterboards.ca.gov/pfas/non_drinking_water.html
[61] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-820 (Sampling and analysis plans.)
[62] https://ecology.wa.gov/About-us/How-we-operate/Scientific-services/Quality-assurance/Quality-assurance-for-NEP-grantees

QAPPs for environmental investigation. Some important PFAS sampling considerations that should be reflected in the QAPP/SAP are:

4.1.1 Assemble a complete PFAS analyte list

At the time we published this guidance, screening levels/cleanup levels protective of human health and/or ecological health were only available for the eleven unique PFAS chemicals identified in Chapters 3 and 5. As more toxicity information becomes available and assessments are completed, the list of PFAS compounds with screening or cleanup levels will expand. Therefore, Ecology recommends analyzing for a comprehensive set of PFAS compounds, consistent with current, available analytical methods and laboratory capabilities. This will allow future assessment of the site once additional screening/cleanup levels for the other PFAS chemicals have been established.

4.1.2 Use accredited laboratory analytical methods

Work closely with an Ecology-accredited laboratory[63] to ensure that whenever possible, the analytical methods achieve reporting limits that meet media-specific PFAS screening/cleanup levels. Section 4.3.1 summarizes the available analytical methods. More detail is provided in Section 11.2 of the ITRC PFAS guidance (ITRC, 2021), where the methods and other relevant information are summarized in downloadable Microsoft Excel tables (Tables 11-2 to 11-5). ITRC intends to periodically update the tables as new information becomes available. Find the resources on their PFAS webpage.[64]

4.1.3 Accounting for precursors

Certain per- and polyfluoroalkyl substances will degrade to form perfluoroalkyl acids (PFAAs), which are referred to as terminal PFAS because they will not further break down in the environment. With the improvement and evolution of PFAS analytical methods, additional precursor compounds can now be quantified. However, there are still a large number of precursors that can't be quantified using existing analytical methods.

The transformation of precursors into terminal PFAS can significantly complicate efforts to identify source areas and ultimately the degree and extent of contamination. Options to help identify precursor compounds are provided in Section 4.3.2.

[63] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation/How-to-choose-an-analytical-laboratory (Choosing an analytical laboratory)

[64] https://pfas-1.itrcweb.org/

4.1.4 Minimize cross contamination

Due to the ubiquitous nature of PFAS, as well as their very low screening/cleanup levels, PFAS sampling requires extra precautions to reduce the potential for cross contamination and false positive sample results. Section 4.4 provides options for minimizing this potential.

4.1.5 Collect field QC samples

Collecting field QC samples is an important element for any environmental sampling and is especially necessary for PFAS compounds. Sample collection and decontamination procedures should be designed and implemented to minimize introduction of PFAS into the sample. Collection of field blanks and equipment rinsate blanks are important for assessing potential cross contamination that may influence the interpretation of sample results. Field duplicates are used to assess the overall precision of sampling and analysis techniques. These types of QC samples are described in more detail in Section 4.4.3 of this document, and Section 11.1.6 of ITRC's PFAS guidance (ITRC, 2021)

4.1.6 Filtration of samples

Ecology recommends that samples collected for PFAS analysis not be field filtered, as there is potential for adsorption to the filter and for the filter to be a source of PFAS. For samples that have a high suspended solids content, work with the laboratory to determine if a sample cleanup step is necessary prior to analysis. More detailed information on this issue is available in Section 11.1.7.2 of the ITRC PFAS Guidance, as well as the Michigan sampling guidance, referenced at the beginning of this section.

4.2 Approved methods and compound list for drinking water

EPA has validated and published three methods (533, 537, and 537.1) to support the analysis of PFAS in drinking water. All three methods utilize solid phase extraction followed by analysis via liquid chromatography-tandem mass spectrometry (LC-MS/MS). Method 537[65] (published in 2008) was used extensively during EPA's UCMR3 sampling conducted between 2013 and 2015 and included 14 PFAS compounds. This method was updated in November 2018 to Method 537.1[66] and updated again in March 2020 to Method 537.1, revision 2.[67] The current version can be used to analyze 18 PFAS compounds. Method 533[68] was finalized in December 2019 and focused on shorter chain PFAS compounds. Both methods 533 and 537.1 measure

[65] https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=198984&simpleSearch=1&searchAll=EPA%2F600%2FR-08%2F092+

[66] https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=343042&Lab=NERL

[67] https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=348508&Lab=CESER&simpleSearch=0&showCriteria=2&searchAll=537.1&TIMSType=&dateBeginPublishedPresented=03%2F24%2F2018

[68] https://www.epa.gov/dwanalyticalmethods/method-533-determination-and-polyfluoroalkyl-substances-drinking-water-isotope

all eleven unique PFAS with Ecology cleanup levels protective of human health and/or ecological health as identified in Chapters 3 and 5.

Method 533 includes all but four of the PFAS compounds listed in Method 537.1, for a total of 25 PFAS. When combined, Methods 537.1 and 533 may be used to measure up to 29 PFAS in drinking water—see Table 11.4 in ITRC's PFAS guidance (ITRC, 2021). When analyzing the PFAS compounds that are found in both methods, Method 533 is generally preferred over 537.1 because it uses a more robust method of quantitation (isotope dilution).

Protocols for sampling PFAS in drinking water are provided in EPA Methods 537.1 and 533, which include discussions on sample bottle preparation, sample collection, field reagent blanks, sample shipment and storage, and sample and extraction holding times. Section 11.1.7.1 of ITRC's PFAS guidance specifically addresses sampling of potable drinking water sources.

4.3 Options for unfinished aqueous and solid matrices

EPA Methods 537.1 and 533 are only approved and validated for finished drinking water (i.e., water ready to drink) that has low total suspended solids (TSS) and total dissolved solids (TDS). These methods are not designed for unfinished water (e.g., untreated surface water or groundwater), soil, or other media that could significantly interfere with the analytical procedures. Analytical options for media other than drinking water are discussed below. Protocols for sampling groundwater, surface water, porewater, sediment, surface soil, subsurface soil, fish, and air are provided in Sections 11.1.7.2 to 11.1.7.9, respectively, in the ITRC PFAS guidance (ITRC, 2022).

4.3.1 Current analytical options

EPA validated and published SW-846 Method 8327[69] in July 2021 (EPA, 2021b). Method 8327 is a direct injection method for non-drinking aqueous matrices (groundwater, surface water, and wastewater) and has been validated for 24 PFAS chemicals. This method uses liquid chromatography/tandem mass spectrometry (LC/MS/MS) and external standards for quantitation (instead of isotope dilution or internal standards). Although the overall quality is less than if isotope dilution were used for quantification, EPA developed this method to find a balance between sensitivity, ease of implementation, and monitoring requirements.

Many laboratories have developed their own user-defined methods to analyze non-drinking water media. Some laboratories refer to their user-defined method as "537 Modified" if they are based on the existing EPA method(s). However, it is important to note that deviations from the procedures listed in 537 or 537.1 are not considered an approved, validated method by EPA.

[69] https://www.epa.gov/hw-sw846/sw-846-test-method-8327-and-polyfluoroalkyl-substances-pfas-liquid-chromatographytandem

When developing user-defined methods to analyze for PFAS compounds, some laboratories use the U.S. Department of Defense/U.S. Department of Energy Quality Systems Manual (QSM) for Environmental Laboratories, Version 5.4[70] (QSM 5.4) to set required QA/QC performance criteria (DOD, 2021). According to ITRC's PFAS guidance, DOD's QSM (specifically Appendix B, Table B-24) provides the most current and comprehensive set of quality standards for PFAS analysis (ITRC, 2021). DOD's QSM requires isotope dilution quantitation of PFAS compounds and provides for specific quality processes for sample preparation, instrument calibration, and analysis for aqueous, solid, and biological matrices (DOD, 2021).

Based on the above information, Ecology recommends using the analytical[71] and QA/QC performance criteria set forth in Table B-24 of DOD's QSM 5.4 for analyzing PFAS in non-drinking water media. Ecology-accredited laboratories that rely on user-defined methods that are compliant with Table B-24 of DOD's QSM 5.4 are preferred for non-drinking water aqueous samples.

EPA is collaborating with DOD to develop and validate EPA Method 1633,[72] which is an LC-MS/MS isotope dilution method for non-drinking water aqueous matrices such as surface water, groundwater, wastewater influent/effluent, and landfill leachate, as well as fish tissue, biosolids, soil, and sediment. EPA Method 1633 will include 40 PFAS compounds with a target quantitation limit of 2 ng/L. This method is anticipated to be generally compliant with DOD's QSM 5.4 Table B-24. EPA draft Method 1633 was published in September 2021 and is currently undergoing a multi-laboratory validation study. In December 2022, EPA issued a memo recommending that Method 1633 now be used for testing of wastewater influent, effluent, and biosolids. The memo is available at: https://www.epa.gov/system/files/documents/2022-12/NPDES_PFAS_State%20Memo_December_2022.pdf. Since there are several labs that have already received accreditation for this Method, Ecology is recommending this Method be used for all media that can be analyzed using Method 1633.

4.3.2 Non-specific test methods

Due to the large number of PFAS compounds and the limited number that can currently be quantified, it can be helpful to use non-specific test methods to get a better understanding of the full extent of PFAS present and how they might affect the sampling results and cleanup actions. For example, in some cases, precursors – PFAS compounds that can eventually break down to PFAAs – could be present. Although Ecology doesn't currently have cleanup levels for precursors, they can serve as a continuing source as they break down into PFAS compounds for which we do have cleanup levels. Although validated analytical methods are not yet

[70] https://denix.osd.mil/edqw/documents/manuals/qsm-version-5-4-final/
[71] Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS) with Isotope Dilution.
[72] https://www.epa.gov/cwa-methods/cwa-analytical-methods-and-polyfluorinated-alkyl-substances-pfas#draft-method-1633

available, these non-specific test methods may be appropriate for situations where the source of the release is unknown or where only limited information is available.

Categories of non-specific PFAS test methods are briefly described below. More detailed information can be found in Section 11.2.2 of the ITRC PFAS guidance (ITRC, 2021). Many of these methods are in relatively early stages of development and validation, so the most up-to-date information will often be found in the scientific literature.

Probably the most common non-specific test method is the Total Oxidizable Precursors (TOP) assay, which is used to help identify PFAS compounds that can be converted into PFAA end products that won't degrade further. The TOP assay is highly specific to PFAS and can be used for both aqueous and solid samples. Incomplete oxidation can result in an underestimate of total PFAS. It does not provide information about PFAS composition (i.e. functional grounps, and branched versus linear isomers). Therefore, the TOP assay could be useful for determining the total quantity of PFAS present, but not for identifying or characterizing sources.

Adsorbable Organic Fluorine (AOF)/Extractable Organic Fluorine (EOF) with Combustion Ion Chromotography (CIC) is a total organic fluorine method that concentrates PFAS compounds on resin, combusts the compounds retained on the resin, then analyzes the inorganic fluoride by ion chromatography. Because this method relies on sorption to resin, it may be biased to longer chain PFAS compounds.

The presence of non-PFAS organic fluorine compounds (e.g. pesticides, pharmaceuticals) in a sample could result in overestimating the total PFAS concentration and high levels of other organic compounds may cause incomplete PFAS retention on the resin. This method is best suited to aqueous samples as solid samples require additional sample preparation, which may result in lower PFAS recovery and other sources of error. As a total method, it does not provide information about PFAS composition. This method may be most appropriate for screening samples prior to targeted analysis. EPA draft method 1621 is an example of an AOF-CIC method.

Another method for quantifying total PFAS is Particle-Induced Gamma Ray Emission (PIGE) spectroscopy, which takes advantage of the characteristic gamma-ray emission of fluorine from proton ion beam impact. This method is non-destructive and can be used to characterize a thin surface layer of a solid sample. Analysis of aqueous or soil samples with this method requires extraction and other sample preparation, and is still in the early stages of development. This method is most appropriate for samples of PFAS-containing products (e.g. paper, textiles, food packaging, especially those containing polymeric PFAS which are not amenable to other analytical techniques. Furthermore, since the PIGE method measures total fluorine, it is only useful for PFAS analysis if the sample material contains negligible quantities of inorganic fluorine and non-PFAS organofluorine compounds.

A final example of non-targeted analysis is high-resolution mass spectrometry, which provides tentative identification of PFAS structures through library matching or other techniques.

Typically, samples are prepared in an aqueous solution, separated using liquid chromatography, and analyzed on a quadrupole time-of-flight (qTOF) tandem mass spectrometer (MS/MS). In contrast to the other methods described here, qTOF-MS/MS provides extentsive information about PFAS composition and molecular structures, typically based on libraries of known molecules and ion fragments. Compound identification is only tentative unless a certified reference material exists for a particular compound. While this method can provide a wealth of information on PFAS composition, it may not capture all PFAS compounds due to differences in extraction and ionization efficiency and is only semi-quantitative at best for determining concentrations. Therefore, this method is most appropriate for identification of PFAS sources and PFAS compounds which are not included in existing targeted methods or are not yet known.

4.3.3 Future analytical options

In April 2022, EPA released draft Method 1621, which is a screening method for determining adsorbable organic fluorine in aqueous matrices using combustion ion chromatograpy. The timeframe for publishing a final method is uncertain.

4.4 Approaches to minimize cross-contamination

Initial PFAS guidance documents often contained lists of materials with fluoropolymer components that should be avoided during sampling to minimize the potential for cross-contamination. These lists often included sampling equipment as well as other products, such as rain gear, food containers, and personal protective equipment that do not come in direct contact with the sample but were thought to be able to contribute to cross-contamination.

More recently, testing completed by Denly et al. (2019) and Rodowa et al. (2020) helps determine the potential for cross-contamination. This testing documented that, in many cases, the evaluated materials do not leach detectable levels of PFAS compounds. However, because this testing was limited, challenges still exist for ensuring sample integrity is maintained.

4.4.1 Materials that may contact the samples

When materials can come in direct contact with a sample, take the necessary actions to document the equipment is free from PFAS-containing substances. This should include either testing to ensure the equipment does not leach PFAS compounds or obtaining information from the manufacturer that their equipment is PFAS-free. Information about PFAS-free products can

be found in MDEQ's General PFAS Sampling Guidance[73] and PFAS Central website[74] (MDEQ, 2018; PFAS Central, 2020).

Before sampling, contact the laboratory to determine whether the materials they provide, such as sampling containers and distilled water, are certified as PFAS-free. If a separate source of rinse water will be used (i.e., water that is not certified as PFAS-free water supplied by the laboratory), at least one sample of that water should be collected and analyzed using the same analytical method and same compound list as for field samples collected at the site.

4.4.2 Other onsite materials that may contain PFAS

For those materials that do not directly contact the sample, a combination of two or all three of the following options can minimize the chance for cross-contamination:

1. Obtain information from the manufacturer on whether the materials are PFAS-free.
2. Implement a QA/QC program that includes a sufficient number of field blanks (see Section 4.4.3 below) to determine if these materials could introduce PFAS compounds into samples.
3. If sampling materials cannot be documented as PFAS-free, limit their use as much as possible.

Given the widespread presence of fluoropolymers, the low laboratory detection levels, and the cost for PFAS analysis, take extra care to ensure data quality is not compromised.

4.4.3 Recommended sampling procedures to minimize cross-contamination

To help minimize the potential for cross-contamination, Ecology recommends devoting a section in the project sampling and analysis plan (SAP) for identifying which specific PFAS sampling procedures will be used. The quality assurance project plan (QAPP) should identify all PFAS-specific quality control samples that will be taken.

If there is historical information about PFAS levels at the site, the preferred sampling sequence should start in areas with the least contamination, then move to more contaminated areas. During the sampling event, liquid PFAS samples should be collected first. For solid phase PFAS samples that are also targeted for VOC analysis, consider collecting the VOC sample first to limit the potential for contaminant volatilization.

[73] https://www.michigan.gov/documents/pfasresponse/General_PFAS_Sampling_Guidance_634597_7.pdf
[74] https://pfascentral.org/pfas-free-products/

When sampling for PFAS, Ecology recommends collecting the following field quality control samples. Any reduction in the recommended QC samples should be discussed with Ecology prior to implementation.

1. **Trip blanks.** One trip blank for each cooler to assess whether contamination is introduced during sample shipment.

2. **Rinse blanks.** One sample collected from the last rinse each day for each type of sampling equipment used for each matrix, to assess the adequacy of the decontamination process.

3. **Duplicate samples.** A minimum of 10% (1 per 10) of the samples for each matrix should be collected in duplicate, but not less than one duplicate per sampling event per matrix to assess precision of the entire effort, including sampling, analysis, and site heterogeneity. Field duplicates should be submitted as discrete samples (i.e., given unique sample identification so the laboratory isn't aware the sample is a duplicate), and should be clearly noted in the field log. More frequent collection of duplicate samples from heterogeneous media—such as soil or sediments where homogenization of samples cannot be performed—should be assessed on a case-by-case basis.

4. **Field blanks.** One PFAS-free field blank sample should be collected daily where the risk for PFAS sample cross-contamination is the most likely, to evaluate the potential for contaminants to be introduced during sample collection, storage, and transport. Options: before the first sample is collected in the morning, before the first sample is collected after lunch, or where the potential for cross-contamination is determined to be the highest.

5. **Pre-field work blanks.** Prior to field work, collect rinse samples from each piece of equipment not certified as PFAS-free, which will be in contact with the samples to be analyzed prior to the start of the field sampling effort.

Potential sources for PFAS cross-contamination should be identified in the field notes. Actions to address these situations should be documented in the data validation section of the sampling report, such as collecting additional quality control samples or making changes to sample handling and decontamination procedures.

Note: Ecology recommends not using sampling devices that contain Teflon (PTFE) or other fluorine containing plastics. If the critical sampling equipment contain fluorinated plastics, collect a pre-field rinse blank to confirm that PFAS do not leach into the sample.

4.5 When to require PFAS sampling and what compounds to sample

4.5.1 Industries where PFAS may be encountered

Table 2.5 in ITRC's PFAS guidance[75] and Appendix 3 in Ecology's PFAS Chemical Action Plan[76] identify industries where PFAS compounds are commonly used or suspected to be used, and how likely they are to be encountered (ITRC, 2021; Ecology, 2021). Section 2.6 of the ITRC PFAS guidance provides a detailed discussion of potential sources of PFAS compounds to the environment. The multitude of PFAS compounds and variety of their applications necessitate looking at each facility or site on a case-by-case basis.

On January 1, 2022, a new ASTM Environmental Site Assessment (ESA) standard (E1527-21) became effective that added guidance for considering PFAS when completing an ESA. On March 14, 2022, EPA published a direct final rule to incorporate ASTM E1527-21[77] into the "all appropriate inquiry" procedures. While the reference to the previous standard (E1527-13) wasn't changed, EPA issued concurrent guidance that allows for using either ASTM standard depending on the situation. Since PFAS compounds are hazardous substances in Washington state, their potential presence should be part of a Phase I evaluation. Trade names or generic descriptions are often used when describing these compounds in the manufacturing process, so give special consideration to employee interviews and carefully review invoices, material usage records, and material safety data sheets when completing a Phase I ESA.

4.5.2 Recommendations for obtaining comprehensive PFAS data

Section 4.2 in this guidance identifies the analytical methods currently approved for analyzing PFAS in finished drinking water. For drinking water samples, if the source of PFAS contamination is unknown or could include short and long chain PFAS compounds, Ecology recommends using both Method 533 and 537.1 to provide a comprehensive assessment of the potential for PFAS impacts.

As of November 2022, the only EPA-approved method for analyzing PFAS in non-drinking water samples was Method 8327. While this is an approved EPA method, it doesn't use isotope dilution and has been viewed by many as a less preferred sample analysis method.

The Department of Defense has its own accreditation program for PFAS analyses and as discussed in Section 4.3.1, Ecology recommends using the analytical[78] and QA/QC performance criteria set forth in Table B-15 of DOD's QSM 5.4 for analyzing PFAS in non-drinking water media. Ecology-accredited laboratories that have user-defined methods consistent with Table B-15 in DOD's QSM 5.4 are preferred when analyzing media other than

[75] https://pfas-1.itrcweb.org/2-5-pfas-uses/
[76] https://apps.ecology.wa.gov/publications/summarypages/2104048.html
[77] https://www.astm.org/e1527-21.html
[78] Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS) with Isotope Dilution.

finished drinking water. If other PFAS compounds require analysis beyond those mentioned elsewhere in this chapter, Ecology recommends contacting the laboratory before sampling to discuss what options are available for generating the necessary data.

Note: As discussed in Section 4.3.3, EPA is currently validating Method 1633, which will provide a comprehensive test method for non-drinking water and solid matrices. Since EPA is currently recommending the use of Method 1633 for various non-drinking water matrices, Ecology will accept results generated by this analytic method. Ecology's Laboratory Accreditation Unit has already begun accrediting labs for Draft 2 of EPA Method 1633.

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Chapter 5: Protective Concentrations for Ecological Receptors

5.0 Introduction

Establishing protective concentrations for ecological receptors is an essential aspect of site cleanup work under the Model Toxics Control Act (Ecology, 2001a in Appendix B). Current research suggests that PFAS compounds are globally distributed in the environment and biota (e.g., plants, algae, invertebrates, mammals, birds, fish), including locally in Washington state. Both short- and long-chain PFAS are environmentally persistent. They bioaccumulate and the effects on ecological receptors range from subtle alterations in gene expression to deficits in apical endpoints (e.g., growth, survival, reproduction). Ecology's PFAS Chemical Action Plan[79] includes the following recommendations in Appendix 6: Ecotoxicology of PFAS (Ecology, 2021):

- Selected individual PFAS, as well as common PFAS mixtures, should be evaluated for ecotoxicity in aquatic and terrestrial biota, using both laboratory and field methods; and
- Cleanup levels should ultimately be developed for PFAS (individually and potentially as mixtures) for soil, sediment, freshwater, and saltwater to protect ecological receptors.

The development and determination of protective concentrations for ecological receptors in both surface waters (marine and freshwater) and upland soil should help achieve these goals. The protective concentrations that appear in this chapter were developed according to the MTCA Cleanup Regulations, guidance, and policy (Ecology, 2001a; Ecology, 2001b in Appendix B).

Note: Use of the terms "Concentration" and "Level." Throughout this chapter, we reference the amount of chemical exposure in a study using the terms *concentration* and *level*. For example, the terms *Lowest Observed Adverse Effects Concentration* (LOAEC) and *Lowest Observed Adverse Effects Level* (LOAEL) are used to describe a similar concept, which is the lowest amount of chemical exposure in a study that resulted in significant effects to the exposed organisms. The term that best applies to a specific study is determined by the exposure route. *Concentration* is used for studies where the exposure is through an external medium, like plants growing in contaminated soil or fish swimming in contaminated water. *Level* is used for studies where the exposure is through ingestion, like most mammalian and avian toxicity studies.

[79] https://apps.ecology.wa.gov/publications/SummaryPages/2104048.html

5.1 Surface water

As of the date of this guidance document, environmental effects-based concentrations for PFAS compounds have not been established under applicable state or federal laws. EPA had a public comment period for the draft national recommended aquatic life criteria for PFOA and PFOS in 2022. Once those values are finalized, they should be used to determine protective values. Consequently, you must establish cleanup levels as provided in the MTCA Cleanup Regulations. Those cleanup levels must have either **no adverse effect** (under Method B) or **no significant adverse effect** (under Method C) on the protection and propagation of wildlife, fish, and other aquatic life.

5.1.1 Applicable Regulatory Authority

WAC 173-340-730(3)(b)(ii)[80] Environmental effects. For hazardous substances for which environmental effects-based concentrations have not been established under applicable state or federal laws, concentrations that are estimated to result in no adverse effects on the protection and propagation of wildlife, fish, and other aquatic life.

Whole effluent toxicity testing using the protocols described in Chapter 173-205 WAC[81] may be used to make this demonstration for fish and aquatic life.

The concentrations included in this chapter are predicted to have **no observed adverse effect** based on a literature review. These protective values should be used when establishing an environmental-effects-based water concentration for sites with PFAS contamination in surface water or for groundwater with the potential to discharge to surface water. If these values are not used, site-specific cleanup levels will need to be established as provided in the regulation (e.g., whole effluent toxicity testing using the protocols described in Chapter 173-205 WAC). In short, Chapter 5 of this guidance provides an off-ramp (screening tool) for some sites to avoid costly environmental studies.

5.1.2. Decision-making process

Table 6 contains a summary of the protective concentrations for marine and fresh surface waters. These protective concentrations were determined by a review of estimated no adverse effects on the protection and propagation of fish, invertebrates, and other aquatic life found in relevant literature. It is important to note that the documented protective concentration is not necessarily the lowest No Observed Effects Concentration (NOEC), but instead represents a value that was chosen to be protective of the individual class of receptors (fish, invertebrates, other) that is also below a Lowest Observed Effects Concentration (LOEC).

[80] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-730 (Surface water cleanup standards.)
[81] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-205 (Whole effluent toxicity testing and limits.)

Note: Appendix B includes a review of the relevant literature and provides a description of how the levels in Table 6 meet the surface water regulations described in Section 5.1.1.

5.2 Uplands

As of the date of this guidance document, soil concentrations for PFAS compounds have not been listed in Table 749-3. Consequently, you must establish protective soil concentrations as provided for in the MTCA Cleanup Regulations.

5.2.1 Applicable Regulatory Authority

WAC 173-340-7493(3)(a)[82] Literature Survey. An analysis based on a literature survey shall be conducted in accordance with subsection (4) of this section and may be used for purposes including the following:

(i) Developing a soil concentration for chemicals not listed in Table 749-3.
(ii) Identifying a soil concentration for the protection of plants or soil biota more relevant to site-specific conditions than the value listed in Table 749-3.
(iii) Obtaining a value for any of the wildlife exposure model variables listed in Table 749-5 to calculate a soil concentration for the protection of wildlife more relevant to site-specific conditions than the values listed in Table 749-3.

WAC 173-340-7493(4) Literature surveys. (a) Toxicity reference values or soil concentrations established from the literature shall represent the lowest relevant LOAEL found in the literature. Bioaccumulation factor values shall represent a reasonable maximum value from relevant information found in the literature. In assessing relevance, the following principles shall be considered:

(i) Literature benchmark values should be obtained from studies that have test conditions as similar as possible to site conditions.
(ii) The literature benchmark values or toxicity reference values should correspond to the exposure route being assessed.
(iii) The toxicity reference value or bioaccumulation factor shall be as appropriate as possible for the receptor being assessed. The toxicity reference value should be based on a significant endpoint, as described in subsection (2) of this section.
(iv) The literature benchmark value or toxicity reference value should preferably be based on chronic exposure.
(v) The literature benchmark value, toxicity reference value, or bioaccumulation factor should preferably correspond to the chemical form being assessed. Exceptions may apply for toxicity reference values where documented biological transformations

[82] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-7493 (Site-specific terrestrial ecological evaluation procedures.)

occur following uptake of the chemical or where chemical transformations are known to occur in the environment under conditions appropriate to the site.

(b) A list of relevant journals and other literature consulted in the survey shall be provided to the department. A table summarizing information from all relevant studies shall be provided to the department in a report, and the studies used to select a proposed value shall be identified. Copies of literature cited in the table that are not in the possession of the department shall be provided with the report. The department may identify relevant articles, books, or other documents that shall be included in the survey.

5.2.2. Literature review

The concentrations included in this chapter are predicted to be protective based on a literature review. You should use these protective values when you need to establish an environmental-effects-based upland soil concentration for sites with PFAS contamination. If you don't use these values, you will need to establish site-specific cleanup levels as provided in the regulation (e.g. site-specific terrestrial ecological evaluation procedures in WAC 173-340-7493). In short, Chapter 5 of this guidance provides an off-ramp (screening tool) for some sites to avoid costly environmental studies.

Note: Appendix B includes a review of the relevant literature and provides a description of how the levels in Table 6 meet the regulations for determining upland soil concentrations protective of ecological receptors.

5.2.3. Decision-making process

Table 6 contains a summary of the protective concentrations that were established for upland ecological receptors. Literature was reviewed with a focus on determining relevant lowest observed adverse effect levels for wildlife. Relevant effects included significant impacts on apical endpoints (survival, growth, reproduction) relative to controls. The lowest relevant LOAEC or LOAEL identified in the literature was generally selected as the toxicity reference value. Toxicity reference values were not established for PFAS compounds when only one LOAEL was identified in the literature.

Plant and soil biota protective concentrations were determined based entirely on LOAECs identified in the literature review. The methods in Efroymson et al. (1997a, 1997b) were used to determine how toxicity reference values were determined for plants and soil invertebrates, consistent with how the values in MTCA Table 749-3 were derived. Since fewer than 10 LOAEC values were identified for each PFAS compound, the lowest LOAEC identified in the literature was selected as the toxicity reference value, as opposed to using the 10th percentile of

literature LOAEC values. Consistent with the derivation of values in Table 749-3, only toxicity studies in earthworms were considered when deriving a soil biota protective value.

Wildlife protective concentrations were established based on the Wildlife Exposure Model described in WAC 173-340-7493(3)(c) and tables 749-4[83] and 749-5 in MTCA. The equations included in the model allow the calculation of protective soil concentrations for a mammalian herbivore (vole), mammalian predator (shrew), and avian predator (robin). Literature-derived values included toxicity reference values for both mammals and birds, earthworm bioaccumulation, and plant uptake. Toxicity reference values for birds and mammals are based on LOAELs identified in the literature.

For mammalian species, to account for differences between laboratory and wildlife species, allometric scaling was applied to toxicity reference values. This was done using the equations in Sample et al. (1996), consistent with the derivation of values in Table 749-3. The reference values for rat, mouse, shrew, and vole body weight were used in the calculations. This resulted in different toxicity reference values for voles and shrews for each PFAS compound.

The literature review provided enough data to establish at least one protective value (plant, soil biota, and/or wildlife) for eight individual PFAS compounds: PFBS, PFHxS, PFOS, PFHxA, PFOA, PFNA, PFDA, and PFDoA.

[83] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-900 (Tables.)

Table 6: PFAS concentrations protective of ecological receptors in surface waters and upland soils.

Contaminant	Organism	PFBS	PFDA	PFNA	PFHxA	PFHxS	PFOA	PFOS	PFBA	PFUnA	PFDoA
Marine (µg/L)	Invertebrates	1.27E+05	7.80E+01	1.04E+01	x	x	5.94E+02	3.30E+01	x	x	x
Marine (µg/L)	Fish	x	x	x	x	x	1.50E+03	1.50E+01	x	x	x
Marine (µg/L)	Other	x	x	x	x	x	1.19E+02	1.10E+00	x	x	x
Marine (µg/L)	**Total protection**	**1.27E+05**	**7.80E+01**	**1.04E+01**	**x**	**x**	**1.19E+02**	**1.10E+00**	**x**	**x**	**x**
Freshwater (µg/L)	Invertebrates	5.02E+05	1.00E+01	8.00E+00	7.24E+05	x	4.91E+01	2.30E+00	8.30E+02	1.00E+01	2.00E+01
Freshwater (µg/L)	Fish	8.88E+05	x	1.00E+01	6.28E+03	x	8.28E+00	5.00E+00	x	x	x
Freshwater (µg/L)	Other	1.08E+06	x	x	5.00E+04	1.00E+01	5.00E+03	1.00E+02	x	x	x
Freshwater (µg/L)	**Total protection**	**5.02E+05**	**1.00E+01**	**8.00E+00**	**6.38E+03**	**1.00E+01**	**8.28E+00**	**2.30E+00**	**8.30E+02**	**1.00E+01**	**2.00E+01**
Uplands (mg/kg)	Plants	x	x	x	x	x	5.00E+01	x	x	x	x
Uplands (mg/kg)	Soil biota	x	x	x	x	x	2.50E+01	1.00E+02	x	x	x
Uplands (mg/kg)	Wildlife	2.02E+01	1.37E-01	2.06E-01	5.92E+01	3.49E-02	4.60E-01	7.84E-02	x	x	1.78E-01
Uplands (mg/kg)	**Total protection**	**2.02E+01**	**1.37E-01**	**2.06E-01**	**5.92E+01**	**3.49E-02**	**4.60E-01**	**7.84E-02**	x	x	**1.78E-01**

Chapter 6: Treatment Technologies

6.0 Overview

This chapter briefly summarizes those technologies that are considered "field demonstrated" for treating or immobilizing various PFAS compounds in water and solid matrices. To be considered field demonstrated, sufficient supporting field data must be available to document that the technology can adequately address the site-specific situation. An in-depth discussion of the various factors that should be considered when selecting an appropriate technology is not included as there are other guidance documents and technical papers that provide this type of information. One of the best documents for a detailed description on all treatment options is available from ITRC at https://pfas-1.itrcweb.org/12-treatment-technologies/.

As part of the evaluation process to select a cleanup remedy, Ecology recommends using our guidance titled Sustainable remediation: Climate change resiliency and green remediation[84] to help improve the resilience of the remedial action. The document's References (Chapter 8) provide additional documents that can help with this effort.

The Department of Defense (DOD) has an environmental technology demonstration and validation program known as Environmental Security Technology Certification Program (ESTCP). This program provides resources for ongoing research work regarding PFAS treatment. A list of the approved projects is available at PFAS Remediation (serdp-estcp.org).[85]

Remedial technologies that are not identified as field demonstrated will typically require additional evaluation and performance monitoring to provide the data necessary to confirm their viability for the site-specific circumstances. Since field-proven technologies will evolve over time, Ecology intends to update this chapter on a periodic basis as other options become available.

The technologies summarized herein represent both in-situ and ex-situ options, but the majority of proven technologies are based on ex-situ implementation. One of the challenges with evaluating performance data is that the number of PFAS compounds that can now be quantified using approved analytical methods has expanded, while the associated detection limits continue to decrease. As a result, earlier studies may not have as robust a data set as those conducted more recently. Even with these limitations, the number of previous studies provide good insights into those technologies that can effectively treat many PFAS compounds. One additional factor that needs to be accounted for is that PFAS compounds can be co-mingled with other contaminants (often petroleum) and previous remedial actions may have affected the concentration and distribution of PFAS present.

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[84] https://apps.ecology.wa.gov/publications/SummaryPages/1709052.html
[85] https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Contaminated-Groundwater-SONs/PFAS-Remediation/(language)/eng-US

Note: Even though these remedial alternatives are considered to be field demonstrated, the selection of the preferred alternative needs to follow the procedures outlined in WAC 173-340-360.[86] This will typically require preparing a disproportionate cost analysis to demonstrate the cleanup action is permanent to the maximum extent practicable.

6.1 Liquid treatment technologies

The treatment options identified in this section have been well demonstrated to remove PFAS compounds from different liquid media, including drinking water, surface water, groundwater, municipal and industrial wastewater, and landfill leachate. However, not all of the identified technologies are appropriate for every situation. Often a site-specific evaluation will be necessary to identify the best alternative for a given media or scenario. In addition, these treatment technologies generate a concentrated matrix requiring management that can result in additional challenges.

A number of factors can influence the performance of liquid treatment options such as the type of PFAS compounds present, the concentrations of the individual compounds, the presence of co-contaminants, natural organic matter, the volume and flow rate of liquid requiring treatment, characteristics and treatment of any residuals produced, and post-treatment remediation goals. For complex waste streams such as wastewater and landfill leachate, pre-treatment to address co-contaminants will often be necessary prior to PFAS removal. Therefore, Ecology recommends completing treatability studies to determine the appropriate design parameters, and to provide the necessary data for establishing a performance monitoring program.

6.1.1. Sorption

Multiple sorption technologies have been used to treat PFAS in liquid media. The focus of this section is on ex-situ options since they are the most common, but a discussion is also included on the in-situ use of colloidal activated carbon (CAC). While there does not appear to be consensus on whether the use of CAC is a field-proven technology, there have been a number of field scale uses throughout the U.S. and abroad, and monitoring data continue to be collected to document performance. Use of the ex-situ technologies will require treating or disposing of the spent media.

6.1.1.1 Granular Activated Carbon (GAC)

Granular activated carbon has been used to remove numerous organic compounds from water for decades. Chapter 12 of the ITRC PFAS guidance provides a number of references to support the effectiveness of GAC in removing longer chain PFAS compounds from water. GAC has also been used to address removal of shorter chain PFAS, although these compounds tend to have faster breakthrough times, which can require more frequent change-out of the carbon.

[86] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-360 (Selection of cleanup actions.)

Note: The distinction between long and short chain PFAS compounds is complicated and varies depending on whether the compound is a perfluororalkyl carboxylic acid (PFCAs) or perfluoroalkane sulfonic acid (PFSAs). Table 2.2 of the ITRC PFAS guidance provides a visual distinction of which PFAS compounds are considered long chain and which are considered short chain.

6.1.1.2 Ion Exchange (IX) Resin

Ion exchange resins have also been used for water treatment for many years and, like GAC, adsorb PFAS (and other compounds) to the treatment media. Anion exchange resins, with their positively charged functional groups can provide improved removal efficiency over other adsorptive media for certain classes of PFAS compounds, by bonding with the negatively charged functional head of the PFAS compound. In addition, the hydrophobic portion of the PFAS molecule can adsorb on the hydrophobic surface of the resin carrier (i.e. the polystyrene beads). As with GAC, the efficiency of the resin is also affected by the factors discussed in Section 6.1 and the type of resin selected will affect the overall performance of the system. Therefore, treatability studies should be conducted to help ensure the selected resin can meet the established treatment goals.

6.1.1.3 Reverse Osmosis (RO)

Reverse osmosis can remove PFAS compounds and many other contaminants by using pressure to move water through a semipermeable membrane while excluding larger molecules including PFAS. One of the most important issues to address when using RO is the reduction in water movement due to clogging from the accumulation of particulates on the membrane surface. In some cases, microbial growth on the membrane surface can occur and this will also reduce the efficiency of contaminant removal due to fouling. This can result in the need for pre-treatment to remove these particulates from the feed water, which is often cheaper than providing for more frequent membrane cleaning or replacement. Other considerations with RO treatment include higher energy requirements and treatment or disposal of reject water, which contains PFAS enriched concentrate.

6.1.1.4 Liquid Colloidal Activated Carbon (CAC)

Liquid colloidal activated carbon contains very small particles of activated carbon, usually 1 to 2 microns in diameter, suspended in an aqueous solution. CAC can be injected into the subsurface either using gravity feed or under low pressure. After injection, the CAC will coat the soil grains below the water table and contaminants moving through the saturated zone are adsorbed to the carbon. The injection of CAC is sometimes referred to as a permeable reactive barrier. CAC was initially used to remove petroleum and chlorinated contamination from groundwater, but more recently has been used to address PFAS contamination.

There have been a number of pilot and full-scale projects that have used CAC to address PFAS impacts. While field scale monitoring data are available for a number of projects, often with impressive results, post-remediation monitoring is typically limited to less than five years.

Modeling studies have predicted positive long-term performance, but sufficient data are not yet available to empirically support this conclusion. While the use of CAC has not been uniformly concluded to be a field-proven technology, Ecology believes this option can provide short-term risk reduction. If this technology is chosen to address PFAS impacts to groundwater, long-term monitoring will be necessary to support the results of the corresponding modeling studies.

6.2 Treatment technologies for solid matrices

The treatment options identified in this section have been field demonstrated to address PFAS contamination in several solid matrices including soil, sediments, and various sludge materials. As with liquid treatment options, these proven technologies have been implemented almost exclusively ex-situ. There are currently two generally accepted field-proven technologies for treating soil contaminated with PFAS: sorption/stabilization and excavation/disposal.

Thermal treatment, which can be used to mobilize or in some cases destroy the compounds of concern, is also included in this section since it has been used for a long time for other contaminants and requires strict permitting criteria so environmental impacts are minimized. Thermal treatment can also provide a finishing step that can be used in conjunction with other technologies.

When soil is highly contaminated, the owner or operator will need to determine whether the soil is a hazardous waste (called “dangerous waste” under Washington state law). Generation, treatment, transportation, and disposal of dangerous wastes are subject to the state’s dangerous waste regulations, Chapter 173-303 WAC. Dangerous wastes can be transported only to specifically permitted facilities for treatment, storage, or disposal. It is possible that PFAS compounds could trigger dangerous waste designation. For additional information on Ecology’s hazardous waste regulations, go to http://www.ecy.wa.gov/programs/hwtr/index.html.

6.2.1 Sorption and stabilization (immobilization)

Immobilization treatment options are intended to minimize the potential for PFAS compounds to leach from solid media. While there are multiple different materials that have been used to bind PFAS compounds, the most common are Portland cement, fly ash, activated carbon, kaolinite clay, and amorphous (non-crystalline) aluminum hydroxide. Given the numerous variables that exist (i.e. PFAS concentrations, soil types, moisture content, treatment goals, etc.) bench scale testing should be completed to document that the preferred mixture can achieve the applicable treatment goals. The primary downside with the use of this technology is that PFAS compounds are not destroyed, but instead only bound in the amendment matrix to reduce leaching. If environmental conditions such as pH, ionic strength, or other variables change, it can result in leaching from the immobilized media. As a result, long-term monitoring will likely be required.

Given the difficulties that can occur with in-situ mixing of stabilization compounds, Ecology does not generally recommend using this approach. If in-situ stabilization will be pursued as the

preferred remedial option, additional performance monitoring will likely be necessary to demonstrate the technology will achieve the desired treatment goals.

6.2.2 Excavation and off-site management

A more permanent option for addressing source area contamination is excavation followed by off-site management at a permitted facility. Off-site management options include: 1) landfilling, 2) treatment with a stabilizing agent prior to disposal to minimize leaching, and 3) thermal treatment. To minimize further leaching of PFAS compounds from source materials, strong consideration should be given to stabilization of the media prior to final management. Since off-site management options may be limited, available alternatives should be evaluated as early as possible in the remedy selection process.

6.2.3 Thermal treatment

This option consists of heating the solids at high temperature to remove or destroy the PFAS compounds. While some field-scale testing has been completed, the performance of these systems is highly site specific and currently there are limited available options. EPA has compiled a database that provides numerous references, including information on incineration and thermal desorption. The document can be found at PFAS Thermal Treatment Database (PFASTT).[87]

To destroy the PFAS compounds that are present, the treatment unit must use extremely high temperatures, potentially upwards of 1,000 degree Celsius for soil, that is delivered uniformly over a sufficient period of time. Significant environmental controls are also necessary to minimize the generation of products of incomplete combustion, the formation of shorter chain PFAS, or other toxic compounds, and to ensure air emissions meet all applicable standards, including greenhouse gases, that are specifically established for the treatment unit. In addition, incineration technology is associated with high energy consumption, which should be considered as part of using sustainable technologies.

6.3 Other treatment technologies

There are a significant number of other technologies being evaluated to treat PFAS contamination. Many of these options are discussed in detail in other guidance documents and research papers. While Ecology does not specify that a proven remedial technology be used to address PFAS contamination, it is very likely that additional testing and documentation will be necessary to select a “non-proven” treatment option.

[87] https://www.epa.gov/chemical-research/pfas-thermal-treatment-database-pfastt#overview

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Glossary

Term	Definition
CLARC	Cleanup Levels and Risk Calculation, Ecology's compendium of technical information related to calculating cleanup levels under Washington's MTCA Cleanup Regulations, Chapter 173-340 WAC @ https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340&full=true
Clean Water Act	33 U.S.C. §1251 et seq. (1972). Federal law that establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters.
community water system	Provides service to 15 or more service connections used by year-round residents for 180 or more days in a calendar year. Examples might be a municipality, subdivision, mobile home park, apartment complex, college with dormitories, nursing home, or prison (WAC 256-290-020 @ https://apps.leg.wa.gov/WAC/default.aspx?cite=246-290&full=true#246-290-010).
contaminated site	Commonly referred to as a cleanup site or a facility where hazardous substances have come to be located (under the MTCA Cleanup Regulations, WAC 173-340-200, https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-200). Contaminated sites can be as small as a gas station spill, or as large and complex as the Tacoma Smelter Plume (CSID 3657) that impacts thousands of acres (https://apps.ecology.wa.gov/cleanupsearch/site/3657).
equipment rinsate blank	The analyte free water collected after it has been poured over or through contaminated field sampling equipment prior to the collection of environmental samples. (iEnvi, 2022 @ https://www.ienvi.com.au/blanks-for-the-field-and-lab-what-are-they/)
field blank	The analyte free water poured into a sampling container in the field and carried with the field samples. This is to assess whether contamination may have occurred in the field during sampling. (iEnvi, 2022 @ https://www.ienvi.com.au/blanks-for-the-field-and-lab-what-are-they/)
formal cleanup	Conducted by a potentially liable person under an order or decree that are supervised by Ecology, or conducted by Ecology through contracted private companies.
Group A public water system	Public water system providing water for human consumption through pipes or other constructed conveyance. Further defined as community and noncommunity water systems (WAC 256-290-020 @ https://apps.leg.wa.gov/WAC/default.aspx?cite=246-290&full=true#246-290-010)
independent cleanup	Conducted by property owners on their own or with technical assistance from Ecology or the Pollution Liability Insurance Agency (PLIA).
Model Toxics Control Act (statute)	Washington's environmental cleanup law, Chapter 70A.305 RCW. https://app.leg.wa.gov/rcw/default.aspx?cite=70A.305.030
Model Toxics Control Act Cleanup Regulations (rule)	Chapter 173-340 WAC, Washington's regulations for cleaning up upland and sediment sites under the Model Toxics Control Act. In 2018, Ecology began updating the rule in stages. http://apps.leg.wa.gov/WAC/default.aspx?cite=173-340 and https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Rulemaking/WAC-173-340

Term	Definition
noncommunity nontransient water system	Provides service opportunity to 25 or more of same nonresidential people for 180 or more days in a calendar year. Examples might be a school, day care center, business, factory, motel, or restaurant with 25 or more employees onsite (WAC 256-290-020 @ https://apps.leg.wa.gov/WAC/default.aspx?cite=246-290&full=true#246-290-010)
noncommunity transient water system	Provides service opportunity to 25 or more different people for 60 or more days in a calendar year, among other distinctions. Examples might be a restaurant, tavern, motel, campground, state or county park, RV park, vacation cottages, highway rest area, or public concert facility (WAC 256-290-020 @ https://apps.leg.wa.gov/WAC/default.aspx?cite=246-290&full=true#246-290-010)
rule, also called regulations	A law adopted by an executive branch agency (such as the Department of Ecology) under the authority of a statute to carry out programs authorized or directed by the statute. Rules specify procedures and set standards and other requirements to implement a statutory program. Rules are developed and enacted through a rulemaking process specified in statute. The public process allows stakeholders to participate in the creation of rules. Agencies can't exceed their statutory authority when adopting rules, and rules can't change statutes. Rules can clarify confusing or unclear statutory directives. Washington's Legislature and voters can change rules by passing new bills or initiatives. The Washington Administrative Code (WAC) codifies rules and arranges them by subject or agency.
Sediment Management Standards (rule)	Chapter 173-204 WAC, Washington's regulations for cleaning up contaminated sediment under the Model Toxics Control Act. Also called the Sediment Rule. http://apps.leg.wa.gov/WAC/default.aspx?cite=173-204
sediment	The settled particulate matter in waterbodies (such as riverbeds, seabeds, lakebeds) where aquatic animals such as crabs and clams live. Sediment can include silt, sand, cobble, and beaches. For the specific legal definition, see the Sediment Management Standards (WAC 173-204-505 (22), https://app.leg.wa.gov/WAC/default.aspx?cite=173-204-505).
Site Register	Ecology's electronic newsletter containing information on cleanups and announcements of public comment opportunities. https://apps.ecology.wa.gov/publications/UIPages/PublicationList.aspx?IndexTypeName=Topic&NameValue=Site+Register&DocumentTypeName=Newsletter
statute	A law passed by the Legislature in a bill or by voters in an initiative. Statutes usually direct or authorize the establishment and implementation of government programs (such as Ecology's Remedial Action Grant Program). Agencies (such as Ecology) are part of the executive branch of state government, and are tasked with carrying out the programs directed or authorized by statute. To carry out these programs, agencies are usually authorized by statute to adopt rules. The Revised Code of Washington (RCW) codifies statutes and arranges them by subject.

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Appendix A: Response to comments on the December 2022 review draft of *Guidance for Investigating and Remediating PFAS Contamination in Washington State* (2022)

A public comment period was held from December 15, 2022, through March 3, 2023, for the review draft of this document. The comments received during that period helped inform modifications made to the final version of the document (published June 2023) and are summarized below. A number of editorial changes were also made to the review draft that are not reflected in this response to comments document.

1. I reside in the Palisades Neighborhood, due north of the Spokane Int'l Airport (SIA) (former Dept of Defense site from 1920s through 1946; site was turned over to Spokane County in 1960, and has been the regional public airport since that time). Airport public records obtained in Dec 2022, from two 2017 sampling events from 3 of 10 SIA monitoring wells, indicate PFAS at levels considerably higher than safety levels issued by WA Dept of Health. Our area is outside (east) of the Fairchild Air Force Base study boundary, which I believe was erroneously drawn, excludes the entire area east of Hayford Road, all the way to the Spokane River breaks in the north and east directions. PFAS levels exist in some of our Palisades domestic wells, the Great Northern School well (very high); the Fire District 10 Station 5 well (very high). Detection of the chemical in the groundwater are hit-and-miss in this area, given the variation in geology, and the prohibitively high cost of sampling and lab analysis. We 'geologically downgradient' property owners and taxpayers are extremely concerned about these chemicals and are working on completion of a TCP grant to study PFAS in this eastern portion of the West Plains outside Spokane. However, there is an obvious need for the state and/or federal authorities to undertake a government-lead (in addition to our volunteer-lead) effort once we accomplish the proposed wellhead groundwater sampling, analysis and fate & transport model intended with the grant. We are working closely with Ecology ERO to secure the grant, but are challenged by the inability of local governments to take on the role of 'Grantee' administration & accounting, as they "have no capacity" with limited or staff not versed in hydrogeology. This is public health fiasco in the making.

Response: Ecology acknowledges that the concerns raised are important and in need of follow-up. However, the purpose of the guidance is to provide general direction on how to investigate and ultimately clean up PFAS-contaminated property. Site-specific issues would need to be addressed individually and outside of the guidance.

2. **Section 1.1.** It is unclear if the purpose of this guidance is to establish promulgated MTCA levels, recommended screening levels, or recommended MTCA levels. If the purpose is to enforce the levels in the 'guidance', then that needs to be clarified. If not, that also should be stated.

Response: Ecology's webpage indicates that guidance "interprets Washington's cleanup law, helps answer frequently asked questions, and offers best practices for successful cleanups." The overall goal of Program guidance is to help people comply with Washington state laws and regulations. Guidance also helps identify and interpret regulatory requirements, but does not create any new legally applicable provisions.

3. **Section 1.2.** In describing PFAA's, perfluoroalkyl means all carbons are fully fluorinated (with the exception of functional groups such as carboxylates); "most" carbons being fluorinated could be used to describe polyfluoroalkyl compounds.

Response: The requested change was made to the guidance.

4. **Section 1.2.** "Because PFAAs are so persistent… they tend to be the focus of environmental investigations" equally important might be mobile, known or suspect toxicity, and bioaccumulative.

Response: The requested change was made to the guidance.

5. **Section 2.0.** It could be useful to include a brief discussion on EPA reference doses (RfDs), since the lack of cancer slope factors is discussed.

Response: The requested change was made to the guidance.

6. **Section 2.1.** "Since the UCMR3 sampling event of 2013–15, several military bases in Washington state have tested drinking water sources in response to a directive from the U.S. Department of Defense (DOD). PFAS were discovered at McChord Airfield and Fort Lewis (located between Olympia and Tacoma), Naval Air Station Whidbey Island (located near Oak Harbor); Naval Base Kitsap- Bangor (located near Poulsbo and Silverdale); Fairchild Air Force Base (located near Airway Heights and Spokane), and the Yakima Training Center (located near Yakima), which is part of JBLM."

   At Whidbey Island, PFAS was only identified in one on base drinking water well at OLF Coupeville in Coupeville, WA. If the 2nd sentence pertains to the Navy's on- and off-base drinking water wells, then that should be clarified.

Response: The 2nd sentence is referring to drinking water sampling that occurred either on or around the referenced military bases. The guidance was revised to clarify this point.

7. **Section 2.1.** "As of May 2022, PFOA and PFOS were identified above the 2016 EPA HAL of 70 ng/L in 6 locations across Washington:…" Same comment as number 6, above.

Response: See response to comment No. 6.

8. **Section 2.2.** Please specify that EPA anticipates to finalize the rule including the release of MCLs by the end of 2023.

Response: Ecology didn't include dates when EPA intends to finalize major PFAS rulemaking actions as their projected timelines often get extended. For example, EPA has acknowledged that completion of MCLs for PFOA and PFOS will not occur until sometime in 2024.

9. **Section 3.1.** This sentence needs a reference "Some PFAS such as PFOA, PFOS, PFHxS and PFNA are readily absorbed into the human body when ingested with food and water, but only slowly eliminated."

   Review document thoroughly for places where facts are stated and no source document is referenced.

Response: A reference has been added to the Guidance.

The Guidance was reviewed, and additional references were added as appropriate.

10. **Section 3.2.** "In the following sections, we discuss how we developed (or will develop) MTCA cleanup levels for PFAS chemicals for each media (groundwater, surface water, soil, and air)."

    What levels are MTCA enforceable numbers? Table 3 includes 'recommended' groundwater cleanup levels. Tables 4 and 5 do not include 'recommended' in the title. Does that mean the soil levels in Table 4 and 5 are enforceable MTCA levels and not just recommended? Please clarify.

Response: Ecology removed the term "recommended" from Table 3. Table 5 was expanded to provide Method B levels protective of groundwater for contaminants in both the vadose and the saturated zone. The Method B and C levels in Chapter 3 are applicable under MTCA.

11. **Section 3.2.1.** "Ecology has consulted with both EPA and DOH on the selection of RfDs identified in this guidance…" Was there a public comment period or formal peer-review prior to issuing these RfD's?

Response: MTCA does not require a public comment period to complete these actions, but the Department of Health accepted comments on their proposed RfDs during the SAL development process.

12. **Section 3.2.2.** ECY ARARs by definition are not the same as federal ARARs in CERCLA. To be a CERCLA ARAR, a state requirement must be promulgated. We are making this distinction in our comments so it is clear to the agency as we start to determine CERCLA ARARs for the Navy projects in NW.

Response: The purpose of this section is to explain how compliance with state ARARS is determined. EPA has specific guidance that provides details on how CERCLA-selected remedial actions must attain ARARs to assure the remedy is protective of human health and the environment. States are responsible for identifying state ARARs and communicating them to EPA.

13. **Section 3.2.5.** **"**MTCA Equation 747-1 does not account for some of the unique transport characteristics of PFAS. Because of their surfactant properties, PFAS tend to sorb preferentially to air-water and NAPL-water interfaces. Studies have shown that air-water interfaces can account for up to 100% of the PFOS and PFOA retained in soil. The Kd parameter in Equation 747-1 accounts for adsorption to organic matter in soil but does not account for interfacial sorption."

    Comment: Since MTCA equation 747-1 doesn't account for interfacial PFAS sorption (up to 100% of PFOS and PFOA in soil), then it is not appropriate to establish soil cleanup levels for migration to groundwater protection. At most a screening level may apply with this important caveat.

    Comment: Further, most labs are not able to detect the values set for saturated zone in Table 5. Thus, these values are impractical.

Response: In Section 3.2.5 of the guidance, Ecology acknowledges that "soil leaching cleanup levels for PFAS are associated with a higher level of uncertainty than for other chemicals. However, soil leaching cleanup levels for PFAS will often be below practical quantitation limits, so an emphasis on attaining low quantitation limits will be more important that the accuracy of the leaching cleanup levels." The guidance also indicates that "another option for evaluating the leaching pathway would be to sample groundwater, then if appropriate, use an empirical demonstration in accordance with WAC 173-340-747(9)." Using an empirical demonstration to establish soil cleanup levels can account for situations where PFAS are preferentially retained in the unsaturated zone. Implementation Memo No. 15 provides additional information on completing an empirical demonstration. The memo is available at: https://apps.ecology.wa.gov/publications/SummaryPages/1609047.html

14. **Section 3.3.2.** Remove the word 'All' from this sentence and replace the words 'and only' with the word 'except' so as not to be misleading. "All PFAS compounds listed in EPA's RSL table have SLs based on noncancer effects, and only PFOA has an SL based on cancer risk.)

Response: Ecology modified this sentence to more clearly explain the intent.

15. **Section 3.4.** Consider removing section 3.4 or move to an appendix. These levels are no longer in use and therefore not important to the meat of the document. Having them here can be confusing to the reader.

Response: Ecology removed Table 6 from the guidance.

16. **Sections 4.1.1, 4.1.2, and 4.1.3.** The screening levels are not considered clean up levels so delete the term "cleanup levels" in these sections. Using the term clean up levels assumes that can be used as replacement for MCLs and this is not the case. There are used for screening sites.

Response: The sections referenced above purposely use both screening levels and cleanup levels. Section 3.2.1 summarizes the three databases that MTCA specifically allows when evaluating potential noncancer health effects. This Section also provides a discussion indicating that "Ecology may determine that development of an alternative RfD is needed." Since the Method B and C levels provided in Tables 3, 4, and 5 were calculated using the criteria set forth in MTCA, they represent cleanup levels for the particular compounds listed. Therefore, unless these levels are superseded by a site-specific ARAR determination, as discussed in Section 3.2.2, they represent MTCA cleanup levels.

17. **Section 4.2.** Too much time is spent discussing EPA Method 537, which is now an outdated method. Space is better-spent discussion Method 537.1.

Response: The limited discussion on Method 537 was included to provide background on when sampling data were generated using this method.

18. **Section 4.3.1.** Remove mention of method 537.

Response: See response to comment No. 17.

19. **Section 4.3.1.** This section does not mention EPA Draft Method 1633. It is presented in section 4.3.3 – Future Analytical Options. We recommend that it is moved up to this section because ECY currently has three labs accredited to this method. There are also ~18 lab across the country accredited for this method by compliant with DoD/DOE Quality Systems Manual (QSM) Table B-24.

Response: Since EPA issued a memo in December 2022 encouraging the use of Method 1633, prior to finalization, Ecology has moved the discussion on Method 1633 to Section 4.3.1.

20. **Section 4.3.2.** This section should mention total organo fluorine or adsorbable organo fluorine. The EPA has a draft method 1621 that has undergone single lab validation and will undergo multilab validation for this method. CWA Analytical Methods for Per- and Polyfluorinated Alkyl Substances (PFAS): CWA Analytical Methods for Per- and Polyfluorinated Alkyl Substances (PFAS) | US EPA.[88]

Response: See response to comment No. 229.

21. **Section 4.3.3.** Draft EPA Method 1633 is listed as a "Future analytical option". We recommend moving it up to Section 4.3.1.

    In addition, this section states that it Draft EPA Method 1633 is compliant with Table B-15. For Draft EPA Method 1633 the QA/QC procedures are in Table B-24. Please revise.

[88] https://www.epa.gov/cwa-methods/cwa-analytical-methods-and-polyfluorinated-alkyl-substances-pfas#AOF

Response: See response to comment No. 19. The reference to Table B-15 was replaced with Table B-24.

22. **Section 4.4.** Denly et al (2019) and Rodowa et al (2020) is not listed in the list of references.

Response: The requested change was made to the guidance**.**

23. **Section 4.4.3.** Trip blanks are most valuable when shipping samples with volatile compounds.

Response: Ecology agrees with this statement and believes that trip blanks should be used as some PFAS compounds would be considered volatile. This may become a more common situation as additional shorter chain PFAS compounds are used.

24. **Section 6.1.1.2.** "These resins can provide improved removal efficiency over other adsorptive media for certain classes of PFAS compounds if they have positively charged functional groups, by bonding with the negatively charged functional head of the PFAS compound." Somewhat confusing since it implies the PFAS have positively charged functional groups. Suggest: Anion exchange resins, with their positively charged functional groups…

Response: The requested change was made to the guidance.

25. **Section 6.1.1.2.** "In addition, the hydrophobic portion of the PFAS molecule can adsorb on the hydrophobic surface of the resin." Suggest: …of the resin carrier (e.g. the polystyrene beads).

Response: The recommended change was made to the guidance.

26. **Section 6.1.1.3.** "…to move water through a semipermeable membrane." Suggest adding to the end of the sentence "while excluding larger molecules including PFAS" Also suggest adding "clogging" to the second sentence, and "fouling" to the third.

Response: The recommended change was made to the guidance.

27. **Section 6.1.1.4.** "CAC was initially used to remove petroleum and chlorinated contamination…" Technically, it didn't remove the contamination, only immobilized it (which could eventually lead to removal through biodegradation).

Response: Ecology clarified that the contamination was removed from groundwater.

28. If PFAS are only removed (transferred) from the soil and captured, this will result in creation of a waste stream containing PFAS that must be disposed of or further treated. The advantage here is that a large volume of soil can be reduced to a much smaller volume of concentrated PFAS waste. Concentration of PFAS from large volumes of impacted water or soil should be mentioned in the treatment chapter as a worthwhile treatment approach.

Response: Section 6.2.4 acknowledges that removal of PFAS from soil can reduce the volume of contaminated material that needs to be treated further or disposed.

29. The Manual incorporates recently established Washington Department of Health State Action Levels (SAL's) imposed upon Group A Public Water Systems as investigatory and cleanup levels for potable groundwater cleanup under MTCA, creating the nexus to DOH WAC 246-290. In essence, this results in applying the DOH SAL's as de facto potable groundwater cleanup levels. The Manual should consider the context of the WAC 246-290 rules related to all other DOH 23-01-59 requirements imposed on Group A Public Water Systems, such as ongoing sampling periods, and public notifications based upon any PFAS investigatory results under MTCA in relation to the levels contained in WAC 246-290. Ongoing sampling/monitoring requirements should not be less stringent than those imposed upon Group A Public Water Systems under WAC 246-290, noting that PFAS monitoring results may vary seasonally or over extended time periods as PFAS migrates through soils and aquifers.

Response: SALs only apply to those MTCA sites where they are determined to be "relevant and appropriate requirements." The monitoring requirements of WAC 246-290 apply to finished drinking water, while the monitoring requirements at MTCA sites apply to groundwater, which may or may not be used drinking water. Sampling of finished drinking water to determine SAL compliance should follow the provisions specified by DOH. Sampling groundwater as part of an investigation of a contaminated site should follow the PFAS guidance.

30. It's unclear how DOE will impose MTCA remediation requirements if monitoring results for PFAS in potable groundwater are at levels below the SAL's. Feedback the District receives from our customers is a preference that the water we provide be completely free of PFAS. A DOE acceptance/tolerance to allow PFAS levels in any concentration in potable groundwater contradicts general customer opinions. This will create significant customer relations challenges for water systems impacted by PFAS contamination.

Response: As discussed in Section 3.2.2 of the guidance, SALs would only apply if Ecology determines they are relevant and appropriate requirements for a particular site. If a SAL is determined appropriate for a site, or if an MCL is subsequently developed, that level would generally become the applicable cleanup level. PLPs may choose to clean up groundwater to concentrations below the cleanup levels required by MTCA. Drinking water purveyors may choose to treat drinking water to concentrations below the applicable levels (i.e. SALs or MCLs). However, Ecology will enforce cleanup to the levels that are determined in accordance with MTCA.

31. DOE has elected to propose the DOH SAL's as the basis for establishing MTCA cleanup levels for potable groundwater during a period when the United States Environmental Protection Agency ("USEPA") is working to establish PFAS Maximum Contaminant Levels ("MCL") for drinking water which may supplant the current USEPA Health Advisory Limit ("HAL"). The DOH SAL's may default to the EPA MCL if more stringent. The Manual also notes USEPA is currently developing ambient water quality criteria which may be applied as ARAR's under MTCA. Given the anticipated release of the USEPA MCL and ambient water quality criteria, consideration should be given to delaying the approval and release of the Manual until the USEPA finalizes its work to ensure regulatory consistency and certainty.

Response: Waiting for EPA to promulgate standards is problematic for at least two reasons. First, the timeframe for issuing final MCLs has already been extended beyond the projected date. Second, EPA is only planning to promulgate MCLs for a limited number of PFAS compounds. Given the number of sites impacted by PFAS contamination, Ecology intends to finalize the guidance as soon as possible.

32. The Sammamish Plateau Water and Sewer District has been directly impacted by the PFAS contamination of potable groundwater in the Lower Issaquah Valley. Raw water from the District's Well 7 and 8 exceed the DOH SAL for PFOS. Since 2017, DOE has been a party to investigatory actions being conducted by East Side Fire and Rescue. Ongoing activities have lacked public process which would include the District, an impacted water system, as a stakeholder, including transparent information sharing. The District has had to file public records requests to get access to investigatory documents, and received no notification of pilot treatment activities using Liquid Colloidal Activated Carbon ("CAC") which the Manual/DOE recognizes "has not (been) uniformly concluded to be a fieldproven technology". Any MTCA investigatory and remediation activities for impacted or potentially impacted potable groundwater where there are known or potential impacts to a water system should include public process and stakeholder engagement of the water system, since the water system is the party responsible for compliance with WAC 246-290 SAL's. In these instances the process should be directly overseen by DOE as a formal cleanup.

Response: As Ecology explained to Sammamish Plateau Water and Sewer District in an email dated September 16, 2022, Ecology has been working with the City of Issaquah and Eastside Fire and Rescue in a cooperative fashion to complete a comprehensive remedial investigation and a Feasibility Study prior to selecting a final cleanup action. Ecology also intends to pursue an agreed order for the site, although the timing has not yet been determined.

Ecology also stated in the September 16th email that the pilot study using colloidal activated carbon was implemented to generate data that will be helpful when evaluating potential remedial actions. While the pilot test was exempt from the public review and comment process, any proposed remedy for the site will follow all applicable public participation requirements.

33. A number of treatment technologies for potable groundwater are unproven, particularly CAC. Since water systems will never be the source of PFAS contamination, but water systems may be impacted by PFAS investigation and remediation actions of others, water systems should be directly engaged in the MTCA investigatory and cleanup scoping process. Our aquifers, groundwater, and water rights should not become laboratories for pilot testing of unproven remediation methods without awareness and input by the water systems.

Response: The use of colloidal activated carbon has been studied and utilized on a field scale for a number of years. The following link provides data for 17 sites using this technology: Longevity of colloidal activated carbon for in situ PFAS remediation at AFFF-contaminated airport sites - Carey - 2022 - Remediation Journal - Wiley Online Library.[89] When contamination remains in-place following remedy implementation, an environmental covenant along with long-term monitoring is necessary.

34. The Manual should include special emphasis and guidance for investigating and remediating known or potential contamination in wellhead protection areas, including groundwater modeling and time of travel analysis where contaminant plumes may potentially impact potable groundwater over extended time periods.

Response: These situations need to be evaluated on a site-specific basis. Attempting to provide this level of information is beyond the scope of this guidance.

[89] https://onlinelibrary.wiley.com/doi/full/10.1002/rem.21741

35. **Section 3.2.2, Page 16 of 64**, states: "However, Ecology can review each cleanup site to determine if there are relevant and appropriate requirements that, while not legally required, should be applied based on circumstances at the site." This statement is unclear and should not allow for cleanup levels above the SAL. Additionally, the "relevant and appropriate requirements" should consider direct impacts to wellhead protection areas and potable groundwater produced by a water system.

Response: As discussed in the response to Comment 30, SALs only apply to sites where Ecology has determined they are relevant and appropriate requirements for a particular site. However, as specified in rules promulgated by the Department of Health, water systems are required to comply with the SALs.

36. **Section 3.2.3, Page 17 of 64,** should be revised to require that any cleanup of groundwater reliant on SALs as the ARAR must include extended/long-term monitoring to ensure future PFAS contaminants do not increase and that detections remain below the SALs. If monitoring results indicate levels are increasing above the SALs/ARAR, further cleanup should be required.

Response: Ecology typically requires long-term monitoring to ensure compliance with the established cleanup levels and periodic reviews are used to assess on-going compliance. However, this is a site-specific determination and therefore "requiring" long-term monitoring is not appropriate to include in this guidance.

37. **Section 3.2.3, Page 18 of 64,** states: "For all contaminated sites, Ecology recommends using a laboratory that can achieve practical quantitation limits (PQLs) at or below the SALs listed in Table 3." DOE's water lab testing requirements should align with the DOH's laboratory requirements imposed on water systems.

Response: This Section provides a discussion on groundwater cleanup levels. Different analytical methods are used for groundwater than for finished drinking water. Information on Ecology's lab accreditation process is available at https://doh.wa.gov/community-and-environment/drinking-water/laboratory-resources

38. Soil cleanup levels under Section 3.2.5, Page 19 of 64, should be required to be protective of groundwater, and soils cleanup should include a process of involving any impacted water system, and include remediation which requires clean up to result in groundwater produced by water systems to achieving PFAS non-detection levels.

Response: Ecology establishes and enforces soil cleanup levels in accordance with the provisions in MTCA. This may not result in achieving non-detectable levels of PFAS in water systems.

39. The cleanup levels in Section 3.2.5, Table 5 Page 21 of 64 for vadose and saturated zones should recognize that PFAS is an inorganic compound which bioaccumilates and is not removed through natural attenuation.

Response: PFAS are organic compounds, many of which can bioaccumulate, and the reference doses used to calculate the SALs and the MTCA groundwater equation reflect the fact that PFAS bioaccumulate in the body. The toxicity data used to develop cleanup levels for ecological receptors reflect any bioaccumulation that occurred in the ecological receptors studied. The levels in Table 5 were calculated using equations in Section 747 of MTCA and

assume attenuation won't occur. Therefore, these levels provide a conservative estimate of soil concentrations protective of groundwater.

40. Section 3.2.5, Page 21 of 64, states: "Another option for evaluating the leaching pathway would be to sample groundwater, then if appropriate, use an empirical demonstration in accordance with WAC 173-340-747(9)." Any evaluation of leaching pathways using groundwater sampling should include long-term monitoring of impacts to aquifers and potable groundwater of a water system.

Response: If an empirical demonstration is being considered, WAC 173-340-747(9) requires a demonstration be made that "the measured soil concentration will not cause an exceedance of the applicable cleanup level at any time in the future." This would typically require long-term groundwater monitoring.

41. One of the treatment technologies proposed is ex-situ "Soil Washing". Soil Washing should be cautiously approached and include engagement of the operators of wastewater treatment facilities since the PFAS by-products attributable to soil washing will remain in the wastewater treatment process. This includes effluent, reclaimed water, and bio-solids. Treatment technologies, such as Soil Washing, should remove PFAS from the environment, rather than perpetuate its transport.

Response: See response to comment 191.

42. The Document, by force of Title, is trying to be something it is not, that is a Guidance Document. The bulk of the document section text and appendices are supporting information that detail how the State has derived the MTCA cleanup levels. This is not guidance, as it is doubtful the audience/user of this document will be allowed to modify these MTCA cleanup levels employing the same risk-based calculations as described in the document. The sections that pertain to some form of guidance (Section 4.0 for example) merely refer to other guidance documents and procedures outlined in Washington State's Administrative Code. Numerous references to other guidance for example, ITRC PFAS Guidance and WAC 173-340-820 are essentially the extent of entire Chapters, sections, and sub-sections (see Chapter 4.0). True guidance documents outline procedures, steps, and best practices for the audience/user of this report to follow. Guidance documents are completed with less technically complex lingo and provides clearer direction what should be performed. The State should recognize that this document is more about the supporting science of risk assessment that supports the development of the MTCA cleanup levels and not portray the document as a "guidance" document. A suggested revised title would be "DRAFT Application and Derivation of Washington State MTCA Cleanup Levels for PFAS".

Response: See the response to comment No. 1 for an explanation of how Ecology's guidance documents are structured. Many of Ecology's guidance documents are technically focused and Section 1.1 explains the purpose of the document is to provide direction for addressing state-specific PFAS related issues. Since the guidance contains more information than just cleanup levels, we are retaining the existing title.

43. Section 2.1. The brief explanation for the work being performed for PFAS in the Lower Iss. Valley does not capture the extent of work being performed at this location and what Ecology has indicated in an October 2, 2022 email to SPWSD, a local water purveyor impacted by this PFAS contamination. Ecology has stated: "It is Ecology's plan to transition the management of the LIVA investigation to the formal process under an agreed order to

ensure adequate oversight and community engagement for a complex site with much public interest. The timing of this transition depends on the availability of Ecology staff to manage both the technical and the outreach components of the project." It is recommended that the overview statement of the PFAS work include Ecology's plan to transition the PFAS work being performed in the Lower Iss. Valley to a formal process under an agreed order.

Response: The intent of Section 2.1 was to provide a brief summary of sites with PFAS impacts, not to describe potential future actions.

44. Section 2.2. This section should include an expanded description, or flow chart identifying what and how regulatory decisions and updated criteria (Federal and/or State) will impact the decision criteria (e.g., MTCA Cleanup Levels) and information presented in this interim guidance. To clarify, the science of and information on PFAS is evolving and there are many statements made to emphasize this point in the Draft document. For example, the end of Section 3.0 states "As new toxicological information emerges, the regulatory levels discussed in this chapter may change and regulatory levels for other PFAS compounds may become available." As such, a document like this, if it is truly to be a "Guidance" document, should include more explanatory text and outline clearly, through flow charts or other visual aids, what primary elements of this Draft guidance are subject to change (e.g., MTCA Cleanup Levels) and how the State and a user of this document addresses these ongoing developments.

Response: Attempting to specifically define what elements of the guidance are subject to change is beyond the scope of the document. In general, Ecology intends to either update the guidance directly to account for major changes, or to issue Implementation Memos or Focus Sheets that explain what in the guidance is being modified until the guidance can be formally updated. We anticipate that multiple changes to the guidance will be necessary over the next several years as new information becomes available.

45. Chapter 2. There were little to no mentions of other key matrices including landfill leachate and sediment. How is Washington State going to address these important media?

Response: Ecology intends to supplement the guidance with information on how to address PFAS impacted sediments at a later date. Questions regarding landfill leachate should be directed to Ecology's Solid Waste Management Program.

46. Chapter 2. Many states have included Gen-X in the list of PFAS under regulatory consideration. Curious why this compound is not being considered by Washington State?

Response: The PFAS compounds listed in Chapter 2 are those that were sampled for during the implementation of EPAs Unregulated Contaminant Monitoring Rule (UCMR3). Chapter 3 of the guidance provides cleanup levels for eight compounds including HFPO-DA (GenX).

47. Chapter 2. How is Washington State going to address the transition from fluorine-containing to fluorine-free foam in fire suppression systems that previously used AFFFs? How it the State going to regulate rinsate generated during cleanout of these systems?

Response: Questions regarding the use of AFFF and transitioning to fluorine-free foam should be directed to Ecology's Hazardous Waste and Toxics Reduction Program

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48. Section 3.1.1. The water ingestion rate from the 2011 edition of the exposure factors handbook (EFH, EPA 2011) was adopted in the derivation of the SALs for PFBS. However, Chapter 3 of the EFH was updated in 2019. As such, the adopted intake rate of 174 mL/kg-day is higher than would be adopted per the 2019 update of 137 mL/kg-day. The PFBS SAL would be equal to 438 ng/L on the basis of this revision.

Response: This comment should be directed to the Washington State Department of Health.

49. Section 3.1.1. Error in footnote 15. The RSC is indicated as being 50%, however the actual SAL derivation uses 20% for PFBS.

Response: The requested change was made to the guidance.

50. Section 3.1.1. The updated MRL for PFNA on the basis of a shorter half-life needs additional discussion. A shorter half-life would be expected to result in a higher (i.e., less conservative), rather than lower, RfD.

Response: Ecology used an RfD of 2.56E-6 mg/kg-day which was developed by DOH. This RfD is similar to the one developed by EPA (3E-6 mg/kg-day). The question about the shorter half-life for PFNA should be directed to DOH.

51. Section 3.1.1. It is unclear what assumptions changed from the 2020 derivation of the SALs for PFHxS, however, the SAL is slightly lower (65 ng/L) than previously derived (70 ng/L).

Response: This question should be directed to the Washington State Department of Health.

52. Section 3.1.2. Should add (where bold) into the first sentence for clarification, “Under the DOH rulemaking, monitoring for PFAS **at detection levels below SALs** will be required by community and nontransient noncommunity Group A water systems (DOH, 2021c).”

Response: The purpose of Section 3.1.2 was to provide general information on the need for certain public water systems to be sampled for PFAS. Water systems should work directly with the Department of Health to ensure the appropriate detection levels are used.

53. Section 3.1.2. Second sentence should explain how "suspected PFAS contamination" is determined.

Response: The potential for suspected PFAS contamination will be evaluated on a case-by-case basis using all available and applicable information. The approach will be similar to the way Ecology handles other cases of suspected contamination.

54. Section 3.1.2. First paragraph at the top of page 13 should clarify what information/lines of evidence the Washington State Department of Health reviews for this waiver determination.

Response: The intent of the guidance is to provide general awareness of the potential for obtaining a waiver for on-going sampling when PFAS are detected. The Department of Health should be contacted to discuss the appropriateness of obtaining a waiver.

55. Section 3.1.2. Last paragraph, first sentence, should clarify the level above detection will require continued monitoring on a more frequent schedule.

Response: The requested change was made to the guidance.

56. Section 3.1.2. Last paragraph, last sentence should be expanded and separated into a separate subsection that explains what information the State will provide Water Systems to help explain in clear laymen terms, than this Draft document currently provides, that PFAS concentrations above detection, but below SALs are deemed acceptable for public consumption. This is imperative for proper consumer notification communication and would be helpful for guidance

Response: Water Systems will need to work with the Department of Health to ensure the required public notice meets their requirements. Including a discussion on this issue is beyond the scope of the guidance document.

57. Section 3.4 should be removed from the main body of text and provided in an appendix, or attachment to avoid confusion with the actual State requirements. As stated in the section intro, there is no substantive purpose to this information for the application and derivation of the State's MTCA Cleanup Levels for PFAS other than being informational. The only relevant information to pull from this section are federal regulatory assessments, such as IRIS assessments (Section 3.3.2) to add to a flow chart, or visual on how federal regulatory changes impact the information in this document, as suggested in the comment on Section 2.2.

Response: Table 6 in Section 3.4 was removed from the document. Ecology added language to Section 3.2.1 to identify how the issuance of new or updated toxicity information to a database identified in MTCA would be used to determine applicable cleanup levels. Section 3.2.2 was also expanded to explain how promulgation of a federal MCL would be used. See response to comment 44 regarding providing an explanation of what portions of the guidance are subject to revision based on federal changes.

58. Section 4.1. per Field et al. 2020 (https://pubs.acs.org/doi/full/10.1021/acs.estlett.0c00036), field sampling equipment represents a very unlikely source of PFAS contamination. The PFAS sampling guidance should be updated appropriately.

Response: While field sampling equipment may represent an unlikely source of PFAS contamination, it is certainly possible that if the device is not adequately cleaned between samples, cross-contamination could result.

59. Section 4.1. EPA method 1621 for ToF should also be considered during PFAS RI work.

Response: Section 4.1 was intended to provide a general overview of sampling options, but doesn't provide specific recommendations for the Methods to use. Section 4.3.2 was expanded to provide additional information on a number of non-specific methods that could be utilized depending on site conditions, and Section 4.3.3 includes a reference to Method 1621. See the response to comment No. 229 for additional information.

60. Section 4.1. No mention of the potential for PFAS sorption onto colloids for water sampling. Filtered vs. non-filtered samples. Should be discussed.

Response: Ecology added Section 4.1.6 to provide recommendations on sample filtration, which is consistent with the provisions in WAC 173-340-720(9)(b).

61. Section 4.1. No real mention of porewater sampling. This is the PRIMARY driver for groundwater contamination at AFFF source areas and should be carefully evaluated during PFAS RI/FS.

Response: In most cases when soil impacts are discovered, the next step is sampling of groundwater. However, WAC 173-340-747(8) does allow for the use of alternative fate and transport models to help establish soil concentrations protective of groundwater. This could include the use of pore water sampling. Since this approach is not used often, Ecology recommends using other guidance documents to help determine if this option is appropriate for the site under evaluation.

62. Section 5. Protective concentrations were derived for more than the five PFAS with SALs (including PFDA, PFHxA, PFBA, PFUnA and PFDoA). Are these values for the additional PFAS to be used in screening purposes?

Response: Yes, all PFAS compounds are hazardous substances under MTCA and those with levels provided should be used for screening purposes. See response to comment No. 81 for additional information.

63. Section 5/Appendix B. Selected endpoints used in the derivation of the ecological protective concentrations should be elaborated upon. It appears that single studies were selected (as opposed to use of a species sensitivity distribution [SSD] or similar process).

Response: Ecology acknowledges that there are multiple valid ways to establish a toxicity benchmark value to be used in deriving a protective concentration, including SSDs for compounds with a sufficient number of toxicity studies. For the purposes of the generally applicable values provided in this chapter, Ecology did select endpoints from single studies, as these meet the MTCA requirements for selection of values (no adverse effects concentration for surface water, and lowest relevant LOAEL for uplands).

64. Table 7. Typo in final row for upland soil (total protecttion).

Response: The suggested change was made to the guidance.

65. Section 6.0. This overview section needs to clarify that "field demonstrated" must include peer reviewed technical evaluation documents. Many pilot tests can have significant pressure towards their success, and they should be vetted by an independent, qualified technical peer review that is not conflicted with regard to its outcome.

Response: Establishing consensus criteria for defining “independent, qualified technical peer review” would be difficult given the potential for varying individual opinions. In addition, since any preferred remedy would need to meet the requirements in WAC 173-340-360, Ecology does not believe this is a necessary component of the guidance.

66. Section 6.1. Several novel sorbents (including Fluoro-Sorb) have shown to be more effective than GACs and IX resins and should be discussed herein.

Response: Ecology is not aware of any field demonstrated studies for this particular remedial action. However, these can be considered as part of the remedy evaluation and selection process.

67. Section 6.1. Need to expand on the discussion of GACs versus IX resins regarding factors that would negatively impact their performance (elevated TOC, co-contaminants, treatment residuals such as residual chlorine, polyphosphates, etc..), design (empty bed contact time, vessel size, pretreatment requirements, etc..), and capital and O&M costs (CAPEX & OPEX).

Response: The intent of this Chapter is to provide a general discussion of those remedies that are considered "field demonstrated." The first paragraph of Section 6.0–Overview indicates that "an in-depth discussion of the various factors that should be considered when selecting an appropriate technology is not included as there are other documents and technical papers that provide this type of information."

68. Section 6.1. No mention of foam fractionation which has been successfully demonstrated at the pilot- and full-scale settings for removal and concentration of PFAS from impacted aqueous waste streams.

Response: See response to comment No. 66.

69. Section 6.1. Need to highlight that all technologies listed for treatment of impacted waste streams are merely designed for PFAS removal or concentration. None of these technologies can readily destroyed PFAS. Need to include a section discussing potentially applicable PFAS destructive technologies.

Response: Section 6.2.3 provides a brief discussion on the use of thermal treatment to remove or destroy PFAS compounds.

70. Section 6.1. Need to include nanofiltration as a potential treatment technology.

Response: See response to Comment No. 66.

71. Section 6.1. There is very little to no long-term performance data associated with CAC. In fact, bench- and pilot-scale testing of CAC is being conducted by DoD-funded research programs including SERDP and ESTCP. This technology should not and cannot be discussed in the same manner as what are considered proven and mature technologies such as GAC and IX resins.

Response: See response to comment No. 33.

72. Section 6.2.1 While this section touches on the issues of long-term effectiveness of Sorption and Stabilization (immobilization) technology, an expanded explanation of the limitations and risks of employing this technology in the subsurface should be included and a more direct discouragement, if not outright ban, on the injection of these immobilization/sorption media into the subsurface at depths where removal/replacement is infeasible and/or cost prohibitive should be stated with this technology. The current

statement in the section that more monitoring will be necessary is not adequate guidance for this technology application.

Response: See response to comment No. 67.

73. Section 6.2. Because a soil cleanup level protective of underlying groundwater has not been established, understanding of how porewater emanating from impacted vadose soils impact potential groundwater contamination is VERY important. This is something that needs to be carefully evaluated via lysimetry or batch desorption studies prior to selection and implementation of ANY remedial action.

Response: Soil leaching cleanup levels protective of groundwater are provided in Table 5. Alternative fate and transport modeling is allowed under WAC 173-340-747(8).

74. Section 6.2. Thermal treatment: DoD is mandating a moratorium on PFAS incineration because of poor understanding of PFAS mass balance during thermal treatment and potential risk of PFAS air emission. This is an area of active research and **MUST** be highlighted!

Response: While the Department of Defense may be mandating a moratorium on PFAS incineration, it does not preclude evaluating this technology. The provisions in WAC 173-340-360 still need to be complied with, as for any potential remedy.

75. Section 6.2. Soil washing: several DoD-funded studies have clearly showed that while soil washing may be effective in removing PFAS from low-TOC, coarse-grained materials, it is very ineffective against TOC-rich fines. Given the high liquid:solid ratio required for effective soil washing and the volume of wash water generated, the economics of soil washing needs to be further studied.

Response: See response to comment 191. Ecology agrees that the economics associated with potential treatment technologies need to be evaluated. The information box at the end of Section 6.0 indicates that a disproportionate cost analysis will typically be required which would include a detailed discussion of costs.

76. How will Ecology respond to unknown sources of PFAS or third-party impacts to a property owner (fire response is dictated by the responder), including use of AFFF outside of intended purpose on a property?

Response: Section 173-340-300 requires releases of hazardous substances to be reported to Ecology if the release poses a threat to human health or the environment. These releases would then be assessed to determine next steps. For situations where an unknown source is impacting a property, Ecology would typically enter information into our online database and ultimately work to identify the source of the impacts.

77. **Section 2.0.** Consider rewording: To date, the potential human health effects of PFOS and PFOA have been the most intensively studied of the PFAS chemicals, but there is also considerable toxicological information on PFNA, PFHxS, PFBS, and hexafluoropropylene oxide dimer acid (HFPO-DA), also known as GenX.

Response: The requested change was made to the guidance.

78. **Chapter 3.0.** How will Ecology address background levels of PFAS, which have been shown in numerous studies to be ubiquitous?

Response: Addressing background is a challenge for other compounds as well, including carcinogenic PAHs. In general, if a natural background concentration is established in accordance with WAC 173-340-709, a cleanup level will not be below that concentration. Ecology considers it premature to develop natural or area background concentrations for PFAS because the occurrence, fate and transport of these chemicals is continuing to evolve. A site-specific study to determine area background cannot be used to develop a cleanup level, but could be considered for remediation levels in accordance with WAC 173-340-355.

79. **Chapter 4.0.** There is no discussion in this section regarding the use of data validation to evaluate laboratory performance. As new methods are approved/used, evaluating laboratory performance will be a critical step to identify laboratory conformance issues and also to assess cross- contamination or sample logging errors from the laboratory.

Response: Data validation is required for RI/FS studies, through implementation of a site-specific quality assurance project plan, approved by Ecology. This is especially important for high resolution analytical work, which would include PFAS. Lab performance is also evaluated through the accreditation process which Ecology is doing for PFAS methods, and TCP requires the use of accredited labs. Additional information is provided at Ecology's webpage on lab accreditation which is available at https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation.

80. **Chapter 4.0.** The draft document contains active links to ITRC or other state-developed guidance. Will Ecology update this guidance when the referenced documents are updated? Maintaining active links and recognizing changes to key referenced documents will ensure that this is a working guidance document and not a one-time issuance.

Response: Ecology intends to update the guidance on an as-needed basis to ensure it remains accurate.

81. **Section 4.1.1.** Ecology recommends analyzing for a comprehensive set of PFAS so that future assessment of the site can be completed once screening/cleanup levels are established. Will this result in a reopener of cases that have closed? Will Ecology reject data from sites that report only the currently regulated compounds (or those regulated at the time of the investigation)? How will this be addressed throughout the course of the project?

    In addition, not all PFAS have screening/cleanup levels. If the full list of PFAS compounds is reported, there is a risk that the public will be confused about how the compounds lacking screening/cleanup levels will be used or evaluated. We recommend that Ecology clearly state what the intent is with respect to non-regulated compounds.

Response: All PFAS compounds are considered hazardous substances (i.e. regulated compounds), and therefore the data for all analytes included in the specific method should be submitted to Ecology. Updated toxicity data will allow for the establishment of cleanup levels for additional PFAS compounds which may be applicable to the site if the criteria in WAC 173-340-702 are met. In addition, using all of the available data can help with the source identification process.

82. **Section 4.1.2.** This section summarizes the currently available analytical methods. It is expected that EPA will issue updated methods for PFAS in solid/chemical materials and non-potable water this year (Method 1633). We recommend that a statement along the following lines be added to this section: "If a laboratory method is accredited at the time of use and is later superseded, additional sampling to confirm non-detect results and/or establish the boundaries of exceedances above the screening/cleanup levels is not required, unless a new release has been identified."

Response: When new analytical methods become available, Ecology will make a site-specific decision on whether to require additional sampling using the new method.

83. **Section 4.2.** This statement conflicts with Section 4.5.2 where Ecology recommends both Method 533 and 537.1 be used. Further, the use of both methods is unnecessary and expensive. It is recommended that the statement in Section 4.5.2 be revised to recommend analysis of drinking water using Method 533 only.

Response: Ecology doesn't believe the referenced sections contain conflicting statements. Section 4.2 generally describes the different drinking water methods available, while Section 4.5.2 indicates that for drinking water samples, if the source of PFAS contamination is unknown or could include short and long chain PFAS compounds, Ecology recommends using both Method 533 and 537.1 to provide a comprehensive assessment of the potential for PFAS impacts. Drinking water sampling during a site investigation would generally be limited to private wells.

84. **Section 4.4.4**. It is recommended that this section regarding Method 1633 move to the top of the list given that many laboratories have already moved to certify for this method.

Response: The discussion on the use of Method 1633 was moved to Section 4.2.

85. **Section 4.4.3**. The recommended field quality control is excessive. We recommend that a field duplicate, field equipment blank, and field (ambient) blank be required, and that all other field quality assurance sampling be optional. We further recommend that field quality assurance sampling can be modified (20 percent vs. 10 percent) as sampling events progress and field procedures are documented to demonstrate that decontamination of field equipment and cross-contamination in the field has been eliminated or is not an issue.

Response: Section 4.4.3 of the guidance recommends duplicate samples be collected for 10% of the samples. It may be possible to reduce the number of field quality control samples needed based on site-specific conditions. With respect to trip blanks, see the response to comment No. 23.

86. Section 4.5.2. We suggest that the statement in Section 4.5.2 be revised to recommend analysis of drinking water using Method 533.

Response: Since Method 537.1 includes several PFAS compounds not covered by Method 533, Ecology believes that consideration should be given to using both Methods when the source in unknown or when both short and long chain PFAS compounds could be present. This is also consistent with EPAs implementation of Uncontaminated Monitoring Rule (UCMR) 5**.**

87. Section 5.1.1. The first paragraph of Section 5.1.1 appears incomplete.

Response: The language in this paragraph is identical to the language in the rule**.** Ecology agrees the rule language needs modification.

88. Section 5.1.1. Regarding whole effluent toxicity testing, how does/will Ecology propose to remove or address confounding chemicals from such an analysis?

Response: Confounding chemicals cannot be accounted for in a whole effluent toxicity test using water collected from a specific site.

89. Section 5.1.1. An important limitation applying the surface water "protective values" from Table 7 to groundwater discharging to surface water is that these values will be overly conservative for fish (but not benthic invertebrates). Fish that live in a lentic or lotic habitat are not exposed to 100 percent groundwater emerging in those habitats because the groundwater quickly dilutes out into the surrounding surface water occupied by fish. Benthic invertebrates would be exposed to 100 percent groundwater as it emerges through the sediment layer into the overlying surface water. So, while it may be appropriate to use the Table 7 values for selecting surface water COPECs based on groundwater analytical data, one would have to apply a site-specific dilution factor when assessing the potential ecological risk of that groundwater to fish.

Response: Ecology acknowledges the information provided in this comment. However, it is important to note that MCTA does not allow consideration of a mixing zone to determine surface water compliance (see WAC 173-340-730(6)(b)), which is why sampling groundwater prior to surface water discharge is the preferred method for evaluating this scenario.

90. Chapter 6. All of the options presented are remedies, which will be cost prohibitive for some responsible parties. Elimination of a direct contact exposure pathway through capping and also limiting the migration of contaminants to groundwater with a monitoring program should be considered as appropriate remedies for some sites.

Response: The guidance does not limit the specific cleanup action that can be selected for a particular site. As discussed in Section 6.0, Ecology anticipates that a disproportionate cost analysis will typically be required in order to support the selection of a permanent remedy**.**

91. Section 6.2.2. Has Ecology identified facilities that are permitted to accept PFAS-impacted soils?

Response: Developing and maintaining a list of facilities that can accept PFAS impacted soils would be resource intensive as it would need to be routinely updated. Providing this type of information is beyond the scope of this guidance.

92. List of Acronyms. AFFF is Aqueous Film Forming Foam, not Aqueous Film Forming Form.

Response: The requested change was made to the guidance**.**

93. The last sentence of Section 6.2.3 on Thermal Treatment mentions states, "...incineration technology is associated with high energy consumption, which should be considered as a part of using sustainable technologies." There is one other mention of energy usage in 6.1.1.3. It is agreed that sustainability is an important consideration for treatment technologies, however there is no other mention of sustainability considerations in the document or for any other technologies. It is therefore requested to add additional language on sustainability considerations within this chapter. This can be done in the Overview of 6.0 and/or within sections 6.1 and 6.2.

Response: A general discussion on sustainability was added to Section 6.0 of the guidance.

94. While sustainability assessments may not be widely available for each technology, a general statement on the need to consider sustainability implications can readily be included, along with examples of technology components or processes that will have the greatest impact on sustainability. For example, expected annual operation and maintenance including energy usage of running a system (especially considering years/decades of expected operation), anticipated equipment changeouts, if waste is continually produced, etc. Some of the more striking comparisons would be between broad technology approaches, for example ex situ versus in situ methods.

Response: See response to comment No. 93. Providing details on the issues identified is site-specific and beyond the scope of this guidance.

95. We understand the rationale to provide a guidance document with flexibility, to allow for site and situational variability, however additional specificity on where, how and when this guidance is intended to be applied would be beneficial to the regulated community. For example, Section 1.1 titled Purpose and Applicability does not include any description or detail about how one might apply this guidance to properties or areas that are not yet engaged in a site cleanup process, or what types of sites, or types of historical activity at a site would indicate a potential for the presence of PFAS. We recommend inclusion of additional text describing the types of historical activities or industries that would be indications to Ecology (or to property owners) that PFAS presence should be considered or investigated. Currently, there is insufficient discussion of how one may determine if they should be considering or investigating the potential for PFAS in soil and groundwater at a site not currently listed under MTCA.

Response: As discussed in Section 1.1, the intent of this guidance is to provide general direction for investigating and cleaning up PFAS contamination. Ecology added a sentence to this section of the guidance indicating that the ITRC guidance provides a significant discussion of factors to be considered when evaluating the potential for PFAS impacts at a particular site**.**

96. Use of Preliminary Cleanup Levels. Section 3 states that a 'preliminary cleanup level gauges whether a hazardous substance is present at a concentration that warrants cleanup actions.' Please expand discussion of Preliminary Cleanup Levels to better explain how these values are used, when they should be applied, and what the outcome of a Preliminary Cleanup Level evaluation process is. The Port has experienced significant project schedule delays,

investigation scope expansion and significant costs associated with Preliminary Cleanup Level screening conducted on existing sites. This process has not yet resulted in an outcome that has modified or changed the outcome of a project. The Contaminant of Concern (COC) Screening process is still conducted following initial Preliminary Cleanup Level screening, and the PCUL screening routinely screens in irrelevant chemicals that are eliminated later. We strongly recommend reconsidering the development and inclusion of Preliminary Cleanup Levels for PFAS without clear explanation of when and how they are to be used, how they vary from COC screening levels and cleanup levels, and how they are applied to Sites. We understand the need to determine what level of contamination at a site warrants cleanup and suggest this is done using the ARAR process and actual cleanup levels (also calculated and included in this guidance document), rather than a different set of values and an additional evaluation step. Alternately, identification of these values as "screening levels" rather than "preliminary cleanup levels" may also assist in avoidance of confusion caused by inclusion of these values without clear guidance on their applicability and use.

Response: The purpose and use of preliminary cleanup levels is explained in Section 3.2. Ecology's experience is that the use of preliminary cleanup levels can be very helpful in ensuring the degree and extent of contamination is adequately defined and for identifying a preliminary set of indicator hazardous substances to consider when developing cleanup options. We apply the strictest applicable PCLs to identify contaminants of potential concern. These are not final cleanup levels at that point in the process, because the conceptual site model (CSM) may change as more information becomes available. Table 3 uses the term to identify that SALs should be considered preliminary cleanup levels, because as discussed in Chapter 3, they will only be applicable if they are determined to be ARARs on a site-specific basis.

97. In multiple places in the document, discussion of existing Sites with PFAS contamination are described. It is unclear the relevance of this information to the guidance document. We encourage you to reconsider the usefulness and necessity of including this site-specific information for existing Sites in a guidance document without explanation of why it is being included, or the relevance of this to other sites.

Response: The reason Ecology included a discussion on existing sites with PFAS contamination is to provide some context on the scope of the problem**.**

98. Page 1, Footnote 2. This footnote refers to the Washington state law restricting AFFF use, and notes AFFF can no longer be manufactured, sold, or used for fire training, although it can still be used for emergencies and actual fire situations until an alternative is found. Alternatives to PFAS-containing foams are already available, and in use in many areas. Suggest rewording to avoid indicating alternatives are not currently available. Chapter 70A.400 allows for ongoing AFFF use where mandated by federal law, not where alternatives have not been found.

Response: The requested change was made to the guidance**.**

99. Section 3.2.2. This section describes the MTCA requirement for compliance with ARARs, and Section 3.2.3 states that the Department of Health's State Action Levels (SALs) "are expected to serve as the groundwater cleanup levels for most sites that have potable groundwater". We would question the applicability of the Department of Health SALs as an ARAR at Sites that are not within a drinking water aquifer. The definition of potable groundwater is broad reaching, and includes many areas of the State where groundwater is not currently and will never be used as a drinking water source. Please provide your specific WAC 173-340-710(4) rationale to apply these SALs as an ARAR, and consider options for sites with

groundwater that may be determined potable that will not have a current or future use as drinking water.

Response: This provision indicates that the SALs are **expected** to serve as the groundwater cleanup levels for **most** sites that have potable groundwater. This language was specifically selected to provide flexibility when evaluating an individual situation. As previously discussed, the SALs do not automatically apply, but instead need to be evaluated on a site-specific basis. If Ecology determines it is appropriate to impose the SALs it would be necessary to provide a discussion on why the SALs are relevant and appropriate requirements**.**

100. Section 3.2.3, Table 3. HFPO-DA is not considered volatile by EPA definition and should not be addressed as such.

Response: HFPO-DA has a Henry's law of 2.5E-04 atm-m3/mol. According to EPA, chemicals with a Henry's law greater than 1E-05 atm-m3/mol are considered sufficiently volatile (EA, 2015). EPA classifies HFPO-DA as volatile in their regional screening level table. The following reference provides additional information: EPA, 2015. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air.* OSWER Publication 9200.2-154. June 2015.

101. Section 3.2.4. Tables of cleanup levels are provided in Chapter 3 for all media except surface water. For clarity, please consider organizing the document so that criteria for all media are provided in the same section.

Response: Ecology intends to supplement the guidance in the future to include cleanup levels for sediments. At that time, we will evaluate reorganizing the document.

102. Section 3.2.5. Soil cleanup levels do not consider the impact of regional background. PFAS are known to occur globally in air deposition and rainfall (see Per- and Polyfluoroalkyl Substances Technical and Regulatory Guidance (Section 6). The Interstate Technology & Regulatory Council PFAS Team. June 2022; and Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS). Ian T. Cousins, Jana H. Johansson, Matthew E. Salter, Bo Sha, and Martin Scheringer. Environmental Science & Technology 2022 56 (16), 11172-11179. DOI: 10.1021/acs.est.2c02765 for a few recent references). The impact of this regional background should be considered in the development of soil cleanup standards, as described in the ITRC guidance noted above, and referenced by Ecology's draft guidance: "The implications of such ambient levels of PFAS should be considered in evaluating exposures and risk levels, establishing site action levels and cleanup goals, and identifying PFAS sources". Similar exercises for other states have considered state background levels in determining protective soil leaching. The November 2022 Sampling, Analysis, and Assessment of PFAS Under New York State Department of Environmental Conservation's Part 375 Remedial Programs publication is a primary example of this.

Response: See response to comment No. 78**.**

103. Table 5. We recommend inclusion of current laboratory Practical Quantitation Limits as a column in this table, given the very low concentrations calculated for soil cleanup levels presented in this table. We also request inclusion of discussion of how Ecology intends to handle situations where the calculated cleanup levels for PFAS are less than laboratories are currently able to detect, should that condition occur.

Response: Current laboratory PQLs will likely be in a state of flux, especially over the short-term, and Ecology's preference is to not include information that requires routine updating. In addition, PQLs may be different depending on the capabilities of the individual laboratories. EPA may be providing guidance on applicable PQLs in the future.

Ecology anticipates that we would address situations where the CUL falls below the PQL using the process set out in WAC 173-340-707 (as we do when this situation arises for other contaminants).

104. Section 3.4. This section, titled Ecology's historical PFAS Investigatory Levels (now superseded) describes an entire site-specific criteria development process for a specific Site that is not current, or relevant to this guidance. To eliminate confusion, we strongly suggest deleting this section from the document. If this section remains in the document, we recommend including an introductory paragraph that explains the relevance of this information and why it is included, and how it should be used by the reader.

Response: See response to comment No. 15**.**

105. Section 4.5.2. The first paragraph of this section states 'For drinking water samples, if the source of PFAS contamination is unknown…. Use both Method 533 and 537.1…" – however it is our understanding this document is providing guidance for the investigation and remediation of soil and groundwater, not drinking water. Please confirm and clarify the text of this section. The recommendation to 'use both methods' should be more clearly explained as to when, and how this may be conducted (analyses of select samples by a different method, duplicate analyses of representative samples, etc.).

Response: As stated in Section 4.5.2, the use of both Method 533 and 537.1 are for finished drinking water. For sites undergoing a site evaluation under MTCA, this sampling would be primarily for private wells. Currently, Method 1633 should be used for soil and groundwater analysis**.**

106. Section 4.2. EPA Methods 533 and EPA 537.1 can be used to analyze potable water for the 6 PFAS compounds included in this guidance. Ecology recommends using EPA 533 because it relies on isotope dilution quantification techniques. Does Ecology require testing for all target PFAS compounds provided by the referenced methods (29 compounds) or just the 6 PFAS compounds currently included in the guidance? Please clarify if Ecology is expecting analyses to be conducted for all possible PFAS, or just the PFAS with current criteria.

Response: See response to comment No. 81**.**

107. Chapter 6.0. Treatment Technologies – please consider expansion of this chapter to discuss emerging technologies for PFAS treatment and destruction and provide additional discussion of the common and known challenges, impacts and costs of the technologies discussed.

Response: During the preparation of this guidance, Ecology initially considered developing information on the various emerging technologies. However, this would have required a significant effort to keep the information up to date, so Ecology opted to limit this Chapter to field proven technologies. ITRC's PFAS guidance document, which is referenced in the first paragraph, does a nice job summarizing emerging technologies**.**

108. Section 6.0. The current draft does not specifically list or discuss acceptable disposal methods. Disposal of PFAS-contaminated waste will be a significant factor in the evaluation of remedial technologies and alternatives. Please update this guidance to include discussion of approved and commercially available disposal options, and if Ecology has guidance or preference for methods of waste disposal.

Response: See response to comment No. 91**.**

109. I support the establishment of standards for cleanup of groundwater to drinking water standards as the highest beneficial use is as potable drinking water source. Voluntary testing of Group A water systems in Island County revealed that 10% of these systems had detections.

There appears to be a correlation between the location of the affected wells and historical use of firefighting foams. This pattern may be expected to be repeated across rural Washington. Cleanup may not always be the most cost-effective solution for water systems. In some cases, treatment may be preferred while in other cases relocating wells to an uncontaminated area may make the most sense. These considerations should be taken into account when prioritizing sites for cleanup.

Another issue of concern is future cleanup levels are the EPA sets MCLs for drinking water and standards under CERCLA. Lastly, it is probable that local fire companies were the parties that discharged the material onto the ground. Although technically Potential Responsible Parties, holding these entities accountable for cleanup costs is not realistic.

Response: Prioritization of sites for investigation and cleanup as well as identifying Potential Responsible Parties will be on a case-by-case determination and typically based on a number of factors**.**

110. There are two sections on cleanup levels and screening levels – one for human health (Chapter 3) and one for ecological receptors (Chapter 5). These chapters are separated by a chapter discussing sampling methodology (Chapter 4). We suggest reorganizing so that the sections on cleanup levels and screening levels are together, followed by the section discussing sampling methodology.

Response: See response to comment No. 101**.**

111. Section 4.1.1 discusses the list of analyses for PFAS compounds that should be collected; however, Section 4.5 discusses when PFAS sampling would be required and what compounds to sample. We suggest moving the current Section 4.1.1 to Section 4.5 to improve readability.

Response: Section 4.1.1 only provides a very general discussion of the importance of using a comprehensive list of PFAS compounds, while Section 4.5 provides the details**.** This is consistent with the other paragraphs included in Sections 4.1

112. The Draft Guidance references and provides links to many documents that are frequently updated as additional PFAS information is released. Will Ecology's Guidance also be continually updated as the referenced links are updated?

Response: See response to comment No. 80**.**

113. Background PFAS levels are not discussed. MTCA defines "natural background" as "the concentration of hazardous substance consistently present in the environment that has not been influenced by localized human activities" (Washington Administrative Code 173-340-200). While PFAS are human-made, the MTCA definition also recognizes that, for instance, certain PCB levels will be considered "natural background." The Draft Guidance does not address background concentrations of PFAS in the environment, despite the fact that they are prevalent in all types of media, and often cannot be traced to a source. As it further develops this Draft Guidance, Ecology should provide information and direction to regulated parties on how it intends to account for background levels of PFAS when setting cleanup levels at a particular property or site.

Response: See response to comment No. 78**.**

114. Six PFAS compounds are identified with screening/cleanup levels in the human health cleanup levels/screening levels discussed in Chapter 3; however, 10 PFAS compounds have concentrations protective of ecological receptors as provided in Chapter 5, Table 7. How will these different compounds with ecological screening levels be addressed and handled by Ecology when evaluating a site under human health issues?

Response: Individual pathways should be assessed separately. If a particular pathway (e.g. groundwater) is complete or likely to be complete, then each compound where there is sufficient toxicity data to establish screening or cleanup levels should be evaluated. Compounds where there is not sufficient toxicity data to establish a cleanup level for a pathway of concern would not be used for evaluating compliance with MTCA.

115. Several sections in the document discuss recommended cleanup levels or identify values as screening levels. Please clearly identify if the values discussed throughout the document are screening levels or are MTCA enforceable cleanup levels.

Response: The document provides information on cleanup levels, screening levels and preliminary cleanup levels. The term cleanup level is defined in MTCA (WAC 173-340-200) and is a level determined to be protective of human health and the environment**.** Section 3.2 of the guidance was modified slightly to better define how preliminary cleanup levels are used early in the process to help assess whether a cleanup action may be warranted.

116. The Draft Guidance does not include information or requirements for data validation to evaluate laboratory performance.

Response: See response to comment No. 79**.**

117. The text states that Department of Health (DOH) State Action Levels (SALs) may be determined as an Applicable or Relevant and Appropriate Requirement (ARAR) for a Site and as such are used as preliminary groundwater cleanup levels. When and how will Ecology determine if DOH SALs are ARARs and as such become enforceable under MTCA?

Response: Prior to the promulgation of Federal maximum contaminant levels (MCLs), Ecology intends to evaluate each situation on a site-by-site basis**.**

118. Within Table 3, the second and third columns labeled "Method B" and "Method C" appear to be formula values and should be identified as such (e.g., Method B Formula Value).

Response: The paragraph preceding Table 3 indicates that MTCA Equation 720-1 was used to generate the levels**.**

119. Same comment as Comment 118, for Table 4.

Response: The paragraph preceding Table 4 indicates that the levels were calculated using MTCA Equations 740-1 and 745-1**.**

120. Analytical methods described in the draft guidance include methods analyzing 24 analytes and 40 analytes. But as Ecology identified, it has only set screening/cleanup levels for 6 PFAS compounds. Analyzing numerous compounds, for which there are currently no screening or cleanup levels (for the purposes of this letter described as "Other PFAS Compounds"), raises a number of questions that Ecology has not addressed in the Draft Guidance, and which create potential complications for parties conducting cleanups. We encourage Ecology to at least consider the following questions before finalizing the Draft Guidance's recommendation to analyze for any PFAS compounds other than the six PFAS chemicals for which there are established screening/cleanup levels:

a. Will parties conducting an investigation (whether voluntary or under formal agency oversight) be required to analyze for the Other PFAS Compounds? If so, has Ecology considered the impact of the cost to conduct such analysis (e.g., lab fees, data validation, and reporting costs)? It may be excessive to require analysis of PFAS compounds that Ecology does not currently, and may never, regulate.

b. If parties analyze for the Other PFAS Compounds, without being required to do so by Ecology, will they be required to submit all of the analytical information they obtain to Ecology? If so, how will Ecology use that information now and/or in the future? For instance, does Ecology plan to use the Other PFAS Compounds analytical data to make cleanup decisions, and if so, on what basis/under what authority?

c. If Ecology requires submission of Other PFAS Compounds analytical information, we assume that information will be accessible to the public. Has Ecology considered the ramifications of sharing data with the public about PFAS compounds for which it has no screening/cleanup levels?

d. Will parties conducting investigation be required to retain analytical information they obtain about the Other PFAS Compounds? If so, in what manner, and for how long?

Response:

a. See response to comment No. 81.

b. See response to comment No. 81.

c. Ecology believes it's important to be transparent with the public and provide access to all available data. There are other analytical methods that include analytes without cleanup levels. Those data are also included in Ecology's EIM database.

d. The same data retention rules should be used for PFAS as for any other hazardous substance.

121. If an investigation uses an accredited method at the time of sampling, will Ecology require future sampling under newer accredited methods as they are developed?

Response: See response to comment No. 82**.**

122. The Draft Guidance indicates: "One trip blank for each cooler to assess whether contamination is introduced during sample shipment." – ITRC guidance does not include trip blanks but does suggest "performance evaluation samples." Is there scientific evidence that supports the need for submitting a trip blank, given that other blank samples will be submitted?

Response: See response to comment No. 23**.**

123. The Draft Guidance states: "One sample collected from the last rinse each day for each type of sampling equipment used for each matrix." Consider revising this statement to indicate rinse blanks are only required for non-dedicated sampling equipment that comes into contact with the sampled matrix.

Response: If the initial sampling of a dedicated piece of equipment documents no PFAS compounds are present, Ecology would agree that further equipment blanks would typically not be necessary.

124. The Draft Guidance indicates: "More frequent collection of duplicate samples from heterogeneous media—such as soil or sediments where homogenization of samples cannot be performed—should be assessed on a case-by-case basis." Is this statement regarding triplicate samples from Incremental Sampling Methodology? If so, please state.

Response: Ecology intended this provision to apply in situations where the sample cannot be homogenized due to concerns about volatilization. Analysis for PFBA may fall in this category. Ecology did not consider the use of Incremental Sampling Methodology when drafting this provision.

125. Treatment assumptions largely consider only active remediation. Passive remediation should also be considered where active remediation may be cost prohibitive or otherwise infeasible.

Response: Ecology tried to focus on those remedies that are considered "field proven." Remedies not mentioned can still be considered and evaluated using the process set out in WAC 173-340-360**.**

126. The Guidance states that the basis for establishing Model Toxics Control Act clean up levels for potable groundwater is the Washington Department of Health's (DOH) State Action Levels (SAL) for PFAS. The Environmental Protection Agency (EPA) is currently working to establish Maximum Contaminant Levels (MCL) for PFAS. There is a potential for the SALs to default to EPA's MCLs if they are more stringent. Additionally, Section 3.2.4 of the Guidance states that EPA is currently developing ambient water quality criteria for PFAS under the Clean Water Act. Regulatory certainty with alignment between state and federal standards is critical. We encourage Ecology to have an explicit process within the Guidance to ensure state clean up levels will be consistent with EPA's MCLs and water quality criteria – including a plan of how active remediation projects will be impacted if clean up levels become more stringent.

Response: Ecology added language to Section 3.2.2 explaining that new Federal MCLs will become applicable requirements under WAC 173-340-720. With respect to ambient water quality criteria, Ecology's Water Quality Program is responsible for implementing these requirements.

127. The Guidance incorporates DOH's PFAS SALs (Chapter 246-290 WAC) as groundwater cleanup levels for potable groundwater. The Guidance should ensure that investigation and remediation sampling and monitoring requirements are consistent with DOH requirements for Group A Public Water Systems in Chapter 246-290 WAC. The Guidance should include a section that outlines ongoing sampling and public notifications for investigation and remediation projects that are consistent with Chapter 246-290 WAC.

Response: See response to comment No. 29.

128. Effectiveness of some treatment technologies for potable groundwater have not been confirmed. Please consider the impact on drinking water utilities for allowing remediation sites to use unproven technologies in potable aquifers, specifically in wellhead protection areas and critical aquifer recharge areas. If the treatment technology is not successful within these areas, the water purveyor will bear the responsibly of treating the water to provide safe drinking water. The cost of treatment will likely impact the rate payer.

Response: The treatment technologies identified in Chapter 6 were determined to be field demonstrated, however they may not be appropriate for all situations. As specified in the information box at the end of Section 6.0, the preferred remedial action will need to follow the procedures in WAC 173-340-360 and demonstrate the remedy is permanent to the maximum extent practicable. One of the goals of this process is to make sure the remedy has a high likelihood of success.

129. The Guidance should include assistance for PFAS investigations and remediation within wellhead protection areas or critical aquifer recharge areas. This should include:

a. Groundwater modeling and time of travel analysis.

b. Section 3.2.2 should include information how direct impacts to wellhead protection area or critical aquifer recharge areas will be a site-specific circumstance to ensure a cleanup level above a SAL is not approved.

c. Soil clean up levels within a wellhead protection area or critical aquifer recharge area should be required to be protective of potable groundwater.

Response: Providing specific details for investigating and remediating PFAS impacts within wellhead protection areas is beyond the scope of this guidance. The necessary provisions will be determined on a case-by-case basis. With respect to soil cleanup levels, Table 5 provides concentrations that are protective of the SALs and also provides levels that are protective of the Method B groundwater cleanup levels provided in Table 3.

130. Section 4.1.1 of the Guidance recommends analyzing for a comprehensive set of PFAS compounds, not just the six PFAS chemicals with screening or clean up levels. Ramifications of collecting data on PFAS compounds with no screening or clean up levels is not addressed in the Guidance. Please clarify the following information in the Guidance:

a. Will Ecology require submittal of all analytical information collected during an investigation (in addition to the six PFAS chemicals with clean up levels)? If so, include information on how Ecology plans to use that information. How does Ecology plan to use the Other PFAS Compounds analytical data to make cleanup decisions?

b. Will guidance be provided on how to communicate to the public regarding for the analysis of PFAS chemicals that have no screening or clean up levels? There is concern for the impact on consumer confidence for analysis on chemicals that have no screening or clean up levels. Redmond encourages Ecology to develop and disseminate public messaging regarding implications of analytical results for PFAS chemicals with no screening or clean up levels.

c. Will Ecology require future sampling under newer accredited methods as they are developed for investigations that use an accredited method at the time of sampling? Will Ecology include a “grandfathering” criterion to ensure remediation projects are not required to chase compliance as technology evolves?

Response:

a. See response to comment No. 81.

b. Ecology intends to work the Department of Health to develop a consistent message on the lack of screening or cleanup levels for numerous PFAS compounds.

c. See response to comment No. 82.

131. Section 3.4 is no longer necessary since these levels have been superseded. We suggest moving this section to an appendix. It is confusing to have Table 6 in the main body of document since these levels are no longer applicable.

Response: See response to comment No. 15**.**

132. It is imperative that there is coordination with Ecology staff who implement the reclaimed water use law (RCW 90.46). That law identifies acceptable uses of reclaimed water to include direct and indirect aquifer recharge. Limited sampling of reclaimed water from LOTT and Brightwater facilities has shown perfluorooctanoic acid (PFOA) detections that exceed the SAL. If this reclaimed water is land applied within a critical aquifer recharge area or wellhead protection area, it could cause SAL exceedances for a water purveyor. At a minimum, this issue must be addressed in an update to Chapter 173-219 WAC (Reclaimed Water). Please consider updating Chapter 173-219 WAC to prohibit land application of reclaimed water within critical aquifer recharge areas and wellhead protection areas if PFAS is detected at levels above a SAL.

Response: Ecology has established an internal workgroup consisting of all the environmental programs with responsibility for PFAS. One of the major goals of the workgroup is to ensure there is coordination and information exchange. For specific questions on reclaimed water, contact Ecology's Water Quality Program.

133. Ecology's draft Per- and polyfluoroalkyl substances (PFAS) guidance is likely to have a significant impact on residents of the state of Washington socially, economically, and environmentally. We request that the guidance be withdrawn and that a robust public process involving representatives of business, industry, and agriculture; banking and finance; environmental, risk, and health professionals; and others be used to develop guidance that is both protective of human health and the environment and implementable while considering the anthropogenic background signature of this class of chemicals.

As proposed, the guidance is likely to adversely impact the redevelopment of every site in the state of Washington, pushing economic progress, affordable housing, environmental justice, and family wage jobs into the distant future.

Response: There are a number of sites throughout Washington state with known PFAS impacts and likely many more that will be discovered over the next several years. Undertaking a "robust" public involvement process as envisioned by the comment, would take a significant amount of time to complete. While that process is ongoing, a number of sites would be in need of direction on how to proceed. In order to provide the necessary assistance, Ecology intends to move forward to complete the guidance. The document will be updated on a routine basis as new information becomes available.

134. We have identified three primary questions that we do not believe are sufficiently addressed in the guidance, areas Ecology should conduct future evaluation, and conditions where we do not believe MTCA provides a flexible framework to utilize this guidance.

> **Question 1: What are the Area-wide Background Levels of PFAS?** A key hallmark of Washington Administrative Code (WAC) 173-303: Model Toxics Control Act (MTCA) is that the permanent remedy often requires the removal of every trace of a compound to the naturally occurring or background level. As a synthetic compound, there are no naturally-occurring levels of PFAS compounds in the environment. However, PFAS compounds have

commonly been found in rain and snowfall precipitation. The ubiquitous nature of nonpoint sources of PFAS means that PFAS contamination will not be geographically limited to areas with known releases, as with the localized impact of an onsite release of a common petroleum, solvent, or metal contaminant, but is instead best considered an area-wide background issue. Background studies of surficial soil completed in other states have consistently detected PFAS in shallow soils across the states, including at properties that have no commercial or industrial development history.

MTCA provides the framework to establish a site-wide background concentration. However, given the low cleanup criteria under the proposed guidance, especially for the soil – protective of groundwater pathway, a site-specific background study would become necessary for every site. The methods and costs of PFAS investigations are extensive and expensive. Given the high costs of PFAS analysis, a simple site, with no historical site use which is likely to have utilized PFAS, would have to spend tens of thousands of dollars on a PFAS investigation and even more to determine the background level of PFAS impact from offsite non-point source releases.

Rather than burden individual sites to study and understand an area-wide concern, Ecology should spend the time necessary to evaluate the regional background levels of PFAS in Washington State before adopting PFAS cleanup levels. This public effort would improve the understanding of the current background nature of PFAS contamination across Washington to distinguish localized contamination that may require cleanup action from area-wide background contamination.

Response: See response to comment No. 78.

Question 2: What assumptions are Made in the Leaching Pathway Calculations? The mobility of PFAS compounds generally, and the relative mobility of each PFAS compound specifically, have not been sufficiently evaluated. Compound mobility is affected by soil type and composition, including soil moisture, organics, and the presence of other compounds. Absent a clearer understanding of the effect of mobility through the soil column, there is an insufficient basis to calculate a groundwater level from a measured soil concentration. Ecology's PFAS Chemical Action Plan states on page 434 that:

"Use of hypothetical leaching models with unrealistic input parameters may calculate unachievable soil contaminant concentration limits. Several states are currently considering a variety of PFAS threshold values for soil based on such modeling. Some of these values for PFAS concentrations in soil may exceed local background levels making them unrealistic and to implement as a regulatory standard. Setting unrealistic (and potentially unenforceable) contaminant thresholds undermines public support for regulation[90]."

Response: See response to comment No. 13.

Question 3: What is the Effect of Changing Standards? PFAS is a developing issue with an incomplete understanding of the sources of PFAS compounds, the relative hazard of PFAS compounds, and the ubiquitous nature of PFAS in the environment, including in

[90] 2022. Washington State Department of Ecology, Hazardous Waste and Toxics Reduction Program, Per- and Polyfluoroalkyl Substances Chemical Action Plan. Publication No. 21-04-048, Revised September 2022. https://apps.ecology.wa.gov/publications/documents/2104048.pdf.

atmospheric deposition. The National Institute for Occupational Safety and Health (NIOSH) reports that there are over 9,000 different PFAS compounds[91]. As more is learned about PFAS, a hierarchy of risk, similar to that employed under MTCA for carcinogenic polyaromatic hydrocarbons (PAHs), should be considered to holistically understand the entire PFAS burden, rather than focusing on individual compounds.

As Ecology's draft PFAS guidance states on page 12:

"The chemical-by-chemical approach to developing action levels for PFAS should be considered an interim solution due to the number of PFAS chemicals and the frequent detections of PFAS mixtures in environmental media. As more information becomes available, it may be possible to evaluate PFAS as a complex mixture according to subclasses based on key characteristics such as chemical structure, bioavailability, bioaccumulation potential, toxicity, or mechanism of action (DOH, 2021a)."

Response: Ecology acknowledges that evaluating PFAS compounds as a mixture is preferred over establishing individual cleanup levels. EPA's recent release of proposed MCLs for a mixture of four PFAS compounds is an important first step. However, the process for addressing PFAS as a mixture is in its infancy and will likely not be available for routine use anytime soon. In addition, EPA is continuing to develop toxicity assessments for other PFAS compounds and for now Ecology will continue to utilize cleanup levels for individual PFAS chemicals.

135. The draft PFAS guidance should be withdrawn until a robust public process, fully evaluating the social, economic and environmental impact of this guidance, can be completed. It is also apparent that legislative review and potential amendment to MTCA should be considered to address this emerging contaminant and better address the presence of and response to PFAS compounds that have become ubiquitous in our environment through nonpoint source pollution.

Response: See response to comment No. 133.

136. We appreciate Ecology for creating this document and being ahead of the curve in regards to tackling widespread PFAS contamination. We are grateful that Ecology is not waiting for PFAS regulation to trickle down from the Federal government at every step of the process. By acting faster, we can prevent and curb more PFAS contamination and the adverse health effects associated with PFAS exposure in Washington state.

Response: Ecology appreciates the support for proceeding ahead with the guidance**.**

[91] 2022. The National Institute for Occupational Safety and Health, Per- and polyfluoroalkyl substances (PFAS), Last Reviewed: September 15, 2022, January 27, 2023. https://www.cdc.gov/niosh/topics/pfas/default.html.

137. Several studies carried out in Bellingham in recent years have detected PFAS. They are in our sewage solids, sewage effluent, marine sediments, and marine mussels[92][93][94]. Furthermore, the detection of PFAS is most likely underestimated as our technology for detecting PFAS has been more accurate and refined in the last couple of years. Because PFAS contamination is so widespread, how will Ecology effectively assess where PFAS contamination is across the state and how will they prioritize the cleanup so it is fair and equitable?

Response: Ecology acknowledges that the presence of PFAS is widespread and will continue to expand over time. There are at least seven Ecology programs that have responsibility for overseeing various portions of the known impacts. Ecology has established an agency workgroup to coordinate and prioritize addressing these impacts**.**

138. People harvest crab and other seafood regularly from Bellingham Bay and to our knowledge there has not been any research to show how much PFAS is found in the crabs, fish, or seaweed harvested here. Since PFAS has been detected in Bellingham Bay mussels at elevated levels, we suspect that will be the case for other seafood as well. We encourage Ecology to prioritize testing commonly harvested seafood in Bellingham Bay for PFAS and other contaminants of concern and to make this information publicly available. Even extremely small amounts of PFAS can have adverse health effects and the crab caught in Bellingham Bay could exceed these small amounts. Despite the ubiquitous nature of PFAS, the general public does not fully understand the hazards of PFAS and the likely routes of exposure.

Response: Questions on testing and providing advisories regarding seafood consumption should be directed the Department of Health.

139. PFAS continues to contaminate our surface waters mainly through stormwater and wastewater discharges, therefore, what efforts will be in place to ensure that the areas that are cleaned up from PFAS and other contaminants are not recontaminated? Millions upon millions of dollars have been spent cleaning up legacy toxics; we need to make sure that the same mistakes are not made today as they were in the past. We feel that it is important to determine where the PFAS is coming from so the sources can be addressed. In Appendix 3 of the PFAS Chemical Action Plan, 43 sites in Whatcom County have been identified as a potential source of PFAS. We think it is important to make this list public and easy to access, so more people are aware of the potential sources of PFAS contamination and can collectively work to curb its release. It will also help people understand how PFAS can travel through the ecosystem.

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[92] City of Bellingham. 2021. Post Point Wastewater Resource Recovery Project Archive. 2021 Wastewater Test Results - full report. Retrieved from: https://cob.org/services/utilities/waste-water-treatment/archived-resource-recovery.

[93] Long, E.R., Dutch, M., Weakland, S., Chandramouli, B., Benskin, J.P., 2013. Quantification of pharmaceuticals, personal care products, and perfluoroalkyl substances in the marine sediments of Puget Sound, Washington, USA. Environ. Toxicol. Chem. 32, 1701–1710.

[94] James C.A, Lanksbury, J.A., Khangaonkar, T., West, J.E., 2020. Evaluating exposures of bay mussels (Mytilus trossulus) to contaminants of emerging concern through environmental sampling and hydrodynamic modeling. Science of The Total Environment 709:136098. https://doi.org/10.1016/j.scitotenv.2019.136098.

Response: Ecology concurs that identifying PFAS source areas is an important step in being able to begin addressing this issue. Ecology's PFAS Chemical Action Plan is currently available to the public from our webpage and can be accessed at Per- and Polyfluoroalkyl Substances Chemical Action Plan.[95]

140. There are currently 12 designated MTCA cleanup sites along Bellingham Bay in varying stages of the cleanup process. How will this guidance document affect cleanup sites already complete or in progress? At one of the cleanup sites, I &J Waterway, there was an industrial fire where a lot of firefighter foam was used. This seems like a potential place for PFAS to be found, will this be assessed prior to its anticipated cleanup this year? Likewise, we have 4 former landfills along the waterfront; will we be able to learn if these are contaminated with PFAS?

Response: Concurrently with the development of this guidance, Ecology is also working on an Implementation Memo that will provide direction on how to prioritize and investigate existing sites with potential PFAS impacts. We anticipate releasing a draft memo for public review and comment later this year.

141. We know that PFAS is found in our sewage sludge and is released back into the environment through the discharge of effluent and the landspreading of biosolids. We need to explore mechanisms to minimize the amount of PFAS being discharged into our surface waters at our wastewater treatment plants and we need to halt the land spreading of biosolids immediately. It is contradictory of Ecology to knowingly (and legally) allow the reintroduction of PFAS into the environment while simultaneously working to reduce the amount of PFAS through the PFAS Chemical Action Plan and this Guidance document. Can you please explain this contradiction?

Response: Addressing the issue of biosolids is beyond the scope of this guidance. However, Ecology's Solid Waste Management Program is currently evaluating PFAS distribution and options for ensuring management of biosolids is protective**.**

142. Currently, a lot of environmental monitoring and reporting is carried out by nonprofits like RE Sources and other community scientists. In recent years we have seen an increase in communication between scientists, regulators, and concerned community members and we hope to see that trend continue. With any document that Ecology produces, we hope that it will be written for a broader audience, not just for experts in the field. One way to make a document more usable is to provide examples of how the information may be used in the field. How would a Site Manager apply the numbers provided in the various tables out in the field? What does it look like to apply the information in this document to a real life situation? It would also be helpful if there were complete descriptions for each table so that each table could stand alone, apart from the body of text. Also, including tables that are no longer relevant is confusing. It is also helpful if the same units are used consistently throughout the document (in this case choosing between mg or µg).

Response: As discussed in Section 1.1, the purpose of the guidance is intended for people who are cleaning up contaminated property, including property owners, potentially liable parties, and cleanup professionals. Given this purpose, Ecology believes the level of detail provided is appropriate. Ecology intends to develop several focus sheets that will contain information for a broader audience**.**

[95] https://apps.ecology.wa.gov/publications/summarypages/2104048.html

143. PFAS is only 1 chemical class amongst hundreds of others that are currently contaminating our environment. We are thankful that Ecology is working to address PFAS contamination and also hope it can work to regulate the thousands of other unregulated chemicals. Holding chemical producers and users accountable needs to be considered so that we can stop making and releasing these chemicals in the first place.

Response: Ecology acknowledges that there are unregulated compounds that warrant further assessment, however addressing those compounds is beyond the scope of this guidance**.**

144. Section 2.2 should be expanded to address state regulatory authority regarding federal actors. This is warranted because US military installations are some of the worst PFAS contamination sources in Washington. The MTCA specifically includes federal agencies in the definition of "person" (RCW 70A.305.020(24)) and "potentially liable person" (§020(26)). Key aspects of state authority to discuss include when, where, and the extent of state authority:

- **a.** Over federally owned land that is contaminated.
- **b.** Over aquifers directly underlying federally owned land. Are these waters of the state with consequent state jurisdiction?
- **c.** Over non-federal lands where underlying aquifers are contaminated from sources on federal land.
- **d.** Over waters of the state being polluted from military sources.

Including this discussion and Ecology's conclusions regarding this subject is important. At the most recent Restoration Advisory Board (RAB) meeting for NAS Whidbey I was informed that the US military response to PFAS contamination has now been centralized at the Dept. of Defense and the military will continue to use the old inadequate EPA advisory contaminant level of 70 ppt until EPA issues its final Safe Drinking Water Act rule, currently expected in late August. However, the timeline presented by consultant's at the RAB meeting would delay actual remediation until the early-mid 2030s.

Response: Ecology agrees that MTCA provides Ecology with jurisdiction over releases from Federal properties. From an implementation standpoint, many of the Department of Defense sites with PFAS impacts receive oversight from U.S. EPA. The Federal CERCLA (Superfund) statute requires the selected remedial action to comply with applicable and relevant and appropriate state requirements (ARARs) to assure the remedy is protective of human health and the environment. Ecology is responsible for identifying state ARARs and communicating them to EPA.

Ecology expects all sites, including Department of Defense facilities, to comply with all applicable MTCA provisions. This includes the SALs if they are determined to be relevant and appropriate to the site.

145. The investigation performed by NAS Whidbey to date has been inadequate to delineate the area currently contaminated and determine movement of this pollution. Given the extremely sluggish response to date by the military, the applicability of Ecology's authority under the MTCA (§305(030)(1)) to require military agency investigation and remediation needs to be

explicitly clarified. The MTCA requires Ecology to "issue orders or agreed orders requiring potentially liable persons to provide the remedial action" (§305(050)(1). Ecology needs to determine under what conditions it can and must use this authority in situations stemming from military caused pollution.

In conclusion, we urge Ecology to clarify its authority regarding PFA pollution caused by the US military and then to use that authority.

Response: As discussed in Section 1.1, the purpose of this guidance is to provide direction for investigating and cleaning up PFAS contamination. The legal and technical approaches that will be used at individual sites are beyond the scope of this guidance**.**

146. Historical Considerations and Uses of PFAS. Petroleum refineries have a history with the use of PFAS-containing aqueous film-forming foams for fire suppression. In an emergency and under certain conditions, these foams are most effective for the protection of the facility workforce, the public, and for physical asset protection. With some conditions, these foams are legal for use in Washington (RCW 70A.400). As Ecology considers regulatory responses to legacy contributions of PFAS chemicals to the environment, the most prudent approach is a careful balancing of benefits and effects. Establishing groundwater or soil cleanup standards which directionally discourage the use of the most effective fire suppression foams and techniques, has the potential for larger public health risks and should not become an unintended consequence of standards development. For example, science- and toxicology-based requirements which mitigate against direct exposure, e.g. drinking water MCLs, are certainly appropriate. However, extremely stringent soil or groundwater cleanup standards based on industrial site theoretical exposures, (e.g., potable water withdrawal or incidental soil ingestion or contact) could simply implicate legal practices and trigger costly investigations and remedial cleanups that provide limited benefit to public health. These measures could be significant which re-enforces the need for a detailed cost-benefit (and operability) analysis.

Response: This guidance does not limit the use of aqueous film-forming foams. As specified in footnote No. 2 on page 1, under state law AFFF can no longer be manufactured, sold, or used for fire training, although it can still be used for emergencies and actual fire situations when mandated by Federal law.

147. Nexus and Potential Inconsistency with Current EPA Actions. Ecology's PFAS Guidance seems out-of-sync with a similar effort underway by the Environmental Protection Agency. The EPA presented its "PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024," in October 2021, in which it commits to a comprehensive multi-media, multi-program national research and risk communication response to the PFAS challenge. Ecology's PFAS Guidance covers much of the same ground. By jumping ahead, Washington creates a risk there will be inconsistencies, confusion and then shifting requirements from the eventual federal programs. Rather than expending significant resources implementing independent standards, it seems a better approach would favor patience to await EPA actions based on the most complete scientific understanding on exposure, dose, and toxicology. The EPA programs then serve as the basis for state adoption of regulatory requirements that would include consideration of state law requirements, physical conditions and state development history, sensitive sub-populations, and more.

Response: See response to comments No. 31 and 133**.**

148. Regulatory Considerations and Uncertainty Around the Use of Guidance Documents. An early example of uncertainty associated with this PFAS Guidance comes with the presentation of "recommended" requirements or "guidance" on necessary actions, or even the regulatory classification of PFAS-containing wastes. For example, it is unclear how an owner/operator or agency staff should apply the "recommended/guidance" verbiage as investigatory data is assessed or possible remedial action considered. Without additional clarity, WSPA is concerned Ecology's Guidance constitutes a de facto rulemaking without adherence to the required Administrative Procedure Act requirements for a rulemaking. The Guidance would have material impacts on the regulated community, which could potentially conflict with EPA developments, if Ecology considers PFAS wastes to be WAC 173-303 Dangerous Waste (for the criteria of persistence). The ramifications of such a determination for the compliant use of PFAS-containing AFFF or the disposal of PFAS-containing consumer products, is unquestionably important.

Response: See responses to comments Nos. 2 and 31. Ecology added a discussion to Section 6.0 that explains the requirements for properly characterizing wastes containing PFAS.

149. WSPA fully supports the important efforts by the Safer Products for Washington team (RCW 70A350) to identify and encourage substitution for PFAS-containing products, along with the earlier Persistent Bioaccumulative Toxins work (WAC 173-333). These regulatory efforts directly influence the routine exposure of humans to PFAS chemicals and thus offer the most tangible path to the avoidance of adverse health impacts.

Response: Ecology appreciates the support for the on-going work in these areas.

150. The manual should provide policy and direction on how water purveyors will be assisted by Ecology in looking for responsible parties in the event of drinking water source impacts. This assistance will be critical to the water purveyor when evaluating options moving forward. Purveyors will need the expertise and resources of Ecology to properly identify responsible parties and contamination sources.

Response: Ecology will work with water purveyors with impacted drinking water to identify potential sources of contamination. However, given the varying circumstances that may occur, it isn't possible to provide direction on how an individual situation will be handled.

151. When PFAS contamination has occurred, and has the potential to contaminate a water source, or is close to a water source, the manual should include language requiring prompt contact of any potentially impacted water purveyor. When an MTCA investigation and remediation effort has occurred for impacted or potentially impacted water sources where there are known or potential impacts to a water system, the procedure should include a public process and stakeholder engagement of the water system, since the water system is the party responsible for compliance with WAC 246-290 SAL's. In these instances, the process should be directly overseen by DOE as a formal cleanup, and the water purveyor should be directly involved in the investigation and cleanup efforts. This will allow the purveyor an opportunity to work with the parties involved and with Ecology to understand the impacts and how to prepare and/or eliminate the PFAS contamination before more costly treatments become necessary. In addition, if the water source is contaminated, the purveyor would have knowledge of the source and can coordinate efforts to find ways to promptly protect public health, treat the current contaminant, and minimize future contamination.

Response: It is Ecology's practice to contact water purveyors and individual consumers in

situations where contamination has been discovered in close proximity to wells or water systems. However, providing a detailed description on the process that will be used could limit flexibility for certain situations.

Once the source of the contamination is determined, Ecology will follow the process set out in MTCA for ensuring an investigation, and if necessary, a cleanup is undertaken. This will include a comprehensive public participation process.

152. Initial testing of source water is critical to understand the impact of any contamination event. Such testing should be required, and mandatory monitoring should continue for an extended period of time based on groundwater modeling and time of travel analysis. This is needed because PFAS is persistent in the environment and contaminant plumes may impact water sources over extended periods of time. Without extended time monitoring, there is no way to know if cleanup efforts were effective in protecting the source water long term.

Response: Ecology typically requires long-term monitoring to ensure compliance with the established cleanup levels and periodic reviews are used to assess on-going compliance.

153. The manual allows what it considers safe levels of PFAS based on current State regulations. Our understanding is that “safe levels” of PFAS will be changing on the federal level (EPA) in the near future. Which means current cleanup with “safe levels” may not be adequate when future regulations are implemented. We also know that most consumers consider any level of PFAS unacceptable. Ecology absolutely cannot allow a link to current levels.

Response: Ecology added language to Section 3.2.1 to identify how the issuance of new or updated toxicity information to a database identified in MTCA would be used to determine applicable cleanup levels. Section 3.2.2 was also expanded to explain how promulgation of a federal MCL would be used.

154. In addition to the manual, we request Ecology to work with the Department of Health and the EPA to try to address the undue and potentially crippling burden that PFAS can place on water purveyors. Beyond contaminant releases from direct use of PFAS containing materials, drinking water sources risk contamination from stormwater infiltration, septic systems, and other potential non-point sources. As these additional PFAS sources become known, we request Ecology to take the lead on protecting drinking water resources by implementing regulations and cleanup programs that focus on these drinking water assets.

Response: The Toxics Cleanup Program intends to work with other Ecology Environmental Programs to help ensure that other sources of PFAS impacts are adequately addressed.

155. The potential for contamination is always a concern, especially since beyond our wellheads and collection points we have no control over what is sprayed, injected, discharged or built near our facilities. The situation with PFAS is especially alarming given the longevity and ease of travel of these compounds. For these reasons, we understand the urgency to have standards in place. However, with EPA on the cusp of releasing new standards, would it not be best to wait to utilize those, and not go back through this process to establish new values? It could amount to a considerable expense to plan and implement a cleanup for one standard, only to have a more restrictive standard implemented during or after the cleanup has commenced.

Response: See response to comment No. 31**.**

156. This document presents itself as guidance, yet it does not contain the procedures and steps needed to prepare and implement a clean-up plan. It does give detail on how standards were derived under MTCA regulations, but does not go into the more practical aspects of how to approach a planning effort, followed by actual clean-up. To be helpful to municipalities facing this kind of effort, more actual guidance is needed for planning, preparation, implementation and techniques for disposal and destruction of PFAS contaminated matrices.

Response: Ecology has developed checklists and templates to assist in preparing site investigation reports and cleanup plans. Thefollowing link provides information on completing a cleanup action plan after preparing a Remedial Investigation/Feasibility Study: Cleanup Action Plan Checklist.[96]

157. We appreciate the recognition of the need for protecting groundwater drinking water sources as presented in the statement on page 16, 3.2.3 which states "MTCA groundwater cleanup levels for PFAS chemicals discussed in this section are based on the assumption that the highest beneficial use and the reasonable maximum exposure at the site is the ingestion of groundwater as a current or potential potable drinking water source". Too often, surface water protection is emphasized due to the presence of aquatic life at the expense of groundwater sources. Yet, as we all know, groundwater also contributes to flows in rivers, lakes and streams.

Response: Ecology appreciates the comment.

158. Utilizing the State Action Limits established by the Department of Health to determine preliminary clean up levels instead of the MTCA regulation methodologies to calculate cleanup levels provides some consistency for protecting drinking water sources. We fully realize, however, that these limits will change as EPA continues with its investigations and sets new standards.

Response: Ecology agrees that cleanup levels will evolve and change over time as more toxicity data become available.

159. Discussion of new Environmental Site Assessment Standards on page 34, section 4.5.1 is a good wake-up call to jurisdictions as it relates to source control of PFAS. Carefully looking at trade and generic names and descriptions in manufacturing to identify PFAS chemicals serves as a reminder to municipalities when issuing construction permits to look at the proposed materials used to construct buildings, to head off problems related to stormwater discharges in the future. This is important to protecting drinking water groundwater sources and would be beneficial to also include in the NPDES Municipal Stormwater Permits which are being drafted now.

Response: Ecology acknowledges this comment.

160. In Chapter 5, Protective Concentrations for Ecological Receptors, it is indicated that there is not enough data locally to use for calculations, so it is based on a literature review (and for soil biota, only earthworms). Does this indicate that local conditions could allow for the ability to set site specific limits on upland contaminated sites? Under what circumstances could this be allowed?

[96] https://apps.ecology.wa.gov/publications/summarypages/1609008.html

Response: Yes. As briefly mentioned in section 5.2.2 of the guidance, it is an option to establish site-specific cleanup levels for upland sites. Additional details on how to complete that evaluation can be found in the site-specific terrestrial ecological evaluation section, WAC 173-340-7493.

161. There is no mention of biosolids in this document (and only one of sludge, in the Treatment section). Use of biosolids as a beneficial soil amendment is utilized by many utilities across the state, and the potential for contamination and cleanup of PFAS is of great concern to the public, utilities, and those that currently benefit from the use of biosolids as fertilizer. Will these cleanup values preclude use of biosolids as a beneficial resource? Will all biosolids need to be incorporated into the soil rather than sprayed? It seems that much more data is needed, and perhaps advisory committees from the wastewater industry need to be formed to determine a path forward that continues beneficial use of biosolids while reassuring the public that food and water sources will not be contaminated by these applications.

Response: Addressing biosolids is beyond the scope of this guidance. Ecology's Solid Waste Management Program is responsible for overseeing the biosolids program and should be contacted with any specific questions.

162. The Treatment section also mentions soil washing. We are concerned about where the water containing the PFAS compounds would be disposed of. Sending that to wastewater facilities would potentially end up in biosolids that are an important tool for managing byproducts of treatment plants. PFAS source control is important for wastewater facilities as well, especially until viable techniques for the destruction of PFAS have been developed.

Response: See response to comment No. 191.

163. Section 3.0 Paragraph 2: We suggest that the document clarify why MTCA CULs would include RSCs. It is our understanding that RSCs are not incorporated into standard MTCA CULs. This would make PLPs for an environmental release liable for background conditions. MTCA normally takes background conditions into account.

Response: Consistent with EPA methods, DOH applied an RSC in the development of the Washington PFAS groundwater SALs. Our Method B and C groundwater cleanup equations (based on tap water ingestion) assume 100 percent of the intake is from drinking water. However, our cleanup levels must also comply with state and federal standards such as the MCLG, which incorporates an RSC. We list the groundwater SALs in CLARC and those must be demonstrated to be relevant and appropriate on a site-specific basis to be applied as an ARAR at the site.

164. Section. 3.1.1 Paragraph 1: Estimation of RSCs from drinking water is appropriate for DOH, but similar to our comment above, we suggest that the document clarify how RSCs are appropriate for MTCA.

Response: See response to No. 163 above.

165. Section 3.1.1 Paragraph 3: Please clarify the duration of breast- or bottle-feed.

Response: This comment should be directed to the Department of Health**.**

166. Section 3.2 Paragraph 1: It is our understanding that presence of COC above a CUL does not in itself trigger a cleanup. To our understanding, there must be actual or potential exposure. "Cleanup" is different from remediation or remedial action. Remedial action can include monitoring. It may be appropriate to modify to "may warrant."

Response: The requested change was made to the guidance.

167. Section 3.2 Paragraphs 3 and 4: Please clarify why non-carcinogenic effects are not included.

Response: Language was added discussing the development of cleanup levels based on noncancer health effects.

168. Section 3.2.1 Title: Section 3.2.1 does not discuss CUL equations. Consider rewording.

Response: The requested change was made to the guidance.

169. Section 3.2.1 Paragraph 4: Please differentiate oral RfD (RfDo) from inhalation RfD, as this is important under MTCA.

Response: Inhalation toxicity criteria are not available for any of the PFAS chemicals. Ecology used available oral RfDs to derive MTCA Method B and C cleanup levels based on incidental soil ingestion and consumption groundwater as drinking water. Language was added to the guidance to clarify that oral RfDs were not used to derive any MTCA cleanup levels for soil and groundwater.

170. Section 3.2.3 Paragraph 4: Change “hazard index” to “hazard quotient” per regulation.

Response: Hazard index (HI) is the correct term when discussing additive noncancer effects from multiple chemicals. Under MTCA, the hazard index cannot exceed 1. The HI is an expression of the additivity of noncarcinogenic health effects. Hazard quotients are determined for individual chemicals. Both terms (HI and HQ) are used in the MTCA Cleanup Regulations.

171. Section 3.2.3 Paragraph 4: Please clarify if data indicate the target organ or toxic endpoint for the individual compounds, or whether the reader should assume they affect the same organ.

Response: clarifying language was added to Section 3.2.3.

172. Section 3.2.3 Paragraph 6: The statement “Until Ecology determines that the DOH SALs are an ARAR for a site” appears to conflict with the earlier discussion that SALs likely will be ARARs. SALs are listed in CLARC.

Response: Ecology doesn’t believe that the two referenced statements are in conflict. Section 3.2.3, paragraph 1 indicates that SALs are expected to serve as the groundwater cleanup levels for most sites that have potable groundwater. However, SALs only apply to those MTCA sites where they are specifically determined to be “relevant and appropriate requirements” using the criteria in WAC 173-340-710(4).

173. Section 3.2.3 Paragraph 6: Please clarify whether SALs or MTCA B/C CULs are to be used and when.

Response: See response to comment No. 16**.**

174. Please clarify if adjustments to soil cleanup levels will be allowed based on site-specific exposure and site-specific soil characteristics per WAC 173-340-740(3) or 173-340-740 (5).

Response: Yes, the potential exists to utilize the adjustments set out in the referenced WAC sections.

175. Section 3.4 Paragraph 1: We suggest changing "contamination" to "identified in a drinking water supply well."

Response: The requested change was made to the guidance.

176. Section 3.4 Paragraph 1: Please clarify the term "Investigatory Levels (ILs)."

Response: Investigatory Levels were used since cleanup levels were not available for any PFAS compound.

177. Section 4.2, Paragraph 1: The text references EPA Method 537 being published in 2009. According to the EPA website, it was published in 2008.

Response: The requested change was made to the guidance.

178. The link to Method 537.1 is currently connected to EPA Method 533, not EPA Method 537.1.

Response: The correct link was inserted into the document.

179. The text states the document was updated in November 2018 to Method 537.1. However, it was also updated in March 2020 to EPA 537.1, revision 2.

Response: The requested change was made to the guidance.

180. Section 4.3.3: This section should reference Table B-24 in the DoD QSM in relation to EPA method 1633 instead of Table B-15. This is consistent with the intent of Table B-24.

Response: The requested change was made to the guidance.

181. Section 4.4.3: Call-out box: Correct acronym to read "PTFE".

Response: The requested change was made to the guidance.

182. It might be helpful to provide guidance on the state's expectation for how laboratories should handle aqueous samples with elevated levels of total suspended solids. Some laboratories centrifuge and decant the aqueous layer off for extraction only. However, some laboratories centrifuge and decant the aqueous layer off for extraction and also perform a separate extraction of the remaining particulate phase and combine both extracts for a "total" measurement. TRC has observed differences in results using these techniques due to the

higher likelihood of longer chain PFAS and sulfonate PFAS to adhere to the particulate.

Response: If this situation arises, Ecology recommends working with the lab and the site manager to determine the best course of action. Justification for the decision should be included with either the QAPP or with the sampling results.

183. Section 5.1: We suggest that the Draft Recommended Aquatic Life Ambient Water Quality Criteria for PFOA and PFOS (https://www.federalregister.gov/documents/2022/05/03/2022-09441/draft-recommended-aquatic-life-ambient-water-quality-criteria-for-perfluorooctanoic-acid-pfoa-and-pfos) be referenced/included here.

Response: Additional language has been added to acknowledge that these values are in development, and when finalized, should be used to determine protective concentrations for surface water.

184. Section 6.0, Paragraph 2, Sentence 2: “ongling” should be “ongoing”.

Response: The requested change was made to the guidance.

185. Section 6.0: Paragraph 4: We recommend including a discussion about the importance of PFAS that are not included in approved analytical method lists, like precursor compounds. These compounds can affect mass removal calculations and can be transformed to PFAA end products depending on treatment conditions.

Response: See response to comment No. 202.

186. Section 6.1, Paragraph 1: We suggest clarifying that for complex waste streams such as municipal and industrial wastewater and landfill leachate, pre-treatment for co-contaminants is typically required prior to PFAS removal.

Response: The requested change was made to the guidance.

187. Section 6.1.1.3: When discussing pre-treatment to remove particulates, it is unclear what particulates are being referenced. We suggest clarifying that pre-treatment may be required to control bacterial growth on the membrane. Also, in the final sentence, we suggest adding “treatment or disposal” of reject water, as the reject may be too concentrated to treat.

Response: Controlling bacterial growth on the membrane surface is addressed in the sentence following the discussion on particulates. The request to add “or disposal” was made to the guidance.

188. Section 6.2.2: For clarity, we suggest that the sentence: To minimize further leaching of PFAS compounds from source materials, strong consideration should be given to stabilization or thermal treatment of the media prior to final management. be modified slightly to: To minimize further leaching of PFAS compounds from source materials, strong consideration should be given to stabilization of the media prior to landfill disposal.

Response: The requested change was made to the guidance.

189. Section 6.2.2: Due to the long-term stability of PFAS, how a landfill or disposal facility manages leachate should be considered when evaluating off-site management and disposal options. For example, is the leachate treated and discharged to a local wastewater treatment plant, managed on-site through evaporation ponds (e.g., US Ecology Beatty), etc.

Response: Ecology agrees that how landfill leachate is managed could be a consideration when selecting a potential disposal facility for management of PFAS wastes. However, Ecology does not have any specific recommendations on how to decide which available option should be selected, and therefore did not include a discussion on this issue.

190. Section 6.2.3: We recommend that Ecology consider referencing the following reports in this section:

a. EA Engineering and Montrose Environmental Group. 2021. Final Report on PFAS Destruction Testing Results at Clean Harbors' Aragonite, Utah Hazardous Waste Incinerator. November 2021. This will help substantiate the statement regarding field-scale testing.

b. Incineration to Manage PFAS Waste Streams, EPA 2019. A statement could also be added noting that per EPA, PFAS thermal destruction technologies are not well understood, and research is ongoing. https://www.epa.gov/sites/default/files/2019-9/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf.

Response: Ecology added a reference prepared by U.S. EPA that provides 80 reference sources documenting the treatability of PFAS in different media using a number of thermal processes.

191. Section 6.2.4: We recommend that Ecology consider removing the subject of soil washing from the discussion. To our knowledge, soil washing for PFAS is not yet at the field-demonstrated level.

Response: The requested change was made to the guidance.

192. Table A-1, Parameter: Potable water ingestion for PNFA. "PNFA" should be "PFNA".

Response: The Tables in Appendix A were removed from the guidance. They were replaced with references to CLARC.

193. Table A-2, Parameter: Soil contact for PFOS+PFOA+PNFA. "+PNFA" should be removed.

Response: See response to comment No. 192.

194. Table A-2, Parameter: Soil contact for PNFA. "PNFA" should be "PFNA".

Response: See response to comment No. 192.

195. As noted in the January 2023 DOE CLARC master data table, soil to groundwater cleanup level calculations should use Henry's law constants at 13 degrees Celsius, whenever available. Table A-3a uses Henry's law constant at 25 degrees Celsius. The following comments are based on the observed differences in the DOE CLARC master data table and Table A-3a:

a. The value "nm" in Table A-3a of PFOS, parameter: Henry's law constant Hcp may be incorrect based on the value of 4.43E-07 published in the DOE CLARC master data table.

b. The value "4.0E-06" in Table A-3a of PFOA, parameter: Henry's law constant Hcp may be high based on the value of 3.57E-06 published in the DOE CLARC master data table.

c. The value "0.0E+00" in Table A-3a of PFOS, parameter: Henry's law constant Hcc may be low based on the value of 1.81E-05 published in the DOE CLARC master data table.

d. The value "1.2E-04" in Table A-3b of Vadose Zone, parameter: Soil leaching SL for PFNA may be high based on the value of 8.00E-05 published in the DOE CLARC master data table.

e. The value "7.5E-06" in Table A-3b of Saturated Zone, parameter: Soil leaching SL for PFNA may be high based on the value of 4.80E-06 published in the DOE CLARC master data table. The value "7.5E-06" in Table A-3b of Saturated Zone, parameter: Soil leaching SL for PFNA may be high based on the value of 4.80E-06 published in the DOE CLARC master data table.

f. The value "4.4E-04" in Table A-3b of Vadose Zone, parameter: Soil leaching SL for PFHxS may be high based on the value of 4.10E-04 published in the DOE CLARC master data table.

g. The value "2.8E-05" in Table A-3b of Saturated Zone, parameter: Soil leaching SL for PFHxS may be high based on the value of 2.60E-05 published in the DOE CLARC master data table.

h. The value "6.8E-03" in Table A-3b of Vadose Zone, parameter: Soil leaching SL for PFBS may be high based on the value of 1.80E-03 published in the DOE CLARC master data table.

i. The value "4.5E-04" in Table A-3b of Saturated Zone, parameter: Soil leaching SL for PFBS may be high based on the value of 1.20E-04 published in the DOE CLARC master data table.

Response: See response to comment No. 192.

196. No plan defined in the guidance to incorporate new science, federal regulations, test methods, cleanup standards, and cleanup technologies. Throughout the document, there are no provisions or clear expectations for site managers, responsible parties, or others to seek out the latest fate and transport or toxicological information about PFAS. As a current example, EPA's draft reference doses for PFOA and PFOS have both been reviewed by the science advisory board for the development of drinking water maximum contaminant limits. It's our understanding that these reference doses (RfDs) are close to adoption in the Integrated Risk Information System (IRIS). Will these RfDs supersede Washington Department of Health (DOH) developed toxicity values? At what point is it prudent for Ecology and responsible parties to anticipate these changes as our understanding of PFAS toxicity changes? We recommend that Ecology build into the guidance a regular schedule to accommodate improved scientific understandings of PFAS fate and toxicity. Ideally, Ecology resources would be dedicated towards biennial updates to this PFAS guidance like Ecology's the sediment cleanup user's manual (SCUM) update schedule.

Response: Ecology anticipates that there will be a number of actions that will require modification of the guidance, especially over the short-term. This may result in updates that are more frequent than biennially. In order to have maximum flexibility, Ecology intends to update the guidance on an as-needed basis to ensure it remains accurate.

197. We did not have sufficient time and resources to review the levels Ecology is proposing for ecological receptors. At minimum, we recommend Ecology add language that states once EPA establishes water quality for protection of aquatic life, those supersede what is in this guidance document.

Response: See response to comment No. 183.

198. More clarity on when drinking water SALs are likely to apply as ARARs is needed. Ecology's Method B and C published groundwater cleanup levels in Table 3 (page 17) are considerably higher than the State Action Levels (SALs) for drinking water developed by DOH. It is not clear under what circumstances the SAL becomes an 'applicable or relevant and appropriate requirement' (ARAR) or not. Please elaborate on when drinking water SALs are likely to apply as ARARs. Our public health staff gets many questions about PFAS in private wells. Improved transparency about the extent of known or suspected PFAS plumes in groundwater and coordination between Ecology, public health, water utilities, and responsible parties would be most helpful. We recommend this guidance discuss how a site manager would inform and communicate groundwater results to other public health agencies for their input and expertise as groundwater cleanup levels are chosen.

Response: As discussed in Section 3.2.3, Ecology expects the SALs to serve as the groundwater cleanup levels for most sites that have potable groundwater. Typically, the selection of final cleanup levels is proposed as part of the cleanup action plan, and one of the major components of this process is obtaining feedback from the public. Additional discussion on the applicability of the SALs in provide in the response to comment No. 30.

199. More guidance on how to develop bioaccumulation models. We are concerned that Ecology is proposing to develop bioconcentration factors (BCFs) for the protection of fish tissues for human consumption. In our decades of experience throughout Washington, BCFs are a primitive tool which rarely align with the site and food-web specific bioaccumulation and bioconcentration. We recommend that Ecology avoid generic or default BCFs for cleanup decision making. We recommend that Ecology provide additional guidance and recommendations on how site managers and responsible parties can develop robust and defensible bioaccumulation models or species-specific BCFs to support cleanup decisions.

Response: Ecology uses BCFs developed by EPA under the Clean Water Act rather than developing our own. We agree that food web modeling can provide more robust estimates of tissue concentrations, but WAC 173-340-730(3)(b)(iii) requires Ecology to use BCFs for calculating surface water cleanup levels. Developing site-specific BCFs is beyond the scope of this guidance.

200. More guidance on laboratory performance and data validation. The guidance document does not discuss data validation. Laboratory or field contamination and laboratory performance can be significant challenges for PFAS, especially in complex matrices or low-level analysis needed to characterize site boundaries. We recommend Ecology add sections related to data validation and usability.

Response: See response to comment No. 79.

201. More guidance on background concentrations and practical quantitation limits (PQLs) for PFAS and compliance. The guidance document does not include discussion of background PFAS levels. We recommend Ecology clarify how background levels and PQLs would be considered in site assessment and cleanup decisions. We also recommend that Ecology outline a prescribed methodology for the regulated community to obtain data and calculate background PFAS levels. Or, if Ecology is working on providing its own guidance (similar to the guidance on background arsenic levels in soil and groundwater), provide its work strategy and timeline to collect the necessary data to determine background PFAS levels.

Response: See response to comment No. 78.

202. Assessing PFAS precursors and compounds not currently included in the existing accredited methods. The guidance document left us with many questions about PFAS precursors and other currently unregulated PFAS how they might be addressed in cleanups. We understand this is another area that presents challenges for assessment based on current science and is likely to evolve in the coming years. In the meantime, we would appreciate discussion about how site managers and responsible parties would handle PFAS precursors in their current or pending site investigations – if at all. This is especially important because established methods do not exist for many PFAS compounds. Cleanups conducted on a limited number of analytical target PFAS may leave residual unidentified PFAS and significant uncertainty. Current science suggests that PFAS be addressed as classes of chemicals based on chemical structures that produce the toxicity, which is contrary to most other MTCA contaminants. How this would happen in practice at a site is very challenging to understand. There are analytical preparations such as the “total oxidizable precursor” (TOP) assay, which is one way to account for some precursors, although this method is unaccredited and is challenging to relate to site-specific conditions. There are also other non-specific PFAS methods incorporating time-of-flight mass spectrometry. This is another area where the scientific future is difficult to predict. Still, test methods such as the TOP assay are already being examined for use

in remediation strategies, such as the Compartmental Retention Framework for PFAS sites proposed by Newell et al. (2021) to assess monitored natural attenuation. From a public health perspective, the availability of test methods like the TOP assay provide a conservative approach to understanding the scope of PFAS contamination and can be useful for informing approaches needed, especially given the unknown toxicities within these classes of chemicals and the rapidly evolving advancements in this field.

In addition to the TOP assay, other non-specific analytical options such as Total Organic Fluorine, Extractable/Adsorbable Organic Fluorine are not noted in the guidance and may be relevant analytical tools in remedial investigations.

Response: Ecology added a general discussion on precursors to Section 4.1, and then expanded the discussion on the use of non-specific test methods in Section 4.3.2 to help identify potential precursors.

203. Clarity on regulation versus guidance and updating. We appreciate Ecology's citation and use of the Interstate Technology and Regulatory Council (ITRC) information on PFAS. We recommend that Ecology more explicitly state what parts of this guidance document are Ecology's scientific or technical recommendations, compared to those Ecology believes are required by law or rule. We also reiterate our recommendation that Ecology dedicate resources to regular, scheduled, biennial guidance updates with public comment opportunities comparable to SCUM updates. PFAS science is an enormous field which is rapidly evolving. It would be difficult and lead to inconsistent outcomes if individual site managers and responsible parties attempted to incorporate best available science from EPA, ITRC, and hundreds of other PFAS resources published almost daily.

Response: Ecology guidance documents use words like "should" or "recommend" to signify that certain provisions are recommended or suggested, but not mandated by rule. When a code citation is included or language such as "MTCA specifies" is used, then the provision is required. See response to comment No. 196 for Ecology's plan for updating the guidance.

204. Page 6 of 64: The hyperlink for Ecology's PFAS Chemical Action Plan is broken.

Response: The requested change was made to the guidance.

205. Section 3: Tables containing State Action Levels (SALs) and MTCA cleanup levels should include columns for PQLs (Practical Quantitation Limits) or similar detection limit metrics and their analytical methods to help readers understand current state of the art in detecting and quantifying PFAS in relation to regulatory criteria. Disclaimers or qualifying language can be added on detection limits as caveats to applying the criteria. In particular, Table 2 needs PQLs and/or necessary detection limits because Section 3.1.2 states that "Water systems that detect PFAS will be required to continue monitoring on a more frequent schedule."

Response: See response to comment No. 103.

206. Section 3.2.4 Surface water cleanup levels and 3.2.5 soil cleanup levels: a discussion on bioassays for compliance monitoring may be useful.

Response: bioassays are used to set cleanup levels that are sufficiently protective for a site, and not for compliance monitoring. Compliance would be determined be sampling soil, groundwater, and/or surface water and comparing concentrations in those media to establish cleanup levels.

207. Page 21 of 64, Table 5; units in parts per trillion (ppt) would be easier to read and consistent with cleanup level tables with similar low orders of magnitude.

Response: Units in mg/kg (part per million) were used to be consistent with how soil cleanup levels are expressed in CLARC.

208. Page 20 of 64: if we assume that the Kd and Koc parameters are based on saturated conditions (solid and liquid phases only), then the tendency for PFAS to sorb preferentially to air-water and NAPL-water interfaces would affect principally the vadose zone calculations. We recommend Ecology highlight this discussion and efforts to incorporate partitioning behavior best available science. The statement: “Studies have shown that air-water interfaces can account for up to 100% of the PFOS and PFOA retained in soil.” Please clarify if this statement is vadose zone soil only or if it includes the water table interface. Preferential partitioning of PFAS in low permeability units like clays is also not covered. This may be important in assessing secondary matrix diffusion, retardation, and back diffusion (rebound) effects.

Response: The referenced language was primarily focused on the vadose zone. PFAS migration from source areas is an area of active research and there are still numerous unknowns. Chapter 5 of the ITRC PFAS guidance document provides an excellent discussion on the current level of understanding.

209. Section 3.2 Establishing MTCA cleanup levels: Under MTCA, the PQL or background concentrations are considered when developing cleanup levels. We recommend a discussion be added to this section regarding role of PQLs and background in developing cleanup levels.

Response: See response to comment No. 78.

210. Section 3.4 might better be placed as an appendix, because it is superseded.

Response: See response to comment No. 15**.**

211. Section 4.3.2 We recommend non-specific test methods: other non-specific methods like TOF (Total Organic Fluorine), total EOF (Extractable Organic Fluorine) be mentioned and their potential uses in remedial investigation.

Response: See response to comment No. 202.

212. Section 5.1 Surface Water: it is not clear where the terms “no adverse effect” and “no significant adverse effect” are derived from.

Response: These terms come directly from MTCA. “No adverse effect” in relation to setting Method B cleanup levels is WAC 173-340-730(3)(b)(ii). “No significant adverse effect” in relation to setting Method C cleanup levels is in WAC173-340-730(4)(b)(ii).

213. Chapter 6 Treatment Technologies: As a cleanup guidance, limiting the topic of remediation to just treatment technologies seems incomplete. We recommend other MTCA remedies (ex situ or otherwise) like containment (capping and/or subsurface barrier walls), hydraulic control, permeable reactive barriers, institutional controls, and monitored natural attenuation be discussed as they relate to PFAS.

Response: The intent of Chapter 6 is to provide a general discussion on those treatment technologies that have been field demonstrated to be able to address PFAS compounds. Other remedial actions, such as those listed, can be considered during the evaluation of potential cleanup alternatives provided the procedures outlined in WAC 173-340-360 are followed.

214. Sections 6.1 (Liquid treatment technologies) and 6.2 (Treatment technologies for solid matrices) seem to lack supporting literature source citations.

Response: There are a number of sources in the reference section that support these sections.

215. Section 6.1.1.4 Liquid Colloidal Activated Carbon (CAC): We recommend mentioning that CAC can be used as a form of permeable reactive barrier wall to treat PFAS plumes near or downgradient from the source.

Response: The requested change was made to the guidance.

216. 6.2.1 Sorption and stabilization (immobilization) does not appear to discuss sorption at all.

Response: The definition of sorption is a physical and chemical process by which one substance becomes attached to another. This section provides examples of different media that are used to bind PFAS compounds which constitutes sorption of these chemicals.

217. 6.2.2 Excavation and off-site management: If possible, please clarify or provide more specificity on source excavation. To what extent (i.e., remediation or cleanup level) will PFAS contaminated soil be excavated? How will confirmation samples be taken? What constitutes effective source removal from a regulatory and exposure path standpoint?

Response: Providing specific details on the extent of PFAS contaminated soil removal necessary or the appropriate number of confirmation samples is site-specific and beyond the scope of this guidance.

218. Section 6.2.3 Thermal treatment. Please clarify or specify temperatures needed instead of just saying “high heat” (ITRC website says it may be temperatures upwards of 1,000^{O}C for soil). Potential adverse effects not mentioned include breakdown into other toxic, volatile chemicals (carbon tetrafluoride, hexafluoroethane, trifluoroacetic acid, and hydrogen fluoride), formation of smaller PFAS, greenhouse gases, and the limited available incinerators approved to completely destroy PFAS.

Response: The requested changes were made to the guidance.

219. Under Glossary: the definition of contaminated site should follow MTCA language (similar to Facility), being an area where hazardous substances have come to be located. Please check that the definition of sediment sites is consistent with Sediment Management Standards. Additionally, why are lakes are not included?

Response: Ecology expanded the definition of contaminated site to include "facility" and edited it to include all potential media such as groundwater, soil, and sediment. The Sediment Management Standards do not include a definition of "sediment sites." We revised the Glossary definition from "sediment site" to "sediment" and added "in waterbodies (such as riverbeds, seabeds, lakebeds)…."

220. Under Glossary: The term "upland site" is not previously used in WAC 173-340. It is not clear why this guidance is trying to use this rather limited definition here in the glossary. To us, an upland site is a contaminated site located in an upland and/or inland location or setting. Upland sites may or may not include incidental surface water bodies that are not the main focus of cleanup or a cleanup unit (unlike aquatic sites).

Response: The term "upland site" was removed from the guidance.

221. Additional matrices including landfill leachates, wastewater, and sediments are not addressed in the cleanup criteria. Could this document be used as a tool of reference for non-drinking water matrices? Criteria for additional matrices are necessary given the increasing number of identified per and polyfluoroalkyl substances (PFAS) sources and should be added in this guidance document.

Response: Ecology intends to expand the guidance in the future to provide information on sediments. Additional information on landfill leachate can be obtained from Ecology's Solid Waste Management Program and wastewater information is available from the Water Quality Program.

222. Though not currently regulated at state or federal levels, it may be worthwhile to consider the fate/transport and toxicological risks of electrochemically fluorinated PFAS such as sulfonamideor sulfonamido acetic acid-based PFAS (e.g., perfluorooctane sulfonamide [PFOSA] or methylperfluorooctane sulfonamido acetic acid [N-MeFOSAA], which are included in EPA method 1633. These classes of PFAS are characterized by a more neutral acid dissociation constant (pKa) compared to the other common perfluoroalkyl acids (PFAAs), which influence partitioning and distribution between soil and groundwater and will affect impacts on toxicological endpoints (Rayne and Forest, 2009; Rericha et al., 2022).

Response: As discussed in the response to comment No. 81, all PFAS compounds are considered hazardous substances under Washington law and rules. Therefore, the compounds listed above should be analyzed and reported when using Method 1633.

223. Chapter 2 provides a good overview of PFAS-polluted sites in Washington, mainly attributed to aqueous film-forming foam (AFFF) releases. The United States military is required to transition to PFAS-free firefighting foams by October 2023, per the National Defense Authorization Act of 2020. The Department of Defense (DoD) is required to stop using all PFAS-based foam by October 2024.

We suggest referencing Ecology's work on AFFF phase-out regulations and clarifying the role of the Department of Ecology in the effort to transition to fluorine-free foams (DOE, n.d.).

Response: Footnote No. 2 on page 1 provides a short description on the use of AFFF in Washington State, along with a link to the applicable state law. More information on Ecology's efforts on AFFF can be obtained from the Hazardous Waste and Toxics Reduction Program, but providing that specific information is beyond the scope of this guidance.

224. Section 3.2: Establishing MTCA Cleanup Levels, page 13. This section mentions: "*While final cleanup levels for a site will be established in the Cleanup Action Plan, it helps to set preliminary cleanup levels early in the cleanup process so all parties have a common understanding of the potential severity of contamination that might be found during the site investigation*."

We recommend adding information regarding how and when to use preliminary cleanup levels. For instance, can they be used for compliance considering that they are preliminary? Is there any qualitative severity scale (H/M/L) based on extent and levels of contamination?

The rapidly changing preliminary cleanup levels create uncertainty in the applicability of these values.

Response: There is no qualitative severity scale based on the levels of contamination. Preliminary cleanup levels are typically used early in the investigation process to help ensure that the detection levels used are low enough. As discussed in Section 3.2, preliminary cleanup levels also help identify whether a hazardous substance is present at concentrations that may warrant a cleanup action.

225. Potable Groundwater Cleanup Levels, page 17. This subsection mentions: "*Ecology expects that the SALS will be considered ARARs and therefore applied as the cleanup levels at sites where groundwater is currently being used, or may be used in the future, as a potable drinking water source*."

The sentence concludes that the established State Action Levels (SALs) pertain to potable drinking water. Please, clarify if the established SALs can be used for non-potable water, as suggested on page 16, and if they can be used for other matrices such as wastewater.

Response: WAC 173-340-720(6)(b)(i) allows Ecology to use the SALs when establishing cleanup levels for non-potable groundwater. However, Ecology would first need to determine the SALs are relevant and appropriate for the site in question, and as a result it is unlikely this approach would be utilized. The applicability of the SALs to wastewater would be determined by Ecology's water program.

226. Surface Water Cleanup Levels, page 18. This subsection states "However, these calculations can't be performed because chemical-specific BCFs are not available at this time for any PFAS." Bioconcentration factors (BCFs) are available from laboratory studies for many PFAS and can be used to support calculations of surface water cleanup levels based on fish or shellfish consumption. Reviews of BCF values for PFAS can be found in Burkhard et al. (2021) and Conder et al. (2021).

Response: Ecology uses BCFs developed by EPA under the Clean Water Act rather than developing BCFs ourselves. The document has been revised to reflect this.

227. Soil Cleanup Levels, page 21. The following comments refer to the PFAS soil concentrations that are estimated to be protective of potable groundwater listed in Table 5 and estimated using Model Toxics Control Act (MTCA) equation 747-1:

a. Does Ecology have plans to generate more site-specific cleanup levels for more specific regional soil types as opposed to the generalized "default soil characteristics" mentioned on page 20? Small variations in soil properties can significantly influence PFAS retention and release (Minh Hong Nguyen et al., 2020; Barzen-Hanson et al., 2017).

Response: At this time, Ecology does not plan to develop cleanup levels based on regional soil types, and would note that we have not developed regional cleanup levels for any compounds. As discussed in response to comment No. 13, an empirical demonstration can be used to account for site-specific conditions.

b. Branched and linear isomers of certain PFAS have been shown to have significantly different retention and transport characteristics under both saturated and unsaturated conditions (Schulz et al., 2020; Stults et al., 2022). Are there plans to differentiate between branched and linear isomers during analytical analyses and/or soil cleanup recommendations?

Response: At this time, Ecology does not plan to evaluate branched and linear isomers separately, for the purposes of developing soil cleanup levels.

c. The current MTCA equation 747-1 does not account for PFAS partitioning to the air-water interface, which can retain a significant proportion of PFAS in soil (Brusseau et al., 2019). Inclusion of an estimate of PFAS partitioning to the air-water interface would improve soil screening levels. Though more comprehensive models are being researched and published, two equations which can currently be found in the literature are listed below (Equations 1 and 2):

$$\mathit{Log}\ (Kia) = (0.020 * Vm) - 8.2 \quad (1)$$

where Vm is molar volume in cubic meters per mol (cm3 /mol) and Kia is air-water partitioning coefficient in cm-1 (Brusseau et al., 2019).

$$Kia = 7.84 * 10^{-6}\ e^{.427 * C18Rt} \quad (2)$$

where $C18_{Rt}$ is C18 retention time in minutes in a liquid chromatography system; Kia is in m-1 (Schaefer et al., 2019).

Response: As discussed in the response to comment No. 73, the use of modeling to develop site specific soil cleanup levels is an option that can be considered.

d. Table 1 shows a comparison table of the soil cleanup levels listed in Table 5 and the limits of quantification (MLs) described in the EPA draft 1633 method. The cleanup levels for all but PFBS and PFHxS are two orders of magnitude below MLs. These soil cleanup levels should be reconsidered due to achievable reported quantitation levels.

Table 1. Comparison of soil concentrations protective of potable groundwater listed in Table 5 to EPA method 1633 draft 3 minimum levels of quantitation.

PFAS	Vadose Zone	Saturated Zone	Units	1633[a] ML[b] (mg/kg)	Vadose Zone	Saturated Zone
PFOA	6.3E-05	4.0E-06	mg/kg	2.00E-04	Below ML	Below ML
PFOS	1.7E-04	9.9E-06	mg/kg	2.00E-04	Below ML	Below ML
PFNA	8.0E-05	4.8E-06	mg/kg	2.00E-04	Below ML	Below ML
PFHxS	4.1E-04	2.6E-05	mg/kg	2.00E-04	Above ML	Below ML
PFBS	1.8E-03	1.2E-04	mg/kg	2.00E-04	Above ML	Below ML
HFPO-DA	1.0E-04	7.2E-06	mg/kg	8.00E-04	Below ML	Below ML

[a] Values are for solid matrices from Table 6 EPA Method 1633 draft 3 (December 2022).
[b] Minimum level of quantitation (MLs) - The lowest level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte.
mg/kg – milligrams per kilogram.

Response: In Section 3.2.5, Ecology acknowledges that soil leaching cleanup levels for PFAS will often be below practical quantitation limits, so an emphasis on attaining low quantitation limits will be more important than the accuracy of the leaching cleanup levels. WAC 173-340-707 contains the criteria to be used when evaluating analytical limitations. In most cases, sites will be in compliance with MTCA if the cleanup level is less than the practical quantitation level. Ecology would note that this situation applies to other compounds such as cPAHs, PCBs, and EDB.

e. The cleanup levels specified in Table 5 do not consider the influence of background levels of PFAS that are ubiquitously present in the environment. For instance, detectable concentrations of PFAS in soils collected at remote locations in North America are generally 1 to 2 nanogram per gram (ng/g) or less (Strynar et al., 2012; Rankin et al., 2016). However, maximum concentrations of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) of 30 and 10 ng/g, respectively, have been found in soil samples collected from ambient background areas not in the known vicinity of PFAS sources in United States, China, Japan, Norway, Greece, and Mexico (Strynar et al., 2012). These values are typically below concentrations observed at sites impacted by AFFF (McGuire et al., 2014; Anderson et al., 2016). Most importantly, the likely upper ranges of ambient PFAS in soils is three to four orders of magnitude higher than some of the screening levels estimated by Ecology (e.g., Table 4 values protective of drinking water sources are as low as 0.004 to 0.010 ng/g for PFOA and PFOS). Thus, it is unlikely to find soils anywhere in the state of Washington that are lower than some of these values simply because of the non-point deposition of PFAS to soils that affect all areas of North America. Having a quantitative understanding of PFAS background is critical for assessing PFAS at a site of interest and for establishing cleaning up levels.

Therefore, background PFAS levels should be established, and these considerations should be included in Ecology's document.

Response: See response to comment No. 78.

228. Subsection 3.2.5 Soil Cleanup Levels (Screening Levels), Appendix A. The following comments are in reference to the default screening levels (SL) for soil leaching of PFAS to potable groundwater, listed in Table A-3b and estimated using MTCA equation 747-1.

The default SLs for soil leaching of PFAS to potable groundwater, shown in Table 2, are overly conservative when compared to the percentage of PFAS leaching from the soil. A 2023 study (Schaefer et al., 2023) demonstrated that for all PFAAs tested, the fractional decrease in porewater concentration exceeded the fractional decrease in mass removal from the soil. For instance, PFOS porewater concentrations decreased by 76% compared to only a 7.4% decrease in overall PFOS mass removed from the unsaturated zone (Schaefer et al., 2023). The general conclusion was that PFAS with six or more fluorinated carbons would desorb more slowly from soils and have less of an impact on soil pore water compared to shorter-chain PFAS. This suggests that less stringent soil cleanup criteria than the presented in Table A-3B (which considers an equivalent relationship between mass removal and mass discharge) should be used.

In addition, most of the values listed in Table 2 are below the ML values of the EPA method 1633 draft 3, which makes these values non-quantifiable.

Finally, Table A-3 in the guidance document mentions that MTCA Eq. 747-1 was used to determine the SL values. The same equation was used to determine the preliminary MTCA cleanup levels (Table 5). If the latter is true, the values in Table 5 and Table A-3 should match, but only PFOS and PFOA values are the same between the two tables.

We understand that screening values should be higher than the cleanup values. Please, clarify how the screening values were calculated. If the values were calculated with the stated criteria (MTCA Eq. 747-1), the screening and cleanup values should match, which is only the case for PFOS and PFOA.

Table 2. Comparison of default SL for soil leaching of PFAS to potable groundwater listed in Table A-3b to EPA method 1633 draft 3 minimum levels of quantitation.

PFAS	Vadose Zone	Saturated Zone	Units	1633[a] ML[b] (mg/kg)	Vadose Zone	Saturated Zone
PFOA	6.3E-05	4.0E-06	mg/kg	2.00E-04	Below ML	Below ML
PFOS	1.7E-04	9.9E-06	mg/kg	2.00E-04	Below ML	Below ML
PFNA	8.0E-05[c]	4.8E-06[c]	mg/kg	2.00E-04	Below ML	Below ML
PFHxS	4.1E-04[c]	2.6E-05[c]	mg/kg	2.00E-04	Above ML	Below ML
PFBS	1.8E-03[c]	1.2E-04[c]	mg/kg	2.00E-04	Above ML	Below ML
HFPO-DA	1.0E-04	7.2E-06	mg/kg	8.00E-04	Below ML	Below ML

[a] Values are for solid matrices from Table 6 EPA Method 1633 draft 3 (December 2022).
[b] Minimum level of quantitation (MLs) - The lowest level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte.
[c] Values that do not match with Table 5.

Response: See response to comment No. 13 for an option to address the potential for the soil to groundwater levels to be overly conservative. With respect to the comments regarding the Tables in Appendix A, these have been removed from the guidance and replaced with references to CLARC.

229. Subsection 4.1.1: Assemble Complete PFAS Analyte List, page 28. It may be valuable to establish a plan to take precursor PFAS into account as they may transform into terminal PFAAs (such as PFOA) and artificially inflate concentrations or create sustained concentrations over time.

Response: Ecology expanded the discussion on non-specific analytical methods in Section 4.3.2 to provide additional information on test methods that can help account for precursor PFAS compounds.

230. Section 4.2: Approved Methods and Compound List for Drinking Water. In this section, Ecology recommends the use of EPA methods 537 and 533 for the analysis of PFAS in drinking water.

Please clarify if Ecology expects analysis for all possible PFAS that can be detected with each method, or only the PFAS specified in the current cleanup criteria (six PFAS)? This is important since the analysis of additional PFAS may affect the detection limits depending on the concentration levels.

Please clarify Ecology's plans for other PFAS in the recommended analytical methods, other than the six for which there are proposed screening levels. Will results for all PFAS analyzed be required to be submitted to Ecology? Could these results be used to improve/establish SALs for other PFAS in the future?

Response: See responses to comments Nos. 81, 83 and 86. With respect to establishing SALs for other PFAS compounds, that decision would be made by the Department of Health.

231. Subsection 4.3.2: Non-Specific Test Methods. This section would benefit from more discussion of the uncertainties related to the Total Oxidizable Precursors (TOP) assay and how resulting data are best applied; specifically, since the TOP assay results in the aggressive chemical oxidation of PFAA precursors to stable PFCAs such as PFOA. This transformation process may not occur under environmental conditions, and data generated from TOP assays should not be directly compared to cleanup levels given the current high level of uncertainty regarding if and how quickly these processes may occur at sites.

Response: See response to comment No. 229.

232. CHAPTER 5 and Appendix B, Ecological Receptors: Concentrations Protective of Surface Water and Upland Soil. Ecology's development of toxicological benchmarks for PFAS should be detailed further. The information provided currently is not sufficient to justify the Ecology's process for selection of benchmarks. In some cases, there are technical challenges and potential errors with the selected benchmarks. Additional information behind Ecology's process would promote confidence and application of this information for decision-making purposes at PFAS sites.

a. For example, the selection of the No Observed Effect Concentration (NOEC) (8.28 micrograms per liter [µg/L]) for PFOA exposure to zebrafish (Jantzen et al., 2016) is unclear and may be overly conservative. From review of the study upon which it is based, Jantzen et al. (2016) noted that the 828 µg/L PFOA exposure (the highest exposure evaluated in the study) resulted in a 2% statistically significant adverse effect on the growth (length) of zebrafish exposed to PFOA. Biologically, a 2% level of adverse effect is generally considered trivial when deriving ecotoxicological benchmarks (often, effect sizes of 10%, 20%, or 50% are considered). Thus, the 828 µg/L PFOA could be considered a no-effect, safe level of PFOA exposure. There is no need to use the next lowest concentration in the study (8.28 µg/L) as the basis for protection.

Response: WAC 173-340-730(3)(b)(C)(ii) states that "For hazardous substances for which environmental effects-based concentrations have not been established under applicable state or federal laws, concentrations that are estimated to result in no adverse effects on the protection of wildlife, fish, and other aquatic life. Whole effluent toxicity testing using the protocols described in chapter 173-205 WAC may be used to make this demonstration."

It is important to note that this value was developed as an additional off-ramp (screening tool) for sites with PFOA contamination. In short, this value is provided to allow the user to possibly avoid costly environmental studies, such as Whole Effluent Toxicity Testing. It is agreed that this value is a conservative concentration – however, it is expected to be protective for aquatic ecological receptors in fresh waters at any MTCA site. It is also important to note that the value of 8.28ug/L is consistent with other documented freshwater references (Ding et al., 2012; Ji et al., 2008; and Spachmo and Arukwe, 2012). When applicable state or federal laws are established, the concentrations should default to those values.

b. It also appears that No Observed Adverse Effect Concentrations (NOAECs) or protective values that are below Low Observed Adverse Effect Concentrations (LOAECs) were applied for aquatic life, but LOAECs were applied for wildlife TRVs. This seems inconsistent. It may be more appropriate to target a threshold ≤ 20% effect (e.g., EC20), as these reflect a dose-response relationship and would provide more consistency in the cleanup level basis.

Response: Ecology acknowledges that there are multiple benchmark doses which may be considered when selecting a TRV, including an EC20 (or other values based on the magnitude of effect). However, NOAECs and LOAECs are currently specified as values to be used in MTCA, so those were used when developing this guidance. We also acknowledge that MTCA is inconsistent in the benchmarks for the different media – NOAECs for surface water and LOAECs for soil.

c. There may be additional instances in which a potentially questionable benchmark value has been selected by Ecology. Ecology should provide more detail on its benchmark derivation process (for all ecological endpoints) and specifically detail the effects and quantitative level of effects observed. Most importantly, Ecology should explicitly note which levels of effect it considers as meaningful points of departure for the regulation of potential adverse risks.

Additionally, the Plant bioaccumulation "KPlant" and earthworm bioaccumulation factor (BAF) values should be detailed further. Specifically, some of these values may be based on measurements of PFAS in tissue on a wet-weight basis and some may be on a dry-weight basis. Presenting the units for the KPlant and BAF values would be helpful, noting if they are on a wet or dry weight basis, and providing more details on the studies from which they were derived. Application of the KPlant and BAF values in models, if used inappropriately, could result in mathematical errors on a factor of as high as 5 to 10. Please be transparent with these calculations and provide more information.

Response:

i. While many of the values in the literature were reported on a dry-weight basis, some were reported on a wet-weight basis or on a "grams of organic carbon" basis. This happened more frequently for worm studies than for plant studies. Adjustments for work studies are described in Section B-4.2. Similar text on adjustments for plant studies has been added to Section B-4.1.

ii. Clarification on the units has been added to the header for Table B-3 and to Appendix Table 3.6, to clarify that all of the values are in the same units, following any necessary adjustments.

iii. The Kplant values in Appendix B, Attachment 3, Table 3.6 are adjusted for literature values, to yield final values of mg/kg $plant_{dw}$ and mg/kg $soil_{dw.}$

233. Section 6.1: Liquid Treatment Technologies. Multiple treatment technologies for PFAS in solid and liquid matrices are presented in the draft document. All the liquid treatment technologies are sorption technologies that generate a concentrated matrix requiring disposal, which may constitute an additional challenge for remediation efforts.

We suggest including the implications and challenges for use of sorptive technologies in terms of concentrated waste generation and/or the next steps/options available for the disposal of waste containing PFAS generated from a treatment technology.

Response: The suggested language on the need for management of a concentrated matrix was added to the guidance. Regarding disposal options for a concentrated waste matrix, see response to comment No. 91.

234. Subsection 6.2.3: Thermal Treatment. Although thermal treatment is included as an option, the ability of thermal treatment technologies to fully degrade PFAS is not fully understood, especially when it comes to mass balance. The pros and cons of thermal treatment options (and other options) should be mentioned in this section so that implications are considered when selecting treatment technologies.

Response: Additional language was added to this section, to better highlight the challenges to consider when evaluating this treatment option.

235. Subsection 6.2.4: Soil Washing. The effectiveness of soil washing for removal of PFAS is still being researched. Removal of PFAS depends on the PFAS of interest, with shorter chain PFAS (C<6) more readily removed while longer chain PFAS exhibit rate-limited, nonideal desorption. Soil type and time since the last PFAS exposure can also significantly influence PFAS removal efficiencies and rates (Minh Hong Nguyen et al., 2022). These complications should be mentioned in this section.

Response: See the response to comment No. 191.

236. General Comment: Off-site Disposal Alternatives for Waste Generated from the Operation of Selected Field-Tested Treatment Technologies. Various treatment technologies for both liquid and solid matrices require additional treatment or disposal. For instance, spent activated carbon, spent ion exchange resins containing PFAS, or contaminated soil recovered from the excavation require off-site disposal. The current draft guidance should include information regarding PFAS waste management strategies or off-site management options. This is a primary concern that should be addressed or referred to in this document so that facilities implementing treatment technologies know how to proceed when PFAS-containing waste is generated.

Response: Ecology acknowledges that some treatment technologies will result in the need for additional treatment or disposal, but including an explanation of the various waste management strategies for each technology is beyond the scope of this guidance. Regarding off-site management options, see the response to comment No. 91.

237. General Comment: Disposal Criteria for Investigation Derived Waste (IDW). The criteria for disposal of IDW is missing in the document and should be added, either in Chapter 6 or as an additional chapter/appendix. A section pertaining to IDW is critical as it constitutes a fundamental part of any investigation and/or cleanup operation.

Response: The suggested change was added to Section 6.2 of the guidance.

238. In the Senate Hearing The Devil They Knew Part III September 10, 2019 3M, Dupont, and Chemours stated that there are no PFAs Experts and request the Federal Government and Senate to please Regulate PFAs Chemicals. Who at the Federal Level is researching PFAs and getting Testing that meets Daubert Standards? These are supposed to be Federally Regulated Chemicals that need to be disposed at Military Radioactive Disposal Sites. Why are they in our National Water and Air? What documents are available from the Federal EPA, NIH, CDC and Senate and House Committees as of 2023?

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

239. Does the Department of Ecology have any Conflict's of Interest or Ethic's Disclosures? (the answer you are looking for is "YES").

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

240. Will the Department of Ecology get an Ethic's Advisor? Since they are trying to Regulate Chemicals/Physic Hazards that are no "Experts" and no Federal Scientific Standard for Testing Methods for Water and Air PFAs Pollution?

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

241. When will a Public Data Base be made that to links up Proprietary PFAs Chemicals back to Corporate Polluters to hold them Accountable for making Water/Air Toxic? What is the plan to make them pay for Clean Up of not properly disposing of their Proprietary Toxic Hazardous Chemicals Under CERLA? and "Failure to Warn".

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

242. How will Tax Paying Citizens be informed that they are Drinking Toxic Water and or Work Environment is Toxic?

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

243. How will this be billed back to the Polluting Companies?

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

244. Which Hospitals will be receiving Federal Funding for Scientific Detection and Documentation of PFAs Poisoning from Drinking Water and Breathing Air that is contaminated with Toxic Hazardous PFAs Chemcials that have no safe exposure rate. (At this moment There is no State of Federal: Public Health Training from Washington Department of Health, UW Medicine, Virgina Mason, and Everett Clinic do not have Training Protocols/ Doctors that are will to treat PFAs Chemicals Poisoning in humans.)

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

245. Is Washington State seeking Guaranteed Federal Funds from the NIH to monitor and get "Medicare For All" to make sure that Long Term Health Problems will not bankrupt exposed communities that have been impacted by Chemicals Poisoning.

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

246. Who is the Federal Contact for PFAs? Name, Agency, Date and Title.

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

247. What Federal Training is scheduled to being given?

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

248. What are the Federal Scientific Daubert Standard for measuring and correctly testing PFAs Contaminations? How will this be made public so affect communities have access.

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

249. The lifetime Safe Exposure Rate per Duponts Internal Worker Data is .01 PPB as of February 11, 2002. This is a 10 year safety stand at the Washington Works Plant and was relayed to EPA as of March 6th, 2002. (Most of the workers in these plants are sick/ dead and their illness was never correctly documented because lack of Federal Public Health Chronic Low Dose PFAs Poisoning Protocol)**.**

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

250. There are over 5,000 PFAs and only 6 that are being monitored. PFAs where never correctly disclosed by TSCA requirements by Manufacture that continued to lie to Federal and State Regulators and the safety of the 5,000 may be questionable at best.

Response: This comment is not germane to the content or overall purpose of the guidance, and therefore a detailed response is not provided.

251. We are unsure regarding the implications of this guidance on Lakewood Water District as a water utility. Because we regularly monitor PFAS levels throughout or water system, does this guidance impose cleanup responsibility on the District? The District has never been a generator or user of PFAS. The PFAS we detect and monitor presents a multi-million burden on the District in form of treatment and other improvements to fulfill our responsibilities to deliver reliable and safe drinking water. If this guidance now also imposes a duty to cleanup the PFAS contamination the District has detected, then those costs would explode exponentially. Please clarify whether water utilities, which are in fact victims of PFAS contamination, will now be required under this Guidance to also initiate Remedial Investigations and Feasibility Studies under CERCLA, RCRA and/or the MTCA.

Response: The guidance does not impose any additional responsibilities that don't currently exist under state law and rules. In general, responsibility for site investigation and cleanup rests with the persons that caused the contamination. The MTCA statute specifically indicates that persons who own, operate or exercise control over property where contamination has come to be located as a result of groundwater migration are exempt from liability provided certain conditions are met. The provisions that are most likely to affect this exemption include the owner of the property in question has not caused the contamination and allows access to their property for sampling and conducting remedial actions.

252. On page 6 of the Draft Guidance it is noted that "*EPA is overseeing the investigation and cleanup of PFAS at most of the federal military facilities with assistance from Ecology.*" Does Ecology expect or intend that the various RI/FS efforts underway at federal military facilities will follow this Guidance once finalized?

Response: Ecology is hopeful that investigation and cleanup actions in Washington state utilize the guidance, but a large portion of the guidance consists of recommendations that can be considered based on the site-specific circumstances. However, there are a number of specific references to MTCA rule language, such as the calculation of Method B cleanup levels, and it is Ecology's expectation that these requirements will be complied with. For sites being addressed under the Federal Superfund Program, Ecology is responsible for identifying state ARARs (i.e. applicable state requirements to the site in question) and communicating them to EPA.

253. Table 3 proposes Groundwater Cleanup Levels that are the same as the SAL established by the Department of Health for drinking water. We appreciate this approach to regulatory consistency.

Response: Ecology appreciates this comment.

254. We have two questions related to the establishment of Cleanup Levels instead of Maximum Contaminant Levels (MCL). The first question is Section 3.2.2 of the guidance document notes that no MCL for PFAS have been established at this time, and therefore, not included in the guidance. This section also notes that factors can be considered on a case-by-case basis. Now that EPA has proposed drinking water MCLs for six different PFAS substances, will the guidance be revised to include updated groundwater cleanup levels to match EPA's drinking water MCLs? We feel they should.

Related to the matter of setting a Cleanup Level rather than an MCL is cleanup funding. Ecology recently has taken the position that because there is no MCL for PFAS in groundwater, water utilities such as Lakewood Water District are not eligible for funding of PFAS removal/mitigation from the Remedial Action Grant (RAG) Safe Drinking Water Action Grant (SDWAG) program. Will water utilities continue to be barred from SDWAG funding after these Guidance Groundwater Cleanup Levels are set because they are not an MCL? Or will the proposed EPA Drinking Water MCLs qualify water utilities for funding from the SDWAG program?

Response: Ecology added a discussion to Section 3.2.2 indicating that once EPA promulgates an MCL for a particular PFAS compound, Ecology will consider the level to be an applicable state and federal requirement under the provisions in WAC 173-340-720. However, since the EPA MCLs for six PFAS compounds are proposed, they are not being used as groundwater cleanup levels at this time.

With respect to potential funding, the reason Safe Drinking Water Grants were not available in the past is because PFAS compounds were not identified as hazardous substances. In October 2021, Ecology concluded that all PFAS compounds meet the definition of hazardous substances, which addressed these specific criteria. The other important criterion is that Ecology needs to have determined the drinking water source exhibits levels of hazardous substances that exceed cleanup levels established by Ecology. There are now cleanup levels available in our CLARC database for seven PFAS compounds. Assuming that the other

applicable eligibility criteria are met, once a determination is made by Ecology that the drinking water source exceeds the appropriate cleanup levels, the applicant would be eligible subject to available funding.

255. Regarding the soil cleanup levels, as this inevitably impacts groundwater levels, how will those cleanup levels will be monitored or adjusted to confirm they result in groundwater PFAS levels lower than the proposed Cleanup Levels. Our concern is that if a site is cleaned up to current guidelines, and if the PFAS MCL is published at a low enough value, that the cleanup levels for indicated for soils may not be adequate.

Response: There are provisions in WAC 173-340-702(12) that address situations where cleanup levels change over time. In particular, the rule specifies that cleanup levels in effect at the time the final cleanup action plan (CAP) is issued are the applicable levels. Sites cleaned up to the levels identified in the CAP are not subject to further cleanup unless Ecology determines that the cleanup action is not protective of human health and the environment. Ecology intends to follow these rule provisions when dealing with changing cleanup levels.

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Appendix B – Ecological Receptors: Concentrations Protective of Surface Water and Upland Soil

B-1 Background information

Chapter 5 of the guidance provides a summary of the recommendations for addressing ecotoxicity from Ecology's PFAS Chemical Action Plan, identifies the applicable regulatory authority in MTCA, summarizes the decision-making process and includes the calculated protective values. This Appendix, along with the supporting Attachments, provides the details for how the protective values were calculated. The methodology is consistent with current rule language and generally accepted approaches for these types of calculations.

B-2 Surface water

Section B-2 provides information on the process used to determine surface water cleanup levels. A table summarizing the protective concentrations is included at the end of this Section.

B-2.1 Literature review

Protective concentrations that were included in the literature review are summarized in Attachment 1 of this Appendix. The literature review includes relevant publications that meet the surface water regulations described above.

B-2.2 Decision-making process

Protective concentrations were determined by a review of estimated no adverse effects on the protection and propagation of fish, invertebrates, and other aquatic life found in relevant literature. It is important to note that the documented protective concentration is not necessarily the lowest No Observed Adverse Effects Concentration (NOAEC), but instead a value was chosen that would be protective of the individual class of receptors (fish, invertebrates, other) that is also below a Lowest Observed Adverse Effects Concentration (LOAEC).

B-2.2.1 Perfluorobutane Sulfonic Acid (PFBS) – CAS# 375735:

- *Marine* – Acute 96 hr. test based on the Mysid, *Mysidopsis bahia. Marine water matrix* (Drottar et al., 2001a).
    - Protective value = 1.27E+05 ug/L. This value is based on a no-mortality concentration. A LOAEC was measured at 2.69E+05 ug/L, and an LC50 was measured at 3.72E+05 ug/L.
    - Confidence in value is low-medium due to a single acute test. Inclusion of both a NOAEC, LOAEC, and LC50 does improve confidence a bit. Also, this value appears consistent with the chronic freshwater value documented below.
- *Freshwater* – Chronic 21 day test based on *Daphnia Magna. Freshwater matrix* (Drottar et al., 2001b).

- ***Protective value = 5.02E+05 ug/L.*** This value is based on no adverse effects measured towards survival, reproduction, or growth. 9.95E+05 ug/L indicated reduced reproduction and length. *Daphnia magna* exposed to 1.88E+06 ug/L had significantly reduced survival. Second generation acute exposure indicated a NOAEC of 9.95E+05 ug/L.
- Confidence in value is medium-high due to a chronic test. Inclusion of both a NOAEC and LOAEC does improve confidence. Also this value appears consistent with the marine water value documented above.

B-2.2.2 Perfluorodecanoic Acid (PFDA) – CAS# 335762:

- **Marine** – 7 day test followed by another 7 days of depuration on the green mussel, *Perna viridis.* Marine water matrix (Lui et al., 2014).
  - ***Protective value = 7.80E+01 ug/L.*** This value is based on an EC50. The effects measured were DNA strand breaks and fragmentation, chromosomal breaks and apoptosis (death of cells).
  - Confidence in value is low-medium due to a single test with an EC50 endpoint. However, this value does appear consistent with freshwater values (NOAEC, EC50, Ding et al., 2011).
- **Freshwater** – 48 hour acute test (immobilization) on the freshwater invertebrate, *Chydorus sphaericus.* Freshwater matrix (Ding et al., 2011).
  - ***Protective value = 1.0E+01 ug/L***. This value is based on a NOAEC. The effects measured was immobilization. A 48-hour EC50 was measured at 8.88E+01 ug/L, a 24-hour NOAEC was measured at 8.00E+01 ug/L, and a 24-hour EC50 was measured at 1.41E+02 ug/L.

  Note: Confidence in value is medium due to NOAEC and EC50 values. In addition, test was completed on another species (*Daphnia magna)*, and the freshwater protective value does appear consistent with the marine water value documented above.

B-2.2.3 Perfluorononanoic Acid (PFNA) – CAS# 375951:

- **Marine** – 7 day test followed by 7 day depuration period on the green mussel *Perna viridis.* Marine water matrix (Liu and Gin, 2018).
  - ***Protective value = 1.04E+01 ug/L.*** This value is based on a NOAEC. The effect measured was biomarkers of the immune profile (neutral red retention, phagocytosis, and spontaneous cytotoxicity. A significant reduction of the immune profile was observed at 1.00E+02 ug/L.
  - Confidence in the value is medium-high due to the chronic test along with consistency with a similar test conducted a few years earlier on the same species with an EC50 (Liu et al., 2014).
- **Freshwater** – 48-hour acute toxicity test, a 21-day chronic test, a feeding experiment, and a biomarker assay were performed on *Daphnia magna.* Freshwater matrix. (Lu et al., 2014).

- ***Protective value = 8.00E+00 ug/L.*** This value is based on a NOAEC. The effects measured were body length, time to first pregnancy, time to first brood, number of first brood and number of offspring per brood per female. A significant difference was found at 4.00E+01 ug/L.

Note: Confidence in this value is high due to chronic testing, endpoints, and consistency with similar tests on invertebrates (Ding et al, 2012, Zhai et al, 2016).

B-2.2.4 Perfluorohexanoic Acid (PFHxA) – CAS# 307244:

- **Marine** – No testing information found/available at the time of this summary.
- **Freshwater** – 120 hours post fertilization toxicity test on larval zebrafish (*Danio rerio*). Additionally, exposed larvae were transferred to clean water and reared until 14 days post fertilization. Freshwater matrix (Annunzaito et al., 2019).
  - ***Protective value = 6.28E+03 ug/L.*** This value is based on 120-hours post fertilization test with endpoints of morphometric and gene expression – at 2 µM .
  - Confidence in this value is medium-high with other freshwater fish testing displaying consistent values (Germany Annex, 2018).

B-2.2.5 Perfluorohexane Sulfonic Acid (PFHxS) – CAS# 355464:

- **Marine** – No testing information found/available at the time of this summary.
- **Freshwater** – Two phase experimental design to assess the effects of exposure on trematode infection risk. Following exposures, parasite exposure on individual tadpoles. Tadpoles were exposed to chemicals for 10 days (Brown et al., 2020).
  - ***Protective value = 1.00E+01 ug/L.*** This value is based on a 10 ppb PFHxS treatment, which increased parasite loads by 17.5% compared with the control (p=0.006).
  - Confidence in this value is medium-high with other testing/recommendations consistent with these results (Persistent Organics Review Committee, 2018).

B-2.2.6 Perfluorooctanoic Acid (PFOA) – CAS# 335671:

- **Marine** – Effects on early life stages of microalgae (*Isochrysis galbana*), a primary consumer (*Paracentrotus lividus*), and two secondary consumers (*Siriella armata* and *Psetta maxima*) (Mhadhbi et al., 2012),
  - ***Protective value = 1.19E+02 ug/L.*** This value is based on a Predicted No Effect Concentration (PNEC) for algae, crustaceans, and fish in marine water. An assessment factor of 100 was used to derive these concentrations.
  - Confidence in this value is high. This value does appear consistent with other studies (Liu et al., 2014).
- **Freshwater** – Morphometric, behavior, and gene expression effects in both yolk fry sac and larval zebrafish. Zebrafish were exposed to the chemical for the first five days post fertilization and analyzed for up to 14 days post fertilization for effects (Jantzen et al., 2016).

- ***Protective value = 8.28E+00 ug/L.*** This value is based on exposure to a low range of concentrations (0.02 uM – 2.0 uM; 20 – 2000 ppb) resulted in chemical specific developmental defects and reduced post hatch survival.
- Confidence in this value is medium-high. While this value is more conservative than other literature values, it remains consistent with other document freshwater references (Ding et al., 2012; Ji et al., 2008; Spachmo and Arukwe, 2012).

B-2.2.7 Perfluorooctane Sulfonic Acid (PFOS) – CAS# 1763231:

- **Marine** – Effects on early life stages of microalgae (*Isochrysis galbana*), a primary consumer (*Paracentrotus lividus*), and two secondary consumers (*Siriella armata* and *Psetta maxima*) (Mhadhbi et al., 2012),
  - ***Protective value = 1.10E+00 ug/L.*** This value is based on a PNEC for algae, crustaceans, and fish in marine water. An assessment factor of 100 was used to derive these concentrations.
  - Confidence in this value is medium-high. This value is more conservative but does appear consistent with other studies (Liu et al., 2014).
- **Freshwater** – Effects are based on total emergence of the insect Chironomus tentans. Total emergence was decreased by 32% as compared to the control. The authors also report an EC10 of 8.9E+01 ug/L for total emergence. When taking a closer look at the data, however, this EC10 seems to be rather uncertain and preference is given to the NOAEC (Moermond et al., 2010; MacDonald et al, 2004).
  - ***Protective value = 2.3E+00 ug/L.*** See above.
  - Confidence in this value is high. Numerous studies support this concentration as a NOAEC (Moermond et al., 2010; MacDonald et al., 2004; Stefani et al., 2014).

B-2.2.8 Perfluorobutanoic Acid (PFBA) – CAS# 375244:

- **Marine** – No testing information found/available at the time of this summary.
- **Freshwater** – 48 hour acute test (immobilization) on the freshwater invertebrate, *Daphnia magna.* Freshwater matrix (Ding et al., 2011).
  - ***Protective value = 8.30E+02 ug/L.*** This value is based on a NOAEC. The effects measured was immobilization. A 48-hour EC50 was measured at 8.48E+02 ug/L, a 24-hour NOAEC was measured at 8.50E+02 ug/L, and a 24-hour EC50 was measured at 8.65E+02 ug/L.
  - Confidence in value is medium due to NOEC and EC50 values. In addition, test was also completed on another species (*Chydorus sphaericus)*.

B-2.2.9 Perfluoroundecanoic Acid (PFUnA) – CAS# 2058948:

- **Marine** – No testing information found/available at the time of this summary.
- **Freshwater** – 48 hour acute test (immobilization) on the freshwater invertebrate, *Chydorus sphaericus.* Freshwater matrix (Ding et al., 2011).
  - ***Protective value = 1.00E+01 ug/L.*** This value is based on a NOAEC. The effects measured was immobilization. A 48-hour EC50 was measured at

3.40E+01 ug/L, a 24-hour NOAEC was measured at 4.00E+01 ug/L, and a 24-hour EC50 was measured at 6.90E+01 ug/L.

- Confidence in value is medium due to NOAEC and EC50 values. In addition, test was completed on another species (*Chydorus sphaericus)*.

B-2.2.10 Perfluorododecanoic Acid (PFDoA) – CAS# = 307551:

- **Marine** – No testing information found/available at the time of this summary.
- **Freshwater** – 48 hour acute test (immobilization) on the freshwater invertebrate, *Chydorus sphaericus.* Freshwater matrix (Ding et al., 2011).
  - ***Protective value = 2.00E+01 ug/L***. This value is based on a NOAEC. The effects measured was immobilization. A 48-hour EC50 was measured at 4.60E+01 ug/L, a 24-hour NOAEC was measured at 2.00E+01 ug/L, and a 24-hour EC50 was measured at 5.40E+01 ug/L.

B-2.3 Summary of Protective Concentrations in Surface Water

Table B-1 Summary of protective concentrations in surface water based on a literature review of select PFAS.

Contaminant	Organism	PFBS	PFDA	PFNA	PFHxA	PFHxS	PFOA	PFOS	PFBA	PFUnA	PFDoA
Marine (µg/L)	**Invertebrates**	1.27E+05	7.80E+01	1.04E+01	x	x	5.94E+02	3.30E+01	x	x	x
Marine (µg/L)	**Fish**	x	x	x	x	x	1.50E+03	1.50E+01	x	x	x
Marine (µg/L)	**Other**	x	x	x	x	x	1.19E+02	1.10E+00	x	x	x
Marine (µg/L)	**Total protection**	**1.27E+05**	**7.80E+01**	**1.04E+01**	**x**	**x**	**1.19E+02**	**1.10E+00**	**x**	**x**	**x**
Freshwater (µg/L)	**Invertebrates**	5.02E+05	1.00E+01	8.00E+00	7.24E+05	x	4.91E+01	2.30E+00	8.30E+02	1.00E+01	2.00E+01
Freshwater (µg/L)	**Fish**	8.88E+05	x	1.00E+01	6.28E+03	x	8.28E+00	5.00E+00	x	x	x
Freshwater (µg/L)	**Other**	1.08E+06	x	x	5.00E+04	1.00E+01	5.00E+03	1.00E+02	x	x	x
Freshwater (µg/L)	**Total protection**	**5.02E+05**	**1.00E+01**	**8.00E+00**	**6.28E+03**	**1.00E+01**	**8.28E+00**	**2.30E+00**	**8.30E+02**	**1.00E+01**	**2.00E+01**

B-3 Uplands

Section B-3 provides information on the process used to determine upland cleanup levels. It is important to note that the methods used to develop the protective concentrations for PFAS are consistent with those methods used to establish the protective concentrations documented in MTCA Table 749-3.

Ecology developed the values in Table 749-3 in consultation with the MTCA Science Advisory Board Ecological Risk Subcommittee. The values are for use at sites where a site-specific terrestrial ecological evaluation is required or otherwise conducted, and are intended to be protective of terrestrial ecological receptors at any site. The values in Table 749-3 were calculated based on a lower level of acceptable risk than the values specified in Table 749-2 for conducting a simplified evaluation. This is the baseline or default level of acceptable risk. A higher level of acceptable risk is allowed for simplified terrestrial ecological evaluations.

Allowing for a lower level of risk, plant and soil biota values are based on the 10th percentile (Q10) of LOAECs instead of the 50th percentile (Q50) used to calculate values in Table 749-2. Wildlife values are the lowest of three values calculated for different wildlife groups using standardized exposure assumptions and chemical-specific toxicity reference values (TRVs) and uptake factors.

The value for unrestricted land use (the total protection value in Table B-4) is the lowest of the values specified for each of the three categories of terrestrial ecological receptors – plant, soil biota, and wildlife. The value for industrial and commercial land uses is the wildlife value.

Table B-2: Values used in Wildlife Exposure Model to calculate protective soil concentrations for wildlife. The equations used to calculate protective concentrations can be found in MTCA Table 749-4.

Parameter in equation	Details	Value
K_{plant}	plant uptake coefficient (mg/kg plant / mg/kg soil; dry weight basis)	derived from literature survey
BAF_{worm}	earthworm bioaccumulation factor (mg/kg worm / mg/kg soil; dry weight basis)	derived from literature survey
P_{SB}	proportion of contaminated food in diet (earthworms for shrew and robin, plants for vole)	0.5 - shrew 1.0 - vole 0.52 - robin
FIR	food ingestion rate (kg food/kg body weight; dry weight basis)	0.45 – shrew 0.315 – vole 0.207 - robin
SIR	soil ingestion rate (kg soil/kg body weight; dry weight basis)	0.0045 – shrew 0.0079 – vole 0.0215 - robin
RGAF	relative gut absorption factor (absorption from soil relative to absorption from food)	1
T	toxicity reference value (mg/kg/day)	derived from literature survey

B-3.1 Literature review

References included in the literature review and values taken from the literature for use in determining protective soil concentrations are presented in Appendix C and D.

Plant and soil biota protective concentrations were determined based entirely on LOAECs identified in the literature review. Details on the derivation of these values is included in the Derivation Process – Toxicity Values section below.

Wildlife protective concentrations were established based on the Wildlife Exposure Model described in the text (WAC 173-340-7493(3) (c)) and tables (Table 749-4 and 749-5) in MTCA. The equations included in the model allow the calculation of protective soil concentrations for a mammalian herbivore (vole), mammalian predator (shrew), and avian predator (robin). The model uses a combination of default and literature-derived values (Table B-2). Literature-derived values included toxicity reference values for both mammals and birds, earthworm bioaccumulation, and plant uptake. Toxicity reference values for birds and mammals are based on Lowest Observed Adverse Effects Levels (LOAELs) identified in the literature. Additional details on the literature-derived values are included in the following sections.

B-3.2 Derivation process – Toxicity values

Literature was reviewed with a focus on determining wildlife relevant lowest observed adverse effect levels. Relevant effects included significant impacts on apical endpoints (survival, growth, reproduction) relative to controls. The lowest relevant LOAEL or LOAEC identified in the literature was generally selected as the toxicity reference value. All relevant LOAELs or LOAECs identified in the literature are included in Appendix C. Toxicity reference values were not established for PFAS with only one LOAEL or LOAEC identified in the literature.

The methods in Efroymson et al. (1997a, 1997b) were used to determine how toxicity reference values were determined for plants and soil invertebrates, consistent with how the values in Table 749-3 were derived. Since less than 10 LOAEC values were identified for each PFAS, the lowest LOAEC identified in the literature was selected as the toxicity reference value, as opposed to using the 10^{th} percentile of literature LOAEC values. Consistent with the derivation of values in Table 749-3, only toxicity studies in earthworms were considered when deriving a soil biota protective value.

For mammalian species, to account for differences between laboratory and wildlife species, allometric scaling was applied to toxicity reference values. This was done using the equations in Sample et al. (1996), consistent with the derivation of values in Table 749-3. The reference values for rat, mouse, shrew, and vole body weight were used in the calculations. This resulted in different toxicity reference values for voles and shrews for each PFAS.

The outcome of the literature review was enough data to establish at least one protective value (plant, soil biota, and/or wildlife) for eight individual PFAS – PFBS, PFHxS, PFOS, PFHxA, PFOA, PFNA, PFDA, and PFDoA.

B-3.2.1 Perfluorobutane Sulfonic Acid (PFBS) – CAS# 375735

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
    - ***Toxicity reference value = 250 mg/kg/day***
    - Based on: NTP 2019a
    - In this study, rats were dosed twice daily via oral gavage for 28 days. One half of the desired total daily dose was administered in each dose. Selected LOAEL is based on increased percentage of females with abnormal estrous cycles.
    - Toxicity reference values, following allometric scaling, are 420 mg/kg/day for vole and 549.5 mg/kg/day for shrew.

B-3.2.2 Perfluorohexane Sulfonic Acid (PFHxS) – CAS# 355464

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
    - ***Toxicity reference value = 1 mg/kg/day***
    - Based on: Chang et al. 2018
    - In this study, mice were dosed daily via oral gavage beginning 14 days prior to mating and continuing through lactation day 21 (females) or 42 days of dosing (males). Pups were dosed for an additional 14 days following weaning, beginning on lactation day 22. Selected LOAEL is based on significantly reduced litter size.
    - Toxicity reference values, following allometric scaling, are 0.9 mg/kg/day for vole and 1.2 mg/kg/day for shrew.

B-3.2.3 Perfluorooctane Sulfonic Acid (PFOS) – CAS# 1763231

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Multiple studies with relevant LOAECs identified in the literature.
    - ***Protective soil concentration = 100 mg/kg soil***
    - Based on: Zareitalabad et al. 2013
    - Earthworms (*Aporrectodea caliginosa*) in this study were exposed to contaminated soil for 40 days. LOAEC based on significantly decreased survival at day 40.
- **Birds** – Multiple studies with relevant LOAELs found in the literature.
    - ***Toxicity reference value = 0.77 mg/kg/day***
    - Based on: Newsted et al. 2007, Gallagher et al. 2003a
    - In this study, bobwhite quail were exposed to PFOS in their feed for 21 weeks. Selected LOAEL is based on decreased survival of offspring at 14 days post-hatch.

- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
    - ***Toxicity reference value = 1.6 mg/kg/day***
    - Based on: Luebker et al. 2005
    - This study was a 2-generation reproduction study in rats. Rats were dosed via oral gavage for at least 42 days prior to mating through mating (males) or postnatal day 20. Dosing of F1 pups began on postnatal day 22. Selected LOAEL is based on significantly reduced viability index for F1 pups.
    - There were other studies with slightly lower LOAELs (1 mg/kg/day). Those LOAELs were based on decreases in adult body weight. The reproductive effects observed in the Luebker study were considered more relevant at the population level, and were selected as the basis for the toxicity reference value.
    - Toxicity reference values, following allometric scaling, are 2.7 mg/kg/day for vole and 3.5 mg/kg/day for shrew.

B-3.2.4 Perfluorohexanoic Acid (PFHxA) – CAS# 307244

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
    - ***Toxicity reference value = 200 mg/kg/day***
    - Based on: Klaunig et al. 2015
    - In this study, rats were dosed daily via oral gavage for 104 weeks. Selected LOAEL is based on significantly decreased survival in females.
    - Toxicity reference values, following allometric scaling, are 336 mg/kg/day for vole and 439.6 mg/kg/day for shrew.

B-3.2.5 Perfluorooctanoic Acid (PFOA) – CAS# 335671

- **Plants** – Multiple studies with relevant LOAECs identified in the literature.
    - ***Protective soil concentration = 50 mg/kg***
    - Based on: Kwak et al. 2020
    - Soil algae (*Chlorococcum infusionum*) was exposed to varying concentrations of PFOA for 6 days. LOAEC based on reduced algal biomass.
- **Soil Biota** – Multiple studies with relevant LOAECs identified in the literature.
    - ***Protective value = 25 mg/kg***
    - Based on: He et al. 2016
    - Earthworms (*Eisenia fetida*) in this study were exposed to contaminated soil for 28 days. LOAEC is based on decreased body weights at day 28.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
    - ***Toxicity reference value = 5 mg/kg/day***
    - Based on: Lau et al. 2006, Wolf et al. 2007

- In both of these studies, mice were dosed daily via oral gavage throughout pregnancy, beginning on gestation day 1. Dosing in the Lau study ended on gestation day 17 or 18 and in the Wolf study dosing continued through lactation for some dose groups. Selected LOAEL is based on significant decreases in reproductive success in both studies.
- Toxicity reference values, following allometric scaling, are 4.5 mg/kg/day for vole and 5.9 mg/kg/day for shrew.

B-3.2.6 Perfluorononanoic Acid (PFNA) – CAS# 375951

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
  - ***Toxicity reference value = 1.1 mg/kg/day***
  - Based on: Wolf et al. 2010
  - In this study, mice were dosed daily via oral gavage throughout pregnancy. Dosing began on gestation day 1. Selected LOAEL is based on significantly decreased reproductive success.
  - Toxicity reference values, following allometric scaling, are 1.0 mg/kg/day for vole and 1.3 mg/kg/day for shrew.

B-3.2.7 Perfluorodecanoic Acid (PFDA) – CAS# 335762

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
  - ***Toxicity reference value = 1 mg/kg/day***
  - Based on: Harris and Birnbaum 1989
  - In this study, mice were dosed daily via oral gavage during pregnancy. Two different dosing regimes were used: mothers were dosed daily on either gestation days 10-13 or on gestation days 6-15. Selected LOAEL is based on significantly decreased fetal weight.
  - Toxicity reference values, following allometric scaling, are 0.9 mg/kg/day for vole and 1.2 mg/kg/day for shrew.

B-3.2.8 Perfluorododecanoic Acid (PFDoA) – CAS# 307551

- **Plants** – Insufficient literature values identified to establish a protective value.
- **Soil Biota** – Insufficient literature values identified to establish a protective value.
- **Birds** – Insufficient literature values identified to establish a protective value.
- **Mammals** – Multiple studies with relevant LOAELs identified in the literature.
  - ***Toxicity reference value = 2.5 mg/kg/day***
  - Based on: Kato et al. 2015

- In this study, rats were dosed daily via oral gavage beginning 14 days prior to mating and continuing through postnatal day 5 (females) or 42 days of dosing (males). Selected LOAEL is based on decreased female survival and reproductive success.
- Toxicity reference values, following allometric scaling, are 4.2 mg/kg/day for vole and 5.5 mg/kg/day for shrew.

B-4 Derivation process – Bioaccumulation values

The studies selected for inclusion in determining the bioaccumulation values to use in the Wildlife Exposure Model were generally conducted in the laboratory, using either PFAS contaminated soils collected from field sites or clean soils spiked with PFAS. Studies that used paired measurements of PFAS in soil and plants or earthworms from a specific location in the field were considered if it seemed likely that the plant or earthworm exposure was primarily from contaminated soil, and not from, for example, potentially contaminated groundwater in the same location. In most of the reviewed studies, the organisms were exposed to a mixture of PFAS.

The 90th percentile of the distribution was selected as the reasonable maximum value of the literature-derived bioaccumulation factors. Statistical analysis, including goodness-of-fit tests and determination of the 10th percentile of the best fitting distribution, were done using ProUCL software.

B-4.1 Plants

Studies identified in the literature primarily focused on uptake in agricultural plants (vegetables, grains, etc.) Observed differences in uptake values for different PFAS were attributed to a number of factors, including carbon chain length, whether they contained a carboxylic acid or sulfonic acid functional group, and the characteristics of the tested soil. Percent organic carbon in the soil was specifically identified as a soil characteristic that impacted uptake into plant tissue. Plants grown in soils with higher organic carbon content exhibited less uptake of PFAS. Soils from studies in the literature review had varying organic carbon content, but generally were between 0 and 5% OC. Another general trend noted in the studies was that uptake factor decreased as the soil concentration of PFAS increased.

In most studies, uptake factors were calculated for subsections of the plant. Uptake factors for each plant part were included as distinct values in the distribution.

Values derived from the literature are presented in Appendix C. One case study reported values based on organic carbon-normalized soil concentrations, which were adjusted to total soil concentration using percent organic carbon reported in the study. One other study reported plant concentrations on a wet weight basis, and a plant wet weight to dry weight adjustment factor of 0.5 was applied to adjust the values. The K_{plant} values derived from those and used in the Wildlife Exposure Model and presented in Table 4.

B-4.2 Earthworms

Bioaccumulation values for earthworms were reported in a variety of units, depending on the study. All values were converted to dry weight worm / dry weight soil values, with adjusted values presented in Appendix C. For studies where the reported values were based on organic carbon-normalized soil concentrations, the organic carbon values reported in the study were used to adjust the values to total soil. For studies where wet weight worm concentrations were used, a worm wet weight to dry weight adjustment factor of 0.3 was applied to adjust the values, consistent with the value used in the derivation of values in Table 749-3.

Values derived from the literature are presented in Appendix C. The BAF values derived from those and used in the Wildlife Exposure Model and presented in Table 4.

Table B-3: Bioaccumulation Factors (K_{plant} and BAF_{worm}) derived from literature survey and used in Wildlife Exposure Model. Units are mg/kg $plant_{dw;}$ mg/kg $soil_{dw}$ for K_{plant} and mg/kg $worm_{dw;}$ mg/kg $soil_{dw}$ for $BAF_{worm.}$

Organism	PFBS	PFDA	PFNA	PFHxA	PFHxS	PFOA	PFOS	PFBA	PFUnA	PFDoA
Plant	6.60E+01	1.80E+00	1.20E+01	1.80E+01	2.20E+01	3.10E+01	1.00E+01	x	x	1.00E+00
Earthworm	2.40E+01	3.90E+01	2.80E+01	2.60E+00	1.53E+02	8.00E+00	9.10E+01	x	x	1.37E+02

B-5 Summary of protective soil concentrations in uplands

T**able B-4:** Summary of protective soil concentrations in uplands for PFAS.

Uplands Organism (mg/kg)	PFBS	PFDA	PFNA	PFHxA	PFHxS	PFOA	PFOS	PFBA	PFUnA	PFDoA
Plants	x	x	x	x	x	5.00E+01	x	x	x	x
Soil biota	x	x	x	x	x	2.50E+01	1.00E+02	x	x	X
Wildlife	2.02E+01	1.37E-01	2.06E-01	5.92E+01	3.49E-02	4.60E-01	7.84E-02	x	x	1.78E-01
Total protection	**2.02E+01**	**1.37E-01**	**2.06E-01**	**5.92E+01**	**3.49E-02**	**4.60E-01**	**7.84E-02**	**x**	**x**	**1.78E-01**

Appendix B Attachment 1: Surface Water Literature Summary

1.1 Marine Invertebrates

Chemical	Species	Concentration (µg/L)	Benchmark	Reference
PFBS	Mysid - *Mysidopsis bahia*	1.27E+05	NOAEC	Drottar, 2001 (a)
PFDA	Green Mussel - *Perna viridis*	7.80E+01	EC 50	Liu et al., 2014
PFNA	Green Mussel - *Perna viridis*	1.95E+02	EC 50	Liu et al., 2014
PFNA	*Perna viridis*	1.04E+01	NOAEC	Liu and Gin, 2018
PFOA	Sea urchin - *Paracentrotus lividius*	1.00E+04	NOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	5.00E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Green Mussel - *Perna viridis*	5.94E+02	EC 50	Liu et al., 2014
PFOA	Sea urchin - *Paracentrotus lividius*	2.00E+04	LOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella armata*	5.00E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Sea urchin - *Paracentrotus lividius*	3.07E+04	EC 10	Mhadhbi et al., 2012
PFOA	Sea urchin - *Paracentrotus lividius*	1.10E+05	EC 50	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	5.00E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	5.00E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	5.00E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	1.00E+04	LOAEC	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	7.80E+03	EC 10	Mhadhbi et al., 2012
PFOA	Zooplankton - *Siriella ormata*	1.55E+04	EC 50	Mhadhbi et al., 2012
PFOS	Zooplankton - *Siriella ormata*	1.25E+03	NOAEC	Mhadhbi et al., 2012
PFOS	Sea urchin - *Paracentrotus lividius*	1.00E+03	NOAEC	Mhadhbi et al., 2012
PFOS	Mysid - *Mysidopsis bahia*	1.10E+03	NOAEC	OECD, 2002
PFOS	Eastern oyster - *Crassostrea virginica*	1.90E+03	NOAEC	OECD, 2002
PFOS	Mysid - *Mysidopsis bahia*	2.50E+02	NOAEC	OECD, 2002
PFOS	Copepod - *Tigriopus japonicus*	1.00E+03	Effects	Jeonghoon et al., 2015
PFOS	Green Mussel - *Perna viridis*	3.30E+01	EC 50	Liu et al., 2014
PFOS	Zooplankton - *Siriella ormata*	1.25E+03	NOAEC	Mhadhbi et al., 2012
PFOS	Crustacean - *Americamysis bahia*	2.50E+02	NOAEC	Moermond et al., 2010
PFOS	*Mysidopsis bahia*	5.30E+02	NOAEC	Drottar and Krueger, 2000
PFOS	Sea urchin - *Paracentrotus lividius*	2.00E+03	LOAEC	Mhadhbi et al., 2012
PFOS	Sea urchin - *Paracentrotus lividius*	2.60E+03	EC 10	Mhadhbi et al., 2012
PFOS	Sea urchin - *Paracentrotus lividius*	2.00E+04	EC 50	Mhadhbi et al., 2012
PFOS	Zooplankton - *Siriella ormata*	2.50E+03	LOAEC	Mhadhbi et al., 2012
PFOS	Zooplankton - *Siriella ormata*	3.20E+03	EC 10	Mhadhbi et al., 2012

Chemical	Species	Concentration (µg/L)	Benchmark	Reference
PFOS	Zooplankton - *Siriella ormata*	6.90E+03	EC 50	Mhadhbi et al., 2012
PFOS	*Crassostrea virginica*	1.80E+03	NOAEC	Robertson, 1986

1.2 Marine Fish

Aquatic - Marine (ug/L)				
Fish				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOA	Turbot - *Psetta maxima*	1.50E+03	NOAEC	Mhadhbi et al., 2012
PFOA	Turbot - *Psetta maxima*	3.00E+03	LOAEC	Mhadhbi et al., 2012
PFOA	Turbot - *Psetta maxima*	3.90E+03	EC 10	Mhadhbi et al., 2012
PFOA	Turbot - *Psetta maxima*	1.19E+04	EC 50	Mhadhbi et al., 2012
PFOS	Turbot - *Psetta maxima*	1.50E+01	NOAEC	Mhadhbi et al., 2012
PFOS	Turbot - *Psetta maxima*	3.00E+01	LOAEC	Mhadhbi et al., 2012
PFOS	Turbot - *Psetta maxima*	2.00E+01	EC 10	Mhadhbi et al., 2012
PFOS	Turbot - *Psetta maxima*	1.10E+02	EC 50	Mhadhbi et al., 2012
PFOS	*Cypinodon variegatus*	1.50E+04	NOAEC	Palmer et al., 2002
PFOS	*Oryzias melastigma*	1.00E+03	NOAEC	Huang et al., 2011

1.3 Marine Other

Aquatic - Marine (ug/L)				
Other				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOA	Microalgae - *Isochrysis galbana*	2.50E+04	NOAEC	Mhadhbi et al., 2012
PFOA	Microalgae - *Isochrysis galbana*	5.00E+04	LOAEC	Mhadhbi et al., 2012
PFOA	Microalgae - *Isochrysis galbana*	4.16E+04	EC 10	Mhadhbi et al., 2012
PFOA	Microalgae - *Isochrysis galbana*	1.64E+05	EC 50	Mhadhbi et al., 2012
PFOA	Baseline Marine Organisms	1.19E+02	PNEC	Mhadhbi et al., 2012
PFOS	Algae - *Skeletonoma costatum*	>3200	NOAEC	OECD, 2002
PFOS	Microalgae - *Isochrysis galbana*	7.50E+03	NOAEC	Mhadhbi et al., 2012
PFOS	Microalgae - *Skeletonema costatum*	3.20E+03	NOAEC	Desjardins et al., 2001b
PFOS	Microalgae - *Isochrysis galbana*	1.50E+04	LOAEC	Mhadhbi et al., 2012
PFOS	Microalgae - *Isochrysis galbana*	1.22E+04	EC 10	Mhadhbi et al., 2012

Aquatic - Marine (ug/L)				
Other				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOS	Microalgae - *Isochrysis galbana*	3.75E+04	EC 50	Mhadhbi et al., 2012
PFOS	Baseline Marine Organisms	1.10E+00	PNEC	Mhadhbi et al., 2012

1.4 Freshwater Invertebrates

Aquatic - Freshwater (ug/L)				
Invertebrates				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFBS	Water flea - *Daphnia magna*	5.02E+05	NOAEC	Drottar et al., 2001(b)
PFHxA	*Daphnia Magna*	7.24E+05	EC5	Germany Annex, 2018
PFDA	*Chydorus sphaericus*	1.00E+01	NOAEC	Ding et al., 2012
PFDA	*Daphnia Magna*	1.50E+02	NOAEC	Ding et al., 2012
PFBA	*Chydorus sphaericus*	2.00E+03	NOAEC	Ding et al., 2012
PFBA	*Daphnia Magna*	8.30E+02	NOAEC	Ding et al., 2012
PFNA	*Chydorus sphaericus*	5.00E+01	NOAEC	Ding et al., 2012
PFNA	*Daphnia Magna*	2.00E+02	NOAEC	Ding et al., 2012
PFNA	*Daphnia Magna*	8.00E+00	NOAEC	Lu et al., 2015
PFNA	*Chironomus plumosus*	9.60E+00	NOAEC	Zhai et al., 2016
PFUnA	*Chydorus sphaericus*	1.00E+01	NOAEC	Ding et al., 2012
PFUnA	*Daphnia Magna*	1.00E+02	NOAEC	Ding et al., 2012
PFUnA	*Chironomus plumosus*	9.32E+02	NOAEC	Zhai et al, 2016
PFDoA	*Chydorus sphaericus*	2.00E+01	NOAEC	Ding et al., 2012
PFDoA	*Daphnia Magna*	1.20E+02	NOAEC	Ding et al., 2012
PFOA	*Daphnia magna*	2.50E+05	NOAEC	Ji et al., 2008
PFOA	*Moina macrocopa*	6.25E+04	NOAEC	Ji et al., 2008
PFOA	*Chydorus sphaericus*	1.00E+02	NOAEC	Ding et al., 2012

Aquatic - Freshwater (ug/L)				
Invertebrates				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOA	*Daphnia Magna*	5.00E+02	NOAEC	Ding et al., 2012
PFOS	*Daphnia magna*	1.25E+04	NOAEC	Ji et al., 2008
PFOS	*Moina macrocopa*	6.25E+03	NOAEC	Ji et al., 2008
PFOS	zooplankton community	3.00E+03	NOAEC	Boudreau et al., 2003
PFOS	cladocera/copepoda	2.00E+02	NOAEC	Boudreau et al., 2003
PFOS	Crustacean - *Daphnia magna*	7.00E+03	NOAEC	Moermond et al., 2010
PFOS	Crustacean - *Moina macrocopa*	4.00E+02	NOAEC	Moermond et al., 2010
PFOS	Insect - *Chironomus tentans*	<2.3	NOAEC	Moermond et al., 2010
PFOS	Insect - *Enallagma cyathigerum*	<10	NOAEC	Moermond et al., 2010
PFOS	*Daphnia pulicaria*	2.20E+03	NOAEC	Boudreau et al., 2003
PFOS	*Daphnia magna*	6.00E+02	NOAEC	Boudreau et al., 2003
PFOS	Chironomid - *Chironomus tentans*	5.00E+01	NOAEC	MacDonald et al., 2004
PFOS	*Chironomus riparius*	3.50E+00	NOAEC	Stefani et al., 2014
PFOS/PFOA	*Chironomus tentans*	4.91E+01	NOAEC	MacDonald et al., 2004

1.5 Freshwater Fish

Aquatic - Freshwater (ug/L)				
Fish				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFBS	*Pimephales promelas*	8.88E+05	NOAEC	WLI, 2001 (c)
PFBS	*Lepomis macrochirus*	2.72E+06	NOAEC	WLI, 2001 (d)
PFHxA	*Oncorhynchus mykiss*	9.96E+03	LOAEC	Germany Annex, 2018
PFHxA	*Danio rerio*	6.28E+03	NOAEC	Annunzaito et al., 2020
PFNA	*Danio rerio*	1.00E+01	NOAEC	Zhang et al., 2016
PFNA	*Danio rerio*	9.20E+02	NOAEC	Jantzen et al., 2016

Aquatic - Freshwater (ug/L)				
Fish				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOA	*Salmo salar*	1.00E+02	LOAEC	Spachmo and Arukwe, 2012
PFOA	*Oryzias latipes*	1.00E+02	NOAEC	Ji et al., 2008
PFOA	*Danio rerio*	8.28E+00	NOAEC	Jantzen et al., 2016
PFOA	*Salmo salar*	1.00E+02	NOAEC	Spachmo and Arukwe, 2012
PFOS	*Pimephales promelas*	3.20E+03	NOAEC	Drottar and Krueger, 2000 (h)
PFOS	Fathead minnow - *Pimephales promelas*	3.00E+02	NOAEC	OECD, 2002
PFOS	Bluegill sunfish - *Lepomis macrochirus*	> 86, < 870	NOAEC	OECD, 2002
PFOS	Fathead minnow - *Pimephales promelas*	2.70E+01	NOAEC	Moermond et al., 2010
PFOS	Japanese rice fish - *Oryzias latipes*	<10	NOAEC	Moermond et al., 2010
PFOS	*Onchorhynchus mykiss*	6.30E+03	NOAEC	Palmer et al., 2002
PFOS	*Oryzias latipes*	1.00E+01	NOAEC	Ji et al., 2008
PFOS	Pimephales promelas	2.90E+02	NOAEC	Drottar and Krueger, 2000
PFOS	*Zebra danio*	5.00E+00	NOAEC	Wang et al., 2011

1.6 Freshwater Other

Aquatic - Freshwater (ug/L)				
Other				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFBS	Algae - *Selenastrum capricornum*	1.08E+06	NOAEC	WLI, 2001 €
PFHxA	Cyanobacteria	5.00E+04	NOAEC	Germany Annex, 2018
PFHxS	*Rana pipiens*	1.00E+01	LOAEC	Persistent Organics Review, 2018
PFHxS	*Lithobates pipiens*	1.00E+01	LOAEC	Brown et al., 2020
PFOA	blue-green algae	5.00E+03	LOAEC	Rodea-Palomares et al., 2015
PFOS	*Xenopus laevis*	1.00E+02	NOAEC	Cheng et al., 2011

Aquatic - Freshwater (ug/L)				
Other				
Chemical	**Species**	**Concentration (µg/L)**	**Benchmark**	**Reference**
PFOS	Algae - *Selenastrum capricornutum*	<26000	NOAEC	OECD, 2002
PFOS	Algae - *Selenastrum capricornutum*	1.60E+04	EC 10	OECD, 2002
PFOS	Algae - *Chorella vulgaris*	8.20E+03	NOAEC	Moermond et al., 2010
PFOS	Algae - *Navicula pelliculosa*	1.91E+05	NOAEC	Moermond et al., 2010
PFOS	Algae - *Pseudokirchneriella subcapitata*	5.30E+04	NOAEC	Moermond et al., 2010
PFOS	Lemna Gibba	6.60E+03	NOAEC	Boudreau et al., 2003a
PFOS	Zooplankton Community	3.00E+03	NOAEC	Boudreau et al., 2003b
PFOS	Macroalgae - *Myriophyllum sibiricum*	3.00E+02	NOAEC	Hansen et al., 2005
PFOS	Xenopus laevis	4.82E+03	NOAEC	Palmer and Krueger, 2001
PFOS	Microalgae - *Chlorella vulgaris*	8.20E+03	NOAEC	Boudreau et al. 2003a
PFOS	Cyanobacteria - Anabaena flos-aqua	9.40E+04	NOAEC	Moermond et al., 2010
PFOS	Amphibian - *Xenopus laevis*	5.00E+03	NOAEC	Moermond et al., 2010
PFOS	*Selanastrum capricortum*	5.30E+03	NOAEC	Boudreau et al., 2003a
PFOS	Macrophyte - *Lemna gibba*	6.60E+03	NOAEC	Moermond et al., 2010
PFOS	Macrophyte - *Myriophyllum sibiricum*	5.60E+02	NOAEC	Moermond et al., 2010
PFOS	Macrophyte - *Myriophyllum spicatum*	3.20E+03	NOAEC	Moermond et al., 2010

Appendix B Attachment 2: Surface Water References

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Appendix B Attachment 3: Upland Literature Summary

3.1 Background

Toxicity tables include relevant LOAELs found during the literature survey. These values were considered in the selection of final protective concentrations for plants and soil biota and toxicity reference values for mammals and birds. Bioaccumulation tables include relevant values identified in the literature and included in the derivation of 90th percentile values. Many of the bioaccumulation studies evaluated multiple soil types or multiple concentrations of PFAS, leading to multiple entries in the tables for a specific PFAS.

The reference list in Appendix D includes all reviewed studies. Reasons a study may be listed in the References but not appear in these tables include providing bioaccumulation data for a PFAS with no identified toxicity data; providing the only relevant LOAEL or LOAEC for a specific PFAS; and that a relevant LOAEL, LOAEC, or bioaccumulation value could not be identified in the study.

3.2 Plant toxicity

CHEMICAL	SPECIES	SOIL CONCENTRATION (mg/kg)	BENCHMARK – EFFECT	REFERENCE
PFOA	sorghum	66	EC50 – chlorophyll	Gonzalez-Naranjo et al. 2015
PFOA	mung bean	100	LOAEC - growth	Kwak et al. 2020
PFOA	rice	300	LOAEC - growth	Kwak et al. 2020
PFOA	soil algae (*Chlorococcum infusionum*)	50	LOAEC - growth	Kwak et al. 2020
PFOA	soil algae (*Chlamydomonas reinhardtii)*	700	LOAEC - growth	Kwak et al. 2020
PFOA	Chinese cabbage	100	LOAEC - growth	Zhao et al. 2011
PFOA	wheat	800	LOAEC - growth	Zhou et al. 2016

3.3 Soil biota (earthworm) toxicity

CHEMICAL	SOIL CONCENTRATION (mg/kg)	BENCHMARK – EFFECT	REFERENCE
PFOA	25	LOAEC - growth	He et al. 2016
PFOA	600	LOAEC - survival	Kwak et al. 2020
PFOA	100	LOAEC - survival	Zareitalabad et al. 2013
PFOS	141	LOAEC - survival	Sindermann et al. 2002
PFOS	120	LOAEC - growth	Xu et al. 2013
PFOS	100	LOAEC - survival	Zareitalabad et al. 2013

3.4 Avian toxicity

CHEMICAL	SPECIES	DOSE (mg/kg/day)	BENCHMARK – EFFECT	REFERENCE
PFOS	bobwhite quail	0.77	LOAEL - reproduction	Newsted et al. 2007/Gallagher 2003a
PFOS	mallard duck	6.4	LOAEL - survival	Newsted et al. 2007/Gallagher 2003b
PFOS	bobwhite quail	61	LD50	Newsted et al. 2006/Gallagher 2004a
PFOS	mallard duck	150	LD50	Newsted et al. 2006/Gallagher 2004b
PFOS	Japanese quail	11	LOAEL - growth	Bursian et al 2020

3.5 Mammalian toxicity

CHEMICAL	SPECIES	LOAEL (mg/kg/day)	REFERENCE
PFBS	rat	600	Lieder et al. 2009a
PFBS	rat	1000	Lieder et al. 2009b
PFBS	rat	250	NTP 2019b
PFDA	mouse	1	Harris and Birnbaum 1988
PFDA	rat	1.25	NTP 2019a
PFDoA	rat	2.5	Kato et al. 2015
PFDoA	rat	3	Shi et al. 2009
PFDoA	rat	5	Shi et al.2007
PFHxA	rat	200	Klaunig et al. 2015
PFHxA	rat	1000	NTP 2019a
PFHxS	rat	1	Butenhoff et al. 2009a
PFHxS	mouse	1	Chang et al. 2018
PFHxS	rat	5	Ramhoj et al. 2018
PFNA	mouse	5	Das et al. 2015
PFNA	rat	5	NTP 2019a
PFNA	mouse	1.1	Wolf et al. 2010
PFOA	rat	30	Butenhoff et al. 2004/York et al. 2010
PFOA	mouse	5	Lau et al. 2006
PFOA	rat	5	NTP 2019a
PFOA	rat (males only)	6.5	Perkins et al. 2004
PFOA	mouse	5	Wolf et al. 2007/White et al. 2009
PFOS	rat	10	Austin et al. 2003
PFOS	rat	1	Butenhoff et al. 2009b
PFOS	rabbit	1	Case et al. 2001
PFOS	mouse	25	Dong et al. 2009
PFOS	rat	10	Gortner 1980
PFOS	rat	3	Lau et al. 2003/Thibodeaux et al. 2003
PFOS	mouse	10	Lau et al. 2003/Thibodeaux et al. 2003
PFOS	rat	1.6	Luebker et al. 2005b
PFOS	rat	20	Thomford 2002/Seacat et al. 2003

3.6 Plant bioaccumulation

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFBS	alfalfa shoot	107	Lasee et al. 2019
PFBS	alfalfa root	36	Lasee et al. 2019
PFBS	carrot shoot	58	Lasee et al. 2019
PFBS	carrot root	5.9	Lasee et al. 2019
PFBS	radish shoot	69	Lasee et al. 2019
PFBS	radish root	72	Lasee et al. 2019
PFBS	radish root	1.3	Blaine et al. 2014
PFBS	radish shoot	3.4	Blaine et al. 2014
PFBS	celery root	2.5	Blaine et al. 2014
PFBS	celery shoot	2.2	Blaine et al. 2014
PFBS	tomato root	0.71	Blaine et al. 2014
PFBS	tomato shoot	3.7	Blaine et al. 2014
PFBS	tomato fruit	0.42	Blaine et al. 2014
PFBS	pea root	0.89	Blaine et al. 2014
PFBS	pea shoot	4.1	Blaine et al. 2014
PFBS	pea fruit	0.33	Blaine et al. 2014
PFBS	radish stem	69	Lasee et al. 2020
PFBS	radish root	72	Lasee et al. 2020
PFBS	carrot stem	77	Lasee et al. 2020
PFBS	carrot root	7.5	Lasee et al. 2020
PFBS	alfalfa stem	114	Lasee et al. 2020
PFBS	alfalfa root	3	Lasee et al. 2020
PFBS	radish stem	22	Lasee et al. 2020
PFBS	radish root	0.86	Lasee et al. 2020
PFBS	carrot stem	24	Lasee et al. 2020
PFBS	carrot root	0.06	Lasee et al. 2020
PFBS	alfalfa stem	6.7	Lasee et al. 2020
PFBS	alfalfa root	0.74	Lasee et al. 2020
PFBS	tomato leaf	3.8	Lasee et al. 2020
PFBS	tomato root	0.61	Lasee et al. 2020
PFBS	tomato stem	0.29	Lasee et al. 2020
PFBS	tomato fruit	0.19	Lasee et al. 2020
PFBS	wheatgrass	28	Braunig et al. 2019
PFBS	wheatgrass	36	Braunig et al. 2019

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFBS	maize straw	3.9	Krippner et al. 2015
PFBS	maize straw	1.8	Krippner et al. 2015
PFBS	maize kernels	0.008	Krippner et al. 2015
PFBS	maize kernels	0.005	Krippner et al. 2015
PFBS	wheat whole plant	39	Zhao et al. 2014
PFBS	wheat whole plant	34	Zhao et al. 2014
PFBS	wheat whole plant	26	Zhao et al. 2014
PFBS	corn leaf	4.0	Navarro et al. 2017
PFDA	maize straw	0.03	Krippner et al. 2015
PFDA	maize straw	0.04	Krippner et al. 2015
PFDA	radish root	0.44	Blaine et al. 2014
PFDA	radish shoot	1.1	Blaine et al. 2014
PFDA	celery root	1.1	Blaine et al. 2014
PFDA	celery shoot	0.32	Blaine et al. 2014
PFDA	tomato root	1.9	Blaine et al. 2014
PFDA	tomato shoot	1.4	Blaine et al. 2014
PFDA	pea root	1.4	Blaine et al. 2014
PFDA	pea shoot	0.15	Blaine et al. 2014
PFDA	wheat whole plant	1.8	Zhao et al. 2014
PFDA	wheat whole plant	1.7	Zhao et al. 2014
PFDA	wheat whole plant	1.5	Zhao et al. 2014
PFDA	tomato stem	0.24	Navarro et al. 2017
PFDA	tomato fruit	0.02	Navarro et al. 2017
PFDA	grass leaf	1.1	Zhu et al. 2019
PFDoA	wheat whole plant	1.0	Zhao et al. 2014
PFDoA	wheat whole plant	1.0	Zhao et al. 2014
PFDoA	wheat whole plant	0.9	Zhao et al. 2014
PFHxA	wheatgrass	15	Braunig et al. 2019
PFHxA	wheatgrass	18	Braunig et al. 2019
PFHxA	maize straw	3.2	Krippner et al. 2015
PFHxA	maize straw	2.8	Krippner et al. 2015
PFHxA	maize kernels	0.12	Krippner et al. 2015
PFHxA	maize kernels	0.22	Krippner et al. 2015
PFHxA	radish root	1.2	Blaine et al. 2014
PFHxA	radish shoot	3.9	Blaine et al. 2014

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFHxA	celery root	4.8	Blaine et al. 2014
PFHxA	celery shoot	12	Blaine et al. 2014
PFHxA	tomato root	1.5	Blaine et al. 2014
PFHxA	tomato shoot	8.9	Blaine et al. 2014
PFHxA	tomato fruit	2.9	Blaine et al. 2014
PFHxA	pea root	1.0	Blaine et al. 2014
PFHxA	pea shoot	3.5	Blaine et al. 2014
PFHxA	pea fruit	1.5	Blaine et al. 2014
PFHxA	wheat kernels	6.8	Liu et al. 2017
PFHxA	maize kernels	2.0	Liu et al. 2017
PFHxA	wheat whole plant	16	Zhao et al. 2014
PFHxA	wheat whole plant	15	Zhao et al. 2014
PFHxA	wheat whole plant	14	Zhao et al. 2014
PFHxA	tomato stem	1.8	Navarro et al. 2017
PFHxA	tomato leaf	6.9	Navarro et al. 2017
PFHxA	tomato fruit	3.6	Navarro et al. 2017
PFHxS	alfalfa shoot	12	Lasee et al. 2019
PFHxS	alfalfa root	11	Lasee et al. 2019
PFHxS	carrot shoot	28	Lasee et al. 2019
PFHxS	carrot root	1.1	Lasee et al. 2019
PFHxS	radish shoot	33	Lasee et al. 2019
PFHxS	radish root	13	Lasee et al. 2019
PFHxS	radish root	2.1	Blaine et al. 2014
PFHxS	radish shoot	7.4	Blaine et al. 2014
PFHxS	celery root	5.0	Blaine et al. 2014
PFHxS	celery shoot	2.3	Blaine et al. 2014
PFHxS	tomato root	1.8	Blaine et al. 2014
PFHxS	tomato shoot	5.6	Blaine et al. 2014
PFHxS	tomato fruit	0.5	Blaine et al. 2014
PFHxS	pea shoot	4.3	Blaine et al. 2014
PFHxS	pea fruit	0.17	Blaine et al. 2014
PFHxS	radish stem	34	Lasee et al. 2020
PFHxS	radish root	13	Lasee et al. 2020
PFHxS	carrot stem	40	Lasee et al. 2020
PFHxS	carrot root	1.6	Lasee et al. 2020

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFHxS	alfalfa stem	14	Lasee et al. 2020
PFHxS	alfalfa root	12	Lasee et al. 2020
PFHxS	radish stem	23	Lasee et al. 2020
PFHxS	radish root	0.59	Lasee et al. 2020
PFHxS	carrot stem	10	Lasee et al. 2020
PFHxS	carrot root	0.09	Lasee et al. 2020
PFHxS	alfalfa stem	2.3	Lasee et al. 2020
PFHxS	alfalfa root	0.45	Lasee et al. 2020
PFHxS	tomato leaf	2.5	Lasee et al. 2020
PFHxS	tomato root	0.4	Lasee et al. 2020
PFHxS	tomato stem	0.11	Lasee et al. 2020
PFHxS	tomato fruit	0.11	Lasee et al. 2020
PFHxS	wheatgrass	12	Braunig et al. 2019
PFHxS	wheatgrass	9.7	Braunig et al. 2019
PFHxS	maize straw	0.84	Krippner et al. 2015
PFHxS	maize straw	0.85	Krippner et al. 2015
PFHxS	wheat whole plant	4.2	Zhao et al. 2014
PFHxS	wheat whole plant	4.0	Zhao et al. 2014
PFHxS	wheat whole plant	3.6	Zhao et al. 2014
PFHxS	corn leaf	9.4	Navarro et al. 2017
PFNA	alfalfa shoot	1.7	Lasee et al. 2019
PFNA	alfalfa root	5.3	Lasee et al. 2019
PFNA	carrot shoot	18	Lasee et al. 2019
PFNA	carrot root	1.4	Lasee et al. 2019
PFNA	radish shoot	36	Lasee et al. 2019
PFNA	radish root	9.6	Lasee et al. 2019
PFNA	radish root	1.3	Blaine et al. 2014
PFNA	radish shoot	5.3	Blaine et al. 2014
PFNA	celery root	1.9	Blaine et al. 2014
PFNA	celery shoot	0.69	Blaine et al. 2014
PFNA	tomato root	1.9	Blaine et al. 2014
PFNA	tomato shoot	2.4	Blaine et al. 2014
PFNA	pea root	1.7	Blaine et al. 2014
PFNA	pea shoot	0.44	Blaine et al. 2014
PFNA	pea fruit	0.07	Blaine et al. 2014

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFNA	radish stem	38	Lasee et al. 2020
PFNA	radish root	10	Lasee et al. 2020
PFNA	carrot stem	23	Lasee et al. 2020
PFNA	carrot root	1.9	Lasee et al. 2020
PFNA	alfalfa stem	1.7	Lasee et al. 2020
PFNA	alfalfa root	5.5	Lasee et al. 2020
PFNA	radish stem	6.9	Lasee et al. 2020
PFNA	radish root	0.61	Lasee et al. 2020
PFNA	carrot stem	1.4	Lasee et al. 2020
PFNA	carrot root	0.21	Lasee et al. 2020
PFNA	alfalfa stem	0.46	Lasee et al. 2020
PFNA	alfalfa root	0.64	Lasee et al. 2020
PFNA	tomato leaf	0.59	Lasee et al. 2020
PFNA	tomato root	0.46	Lasee et al. 2020
PFNA	tomato stem	0.09	Lasee et al. 2020
PFNA	tomato fruit	0.02	Lasee et al. 2020
PFNA	wheatgrass	0.13	Braunig et al. 2019
PFNA	maize straw	0.12	Krippner et al. 2015
PFNA	maize straw	0.16	Krippner et al. 2015
PFNA	wheat kernels	1.1	Liu et al. 2017
PFNA	wheat whole plant	2.1	Zhao et al. 2014
PFNA	wheat whole plant	2.0	Zhao et al. 2014
PFNA	wheat whole plant	1.6	Zhao et al. 2014
PFNA	tomato leaf	0.28	Navarro et al. 2017
PFNA	grass leaf	2.0	Zhu et al. 2019
PFOA	alfalfa shoot	10	Lasee et al. 2019
PFOA	alfalfa root	19	Lasee et al. 2019
PFOA	carrot shoot	54	Lasee et al. 2019
PFOA	carrot root	3.1	Lasee et al. 2019
PFOA	radish shoot	47	Lasee et al. 2019
PFOA	radish root	18	Lasee et al. 2019
PFOA	radish root	0.85	Blaine et al. 2014
PFOA	radish shoot	7.6	Blaine et al. 2014
PFOA	celery root	1.4	Blaine et al. 2014
PFOA	celery shoot	0.71	Blaine et al. 2014

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFOA	tomato root	0.96	Blaine et al. 2014
PFOA	tomato shoot	2.4	Blaine et al. 2014
PFOA	tomato fruit	0.11	Blaine et al. 2014
PFOA	pea root	0.79	Blaine et al. 2014
PFOA	pea shoot	0.52	Blaine et al. 2014
PFOA	pea fruit	0.03	Blaine et al. 2014
PFOA	alfalfa shoot	3.1	Wen et al. 2016
PFOA	radish stem	46	Lasee et al. 2020
PFOA	radish root	18	Lasee et al. 2020
PFOA	carrot stem	74	Lasee et al. 2020
PFOA	carrot root	3.8	Lasee et al. 2020
PFOA	alfalfa stem	10	Lasee et al. 2020
PFOA	alfalfa root	19	Lasee et al. 2020
PFOA	radish stem	8.8	Lasee et al. 2020
PFOA	radish root	0.54	Lasee et al. 2020
PFOA	carrot stem	2.7	Lasee et al. 2020
PFOA	carrot root	0.1	Lasee et al. 2020
PFOA	alfalfa stem	0.61	Lasee et al. 2020
PFOA	alfalfa root	0.19	Lasee et al. 2020
PFOA	tomato leaf	1.9	Lasee et al. 2020
PFOA	tomato root	0.23	Lasee et al. 2020
PFOA	tomato stem	0.08	Lasee et al. 2020
PFOA	tomato fruit	0.04	Lasee et al. 2020
PFOA	wheatgrass	0.58	Braunig et al. 2019
PFOA	wheatgrass	1.1	Braunig et al. 2019
PFOA	maize straw	0.56	Krippner et al. 2015
PFOA	maize straw	0.65	Krippner et al. 2015
PFOA	maize kernels	0.002	Krippner et al. 2015
PFOA	wheat kernels	0.04	Liu et al. 2017
PFOA	maize kernels	0.002	Liu et al. 2017
PFOA	wheat whole plant	2.7	Zhao et al. 2014
PFOA	wheat whole plant	2.1	Zhao et al. 2014
PFOA	wheat whole plant	1.7	Zhao et al. 2014
PFOA	spinach	1.6	Navarro et al. 2017
PFOA	tomato stem	0.55	Navarro et al. 2017
PFOA	tomato leaf	3.6	Navarro et al. 2017

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFOA	tomato fruit	0.08	Navarro et al. 2017
PFOA	grass leaf	113	Zhu et al. 2019
PFOS	alfalfa shoot	1.4	Lasee et al. 2019
PFOS	alfalfa root	4.3	Lasee et al. 2019
PFOS	carrot shoot	54	Lasee et al. 2019
PFOS	carrot root	1	Lasee et al. 2019
PFOS	radish shoot	10	Lasee et al. 2019
PFOS	carrot shoot	2.9	Lasee et al. 2019
PFOS	radish root	0.7	Blaine et al. 2014
PFOS	radish shoot	3.7	Blaine et al. 2014
PFOS	celery root	4.2	Blaine et al. 2014
PFOS	celery shoot	1.4	Blaine et al. 2014
PFOS	tomato root	4.5	Blaine et al. 2014
PFOS	tomato shoot	4.2	Blaine et al. 2014
PFOS	pea root	2.4	Blaine et al. 2014
PFOS	pea shoot	1.2	Blaine et al. 2014
PFOS	pea fruit	0.03	Blaine et al. 2014
PFOS	alfalfa shoot	0.4	Wen et al. 2016
PFOS	radish stem	9.6	Lasee et al. 2020
PFOS	radish root	2.7	Lasee et al. 2020
PFOS	carrot stem	25	Lasee et al. 2020
PFOS	carrot root	1.2	Lasee et al. 2020
PFOS	alfalfa stem	1.3	Lasee et al. 2020
PFOS	alfalfa root	4.0	Lasee et al. 2020
PFOS	radish stem	14	Lasee et al. 2020
PFOS	radish root	1.1	Lasee et al. 2020
PFOS	carrot stem	4.7	Lasee et al. 2020
PFOS	carrot root	0.17	Lasee et al. 2020
PFOS	alfalfa stem	0.49	Lasee et al. 2020
PFOS	alfalfa root	1.2	Lasee et al. 2020
PFOS	tomato leaf	1	Lasee et al. 2020
PFOS	tomato root	1.7	Lasee et al. 2020
PFOS	tomato stem	0.17	Lasee et al. 2020
PFOS	tomato fruit	0.03	Lasee et al. 2020
PFOS	wheatgrass	0.16	Braunig et al. 2019

CHEMICAL	SPECIES/PART OF PLANT	K_{plant}	REFERENCE
PFOS	wheatgrass	0.37	Braunig et al. 2019
PFOS	maize straw	0.32	Krippner et al. 2015
PFOS	maize straw	0.62	Krippner et al. 2015
PFOS	wheat kernels	1.2	Liu et al. 2017
PFOS	maize kernels	1.1	Liu et al. 2017
PFOS	wheat whole plant	3.7	Zhao et al. 2014
PFOS	wheat whole plant	3.1	Zhao et al. 2014
PFOS	wheat whole plant	2.5	Zhao et al. 2014
PFOS	spinach	3.8	Navarro et al. 2017
PFOS	tomato stem	0.45	Navarro et al. 2017
PFOS	tomato leaf	1.2	Navarro et al. 2017
PFOS	tomato fruit	0.06	Navarro et al. 2017
PFOS	corn leaf	0.8	Navarro et al. 2017

3.7 Earthworm bioaccumulation

BAF values in the table are the adjusted literature values, to yield final values of mg/kg $worm_{dw}$ / mg/kg $soil_{dw}$.

CHEMICAL	BAF	REFERENCE
PFBS	0.83	Karnjanapiboonwong et al. 2018
PFBS	4.7	Karnjanapiboonwong et al. 2018
PFBS	7.7	Karnjanapiboonwong et al. 2018
PFBS	1.4	Zhao et al. 2013b
PFBS	0.75	Zhao et al. 2013b
PFBS	0.55	Zhao et al. 2013b
PFBS	17	Braunig et al. 2019
PFBS	16	Braunig et al. 2019
PFBS	15	Zhao et al. 2014
PFBS	14	Zhao et al. 2014
PFBS	12	Zhao et al. 2014
PFBS	2.8	Navarro et al. 2017
PFDA	5.2	Rich et al. 2015
PFDA	18	Rich et al. 2015
PFDA	21	Rich et al. 2015
PFDA	6.3	Rich et al. 2015
PFDA	8.0	Zhao et al. 2013b
PFDA	7.1	Zhao et al. 2013b
PFDA	5.3	Zhao et al. 2013b
PFDA	5.7	Braunig et al. 2019
PFDA	12	Braunig et al. 2019
PFDA	12	Navarro et al. 2016
PFDA	44	Zhao et al. 2014
PFDA	39	Zhao et al. 2014
PFDA	38	Zhao et al. 2014
PFDA	6.7	Zhu et al. 2019
PFDoA	9.8	Rich et al. 2015
PFDoA	41	Rich et al. 2015
PFDoA	91	Rich et al. 2015
PFDoA	51	Rich et al. 2015
PFDoA	37	Zhao et al. 2013b
PFDoA	22	Zhao et al. 2013b

CHEMICAL	BAF	REFERENCE
PFDoA	18	Zhao et al. 2013b
PFDoA	30	Braunig et al. 2019
PFDoA	76	Braunig et al. 2019
PFDoA	199	Navarro et al. 2016
PFDoA	112	Zhao et al. 2014
PFDoA	88	Zhao et al. 2014
PFDoA	80	Zhao et al. 2014
PFDoA	49	Zhu et al. 2019
PFHxA	2.3	Zhao et al. 2013b
PFHxA	1.2	Zhao et al. 2013b
PFHxA	0.89	Zhao et al. 2013b
PFHxA	1.1	Braunig et al. 2019
PFHxA	0.40	Braunig et al. 2019
PFHxA	2.4	Zhao et al. 2014
PFHxA	1.6	Zhao et al. 2014
PFHxA	1.3	Zhao et al. 2014
PFHxS	24.6	Rich et al. 2015
PFHxS	14.2	Rich et al. 2015
PFHxS	139	Rich et al. 2015
PFHxS	100	Rich et al. 2015
PFHxS	2.2	Karnjanapiboonwong et al. 2018
PFHxS	20	Karnjanapiboonwong et al. 2018
PFHxS	40	Karnjanapiboonwong et al. 2018
PFHxS	113	Karnjanapiboonwong et al. 2018
PFHxS	4.9	Zhao et al. 2013b
PFHxS	4.0	Zhao et al. 2013b
PFHxS	2.7	Zhao et al. 2013b
PFHxS	20	Braunig et al. 2019
PFHxS	21	Braunig et al. 2019
PFHxS	58	Zhao et al. 2014
PFHxS	50	Zhao et al. 2014
PFHxS	48	Zhao et al. 2014
PFHxS	3.4	Navarro et al. 2016
PFNA	3.6	Rich et al. 2015
PFNA	5.0	Rich et al. 2015
PFNA	18	Rich et al. 2015

CHEMICAL	BAF	REFERENCE
PFNA	14	Rich et al. 2015
PFNA	4.2	Karnjanapiboonwong et al. 2018
PFNA	29	Karnjanapiboonwong et al. 2018
PFNA	80	Karnjanapiboonwong et al. 2018
PFNA	5.5	Zhao et al. 2013b
PFNA	3.1	Zhao et al. 2013b
PFNA	3.0	Zhao et al. 2013b
PFNA	3.3	Braunig et al. 2019
PFNA	6.7	Braunig et al. 2019
PFNA	17	Zhao et al. 2014
PFNA	13	Zhao et al. 2014
PFNA	12	Zhao et al. 2014
PFNA	5.6	Zhu et al. 2019
PFOA	2.1	Rich et al. 2015
PFOA	4.0	Rich et al. 2015
PFOA	8.3	Rich et al. 2015
PFOA	6.0	Rich et al. 2015
PFOA	2.5	Zhao et al. 2013b
PFOA	1.6	Zhao et al. 2013b
PFOA	0.96	Zhao et al. 2013b
PFOA	2.7	Braunig et al. 2019
PFOA	2.2	Braunig et al. 2019
PFOA	2.0	Navarro et al. 2016
PFOA	7.7	Zhao et al. 2014
PFOA	7.2	Zhao et al. 2014
PFOA	6.8	Zhao et al. 2014
PFOA	3.3	Zhu et al. 2019
PFOS	18	Rich et al. 2015
PFOS	23	Rich et al. 2015
PFOS	75	Rich et al. 2015
PFOS	55	Rich et al. 2015
PFOS	9.9	Zhao et al. 2013b
PFOS	8.9	Zhao et al. 2013b
PFOS	6.6	Zhao et al. 2013b
PFOS	16	Braunig et al. 2019
PFOS	27	Braunig et al. 2019

CHEMICAL	BAF	REFERENCE
PFOS	23	Navarro et al. 2016
PFOS	102	Zhao et al. 2014
PFOS	82	Zhao et al. 2014
PFOS	72	Zhao et al. 2014
PFOS	3.9	Navarro et al. 2016

Appendix B Attachment 4: Upland References

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